THE 14TH INTERNATIONAL CONFERENCE ON MODELING AND APPLIED SIMULATION

SEPTEMBER 21-23 2015
BERGEGGI, ITALY

MAS
2015

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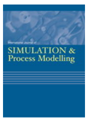

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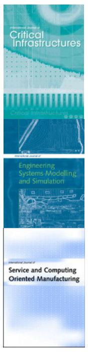

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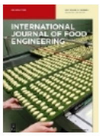

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We are pleased to welcome all the delegates to The 14th Conference on Modeling and Applied Simulation (MAS 2015) one of the most important events in Europe in the field of Modeling and Simulation (M&S) and Computer Technologies applications.

In the breath-taking panorama of the Italian Riviera, MAS 2015 is a renewed opportunity for its participants to exchange ideas, discover and create opportunities, meet colleagues and acquire new insights. The MAS conference has reached its 14th edition proving a showcase of world-leading research approaches and practices in an international context where people from all over the world are involved. Indeed, it features highly internationally renowned speakers who will share, discuss and debate significant new developments and scientific advancements that will impact on the future of Modeling and Simulation approaches and applications. Beside, MAS 2015 covers many application fields that include logistics, supply chain management, production control, business and industrial organization; as a consequence, it reaches out to a huge and multidisciplinary community of experts and scientists paving the way for fruitful collaborations and cutting-edge research and development ideas. Hence MAS 2015 offers the great opportunity to find out what it is to come, meanwhile, everybody can make his voice heard in thought provoking forums and interactive sessions but not only.

Aside from the scientific program, MAS 2015 includes social events with the chance to enjoy the Italian cuisine, culture, and warm hospitality. The conference location is set in a rock with a magnificent terrace that seems to jut into the sea offering memorable experiences especially at sunset. It provides the ideal framework to combine duty and pleasure.

Finally, on behalf of the Organization Committee, we would like to thank the Conference Chairs, the International Program Committee, our dedicated volunteers, sponsors and obviously all the authors for their invaluable contribution in making MAS a truly great Conference that grows year by year.

Welcome to Bergeggi with the hope that your involvement could grow and last over time.

Adriano Solis
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The MAS 2015 International Program Committee (IPC) has selected the papers for the Conference among many submissions; therefore, based on this effort, a very successful event is expected. The MAS 2015 IPC would like to thank all the authors as well as the reviewers for their invaluable work.
A special thank goes to all the organizations, institutions and societies that have supported and technically sponsored the event.

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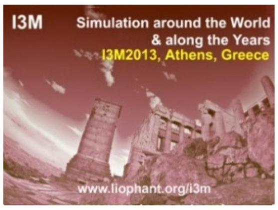

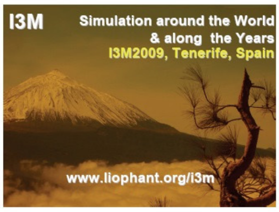

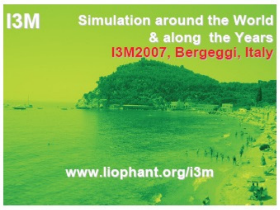

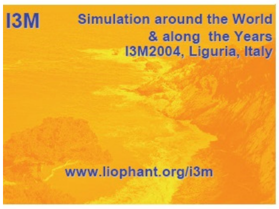

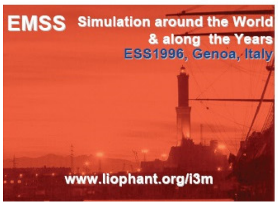

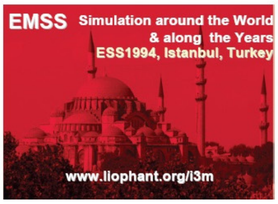

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OPTIMAL CONTROL STRATEGY OF PLUG-IN HYBRID ELECTRIC VEHICLES

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ABSTRACT

Development of eco-friendly vehicles is in progress in order to reduce emissions of greenhouse gas and oil usage. Among the eco-friendly vehicles, plug-in hybrid electric vehicles (plug-in HEV) have attracted much attention. Unlike the existing hybrid vehicle, the control method of the plug-in hybrid vehicle is different, because the distance that can be driven only by the motor increases now. In this paper, we'll describe the equivalent consumption minimization strategy (ECMS) that has been used in hybrid vehicles. However, this control strategy is difficult to be applied for to an actual vehicle because parameters are changed according to the driving cycle. Thus, this paper suggests a novel ECMS control strategy to overcome these limitations. As a result, compared with other control strategies, the novel ECMS control strategy can appear the best result of improving the fuel economy, and it is less sensitive to changes in the driving cycle.

Keywords: Plug-in hybrid electric vehicle, Equivalent Consumption Minimization Strategy, Energy management control, Parallel hybrid vehicle system

1. INTRODUCTION

Currently, the automotive industry′s fuel economy regulation has been continued to be strengthened for reducing green house gas emissions due to the destruction of the natural environment, such as air pollution. A variety of eco-friendly vehicles are released to correspond these regulations and the eco-friendly vehicles such as the HEV, plug-in HEV, Electric vehicle are getting the attention. Also, the conventional vehicle has used only the engine as a power, but otherwise in the HEV, the motor is added. Thus, various control strategies have been studied for power distribution of the engine and the motor (Al-Alawi, et al. 2013, Shaik, et al. 2010).

Due to the limitations in the battery capacity, the conventional HEV supports to assist the power of the engine. If the battery capacity is increased slightly, it supports the EV function at low speed. However, in the case of plug-in HEV, the power of the battery capacity and the motor is greatly increased, so that the distance that can be driven motor is dramatically increased. A range of driving using only the electric motor is called a CD (Charging-Depletion) and in the case of that the battery reaches a threshold, a driving range in the normal hybrid drive mode is called CS (Charging-Sustaining). Unlike the hybrid vehicle, plug-in HEV control method is classified into two types due to the CD-CS mode. The first is the CDCS control strategy, and the second is a Blended mode control strategy (Sharer, et al. 2012, Gonder, et al. 2007, Torres, et al. 2014, Zhang, et al. 2011).

In the CDCS control strategy, the vehicle initially uses the motor only, and when the SOC has reached the limit value, it uses the motor and engine. On the other hand, Blended-mode is a control strategy that distributes the entire driving range into motor and the engine properly. Assuming that the total trip distance is longer than the distance which can be driven by a motor, when the battery reaches a threshold, the CD stage ends and CS stage that frequently uses the engine at low speed begins, so that it takes an adverse effect on fuel economy. Blended mode control Strategy can overcome this disadvantage according to the distribution of the torque. In this regard, various studies have been proceeding.

There have been a lot of studies for distributing power of HEV and plug-in HEV. There is a way that minimize the fuel consumption by optimizing the parameters using the Genetic Algorithm, which is one of the way to find a optimal solution and simulate the process of evolution (Salisa, et al. 2009, Piccolo, et al. 2001, Chen, et al. 2014). Also, by using the road traffic information such as GPS and GIS, if the starting point and destination are determined by reflecting the traffic information, modelling the optimized driving cycle has been conducted as to the global optimization with Dynamic Programming method (Gong, et al, 2007, Karbowski, et al, 2013, Gong, et al, 2009, Zhang, et al, 2010). And it is in progress to use a Utility Factor, which is one of methods for calculating the fuel consumption of the plug-in HEV to improve the fuel economy based on the driving statistical data of the vehicle (SAE J2841 2010, SAE J1711 2010, Wang, et al. 2013, Hou, et al. 2014). In addition, there are many studies of the control strategy to distribute the torque of the engine and the motor so as to minimize the objective function with the battery power and the fuel consumption by the equivalent (Pourabdollag, et al 2012, Geng, et al. 2011, Paganelli, et al. 2010, Sciarretta, et al. 2004, Musardo, et al. 2005, Tulpule, et al. 2009, Paganelli, et al. 2002). Assuming that drivers entry the distance into the vehicle, optimal control as the Pontryagin's Mimimum Principle using the optimal solution of Euler-Lagrange equation is also studied (Kim, et al. 2012, Kim, et al. 2011, Hou, et al, 2014, Yuan, et al. 2013).

This paper will point out the limitations of previous ECMS (P-ECMS) control depending on the parameters according to the driving cycle. Next, for solving the problems, we will suggest a novel ECMS control (N-ECMS) strategy that is adaptive to changes in the driving cycle. Also, the simulation will be carried out in two aspects. First, CDCS and N-ECMS control strategy will be compared in terms of fuel consumption. Second, P-ECMS and N-ECMS control strategies will be analyzed in respect of the fuel economy with the driving cycle of the NEDC and UDDS. Overview of the paper will be described in the model of the vehicle and then will present N-ECMS control strategy in comparison with other strategies. The proposed algorithm will be simulated by the driving cycles such as the NEDC and UDDS cycle.

2. THE MODELING OF THE PARALLEL HEV

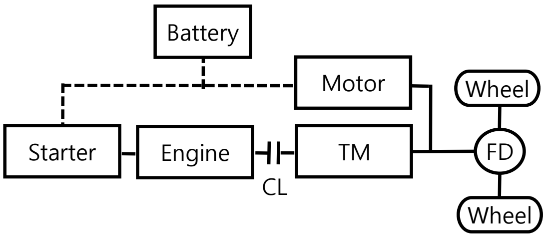

Figure 1: Reference Vehicle

Fig.1 is a model of the vehicle, which was constructed based on the Autonomie developed by the Argonne Institute testing the performance and fuel economy of the various vehicle. Starter represents the start Engine, TM is the transmission, CL is the clutch, FD is the final drive. The Structure of the system is a parallel type hybrid vehicle architecture. The engine is connected to the transmission via the clutch. Then, the sum of the engine and motor power is delivered to the final drive. Information from the main components of the vehicle is in the table 1 and the parameters of the vehicle are in the table 2.

Table 1: The main components of Plug-in hybrid electric vehicle

Engine	75kW 1.8L diesel engine
Motor	50kW PM motor
Battery	240V, 41Ah lithium-ion battery

Table 2: Vehicle Parameters

Curb Weight (kg)	1680
Frontal Area (m^2)	1.23
Rolling Coefficient	0.008
Aerodynamic Coefficient	0.3
Air density (kg/m^3)	1.23
Final drive ratio	3.63

2.1. Power distribution model

The variable u(t) distributes the torque of the engine and the motor. The torque of the engine and the motor is composed of a combination of the demand wheel torque and u(t) represented by the following formula. :

$$u(t) = \frac{T_{mot}}{T_{whl.dmd}} \quad where \;\; 0 < u < 1 \qquad (1)$$

where T_{mot} is the motor torque, $T_{whl.mot}$ is the demand wheel torque, u(t) is the control variable for distribution the engine and motor power.

$$\begin{aligned} T_{mot} &= u(t) \cdot \frac{T_{whl.dmd}}{R_{fd}} \\ T_{eng} &= (1 - u(t)) \cdot \frac{T_{whl.dmd}}{R_{fd}} \cdot \frac{1}{R_{gb}} \end{aligned} \qquad (2)$$

where T_{eng} is the engine torque, R_{fd} is the Final drive ratio, R_{gd} is the Gear ratio

2.2. Fuel and Battery power consumption model

The fuel consumption of the engine consists of a lookup table of the engine map with torque and speed of engine. Battery power is also configured with a motor map receiving the motor torque and speed. The formula is expressed as follows :

$$\begin{aligned} \dot{m}_{eng} &= f_{eng}(T_{eng}(t), w_{eng}(t)) \\ P_b &= f_b(T_{mot}(t), w_{mot}(t)) \end{aligned} \qquad (3)$$

where $w_{eng}(t)$ is the engine speed, $\dot{m}_{eng}$ is the fuel rate. $w_{mot}(t)$ is the motor speed, $P_b(t)$ is the battery power.

2.3. Battery model

The battery model is to be applied for the actual real-time due to the complex chemical model. Therefore, the simplified internal resistance model (Rint model) is used for use in the control strategy. The relationship between the parameters of the battery is represented by the following formula:

$$\frac{dSOC}{dt} = -\frac{i_b(t)}{Q_b}$$

$$i_b(t) = \frac{V_{oc} - \sqrt{V_{oc}^2 - 4R * P_b}}{2R} \qquad (4)$$

where SOC is the battery state of charge, $i_b(t)$ is the battery current, Q_b is the nominal capacity of the battery, V_{oc} is the open circuit voltage, R is the constant battery resistance.

2.4. Vehicle model

A longitudinal dynamic model is applied to the vehicle and losses, such as air resistance, gravity, degree are considered. The traction force at the wheel is computed as follow :

$$F_{veh}(t) = F_r + F_w + F_g + F_a + F_{brk}$$
$$= \frac{1}{2}\rho C_D A_f v(t)^2 + mg\sin\theta + mg \cdot f_r \cos\theta + m\frac{dv}{dt} + F_{brk}(t)$$

(5)

where F_r , F_w , F_g , F_a , m , g , ρ , f_r , A_f , C_D , θ , v and F_{brk} is the rolling resistance, the aerodynamic drag, the grade, the acceleration force, the vehicle mass, the gravitational acceleration, the air density, the rolling resistance, the front area, the air drag coefficient, the road angle, the vehicle speed and the braking force.

3. CONTROL STRATEGY

Fig.2 is a graph referred to (Sharer, et al. 2012). The first graph represents a case of using the CDCS control. In CD stage, the engine is off and the motor is only driven. The CS stage is operating in the hybrid mode, and it gives an adverse effect on fuel economy because the engine is operating in the low speed range at low efficiency. The second graph represents a case of using a Blended mode control (Hou, et al. 2014). In the low-speed range, for the efficiency of the engine is low, the vehicle is driven by the motor. On the other hand, in high-speed range, the vehicle is driven by the engine for the efficiency of engine is high. As a result, the overall fuel economy is improved. Fig.3 is a graph of the SOC of the CDCS and Blended strategy based on the NEDC cycle. CDCS is clearly divided into two sections, as a CD and CS stage, and the SOC is quickly exhausted, whereas Blended mode falls slowly and steadily the SOC. Consequently, this process brings the more efficient distribution of the engine and the motor torque in the high and low speed, and SOC is used to the last. Also, time to reach the limit SOC and the end time of trip are almost similar. That is, blended mode uses the engine and the motor more efficiently. After that, CDCS, P-ECMS and N-ECMS control strategies will be described.

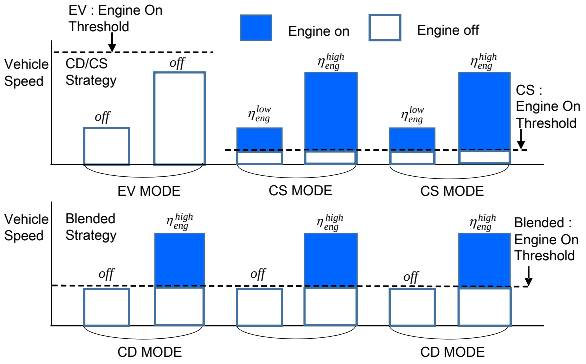

Figure 2: CDCS strategy and Blended Strategy

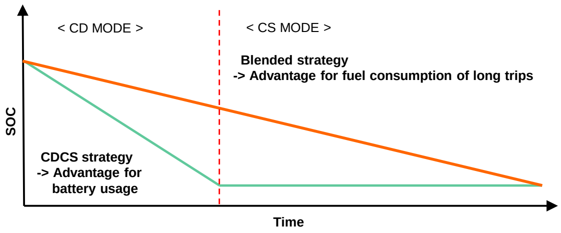

Figure 3: SOC of the CDCS and Blended Strategy

3.1. CDCS Control Strategy

The CDCS control strategy is divided into a total of two steps. The first step is a CD (Charging-Depletion) stage. In this case, the formula is represented as (6). The value is divided into the gear ratio by the demand torque of the wheel of the motor torque. Only the vehicle is driven by battery power and the engine is turned off. The second is the CS (Charging-Sustaining) stage. The vehicle is operating in hybrid mode and the engine is switched on to maintain the SOC. It can be shown that (7). The torque of the engine and the motor is calculated by a method using the maximum torque of the engine and vehicle model. The advantage of the CDCS is what uses the battery to the maximum. If the distance is shorter than the total trip to drive only a motor, it is possible that the vehicle is driven by electric without the fuel consumption at all. However, when the total distance is longer than the trip to drive only a motor, it will increase the stage of the hybrid mode. Therefore, the fuel consumption drastically increases. For this reason, the optimal strategy such as blended mode will be required for optimal distributing the torque of the engine and motor over the entire trip.

$$CD\ stage\ :$$
$$T_{mot} = \frac{T_{whl.dmd}}{R_{fd}} \qquad (6)$$

$$CS\ stage:$$
$$\begin{cases} T_{eng} = \min\left(T_{eng.\max}, (\frac{T_{whl.dmd}}{R_{fd}} - T_{mot}) \cdot \frac{1}{R_{gb}}\right) \\ T_{mot} = \frac{T_{whl.dmd}}{R_{fd}} - \min\left(T_{eng.\max}, \frac{P_{whl}}{w_{eng}}\right) \cdot R_{gb} \end{cases} \qquad (7)$$

Where $T_{eng.\max}$ is defined as the maximum torque of the engine, P_{whl} is the power of wheel.

3.2. ECMS Control Strategy

3.2.1. The Basic Idea of Control

In this paper, to compensate for the weaknesses of the CDCS control strategy, the ECMS control strategy that has been studied in a hybrid system is proposed in consideration of the plug-in hybrid system. The real-time control of ECMS control strategy first obtains the fuel consumption for the demand power of the engine and the equivalent of the demand power of the battery. Then, it distributes the torque to the engine and the motor so as to minimize the sum of the fuel consumption and equivalent fuel. The objective function of ECMS is

$$\min J(t) = E_f(t) + s(t) \cdot E_e(t) \qquad (8)$$

$$\begin{aligned} \mathrm{E_f}(t) &= \dot{m}_f(T_{eng}(t), w_{eng}(t)) \cdot H_{LHV} \\ \mathrm{E_e}(t) &= V_{bat.oc}(t) \cdot I_{bat}(t) \end{aligned} \qquad (9)$$

$E_f(t)$ represents energy of the fuel consumption for the demand power of the engine. $E_e(t)$ is the energy for the demand power of the battery. H_{LHV} is low heating value of fuel. Energy per unit time of the engine is calculated by a product with fuel consumption and H_{LHV}. The variable s(t) is an equivalent factor between the fuel energy and electric energy. That is, s(t) is a factor that adjusts the cost between energies. If equivalent factor is large, the electric energy usage is penalized and the fuel energy is used more. On the other hand, if the equivalent factor is small, the electric energy is used more and the fuel energy is saved, but the battery is exhausted before the entire trip. In other words, the equivalent factor directly affects the fuel consumption by determining remained capacity of the battery. Therefore, it is necessary to select the appropriate equivalent factor.

3.2.2. P-ECMS control strategy

The typical ECMS control strategy is to use the Self-sustaining in the electrical path (Pourabdollah , et al. 2012, Sciarretta, et al. 2004, Musardo, et al. 2005). Sciarretta suggests method of calculating the equivalent factor to use two constant factors of s_{dis} , s_{chg} . It is related with energy route for the equivalent fuel flow consumption of electric path (Paganelli, et al. 2002).

3.2.2.1. Calculation of the ECMS parameters

In order to obtain the equivalent factor, control system is calculating the parameters. Equation of (1), u is control variable to determine ratio of the engine and motor torque. In the case of plug-in HEV, the maximum of SOC is 90% and minimum of SOC is 20%. The goal here is to analysis the tendency of the charge and discharge rate. Thus, the SOC initial is setting 60%. u_r of the maximum value of u is the value that it is reached the maximum SOC and u_l of the minimum value of u is the value that it is reached the minimum SOC. Also, U_o represents point of the battery of first turning to negative energy. On the basis of the point U_o , the slope of the points with the positive energy is defined as s_{chg} and the slope of the point with the negative energy is s_{dis} . Simulation with respect to the input value between 0 and 1 can be obtained the total fuel energy and battery energy, such as Fig.4. The elements relate with the efficiency of mechanical and electrical power-train connection. Two elements will depend on the driving cycle, thus, the values will be calculated in advance.

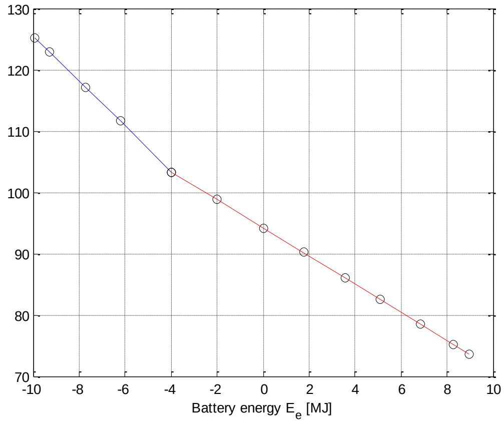

Figure 4: Relation of Fuel and Battery energy

3.2.2.2. Equivalent Factor

$$s(t) = p(t)s_{dis} + (1 - p(t))s_{chg}$$

$$p(t) = \frac{E_e^+(t)}{E_e^+(t) - E_e^-(t)} \qquad (10)$$

The probability factors are represented in the equation (10) and the probability of the fuel energy consumption during the remaining distance from the current point is estimated. If p(t) is 1, s(t) is the s_{dis}. Then, the battery will be charged and fuel consumption will increase. On the contrary, if p(t) is 0, s(t) is the s_{chg}. In this case, the battery will be discharged and the fuel is to be saved. That is, p(t) is a factor for calculating a probability charge and discharge. $E_e^+(t)$ and $E_e^-(t)$ is the estimating value of the maximum positive and negative energy during the remaining trip, considering the current value of $E_e(t)$.

$$\begin{aligned} E_e^+(t) &= E_e(t) + E_{\max}^+(t) - E_{rebrake}(t) \\ E_e^-(t) &= E_e(t) - E_{\max}^-(t) - E_{rebrake}(t) \end{aligned} \qquad (11)$$

Equation of (11), The $E_e(t)$ represents a difference in initial battery energy and the current battery energy. The $E^+_{\max}(t)$ means the maximum electrical energy used to propel the vehicle when u_r reaching the 20% of the SOC for the rest of the trip is entered into the input. The $E_{brake}(t)$ is a braking energy capable of regenerative braking energy for the rest of the trip. The $E^-_{\max}(t)$ is the maximum electrical energy to be charged when $-u_l$ reaching the 90% of the SOC for the rest of the trip is entered into the input. The detailed description of the individual equation is the following paper (Sciarretta, et al. 2004). Here, the second and third elements are calculated as parameters obtained through the driving cycle.

In this process, p(t) is calculated. In addition, equivalent factor is determined through s_{dis}, s_{chg} . p(t) in the graph is obtained by the driving cycle in advance. As a result, equation (8) is applied to s(t) and finds the minimize control value u(t) to the cost function. ECMS control instantaneously selects the control variable u(t) to distributes the optimal torque of the engine and motor.

3.2.3. N-ECMS control strategy

P-ECMS control strategy has the advantage to allocate the optimal torque of the engine and motor but the disadvantage to depend on the driving cycle determining the equivalent factor. Figure.5 shows a flow chart for selecting the equivalent factor to P-ECMS control strategy.

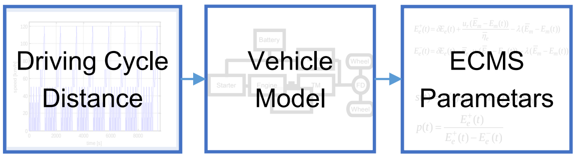

Figure 5: Flow chart to determine the equivalent factor

Determining the equivalent factor can be accomplished in three steps. First, the simulation corresponding the driving cycle is repeatedly performed. Then, the values $E_e(t)$, $E_f(t)$ are collected while the vehicle model applied in the equation (2) according to the input u which distributes the torque of engine and motor. The relationship between the two values is represented by a graph as shown in Fig.4. And parameter like slope is substituted in the equation (11). As a result, the corresponding parameters are fixed according the driving cycle. It is difficult to use in real time. Also, the plug-in HEV is added to the concept of driving distance to the motor. If the distance is changed, the parameters also vary as well. That is, the previous control method is dependent on these parameters in two aspects, such as the driving cycle and distance. Thus, the control does not work properly with this difficulty. Therefore, even if there are no the knowledge about driving and distance, a new control way should be adopt to get the best fuel economy effects.

3.2.3.1. The Relation between the energy at the wheel and distance

Fig.4-1 represents the energy at the wheel about the NEDC driving cycle repeated 8 times.

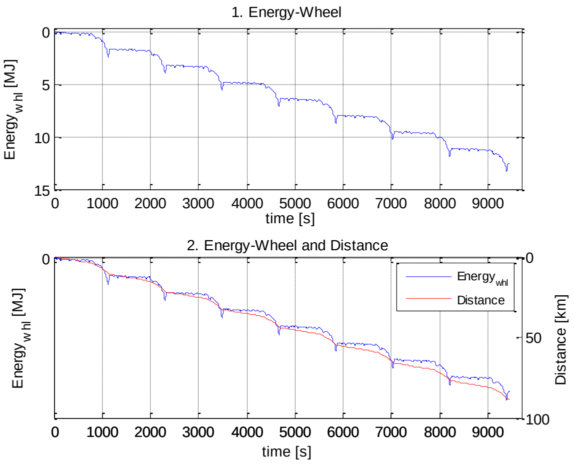

Figure 6: The energy in the wheel and Distance

The wheel at the energy is computed by first term of equation (12). The t_{final} represents the final time of the driving cycle. If the current time is the t_{final} , the total wheel energy has the maximum value. In case that the battery is used to decrease the wheel at the energy and the battery SOC with the same slope, the SOC reaches the $SOC_{\min}$ at the end of the trip. In other words, when s(t) is chosen, the criterion about decreasing the any slope is needed and s(t) has to be selected by that criterion.

$$\begin{aligned} E_{whl}(t) &= \int_0^{t_{final}} T_{whl}(t)\cdot w_{whl}(t)\,dt \\ D(t) &= \int_0^{t_{final}} Chas_{spd}(t)\,dt \end{aligned} \qquad (12)$$

where E_{whl} represents the energy at the wheel, D(t) is the current distance, $Chas_{spd}(t)$ is the vehicle speed.

Fig.4-2 is a plot concerning the energy in the wheel and distance. The distance of the vehicle is computed by second term of equation (12). If the current time is t_{final} , the trip is finished and then it means that the total trip is completed. The energy of the wheel and distance is similarly dropped. Namely, SOC_{ref} , the reference decreasing the battery SOC, has to been chosen via the data of the trip distance. Then, s(t) is determined by tracking the SOC and this is the most important algorithm in the paper.

3.2.3.2. Determination of the equivalent factor

Next, SOC_{ref} and s(t) is defined as (13).

$$SOC_{ref}(t) = SOC_{init} - \frac{D(t)}{D_{tot.d}} \cdot (SOC_{init} - SOC_{end})$$
$$s(t) = K \cdot (SOC_{ref}(t) - SOC(t)) \qquad (13)$$

where SOC_{init} is the initial value of the battery SOC, SOC_{end} is the final value of the SOC, SOC_{ref} is the reference value of the SOC, $D_{tot.d}$ is the total distance.

The method of calculating SOC_{ref} is referred to the [18]. If the total distance is known in advance, SOC_{ref} represents the equation of decreasing the SOC according to trip range. The variable s(t) is to reduce the difference between the SOC_{ref} and SOC to be feedback. The factor of K is feedback gain to reduce them. Fig.7 is a graph about SOC and equivalent factor over the NEDC cycle repeated 1 times.

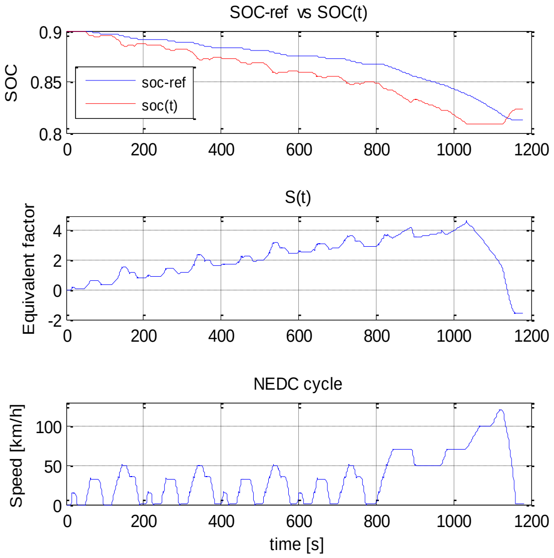

Figure 6: Relations between SOC and s(t)

When the driving cycle becomes the end time, the battery SOC is able to track the SOC_{ref} in order to coincide them. Then, s(t) is changed by depending the difference between the current SOC and SOC_{ref} . If equivalent factor is small, the motor is frequently used. In contrast, if it is large, the engine is mainly operated. SOC_{ref} is suddenly decreased after 800 second, It is because that the distance is increased according to high speed. Thus, s(t) is increased and then the equivalent factor is determined to use the engine primarily.

4. SIMULATION RESULTS

The data of reference vehicle is applied by Autonomie software. The simulation is performed by the NEDC and UDDS cycle in the Fig 7-8. The NEDC cycle reflects the circumstance of the urban and highway. It is repeated 8 times and the driving distance is about 89km. The UDDS is the urban driving cycle. It is repeated 7 times and the total trip is about 83km. With these data, the algorithm will be analyzed in aspect of fuel consumption. First, the ECMS control is compared to the CDCS control in terms of fuel economy using the Matlab/Simulink. Second, using the two driving cycle, P-ECMS control strategy utilizing the parameters optimized in the NEDC cycle will be compared and analyzed with N-ECMS control strategy. Control logic used in the simulation parameters are as follows.

Table 3: Simulation Parameters

Type of Data	Parameters	Values
Equivalent Factor	s_{dis}	3.63
	s_{chg}	2.31
SOC	SOC_{init}	0.9
	SOC_{final}	0.2
Distance	$D_{nedc\cdot 8cycle}$	88.1km
	$D_{nedc\cdot 7cycle}$	83.9 km
K factor	K	1000

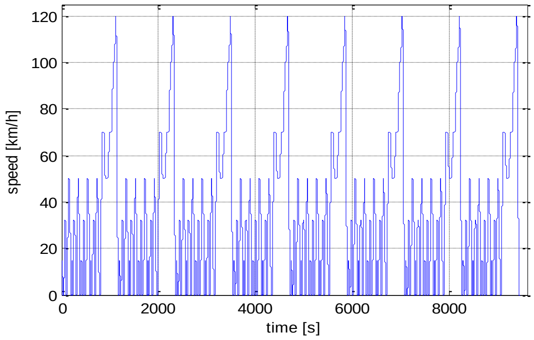

Figure 7: NEDC repeated 8cycle

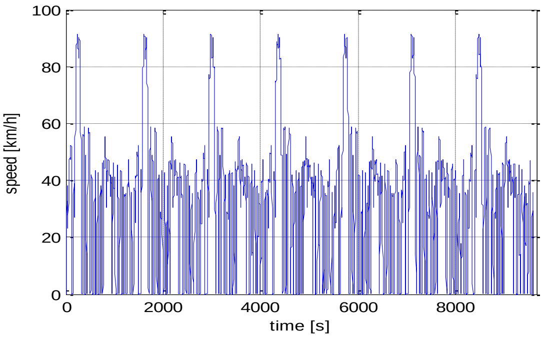

Figure 8: UDDS repeated 7cycle

4.1. Comparison with CDCS and ECMS control strategy

In this section, the simulation is performed about the CDCS and N-ECMS control strategies. Each control strategies to the power of the engine and motor are shown in Fig 9-10. The power of the engine has not been changed in the CDCS before the battery SOC drops below 0.2 and the engine is operated since 4500s. Also, in the CS stage, the vehicle is to be operated in the hybrid mode and the engine is frequently worked. Fig.10 is the plot of the ECMS control and the engine evenly works over a total trip. Because the equivalent factor is selected by tracking the SOC_{ref} , time to reach the limit SOC and trip end time become similar. In result, the torque of the motor and engine is efficiently distributed. In other words, ECMS control little uses the engine in terms of fuel consumption to minimize the fuel consumption by the objective function in comparison to the CDCS control. Also, in the Fig.11, ECMS control uses the motor to track SOC_{ref} and SOC is used up to $SOC_{\min}$. Thus, N-ECMS can distribute the torque to the engine and motor optimally than CDCS.

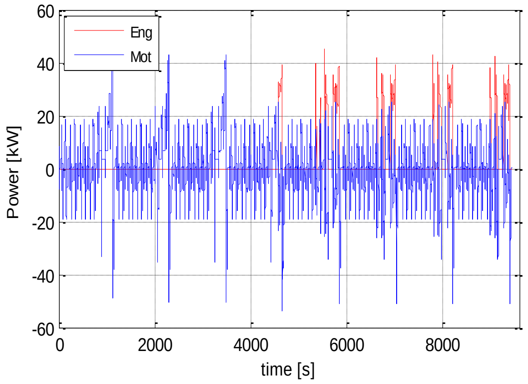

Figure 9: CDCS control the power of Engine and Motor

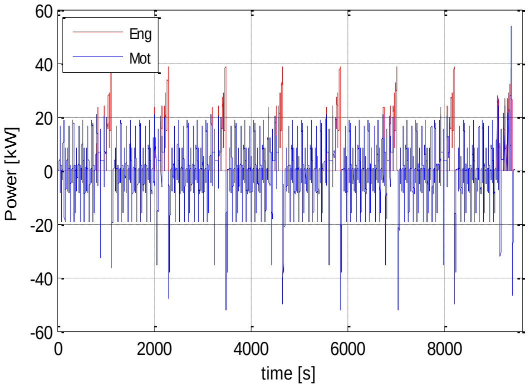

Figure 10: ECMS control of the power of Engine and Motor

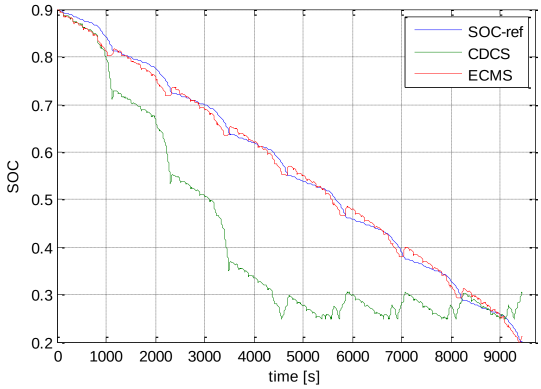

Figure 11: The SOC of the CDCS and ECMS

Fig.12 is a graph in the Fuel consumption. The ECMS control strategy has better fuel economy compared with other control strategies. Total fuel consumption of each control is represented in the Table.4 and ECMS control improves fuel economy approximately 13.1%, compared the CDCS control.

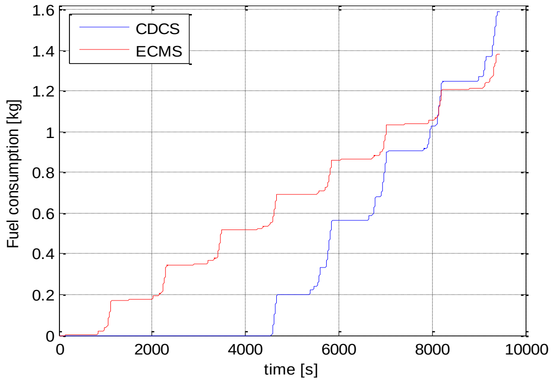

Figure 12: Fuel consumption of CDCS and ECMS control

Table 4: Fuel consumption and SOC over NEDC cycle

Parameters	Control strategy	
	CDCS	ECMS
Fuel (kg)	1.5892	1.3814
Fuel (km/l)	30.86	35.51
$SOC_{\min}$ time	6730.4	9383.1

4.2. Comparison with P-ECMS and N-ECMS control strategy

In P-ECMS control, the control parameters that are specific to NEDC cycle are set. It was simulated in NEDC and UDDS two cycles to compare N-ECMS control unrelated to the driving cycle and P-ECMS control depending the cycle.

Fig.13 is a simulation result by repeating the NEDC driving cycle 8 times. In terms of the battery SOC, the P-ECMS and N-ECMS follow the SOC reference well. However, from the point of view of fuel consumption, N-ECMS will have better fuel economy than P-ECMS. The reason for this is that while controlling SOC along the SOC reference, P-ECMS determines in advance the equivalent factor to the optimal power distribution over the driving cycle. Therefore, it is possible to have little more optimal control. In the table 5, P-ECMS improved about 3% fuel economy than N-ECMS and this difference is very minor.

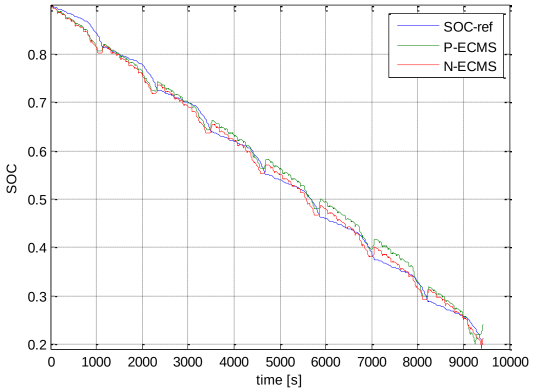

Figure 13: SOC of P-ECMS and N-ECMS in the NEDC cycle

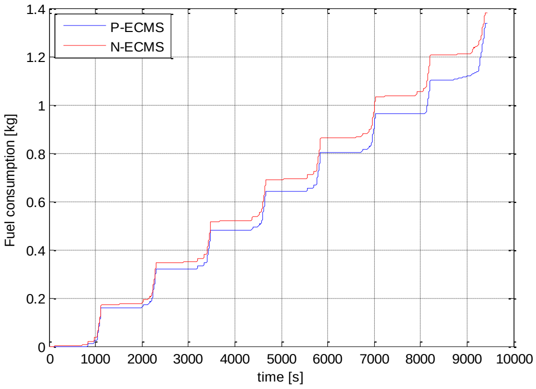

Figure 14: Fuel consumption of P-ECMS and N-ECMS in the NEDC cycle

Table 5: Fuel consumption and SOC over NEDC cycle

Parameters	Control strategy	
	P-ECMS	N-ECMS
Fuel (kg)	1.3377	1.3814
Fuel (km/l)	36.6649	35.51
$SOC_{\min}$ time	9254.6	9383.1

Fig.15 is simulated by UDDS cycle repeated 7 times. P-ECMS has a simulation with optimized parameters in the NEDC cycle. Characteristics of the NEDC cycle very differ considerably from UDDS. A comparison of detailed parameters is in Table 6.

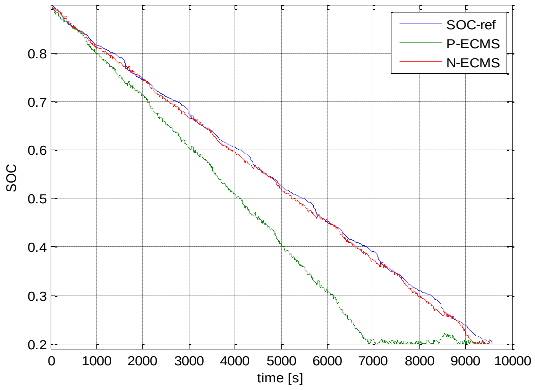

Figure 15: SOC of P-ECMS and N-ECMS in the UDDS cycle

UDDS cycle has much rapid acceleration and deceleration and the figures are higher approximately 1.4 times than NEDC cycles. In other words, it reflects the rapidly changing road conditions in the urban. On the other hand, NEDC cycle is smoothly accelerated and decelerated. NEDC cycle is divided into two stages of the urban and highway. Acceleration and deceleration are repeated slowly in the urban. In the highway, Acceleration, constant speed, and deceleration time are smooth in progress. When viewed in numerically, the values of acceleration and deceleration are very low compared to the value of UDDS cycle.

Table 6: Statistical features of Driving cycles

Features	Driving Cycle	
	NEDC 8 cycle	UDDS 7 cycle
Total time (s)	9449	9590
Average Speed (km/h)	33.57	31.51
Maximum Speed (km/h)	120.06	91.25
Average Acceleration (m/s^2)	0.12	0.20
Average Deceleration(m/s^2)	-0.12	-0.20
Maximum Acceleration (m/s^2)	1.08	1.48
Maximum Deceleration(m/s^2)	-1.43	-1.48
Idling Percentage (%)	24.90	18.91

In terms of the battery, the SOC of P-ECMS reaches the lowest value at 7000s. The reason is that it could not reflect the properties of parameters of UDDS which are repeated acceleration and deceleration unlike the NEDC. On the other hand, in the N-ECMS control, the battery reaches a minimum SOC at 9000s nearly finishing the driving cycle, because it is to track the SOC_{ref} .

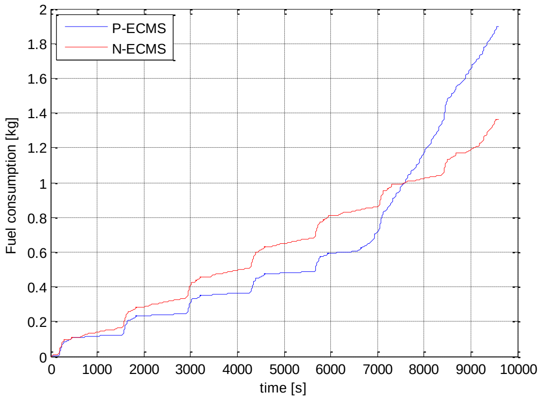

Figure 16: Fuel consumption of P-ECMS and N-ECMS in the UDDS cycle

With regard to the fuel consumption, there are many differences. N-ECMS improves approximately 72% in fuel economy compared P-ECMS. The reason for this is that the engine is mainly operated in the CS stage and the fuel consumption is suddenly increased. The CS stage starts after 7000s and the fuel consumption is twice compared before 7000s according to repeat of acceleration and deceleration. On the other hands, the fuel consumption is a steady increase in the N-ECMS control, without the case suddenly increasing it because the torque of the engine and the motor is evenly distributed.

Table 7: Fuel consumption and SOC over UDDS cycle

Parameters	Control strategy	
	P-ECMS	N-ECMS
Fuel (kg)	1.8972	1.3646
Fuel (km/l)	25.8525	35.9428
$SOC_{\min}$ time	7306.9	9383.1

5. CONCLUSIONS

This describes the result which reflects the property of the plug-in HEV according to increasing driving distance by using only the motor in aspect of the fuel consumption. Unlike previous HEV, plug-in HEV increases the driving distance using only the motor, therefore a novel control strategy is needed.

1. A control strategy of plug-in HEV is divided into CDCS and blended mode control strategies. In this paper, ECMS control used in previous hybrid system is applied with the property of the plug-in HEV.
2. A previous ECMS control can distribute torque properly into the engine and the motor. However, it has the disadvantage which the parameters depend on the driving cycle and the distance. Therefore, to overcome this disadvantage, N-ECMS control is proposed. While P-ECMS control requires the complex process calculating the parameters, N-ECMS control has simple and easy applied control algorithms, which in assumption that the total driving distance is known.
3. CDCS, ECMS control system is simulated in aspect of fuel consumption, and ECMS control has the improved fuel consumption than CDCS by 14%. Also, P-ECMS and N-ECMS are simulated with NEDC 8 cycle and UDDS 7 cycles. P- ECMS represents the improved fuel consumption than N-ECMS by 2% in NEDC, because it is composed of proper parameters. In contrast, N-ECMS has improved fuel consumption by 72% in UDDS driving cycle that acceleration and deceleration are repeated frequently. As a result, N-ECMS shows the efficient fuel consumption regardless of driving cycle.

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SYNTHESIS OF ADEQUATE MATHEMATICAL DESCRIPTION AND ITS APPLICATIONS

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ABSTRACT

The problems of the synthesis of an adequate mathematical description and his further use are considered. The definition of an adequate mathematical description of the physical process was given. In paper an analysis of methods for constructing such descriptions were performed. Algorithm of the synthesis of adequate mathematical description was described in the frame of one method. For the case when the parameters of the mathematical model are given approximately a few of non-standard synthesis problems of adequate mathematical description were formulated. Some results of the construction of such descriptions are given in the references. The problems of use the results of mathematical simulation for constructing of reliable forecast were discussed. One of possible algorithms of obtaining of reliable results of forecasting using the adequate mathematical description is suggested.

Keywords: adequate mathematical description, reliable prediction, non-standard synthesis problems.

1. INTRODUCTION

The main objective of mathematical simulation of the behavior of dynamic systems and physical processes is an coincidence of results of mathematical modeling of selected mathematical description of the real process with the experimental data. Under the mathematical description of the physical process is understood analytical relationship (differential, algebraic, integrated, etc.) of defined structure between the selected state variables of the system under study (mathematical model) and external influences (load). Naturally the structure of the mathematical model, the number of state variables, the coefficients may be differently and they are determined by objectives of study of particular physical of the process.

If the results of mathematical modeling do not match with experimental data, then further use of these results is problematic. Consequently such a coincidence is the sufficient and necessary conditions for the successful use of mathematical simulation in practice.

An important concept in this regard is the adequacy of the constructed mathematical description of the physical process under study. Let us give the possible definition of such description.

2. DEFINITION OF ADEQUATE MATHEMATICAL DESCRIPTION

Definition. Mathematical description will be called the local stable adequate mathematical description (ALSMD) of the investigated process if the results of mathematical simulation using this description coincide with the experimental data with an accuracy of measurements in a small neighborhood of the initial data; parameters of ALSMD resistant to small changes of the input data.

The comparison of the results of mathematical modeling with experimental data in determining ALSMD ensures objectivity of the results of mathematical modeling.

In the given work the mathematical models of physical processes described only by the linear system of the ordinary differential equations will be examined. Such idealization of real processes or dynamic systems is widely used in various areas for the description of control systems, as well as of mechanical systems with the concentrated parameters (Stepanov, Shorkin and Gordon 2004; Lino, Maione 2008; Pop, Valle and Cottron 2004; Krasovskij 1968; Sarmar, Malik 2008; Porter 1970; as well as economic processes (Laitinen 2013), biological and ecological processes (Alexik 2000; Thomas 2004) etc. It is shown that with the help of such systems in some works even human emotions is simulated (Breitenecker, et al 2009). This, of course limits the class of the physical processes. However, all the features of the solution of this problem are also valid for most other types of physical processes.

We assume that the mathematical model of the physical process is represented in the form:

$$\dot{x}(t) = \tilde{C}\, x(t) + \tilde{D}\, z(t)\,, \tag{1}$$

with the observation equation

$$y(t) = \widetilde{F}\, x(t)\,, \qquad (2)$$

where $x(t) = (x_1(t), x_2(t), ..., x_n(t))^T$ is vector-function variables characterized the state of process, $z(t) = (z_1(t), z_2(t), ..., z_l(t))^T$ is vector-function of unknown external loads, $y(t) = (y_1(t), y_2(t), ..., y_m(t))^T$; $\widetilde{C}, \widetilde{D}, \widetilde{F}$ are matrices of the appropriate dimension with constant coefficients which are given approximately, $\widetilde{F}$ is nonsingular matrix dimension $m \times n$ and rang $\widetilde{F} = n$; X, Y, Z – complete valued function spaces; $(.)^T$ is a mark of transposition. We assume that the matrix $\widetilde{F}$ is the identity matrix $\widetilde{F} = E$, then $m = n$ for simplicity.

There are two main approaches for the synthesis of an adequate mathematical description using experimental measurements (Stepashko 2008; Gubarev 2008; Gukov 2008; Menshikov 2009):

- a priori selected a particular mathematical model of the physical process and its structure (matrixes $\widetilde{C}, \widetilde{D}, \widetilde{F}$) and then selected such model of external load which together with the chosen mathematical process gives the results of mathematical modelling which coincide with experiment with precision of measurements (Menshikov 2008, 2009a, 2009b);
- Some models of external loads are given a priori and then mathematical model of process of type (1) is chosen for which the results of mathematical simulation coincide with experiment (Stepashko 2008; Gubarev 2008; Gukov 2008).

Now we will consider the synthesis of adequate mathematical description in the frame of first approach analyzing the process with the concentrated parameters, for which the motion is described by ordinary differential equations of n-order (1) (Menshikov 2008, 2009a, 2009b).

The problem of constructing an *adequate mathematical description* of physical processes that are described by the mathematical model (1), (2) can be formulated as follows: it is necessary to find an unknown vector function $z(t) = (z_1(t), z_2(t), \ldots, z_l(t))^*$ so that the vector function $y(t) = (y_1(t), y_2(t), \ldots, y_n(t))^*$, which is obtained from the system (1), (2), coincides with the experimental data $\widetilde{y}(t) = (\widetilde{y}_1(t), \widetilde{y}_2(t), \ldots, \widetilde{y}_m(t))^*$ with an accuracy of obtaining experimental measurements in the selected functional metric.

In this definition of adequate mathematical description there are a number of shortcomings which do not allow you to uniquely identify an adequate description among of all possible. The first of these shortcomings is the lack of ambiguity in the case if not all state variables are measured (the matrix is not the identity or matrix is a degenerate, etc.). The coincidence of part of the state variables with the experimental data does not guarantee the coincidence of the remaining state variables with experiment. In addition, the deviation of the results of mathematical simulation of experimental data is determined by the properties of the function spaces X, Z, U , as well as the type of norms defined in these spaces.

Of great importance is also the value of $[\, a, b\,]$ of independent variable. If the size of this interval is increased several times then an adequate mathematical description may lose its properties. Therefore, the above definition of an adequate mathematical description gives only the basic necessary requirements, but does not give a clear definition of an adequate description.

Let us consider questions what prospects of adequate mathematical descriptions are valid for further use and what goals should be selected at the creation of adequate mathematical descriptions.

It will be useful to address to classical works in this area. In work (Shanon 1975) the following statement was done: "…the goal of the imitation simulation is the creation of experimental and applied methodology which aimed at the use of it’s for a prediction of the future behaviour of system".

So the mathematical simulation using the adequate mathematical descriptions first of all are aimed at the forecast of behaviour of real processes. With the help of mathematical cimulation (iclude of adequate mathematical description) must have the possiblity to predict of behaviour of real process in new conditions of operation. For example, it is possible to test more intensive mode of operations of the real machine without risk of its destruction. Such tool (right mathematical description) allows to simulate the characteristics of process in the unconventional modes of operations, and also to determine optimum parameters of real process.

The considered situation requires the formation of some uniform methodological approach to this problem, creation of general algorithms and common criteria of adequacy evaluation (Menshikov 2008, 2009a, 2009b).

3. STATEMENT OF THE SYNTHESIS PROBLEMS

In (Menshikov 2008, 2009a, 2009b) proposed an algorithm for constructing an adequate mathematical description in frame of the first approach. The problem is reduced to the solution of several integral equations of the first kind:

$$A_{p,i}\, z_i = B_{p,i}\, x,\; i = 1,2,...,l \qquad (3)$$

where $A_{p,i}$ are integral completely continuous operators; $A_{p,i} : Z \to U$; $B_{p,i} : X \to U$ are continuous linear operators; $z_i(t)$ is i -th component of the vector of unknown function $z(t) = (z_1(t), z_2(t), \dots, z_l(t))^*$; $x(t) = (x_1(t), x_2(t), \dots, x_n(t))^*$ is a vector function of the state variables of the system (1); Z, X, U there are some normalized functional spaces. Operators $A_{p,i}, B_{p,i}$ depend continuously on the vector parameter $p = (p_1, p_2, \dots, p_q)^*$ mathematical model of the physical process (the coefficients of the matrices $\tilde{C}, \tilde{D}$).

If the part of external loads of real process is known, this case can be reduced to one which is examined earlier with using the linearity of initial dynamic system (1).

We assume that state variables $x_i(t), 1 \le i \le n$ of system (1) correspond to some real characteristics $\tilde{x}_i(t), 1 \le i \le n$ of physical process which are investigated and that the vector function $\tilde{y}(t) = \tilde{F}\,\tilde{x}(t)$ was obtained from experimental measurements and presented by graphics $x_{\delta_0}(t) = (\tilde{x}_1(t), \tilde{x}_2(t), \dots, \tilde{x}_n(t))^*$. Due to the measurement error, we assume that the inequality is valid

$$\left\| x_{ex} - x_{\delta_0} \right\|_X \le \delta_0 , \qquad (4)$$

where δ_0 there is a given value; $x_{\text{ex}}(t) = (x_{1,ex}(t), x_{2,ex}(t), \dots, x_{n,ex}(t))^*$ is the exact function of the vector of state variables.

Then equation (3) can be rewritten as

$$A_{p,i}\, z_i = B_{p,i}\, x_\delta = u_{\delta_i} ,\ i = 1,2,...,l . \qquad (5)$$

Let us consider the set of possible solutions $Q_{\delta,p,i}$ of the equation (5), taking into account only the error in the initial data x_{δ_0} :

$$Q_{\delta_i,p} = \left\{ z \in Z : \left\| A_{p,i} z - B_{p,i} x_{\delta_0} \right\| \le \left\| B_{p,i} \right\|_{X \to U} \delta_o = \delta_i \right\}$$

. (6)

Due to the fact that the operators $A_{p,i}$ are completely continuous, the set $Q_{\delta_i,p}$ is unlimited for any i, p, δ in norm of Z (Tikhonov, Arsenin 1975).

Suppose $\Omega[z]$ is some positive continuous functional which is defined on a normed function space Z .

To obtain the stable solutions of ill-posed problem (5) we can use the variation principle of their construction proposed by (Tikhonov, Arsenin 1975).

Consider now the following extreme problem:

$$\Omega[z_{\delta,p}] = \inf_{z \in Q_{\delta,p}} \Omega[z] , \qquad (7)$$

where functional $\Omega\,[z]$ has been defined on set Z (Tikhonov, Arsenin 1975).

Theorem. If the functional space Z is reflex Banach space, the functional $\Omega[z]$ is convex and lower semi-continuity on Z , Lebesgue set $Q_{\delta_i,p}$ $Z_d = \{z : \Omega[z] \le \Omega[z_0]\}$ for some function from $Q_{\delta,p}$ is bounded then the function $z_{\delta,p} \in Q_{\delta,p}$ exists.

It was shown that under certain conditions the solution of the extreme problem (7) exists, is unique and stable with respect to small change of initial data u_δ (Tikhonov, Arsenin 1975).

Note that there is no sense to investigate behaviour of the obtained solution at $\delta \to 0$.

4. THE SYNTHESIS PROBLEMS FOR CLASS OPERATORS

Consider a situation where adequate and sustainable mathematical description of the physical process (for fixed parameters of the mathematical model and its structure) has already been constructed using any method.

What practical value will have this description in the prediction of the physical process, considering that the parameters of the original mathematical model and its structure is given approximately with a given accuracy?

So, it is supposed that the vector parameters p is given inexactly. So vector p can get different values in given closed domain $D : p \in D \subset R^N$.

Some operators $A_{p,i}, B_{p,i}$ correspond to each vector from D . The sets of possible operators $A_{p,i}, B_{p,i}$ have been denoted as classes of operators $K_A = \{A_{p,i}\}, K_B = \{B_{p,i}\}$. So we have $A_{p,i} \in K_A, B_{p,i} \in K_B$. The deviations of operators $A_{p,i} \in K_A$ between themselves from set K_A and operators $B_{p,i} \in K_B$ from set K_B are given:

$$\sup_{p_\alpha,\, p_\beta \in D} \left\| A_{p_\alpha,i} - A_{p_\beta,i} \right\| \le h_1, \sup_{p_\gamma,\, p_\lambda \in D} \left\| B_{p_\gamma,i} - B_{p_\lambda,i} \right\| \le d_1$$

.

Now we transfer to consideration of a more general problem of synthesis of external loads functions in which the inaccuracy of operators $A_{p,i}, B_{p,i}$ will be taken into account.

The set of possible solution of equation (6) is necessary to extend to set $Q_{h_1,d_1,\delta}$ taking into account the inaccuracy of the operators $A_{p,i}, B_{p,i}, p \in D$ (Tikhonov, Arsenin 1975):

$$Q_{h_1,d_1,\delta} = \{z : \| A_{p,i} z - B_{p,i} x_\delta \| \le h_1 \| z \|_U + B_0 \},$$

where $B_0 = d_1 \| x_g \| + \| B_{p,i} \| \delta$.

Any function from $Q_{h_1,d_1,\delta}$ causes the response of mathematical model coinciding with the response of investigated object with an error into which errors of experimental measurements and errors of a possible deviation of parameters of a vector $p \in D$ are included. A problem of a finding $z \in Q_{h_1,d_1,\delta}$ will be entitled by analogy to the previous one as a *problem of synthesis for a class of operators (*Menshikov 2008, 2009b).

It should be noted that the set of the solutions of a problem of synthesis $Q_{h_1,d_1,\delta}$ at the fixed operators $A_{p,i} \in K_A, B_{p,i} \in K_B$ in $Q_{h_1,d_1,\delta}$ contain elements with unlimited norm (incorrect problem) therefore the value $(h_1 \|z\|_U + B_0 \cdot \delta)$ can be infinitely large. Formally speaking, such situation is unacceptable as it means that the error of mathematical simulation tends to infinity, if for the simulation of external load is used the arbitrary function from $Q_{h_1,d_1,\delta}$ as functions of external load. Hence not all functions from $Q_{h_1,d_1,\delta}$ will serve as "good" functions of external load.

The function of external loads $z(t)$ in this case can be different. They will depend on final goals of mathematical simulation. For example, we can obtain model z_{p_0}, z_{p_1} for simulation of given motion of system as solution of extreme problems (Menshikov 2011, 2013):

$$\Omega[z_{p_0}] = \inf_{p \in D} \inf_{z \in Q_{\delta,p} \cap Z_1} \Omega[z], \; p \in R^N, \qquad (8)$$

$$\Omega[z_{p_1}] = \sup_{p \in D} \inf_{z \in Q_{\delta,p} \cap Z_1} \Omega[z], \; p \in R^N. \qquad (9)$$

Model z_{p_0} together with the matrices $\tilde{C}, \tilde{D}$ (coefficients of which are determined by the vector of parameters $p_0 \in D$) provide an adequate mathematical description of the physical process. If the functional $\Omega[z]$ characterizes energy of the external control a physical process, then the result is the solution of the extreme problem (8) gives the optimal adequate mathematical description with minimum energy.

Model z_{p_1} together with the matrices $\tilde{C}, \tilde{D}$ (coefficients of which are determined by the vector parameters $p_1 \in D$) provide an adequate mathematical description of the physical process. If the functional $\Omega[z]$ characterizes energy of the external control a physical process, then the result is the solution of the extreme problem (9) gives the optimal adequate mathematical description with maximum energy.

The function of external loads which is necessary for estimation from below of output of dynamic system (process) can be obtained as solution of the following extreme problem (Menshikov 2008, 2009a, 2009b):

$$\| A_{p_b} z_b \| = \inf_{p \in D} \| A_p z_{\delta,p} \|. \qquad (10)$$

where $z_{\delta,p}$ is the solution of extreme problem (7).

Another model for estimation from above of output of dynamic system (process) can be obtained as solution the extreme problem (Menshikov 2011, 2013):

$$\| A_{p_c} z_c \| = \sup_{p \in D} \| A_p z_{\delta,p} \|. \qquad (11)$$

As unitary model z_{un} we can call the solution of following extreme problem (Menshikov 2008, 2009a, 2009b):

$$\| A_{p_{un}} z_{un} - B_{p_{un}} x_\delta \| = \inf_{p \in D} \sup_{p \in D} \| A_p z_{\delta,a} - B_p x_\delta \|_U$$

(12)

where $z_{\delta,a}$ is the solution of extreme problem (7) with $p = a, a \in D$.

The triple $\{A_{p_{un}}, B_{p_{un}}, z_{un}\}$ gives the stable adequate mathematical description for class of operators of process as example of possible one. Function z_{un} provides a minimum deviation of the state variables of the mathematical model of the physical process under the worst combination of parameters (coefficients of the matrices $\tilde{C}, \tilde{D}$).

The method of special mathematical model selection was suggested to increase of approximate solution exactness of extreme problems (8) – (12).

The problems of synthesis of steady adequate mathematical models of special use are investigated. The examples are given (Menshikov 2011, 2013).

5. POSSIBLE USE OF ADEQUATE MATHEMATICAL DESCRIPTION FOR FORECAST

Suppose that an ALSMD has already been constructed, using some approach. For further use of it for the purpose of predicting the behavior of a physical process, it is important to have confidence in the fact that the description in the new conditions will remain adequate. According to the definition given above, the check-up of adequacy of the mathematical description can be performed only in the presence of experimental measurements, which correspond to the new conditions. But then it defeats the purpose of predicting the behavior of a physical process by means of mathematical simulation. Thus, in regime of forecasting cannot be verified adequacy in principle.

To justify the plausibility (reliability) forecasting in the new environment may use the property of inertia of dynamical systems: small changes in the initial data correspond to small changes in the behavior characteristics of dynamic systems. Therefore, if you use an ALSMD in the new conditions, which vary only slightly, then the results of mathematical simulation will be a little different from the previous results, for which experimental data are available. But in this case also defeats the purpose of mathematical simulation.

Similar results will be obtained if we consider that an ALSMD is robust to small changes in the initial data. For example, if the model of external load (which is part of an ALSMD) is robust to small changes in the initial data (matrixes and vector function), then in the new close conditions the results of mathematical simulation will differ little from the future experiments. In this case, the results of mathematical simulation will not have a scientific interest as they will be almost the same as the previously conducted mathematical simulation and experiment.

Here is proposed the following algorithm for the use of mathematical modeling to build of reliable forecast: for each of several small neighborhoods of change the parameters of the physical process is synthesized its ALSMD further options of ALSMD extrapolated (or interpolated) to the new neighborhood change the parameters of the physical process and conducted mathematical modeling in the new environment.

Suppose that the researcher is interested in the behavior of the physical process in fundamentally new conditions, for example, in a significant increase in the temperature of the process.

In this case, even an ALSMD will not give reliable results predict the behavior of the physical process in the new environment. Let under the temperature t_1 an ALSMD (function $z_1(t)$ for given matrices $\tilde{A}, \tilde{C}, \tilde{F}$ in equation (1)) was obtained.

Then the experimental measurements of the state variables of the mathematical model (1) are carried out for considerable increase of temperature t_2. And in this case a new ALSMD (new function $z_2(t)$ for a given matrixes $\tilde{C}, \tilde{D}$ in equation (1)) will be constructed.

Further analysis of changes in the functions $z_1(t)$, $z_2(t)$ (it is important that ALSMD is stable to small changes of the initial data) when the temperature of the physical process changes from t_1 till t_2. These changes in the function $z(t)$ extrapolated to the new function $z_3(t)$ for temperature t_3 (when $t_1 < t_2 < t_3$) or make interpolation to a new function $z_3(t)$ for the temperature t_3 (when $t_1 < t_3 < t_2$). Using for mathematical simulation of the physical process a new function $z_3(t)$ for fixed matrices $\tilde{C}, \tilde{D}$ we can obtain reliable results of mathematical simulation. It is obvious that such an approach should have reliable information about the continuous change of the parameters of the physical process by change of temperature from t_1 to t_3. This information can only be obtained from physical experiments and observations. It is necessary to be sure that the physical process does not change qualitatively. For example, the object does not melt at the new temperature t_3.

Mathematical description of physical process do not checked for adequacy before simulation and after it. Therefore mathematical simulation is often compared with art (Shanon 1975).

This situation greatly reduces the usefulness of mathematical simulation (sometimes to negative values). This happens in cases where the results of mathematical simulation are contrary to the experimental measurements.

So it is necessary to have the unified methodological approach to solving this problem, creation of synthesis algorithms and formation of evaluation criteria of reliability of the results of mathematical simulation (Menshikov 2008, 2009a, 2009b).

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A HEURISTICS WITH SIMULATIVE APPROACH FOR THE DETERMINATION OF THE OPTIMAL OFFSETTING REPLENISHMENT CYCLES TO REDUCE THE WAREHOUSE SPACE

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ABSTRACT

An important issue in a supply chain is to manage carefully replenishment cycles of stored items because of its strong impact both on production and stock management costs. The literature offers several papers debating this issue with a recent focus on the possibility to offset the items inventory cycles in order to reduce the maximum required space. A genetic algorithm (GA) is proposed in order to determine the optimal offsetting inventory cycles of items stored in the same warehouse. The heuristics was validated through the comparison with the most adopted and cited methodology, showing the effectiveness of the GA, able to provide better results than those previously presented in the literature. The GA was finally applied to a realistic case of a production system, showing a minimization of the maximum peak in the time horizon without relevant additional costs, together with a higher and more regular saturation of the warehouse.

Keywords: Offsetting, Genetic Algorithm, Inventory Management, Warehouse.

1. INTRODUCTION

The JRP (Joint Replenishment Problem) is one of the fundamental problem in the inventory management and its classic assumptions are similar to the EOQ (Economic Order Quantity) model: the problem includes deterministic and uniform demand, no shortages allowed, no quantity discounts and linear holding costs. The purpose of JRP is to minimize the total costs incurred per unit time: generally the considered cost terms include setup costs and inventory holding costs. A decision maker may ignore the warehouse-space restrictions and then he/she may apply the conventional heuristics developed over the years to solve the JRP, but he/she will often find that the obtained solutions are not applicable in a real case because the maximum required warehouse-space is greater than available. The JRP, in fact, does not evaluate the existence of space constraints, therefore, several researchers have already proposed an extension of the JRP that presented warehouse-space restrictions. It is known in literature also as "staggering problem" or "inventory cycle offsetting problem (ICOP)" and consists of offsetting the replenishment cycles of a large number of items stored in the same warehouse with the aim to minimize the peak usage of the aforementioned resource. To solve this problem, or at least try to reduce the maximum peak in stock, it is necessary to determine the optimal offsetting of many items' replenishment cycles, develop methodologies able to do it and, therefore, minimize the maximum volume peak. This issue has assumed considerable importance in research as early as the 80s and Gallego, Shaw and Simchi-Levi (1992) showed that the class of complexity of the problem is NP-complete: it justifies the efforts that have been made to develop appropriate heuristics that can lead to tangible improvements in practical cases.

This research was focused to study how to offset the inventory cycles of many products stored in the warehouse in order to minimize the maximum warehouse-space. In particular, a genetic algorithm (GA) was proposed to search the optimal replenishment schedule.

The paper is organized as follows.

Section 2 presents a review of existing relevant literature. Section 3 shows firstly the description of the problem, secondly the mathematical formulation of the problem and, finally, a short description of the generic genetic algorithms and their characterizing parameters. Section 4 presents the heuristics developed in this paper for the specific issue. Section 5 shows the validation of the genetic algorithm through its application to a benchmark example (Murthy, Benton, and Rubin 2003) and reveals the superiority of the obtained results both compared to Murthy et al.'s procedure and a heuristics later proposed by Moon, Cha, and Kim (2008). Furthermore, the algorithm is applied to a case of a production system, and also in this case, its application leads to a considerable reduction of the maximum peak observed in the time horizon. Finally, section 6 presents the conclusions of the work.

2. LITERATURE REVIEW

The JRP has been studied over thirty years, a lot of heuristics may be used for solving it and many researches addressed their efforts to lot sizing problems with limited warehouse-space, namely "the staggering problem": Goyal (1975) introduced the JRP with one resource constraint and developed a heuristic algorithm using the Lagrangian multiplier; Silver (1976) developed a simply methodology to determine the order quantity of each product in the warehouse, whose demand is supposed constant, and discussed the advantage and disadvantage of coordinating replenishments; Kaspi and Rosenblatt (1983) have made an improvement to the algorithm previously developed by Silver (1976), showing that the errors of the algorithm can be reduced, on average, of an order of magnitude; later Kaspi and Rosenblatt (1991) proposed an approach based on trying several values of the basic cycle time between a minimum and a maximum value, then they ran the heuristic of Kaspi and Rosenblatt (1983) for each value of the basic cycle time and they showed that their procedure (called RAND) outperforms all available heuristics; Gallego, Shaw, and Simchi-Levi (1992) showed that "the staggering problem" is NP-complete even if only one item has a different reorder interval and, thus, it is not possible to find an optimal solution but it must use a heuristic technique, then this problem is not solvable by polynomial-time algorithms. Other studies have been made by Hariga and Jackson (1995) and by Hall (1998), that examined the case in which all cycle lengths are equal, and showed that the problem is NP-hard. Khouja, Michalewicz and Satoskar (2000) applied the GA approach to the basic JRP and compared the performance of their GA with Kaspi and Rosenblatt's heuristic algorithm (1991). Murthy, Benton, and Rubin (2003) considered the presence of space constraints and presented an interesting heuristics for offsetting independent and unrestricted ordering cycles for items on the time axis to minimize their joint storage requirements over an infinite time horizon when warehouse-space is limited. Given that the aforementioned procedure represents the benchmark of many subsequent works in this field, for simplicity, from now on we will call the method as MBRP, stands for Murthy, Benton and Rubin Procedure. Moon and Cha (2006) were focused on the development of two algorithms to solve the JRP with resource restrictions: firstly they modified the existing RAND algorithm, then they developed a GA for the JRP with resource restriction; Yao (2007) conducted a research, focused on JRP with warehouse-space restrictions, establishing the lot size of each item, with the aim to minimize the total cost per unit of time and generate a program supply for many products without exceeding the available space: he has proposed a hybrid genetic algorithm. Yao and Chu (2008) conducted theoretical analysis based on Fourier series and Fourier transforms, proposing a procedure to calculate maximum warehouse space requirement; then, they employed this procedure in a genetic algorithm showing improvements, compared to the MBRP. In the same year Moon, Cha, and Kim (2008) proposed a Mixed Integer Programming (MIP), based on the same assumptions imposed by MBRP, and a GA, realizing that both led to the same results and, by comparison with the example presented by Murthy, Benton and Rubin (2003), which from now on we will call MBRE, were able to obtain better results; furthermore, they implemented a MIP for a finite time horizon and applied the GA to this case. Then, Boctor (2010) proposed a new formulation of the problem proposed by MBRP, and a heuristic algorithm based on Simulated Annealing through which they achieved the same results as Moon, Cha, and Kim (2008). Successively, Boctor and Bolduc (2012) presented a new mathematical formulation for the "staggering problem", showed two heuristic approaches and evaluated the obtained performance using their techniques. Finally, Croot and Huang (2013) proposed a series of algorithms, operating randomly, for the determination of offsetting inventory cycles: they studied this problem from the view of probability theory and their algorithm can work when the number of item is large, while the time horizon and unit volumes are not too large.

Despite of the several researches, there is not yet a procedure which leads to the optimal solution or, in other words, to an exact methodology for the resolution of the above mentioned problem. Furthermore, the heuristics developed in the course of the years, hint at a wide margin for improvements and, for this reason, the idea of developing a new algorithm able to bring to most interesting solutions is becoming very relevant.

3. PROBLEM DESCRIPTION AND FORMULATION

As shown in the following example (which reproduces the MBRE), the offsetting of items' inventory cycles in the warehouse does not alter the stock management costs and reduces the maximum volume peak in storage. Consider the data reported in Table 1 and see the trend of the two items in Figure 1. In particular, the maximum peak without the offsetting is equal to 2Q because both the items will be ordered for the first time at the beginning of the time horizon; with the application of MBRP, the order of item 2 slides to the right of P units of time while the item 1 is always ordered for the first time at the initial instant: in this way the maximum peak will be equal to 1.75Q (Figure 2) and will occur at P unit of time.

Table 1: MBRE

Item	Storage space per unit time	Time between orders (TBO)	Order quantity
#1	s=1	4T	Q
#2	s=1	2T	Q

In conclusion, instead of ordering all EOQs immediately, as predicted by the Wilson model, initial stocks are supposed for satisfying the demand of the early days and, then, the respective EOQ will be ordered only when it is really necessary, namely when these stocks are inferior to the demand. In this way, it is possible to have a better use of warehouse-space. Then, the objective is the determination of the optimal offsetting for each item with the aim to minimize the maximum peak over time.

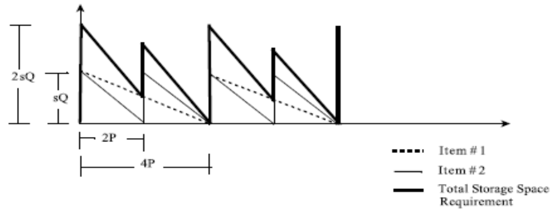

Figure 1: Space Requirement Without Offsetting

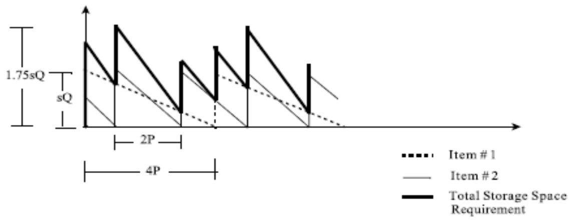

Figure 2: Space Requirement With Offsetting

The problem supposed the same assumptions of MBRP:

- the daily demand rate is deterministic and constant;
- the replenishment is instantaneous;
- the Time Between Order (TBO) is known and constant.

The objective is to minimize the maximum peak in the time horizon.
We introduce the following notation:

N → number of items
d_j → daily demand for the jth item
TBO_j→ time between orders for the jth item
$Q_{j,t}$ → replenishment quantity for the jth item at time t
$y_{j,t}$→ occupied quantity from item j in the warehouse at time t
$q_{iniz,j}$→ initial stock of the jth item
S_t → total storage space required for all items at time t
s_j→ required space per unit time for the jth item
S_{max}→ maximum storage space required for all items in the time horizon T

The mathematical model of the problem is shown below:

$$\min S_{max} \tag{1}$$

subject to:

$$y_{j,t} = q_{iniz,j} \qquad t = 0 \tag{2}$$

$$y_{j,t} = y_{j,t-1} + Q_{j,t} - d_j \quad t = 1,\ldots,T \tag{3}$$

$$\begin{cases} Q_{j,t} = 0 & if\ \ y_{j,t-1} \geq d_j \\ Q_{j,t} = d_j TBO_j & if\ \ y_{j,t-1} < d_j \end{cases}$$

$$S_t = \sum_{j=1}^{N} s_j \times y_{j,t} \quad j = 1,\ldots,N \text{ and } t = 0,\ldots,T \tag{4}$$

$$S_{max} = max_t\{S_t\} \qquad t = 0,\ldots,T \tag{5}$$

The objective (1) is to minimize the maximum space required in stock over the considered time horizon. The constraint (2) indicates that the present quantities at $t = 0$ must be equal to the assumed initial quantities for each item; the constraint (3), however, indicates that the present quantities from the second day onwards, until the end of the time horizon T, will be equal to the sum of the present amount on the previous day and the lot Q_j less demand of the jth item. The equation (4) establishes the total space occupied by the items at all time instants, while the constraint (5), finally, defines the peak capacity utilization.
As regards the time horizon, since the total space requirement pattern is periodic, the maximum will occur in the time interval from t = 0 to t = LCM (TBO$_1$,…, TBO$_n$) where LCM is the acronym of least common multiple. However, in the real cases, the items in the warehouse are numerous and, consequently, the time horizon (the LCM of the TBOs) growths exponentially. But, as also observed by Moon, Cha, and Kim (2008), it is totally unrealistic to think that the daily demand, the price and the management costs of each product do not change during a so long period. For these reasons, we assume a more realistic time horizon which has been prudentially fixed to a working year, namely $T = 220$ days. During such period, the order quantities (EOQs), the daily demands, the purchasing, ordering and holding costs are supposed known and constant.
Moreover, as mentioned above, many studies suggest that the replenishment of each item must be present at the beginning of the considered time horizon, namely at $t = 0$. We relax this hypothesis and, to determine the optimal offsetting in order to minimize the maximum peak in the store, suppose initial quantities for the items that, when satisfying the demand of the first days, delay consequently the time of the first replenishment. In other words, the day in which the satisfaction of the demand is not more possible with the assumed initial quantities, the lot EOQ_j is ordered and that day represents the offsetting of the item j. For example, if in the third day it is not more possible to satisfy the demand of the product j with the assumed initial amount, then $t = 3$ represent the offsetting of the jth item. The optimal offsetting is therefore the combination of the single delays which minimizes the peak of required space in stock.
To obtain the initial quantities that allow to minimize the maximum peak and maximizing the saturation, we performed a series of simulations using the genetic algorithm developed for the specific issue that can establish the best case, among all those assumed, namely the optimal initial quantities that will be needed in the warehouse for a better management of the space and a more regular saturation.

Genetic Algorithms (GAs), widely used in recent decades by various researchers, are techniques based on

the population, have an objective dynamic function, memory and methods are inspired by nature, unlike traditional methods that are based on research of single point, have an objective static function, have no memory and are not inspired by nature.
In particular, GA have demonstrated good performances in lot sizing issues (Macchiaroli and Riemma 2002), also in presence of space and budget constraints (Yang and Wu 2003).
The main parameters of the genetic algorithms are numerous and known from the literature thanks to many articles such as in Dowsland (1996) and to several books as in Mitchell (1998).

The principal steps of the GAs are:

1. The choice of an initial ***population***, namely the first set of possible solutions, is generated randomly. Each individual of the population is known as chromosome representing a possible solution to the problem and evolves through the iterations called generations. The size of the population can vary considerably according to the kind of problem.
2. The ***fitness function*** is used to measure the goodness of the founded solutions at each iteration, the individuals are tested, are given them a value that will be considered in subsequent phases and will allow to the algorithm to move toward the best solution.
3. The ***fitness scaling*** converts the raw scores returned by the fitness function, in values, in a range that is suitable for selection.
4. The ***selection*** chooses at each generation the most promising solutions to create the next population of solutions.
5. The ***reproduction*** determines how the GA creates the children at each generation: from two parents, GA creates a child who will have similar characteristics to the parents and, therefore, later, it is appropriate to apply techniques of crossover and mutation.
6. Through the ***mutation*** is possible to make small random changes in the individuals of the population in order to have a wider genetic diversity and to allow for a broader search space of the solutions.
7. The ***crossover*** combines two chromosomes to form a new one for the next generation.
8. The process of generation of populations is repeated until a ***stop condition***, set by the user, is reached (for example, it is reached the maximum number of generations or is exceeded the imposed temporal/economical limit, etc.).

4. THE PROPOSED PROCEDURE

In this section we propose a specific genetic algorithm to obtain an optimal solution for the JRP with warehouse-space constraints.
Due to the large number of available techniques for each step described above, several configurations could be used for the genetic algorithm and, for this reason, an experimental analysis, based on the ANOVA technique, was conducted in order to investigate the effect of the most influencing parameters and to identify the optimal configuration of the proposed procedure: it is necessary to set properly control parameters so that GA is able to search for good solutions.
After this analysis has been performed, the techniques for each step were chosen and the parameters have been established for the best configuration.

1. The ***population size***, in this case, was set equal to 50 individuals after a series of tests carried out firstly with 20 individuals and then with 100 and 200, and it was found that if it increases the size of the population, it does not significantly improve the results in a meaningful way, but rather the duration of the algorithm for the research of the optimal solution, growths appreciably; instead, if the population is too small (20 chromosomes) there is little variability of the possible solutions and then there is the risk of not finding the correct solutions for the specific case.
2. The ***fitness function***, subsequently implemented in MatLab 7.9 and explained by the flow chart in Figure 3, was built specifically for the JRP with space constraints, assumes the values of initial quantities for each item and searches, in every generation, those that lead to the minimization of the maximum peak.
3. The technique used for the ***fitness scaling*** is called “Shift Linear”, namely scale raw scores so that the expectation of the stronger individual is equal to a constant multiplied per an average score: during each generation chromosomes are evaluated using the fitness function;
4. The technique used for the ***selection*** is the so-called “Remainder”, that assigns a parent from the integer part of each individual’s scaled value, while the rest of the parents are chosen stochastically by the fractional part of the scaled value (for example, if the scaled value of an individual is 2.3, that individual is listed twice as a parent, while the probability that other additional parents will be choose for the next generation is proportional to the fractional part, in this specific case to 0.3);
5. As for the ***reproduction***, in this case we have established, as suggested by the literature, that 5 individuals of 50 (10%) of the new created population have direct access to the next population (formed at the subsequent generation) because they are considered the best, while it is necessary to apply mutation and crossover techniques to the remaining population;
6. The utilized technique for the ***mutation*** is the so-called “Uniform”: the value of the gene is replaced with the uniform value between the minimum and the maximum specified for that gene: through mutation, the small changes in individuals are carried out according to a random mutation probability p_m established equal to 0.05;
7. The ***crossover*** probability p_c was established equal to 0.8. The used technique is called “Scattered”, which involves creation of a random binary vector and the genes of the first parent are inserted in the above-mentioned binary vector if it present the number ‘1’,

otherwise, if there is the number ‘0’, the genes of the second parent are inserted: so, by these two parents, will born the new chromosome;

8. In this case, the established ***stopping condition*** is the number of generations equal to 300, exhaustive number allowing convergence to optimal solutions.

Figure 3 schematizes the logic of the model created and subsequently implemented in MatLab that represent the fitness function of the proposed GA.

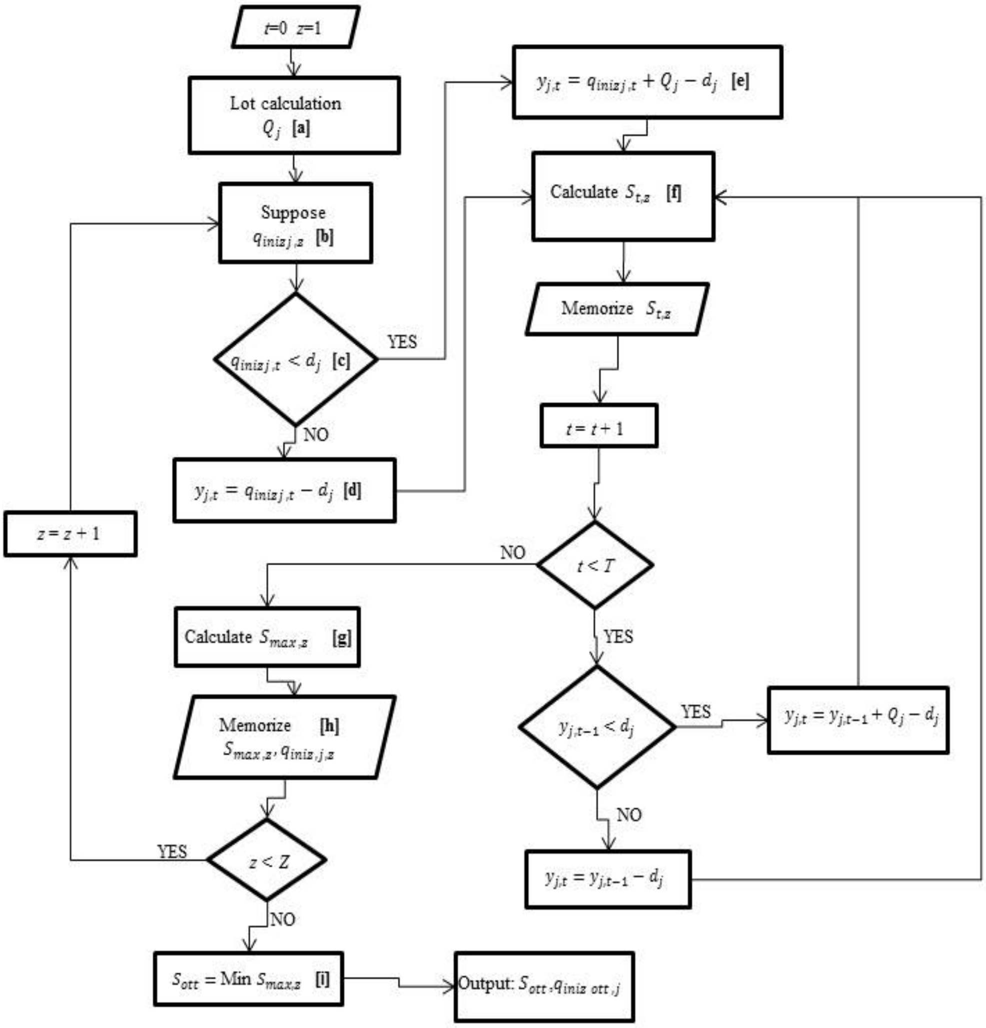

Figure 3 – Flow chart of the proposed fitness function

The model needs in input the number of items, the required unit space for each item, the daily demand, the Time Between Orders (*TBOj*) for the *j*th item and the time horizon *T*. Once this information is known, it is possible to calculate the EOQ for each item **[a]** using the following formula:

$$Q_j = d_j TBO_j \qquad (6)$$

where Q_j represent the EOQ which must be ordered for the *j*th item. Consider that *z* represents the subscript of each GA’s generation, and that the total number of generations (*Z*) is equal to 300, as mentioned before.

The model must hypothesize randomly the values of the initial quantities **[b]** for the first generation (z = 1) and for each item that are included within the lower and upper limits:

$$0 \leq q_{iniz,j} \leq Q_j \qquad (7)$$

Based on the presumed values, it will have a certain inventory trend: as long as the initial stock $q_{iniz,j}$ can satisfy the demand d_j **[c]**, then it is unnecessary to order Q_j, and the present quantity in the second day, $y_{j,t}$, will be equal to $q_{iniz,j} - d_j$ **[d]**; when the demand of the *j*th item is greater than the initial quantity, then order Q_j, that will add up to the remaining quantity of the *j*th item, namely $y_{j,t} = q_{iniz,j} - d_j + Q_j$ **[e]**; at this point, the algorithm calculates the space occupied by the items **[f]** according to (4) which will be particularized considering also the subscript z for the number of generations and, consequently, becomes:

$$S_{t,z} = \sum_{j=1}^{N} s_j \times y_{j,t} \qquad (8)$$

for $t = 0,1,\ldots,T$ $j = 1,2,\ldots,N$ and $z = 1,2,\ldots,Z$

Then the heuristics memorizes this value. From the later instant of time, and until the last day of the required time horizon, the procedure is repeated; when the condition $t > T$ occurs (whereas $T = 220$ days, it will have as a result 220 spaces calculated for each generation), the algorithm calculates the maximum occupied space **[g]** according to (5) but particularized with the subscript z as follows:

$$S_{max,z} = \max S_{t,z} \qquad (9)$$

The algorithm stores both the peak $S_{max,z}$ and the value of the initial quantities that have brought such peak **[h]**. Until $z \leq Z$ the entire procedure is repeated and new initial quantities are assumed, according to (7) and to the established parameters for the GA configuration with the aim to hypothesize, at each generation, new initial quantities that lead to a maximum peak $S_{max,z}$ equal or lower than previous one ($S_{max,z-1}$). When the condition $z > Z$ occurs, **[i]** the algorithm shows its best solution corresponding to the minimum required space S_{ott} given by:

$$S_{ott} = min\, S_{max,z} \quad \text{for } z = 1,2,\ldots,Z \qquad (10)$$

and the corresponding initial quantities that led to this value: then, as the algorithm is structured, S_{ott} will coincide to S_{max} of the last generation.

5. GA VALIDATION AND APPLICATION

5.1. Validation

Until this time, many heuristics or procedures have been tested on the MBRE (whose data are shown in Table 2), achieving large improvements: for example, the algorithm developed by Moon, Cha, and Kim (2008), implemented on the MBRE, shows a reduction of the maximum peak equal to 24.06% compared to the case without offsetting while the MBRP applied to the MBRE has led to a reduction of 15.46% compared to the same case without offsetting. In the same way, the algorithm implemented in this paper was applied to the MBRE, obtaining a huge reduction of the maximum peak in the time horizon.

Table 3 reports the results obtained in the case without offsetting, with the application of MBRP, Moon et al.'s procedure and, finally, the proposed algorithm, showing that in the first three cases the maximum peak in the time horizon always occurs at the initial instant while with the application of the developed GA, the maximum peak occurs on day 42 and is equal to 700m^3 with a reduction of 32.37% (compared to the case without offsetting). This percentage is obtained thanks to the values of the initial quantities, indicated in Table 3, leading, consequently, to the shown values of $y_{j,42}$, and then to the maximum peak of 700m^3.

Figures 4, 5, 6 and 7 show respectively: the trend of the total warehouse required by the items without offsetting (the classic EOQ model), in the case of application of MBRP, Moon et al.'s procedure and, finally, with the application of the GA developed in this paper. In the last case it is interesting to note the significant reduction of the maximum peak in the stock and the evident increase of the regularity of the saturation. Moreover, it can be noted that in these figures only the trends for the first 50 days are reported because these are considered sufficient for the understanding of the trends which, after that moment, present a similar behaviour.

Table 2 – Data of MBRE

Item j	1	2	3	4	5	6	7	8	9
$s_j Q_j$	100	200	81	144	150	160	90	60	50
TBO_j	4	5	9	12	15	8	6	12	2

Table 3 – Comparison with literature

	Without Offsetting	MBRP	Moon et al.'s Procedure	The Proposed Procedure	
Item	$q_{iniz,j}$= max peak	$q_{iniz,j}$=max peak	$q_{iniz,j}$=max peak	$q_{iniz,j}$	$y_{j,42}$= max peak
1	100	100	100	50	25
2	200	160	200	40	200
3	81	81	72	63	18
4	144	144	84	36	120
5	150	150	120	82	122
6	160	120	120	80	60
7	90	75	60	75	90
8	60	20	5	40	15
9	50	25	25	25	50
Sum	1035	875	786	491	700
Reduction	-	15.46%	24.06%		32.37%

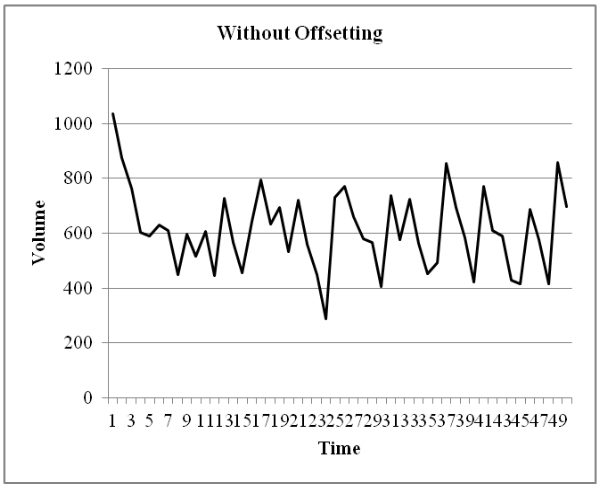

Figure 4 – Trend without offsetting.

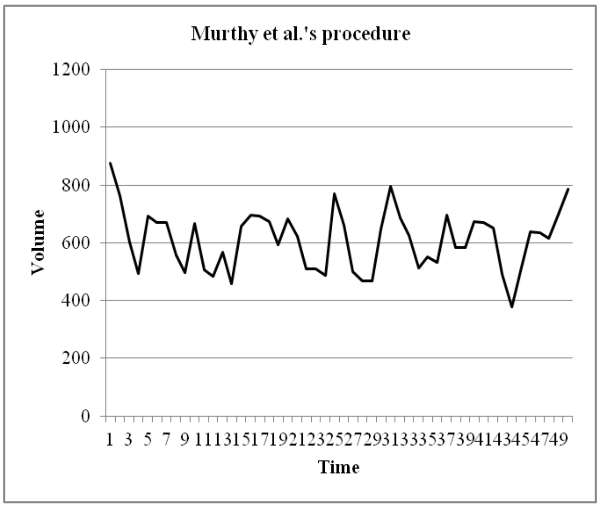

Figure 5 – Trend with Murthy et al.'s procedure.

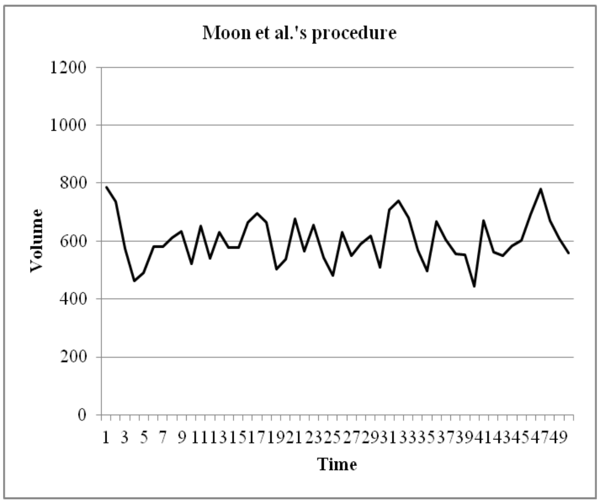

Figure 6 – Trend with Moon et al.'s procedure

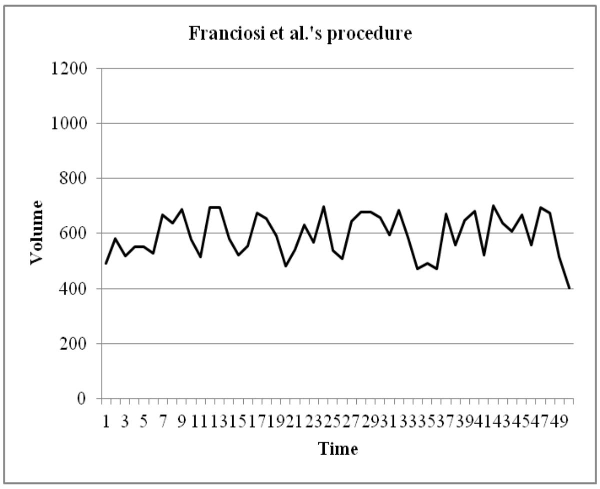

Figure 7 – Trend with the proposed procedure.

5.2. Application

After its validation, the proposed heuristics was applied to a case of a production system operating in the engineering sector which manages 200 items in warehouse that has a volume capacity of 21.000 m^3 and, then, this value will represent the space constraint. Table 4 indicates the range of values in which the characteristics of the items are included.

Table 4 - Characteristics of items

Characteristic	Measure Unit	Range
Daily Demand (d_j)	units/day	1÷100
Ordering Cost (Cl_j)	€	50÷100
Holding Cost (k_j)	€/(unit*day)	0,001÷0,05
Specific Volume (v_j)	m^3/unit	0,001÷1
Purchasing Cost (p_j)	€/unit	1÷100

Initially, the EOQ model is applied to this case, the individual cost of the items, the total cost and the maximum peak are calculated (see Table 5), noting that the peak occurs at the initial instant, as shown in Figure 8, and the space constraint is violated.

Table 5 - EOQ model's costs and max volume

Cost Type	Value
Purchasing Cost (€)	113.840.980
Ordering Cost (€)	274.974
Holding Cost (€)	274.990
Total Cost (€)	114.390.944
Max Volume (m^3)	32.507

With the application of the GA, on the contrary, the costs remain almost constant (consider only an extra ordering cost for the initial hypothesized quantities that is negligible compared to the total cost), while the maximum peak is significantly reduced (see Table 6).

Table 6 - GA’s costs and max volume

Cost Type	Value
Purchasing Cost (€)	113.840.980
Ordering Cost (€)	274.974
Extra Ordering Cost (€)	3.253
Holding Cost (€)	274.990
Total Cost (€)	114.394.197
Max Volume (m^3)	20.020

Such peak does not occur at the first day, as indicated in Figure 8: in this way the space constraint is respected. From the Figure 8, that shows the trend of the total warehouse required by the items over the time with the application of the traditional EOQ model, the MBRP and finally the GA, it may be noted, moreover, that in the second case the initial peak decreases significantly but the saturation of the warehouse is not much constant because of the initial peak. In the third case, however, the saturation is more regular than the two previous cases, the peak is strongly lower, does not occur at the initial time and allows to respect the space constraint. Moreover, since there will be approximately 1.000 m^3 on average that can be used for possible safety stocks, a better management of the space is achievable.

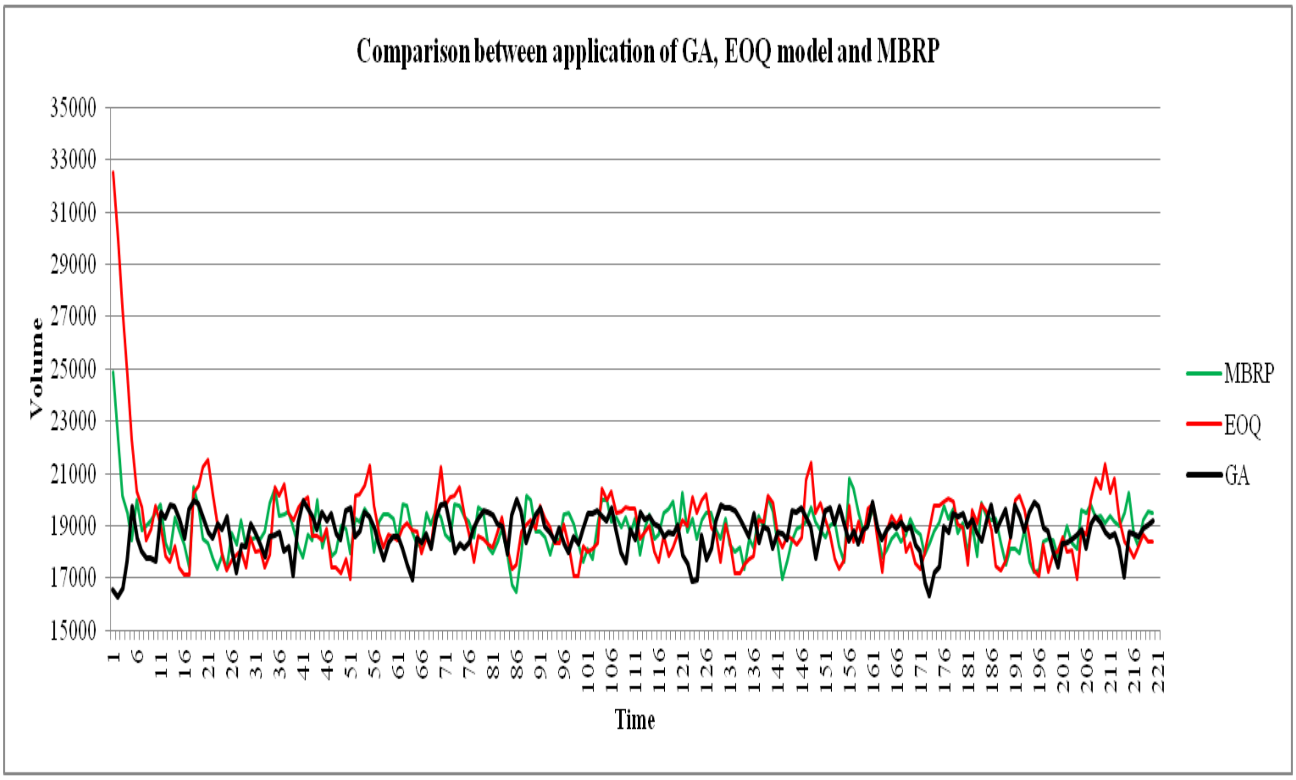

Figure 8 – Comparison between application of GA, EOQ model and MBRP

6. CONCLUSIONS

This paper deals with the joint replenishment problem subject to space constraints assuming constant and deterministic demand rates, instantaneous replenishments, known and constant time between orders for all items and a finite time horizon, which is more realistic than the infinite time horizon.

A genetic algorithm, which allows to calculate the optimal initial quantities required to minimize the maximum peak in the warehouse over the time horizon, has been implemented for the above mentioned problem.

Using the proposed algorithm it is possible to improve the process of inventory management by reducing the maximum peak and maximizing the saturation. GA is able to reduce inefficiencies because the warehouse is better used for the majority of its time, but without excessive peaks and, consequently, very often it can respect the space constraints.

The heuristics has been tested and compared with some procedures previously made available in the literature that consider an infinite time horizon (Murthy, Benton and Rubin 2003; Moon, Cha and Kim 2008), showing better results as regards the maximum peak, which is much lower and not necessarily occurs at t = 0.

The algorithm can be used as a tool to support business decisions as it increases the ability to handle multiple items, avoiding the need to rent additional space. Furthermore, it can be considered as an interesting contribution to the study of the heuristic techniques applied to the stock management issue.

This work represents the starting point of possible future developments: firstly a Design of Experiment with ANOVA will be implemented with the purpose of finding a better configuration of the genetic algorithm and an optimal setting of heuristics’ parameters; secondly the idea of applying other heuristic techniques to the offsetting problem with the aim of comparing the results achieved by the GA could be evaluated. Another possible future development could be the comparison of the proposed GA with procedures that consider a finite time horizon, with the aim of making improvements as regards both the computational time and maximum peak in storage, also in presence of high number of items.

Moreover it is necessary to highlight that the proposed procedure leads to a considerable reduction of the maximum peak in the warehouse, but does not guarantee the respect of the imposed space constraints. For this reason, a further interesting possible future development could be the implementation of a procedure able to minimize the maximum peak in the stock, maximize the saturation and, at the same time, respect the space constraints.

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Clothes maketh the man and the regional mall

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ABSTRACT

The attraction of shopping malls as a retailing structure can be explained by the interrelationships that exist between stores and the benefits these provide consumers. Malls can provide centers or anchors, (department and supermarkets), attractions (fashion, cinema and entertainment) and reasons to prolong a shopping trip (or stickiness, such as coffee, snacks and meals), which benefit in an ecological sense other retailers. In this paper we argue that the importance of attractions (destinations) is crucial for the survival of regional malls.

Keywords: simulation, agent based modelling, malls, regional development, anchors, attractions, stickiness, consumer behavior, retailing

1. INTRODUCTION

Shopping malls, are an important part of any developing and advanced economy. In the United States, for example, there are over 50 000 shopping centers and malls, which contribute an estimated 2.3 trillion dollars in sales to the world's largest economy and account for 75% of all non-automotive consumer sales (Miller & Washington, 2011). Shopping malls are also a feature of many towns and cities around the world. In fact, they are built to international templates: inside a mall in Rio de Janeiro looks just like inside a mall in Sydney or Paris, with the same brands and structure. Thus it is reasonable to suppose that malls have effectively evolved to an optimal layout and balance of retail options (Yuo & Lizieri, 2013).

There is evidence that shopping malls have been slowly disappearing in the developed world. Retail consultant Howard Davidowitz (cited in Peterson, 2014) predicts half of all shopping malls to fail within the next 15 to 20 years. Current estimates also suggest that 15% of all current US malls will fail in the next years and this is reflected in US retailer *Sears* closing some 300 stores since 2010 (Peterson, 2014) and the investment in malls falling in the US from a high 175 million square feet in 2002 to 50 million square feet in 2011 (Miller & Washington, 2011). Malls in lower and middle class areas are expected to suffer the most (Peterson, 2014). The picture in Europe appears a little different, where there remains continued investment in malls, despite concerns about the effects of government austerity and economic conditions (Taylor, 2011). Malls, as do other brick and mortar retailers, also face the global threat of increasing online purchases by consumers (Book Publishing Report, 2012; French, 2013; Speer, 2012).
While the economic impacts of malls are well understood, malls can also provide community benefits in regional areas:

- They provide a destination, especially in regional, or poor neighbourhoods, where other leisure options might be limited (West & Orr, 2003).
- They provide retail and service jobs with additional support jobs in mall management and maintenance (Bernat, 2005).

- They may contribute to a sense of well-being and satisfaction of consumers (El Hedhli, Chebat, & Sirgy, 2013).

Note that these community benefits, have lead some commentators to suggest that regional malls are commercially more viable than those in urban centers, partly because of their different structures and their fostering of consumer loyalty (Bodamer, 2011).
Given these community and economic benefits, there is need to investigate how regional shopping centers can be designed to attract and retain consumers so that a greater amount of purchases occur locally. The research also sought to understand the drivers of mall structure and the threats it might experience. This paper outlines a simulation model based on data from malls in Australia in regional and big city environments. We find that there are tipping points of mall survival based on the mix of attractions (destinations effects) and retention (coffee shops and food outlets), when compared to the option of purchasing online. Our preliminary results suggest the importance of fashion outlets as attractors of consumers to malls, which is mirrored in the occupancy statistics we collected. The danger, we caution, is that the consumers of fashion, especially Gen Y and young consumers are being drawn to online purchases, and without such a group's patronage, malls in both regional and urban centers may come under significant threat.

2. LITERATURE REVIEW

2.1. Choice of channel: Traditional channels versus online retailing

The choice between online versus traditional retail bricks and mortar buying behavior has been a topic of much debate over the last decade. The research has focused on the explanation of the migration to online, away from traditional retail purchases. Reasons for purchasing online rather than in-store include convenience (Rohm & Swaminathan, 2004), lower prices (Junhong, Chintagunta, & Cebollada, 2008) and greater choice (Liu, Burns, & Hou, 2013). Factors which inhibit online purchasing are; risk of fraud (Huong & Coghill, 2008), lack of trust (Toufaily, Souiden, & Ladhari, 2013) and the presence of incomplete information about the retailer (Dennis, Jayawardhena, & Papamatthaiou, 2010).
Because of the perceived risk of fraud, the need to develop trusting relationships with online retailers in an arena of incomplete and misleading information, consumers rely on word of mouth (WOM) and online reviews more than they do for traditional retailers (Utz, Kerkhof, & van den Bos, 2012). Related to WOM, is the role of social norms of behavior. That is, consumers see online retailing as becoming more useful and easier to use, because of the beliefs and actions of others (Činjarević, Tatić, & Petrić, 2011; Pavlou, 2002; Pookulangara, Hawley, & Xiao, 2011).
Consumers do not only decide to use one channel of distribution (online versus brick and mortar retail) for all aspects of decision making. There is emerging evidence that consumers may use some channels to search for information such as online for prices and product availability (often called 'webrooming'), see (Anderson, Fong, Simester, & Tucker, 2010; Sands, Ferraro, & Luxton, 2010) and for others, use retail stores for purchases and deliveries (Chatterjee, 2010; Tuttle, 2013) The deciding factor as to whether the final purchase is made online or offline, appears to be the expertise and the fulfillment of gratification of consumers (Boyer & Hult, 2006; Činjarević et al., 2011). Consumers, who use traditional retailing as delivery or purchase points, can have a faster gratification of needs and wants than consumers who have to wait for delivery, and also may experience less risk since they are purchasing or receiving product or services through more traditional channels. There is also a risk for online retailers that a failure to deliver a product or service within a specified time can lead to greater consumer anxiety and smaller future order sizes (Rao, Griffis, & Goldsby, 2011).

2.2. Consumer behavior within a shopping mall and the mall as an ecosystem

While the growth of online purchasing has received considerable attention by researchers, as alluded to earlier, many consumer decisions still take place in more traditional retail formats such as malls. Malls themselves are significant attractors of consumer patronage, especially in developing economies, where they represent the advent of progress and western mystique (Arslan, Sezer, & Isigicok, 2010). One could also argue that malls provide people in rural and regional areas, experiences and access the consumer lifestyles of the bigger cities. Research suggests that the reasons consumer like to go to shopping malls include: comfort, entertainment, diversity, mall essence (or atmospherics), convenience, and luxury (Ammani, 2013; El-Adly, 2007). Other studies have conceptualized the mall experience of consumers as being either seductive, acting as interactive museum, a social arena, and functional means of obtaining of goods and services (Gilboa & Vilnai-Yavetz, 2013). Mall attendance has also been linked to a personality trait of fashion orientation (Michon, Chebat, Yu, & Lemarié, 2015). Research from India, suggests that anchor stores (supermarket and department stores), or one stop shopping, are an important driver for mall patronage (Swamynathan, Mansurali, & Chandrasekhar, 2013).
There are also benefits (increased traffic and complementary sales) for other retail chains collocating with anchor stores in shopping centers. Importantly, these benefits outweigh any increased competition from similar stores (Vitorino, 2012). This led some researchers to argue that the tenant-mix of types of stores (anchors and attractors) can be viewed as an ecosystem, where there are symbiotic relationships between different types of stores (Yiu & Xu, 2012). Importantly,

smaller stores, which may pay more rent per floor-space area have been shown to benefit from a "free rider" effect and access to externalities available to them in a shopping mall (Carter, 2009, p. 177). Other stores which provide benefits to consumers, and help retain them longer in malls are food and beverage outlets. US research suggests about 7% of consumers go to malls primarily for food and these venues encourage consumers to stay on average an extra 45 minutes in a mall, and will double their spend to an average of $98.40 per trip (Miller, 2011, p. 112). It would therefore seem that the success of a mall depends on the interrelationships between three types of stores:

- Anchors (which attract consumers to the mall for functional reasons, such as grocery shopping and help generate mall traffic and externalities.
- Attractors (fashion and speciality retailers) which attract consumers for more discretionary spends.
- Retainers, such as coffee shops and food outlets, which make the consumer stay longer in the mall and so increase their discretionary spend.

The next section of this paper outlines the design of the simulation to examine what combinations of these factors make a sustainable retail ecosystem.

3. METHOD

3.1. Preliminary analysis on retail structure

We collected data on regional and suburban malls from two mall chains in Australia, the *Stockland* and *Westfield* chains. The information was downloaded from the respective websites of the chains at: http://www.stockland.com.au and http://www.westfield.com.au/. Regional malls are typically an order smaller than suburban and urban malls. Figure 1 shows the distribution of retailers in ten regional malls as compared to a suburban mall. Being designed around the department or "anchor" stores, regional malls have 0-3 department stores, while a standard suburban mall might have 5 or more department stores. As can be seen from Figure 1, the number of specialist retailers in a mall scales with the number of department stores.

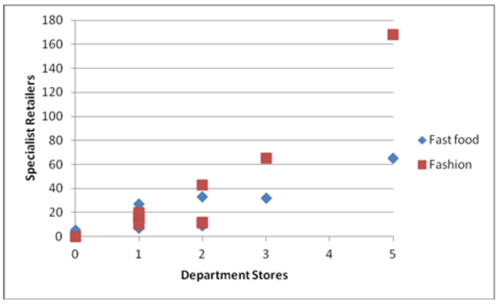

Figure 1: Distribution of specialty and department stores in malls

3.2. Simulation Model

An Agent Based Model (ABM) based simulation was constructed of a regional mall based around the mall designs from Stockland and Westfield mall chains examined in the previous section. Only two department stores were placed in the regional mall with 30 specialty stores, which would include "fast food" and coffee chains as well as fashion retailers and service providers such as hair and nail salons, massage parlors, bank branches and other services. A regional mall would not typically include the more extensive entertainment services that would be seen in a suburban mall, such as cinema complexes or gyms. .This model simulates the choice of consumers whether to purchase a particular product through a bricks and mortar store or through an online retailer. For simplicity we assume that the customers make such a choice for each type of product. Different products are accommodated by altering parameters in the model to produce a prediction of the social norm for retailing choice for each product.

3.2.1. Customers

The customers are represented by an agent, denoted i. Customers are randomly connected to other customers and exchange information about their retailing experiences through these social networks. The more links within the networks of customers the more effectively information about retailing alternatives can pass through the customers. The probability of agent i linking to another agent is given by the parameter η, which is randomly calculated for each agent.

Each time step t, there is a chance that the agent will perceive a need to make a purchase. The agent then chooses whether to purchase the product from the bricks and mortar retailer at a mall (BMR) or the online retailer (OR). The retailing choice of customer i at time step t denoted $c_i(t)$ depends on its experience $x_{ij}(t)$ with the j being one of the categories of retailer (BMR or OR).

We assume the probability of choosing between the option of shopping from a retailer at a mall or an online retailer is a logistic function of the customer's levels of past experience with the retailers. The probability of customer i choosing BMR at time step t is then:

$$P\{i\ chooses\ BMR\} = \frac{e^{\beta(x_{i,BMR}(t) - x_{i,OR}(t))}}{1+ e^{\beta(x_{i,BMR}(t) - x_{i,OR}(t))}} \qquad (1)$$

This logistic equation is in common use in studying choice in economics (McFadden, 1974) and in marketing. The beta parameter controls the degree of noise in the model. When beta is zero, all options have equal likelihood. As beta increases, one choice (the higher experience or utility) increases in probability eventually excluding the alternative choice. The probability function (Eq. 1) arises naturally as the equilibrium solution to a variety of equations, such as the Fokker Planck diffusion equation and classical thermodynamics (Solé, 2011).

After the calculation of all the customers' experiences, the customers then share the experiences across their social networks. To calculate the sharing of information about retailers, each agent calculates a weighted average of their own experience with each type of retailer this time step with the experience of each of their network neighbors. The weight given to the neighbors' experience is α ϵ [0-1].

3.2.2. Department stores and specialist retailers

To simplify the simulation we assume only two types of retailers at the mall, department stores and specialist retailers. All department stores are retail destinations, so can initiate an agent's visit to a mall. For the specialist retailers, only a portion are retail destinations, which might be a hair salon or a gym and thus might be able to initiate an agent's decision to visit the mall, but the majority are coffee shops or fast food stores and are assumed to only generate impulse purchases from customers passing by the store on the way to their intended retail destination.

This ability of some stores to generate purchases from passing customers is what we call "stickiness". However this feature of malls is critical to their designs, which generally force customers to travel past multiple other retailers on their path to their intended destination at the mall. We assume that the number of impulse purchases customers make while in the mall is an important consideration in their choice to visit the mall.

3.2.3. Environment

Figure 2 shows the details of the mall environment with the regional mall pictured in the upper half of the environment and the regional community pictured in the lower. The social network of the agents is represented by lines joining other agents.

The mall is composed of two department stores: the larger house symbols colored red and blue. The retail specialists represented by the smaller house symbols colored in yellow. Each time step, there is a chance of an agent visiting the mall. For a visit the agent is randomly placed in the mall entrance area- the grey area between the mall and the community- and then the agent travels towards the retail destination which initiated the shopping trip. As the agent travels to their chosen destination retailer, either a department store or one of the destination specialist retailers, the agent may come within a maximum distance of a specialist store or a department store. There is a chance, determined by the stickiness of the retailer and department store, that the agent will make a purchase with that store which was not the intended destination for the agent's visit to the mall. The agent then makes a purchase, incrementing the resources of the store.

When the agent reaches their destination retailer, the agent makes the purchase which was the initiation of the shopping trip, increasing the resources of the store and is then returned to the community. The number of transactions- both intended and impulse- that the agent made on the shopping trip then determines the agent's experience of the shopping trip, which the agent then shares with their social network on returning to the community. The greater the number of purchases at the mall, the better the experience and thus the more likely an agent and the agent's social network is to return to the mall on future time steps. Thus stickiness has a benefit to an individual store by generating a purchase, but also a benefit for all other retailers by increasing future visits to the mall.

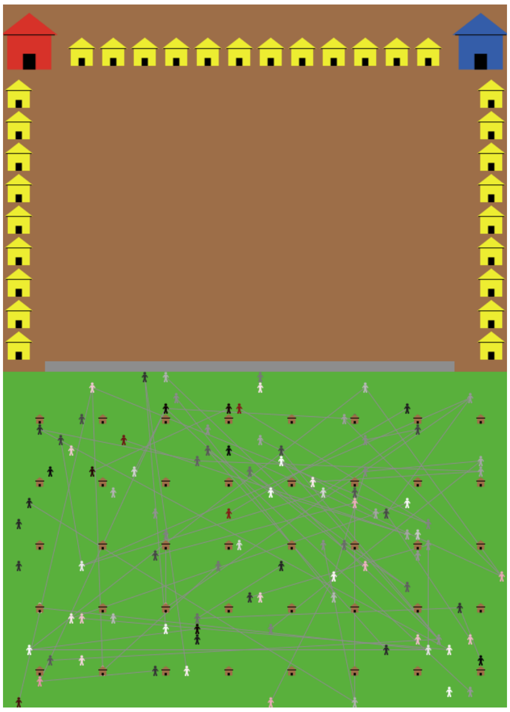

Figure 2: Environment of the simulation

3.2.4. Simulation values and methodology

The ABM was created in *NetLogo* (Wilensky, 1999). In this version the only agents are the consumers, who all buy the same product, but choose between OR and BMR. The number of consumers is set at 100. The customers' initial levels of experience of the two categories of retails are randomized. The levels of the other parameters for the simulations are presented in Table 2 (see results of simulation runs).

Table 1: Model parameters and their values

Parameter	Symbol	Value
Probability of forming links with other customers	H	0.7
Degree of noise in customer decision	B	[0..100]
Importance of social network information	α	0.5
Average stickiness of specialist retailers		[0...1]
Number of specialist retail destinations		[0...30]

We simulate various designs of a regional mall by varying the parameters which we assume a mall manager might have some control over, being the types of stores put in each location (the number of destination retailers chosen, as well as the average attractiveness/stickiness of specialist retailers in the mall).

4. RESULTS

Table 2 and Table 3 show the results of simulations in each of the models for differing designs of the regional mall. For each level of average stickiness and number of destinations, the average number of surviving specialist retailers (out of 30 original retailers in the simulation) for 50 runs is presented. As can be seen from Table 2, the number of surviving specialist retailers increases in the number of retail destinations as well as the average stickiness of the retailers. There is also significant complementarity among the specialist retailers so that at low levels of average stickiness even being a retail destination is not a guarantee of survival, while at high stickiness many of the retailers which are not destinations survive, as well as the destination retailers.

Table 2: Results of the simulations: Number of surviving specialist retailers out of 30 originals, β=2

	Average stickiness of specialist retailers			
Number of destinations	**0.1**	**0.3**	**0.5**	**0.7**
1	1.9	6.5	9.5	12.0
4	4.5	8.4	12.4	15.4
7	6.7	10.6	14.2	17.5
10	6.7	11.4	15.6	18.9
13	6.5	11.5	15.9	19.4

Table 3 shows the effect of a rise of the β or noise factor in the decision of consumers between shopping at the mall and shopping online. It can be seen from Table 3 that a rise in β leads to a decline in the average number of surviving specialist retailers.

A higher β means that consumers have less randomness in their decision between the two options and are thus more likely to make the decision based on the past shopping experiences and other known factors. Assuming that the online option is cheaper, one interpretation of a rise in β is that it represents a fall in income, which makes consumers more price-conscious. A fall in customer incomes leads to a drop in the average number of surviving retailers in the regional malls.

Table 3: Results of the simulations: Number of surviving specialist retailers out of 30 originals, β=20

	Average stickiness of specialist retailers			
Number of destinations	**0.1**	**0.3**	**0.5**	**0.7**
1	1.5	5.3	8.5	10.8
4	4.3	7.5	10.9	14.12
7	5.4	9.2	13.0	16.14
10	5.4	9.4	13.7	16.9
13	5.2	9.8	14.4	17.8

5. DISCUSSIONS

As we noted in the introduction, shopping malls are an endangered species. The simulation model demonstrates that the number of sticky shops (fashion etc) increases nonlinearly with mall size, where the indicator of mall size is the number of big anchor stores.

The tipping point in a mall's survival is an interesting mixture of positive feedback and other factors related to the mall strategy in terms of activity balance. If the mall experience declines, more shops will go bankrupt, making the experience decline even further. Without the specialist retailers (fashion etc), the mall will have very few shops, the anchor stores will pull out and the mall will close. But the specialist retailers may be exploited by the mall management, paying higher costs, both in rent, and in profit creaming. The mall can respond to this type of positive feedback effect, by reducing costs and adding incentives for the stickies, if the numbers start to decline, and there is already evidence of this occurring. A more dire situation is if the tipping point is a second order phase transition; such transitions, as for example in stock market crashes (Bossomaier, Barnett, & Harre, 2013).The essential feature of such tipping points is that a lot of information flows among the agents which make up the system, then everything goes quiet, and the system falls over (Harré & Bossomaier, 2009). The challenge, still an open research question for complex systems in general, is detecting and acting, before the system goes quiet.

So, given the social context of malls, especially in smaller communities, what can be done? The indications from the simulation model, are that the number of honey pots needs to be a higher proportion of the total venues, than in the biggest premium malls. One strategy is the *deus ex machina* fusion of clothes with food and other things, combining stickiness and destination effects. Other mixed mode offerings might include free internet access, and mixed-mode retailing which combines web-browsing and bricks and mortar retailing like the searchable mall concept of Westfield.

Other honey pots might include child play areas (such as McDonalds have already introduced), and entertainment areas. Cinemas may require a threshold mall size to be viable, but there could be options in terms of games rooms, ranging from multi-player computer games to card and board games for seniors.

An additional, important consideration is the way the mall tipping point is very sensitive to the β parameter. At high β values, low noise, the tipping point as a function of number of honey points is sharp. But low noise corresponds to reduced money, or reduced willingness to explore and take risks. Thus as economic conditions decline, the mall may rapidly enter a domain, where it could go over the tipping point with little warning and opportunity to take ameliorative action.

The evidence, though, from the simulation model is clear: malls need to be proactive in generating new strategies to ensure their survival. Is the future in the US one of discount malls and premium malls only?

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A MULTIMODAL APPROACH TO SIMULATION FIDELITY

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ABSTRACT

A process oriented view of a multimodal approach to simulation fidelity is discussed in the context of system verification and validation in industry. An overview of classical simulation product development is given and the problem of developing models through the inclusion of simulation objectives is presented in terms of this process. A multi modal approach for improving the syntactic fidelity of simulation by using meta-modeling techniques and semantic web principles is presented in an operational context. The domain model is briefly presented and a concept of operating mode is proposed in the model teleological framework of Structure, Behavior, Function and Interface. The relation with the study of formal techniques on semantic or behavioral fidelity is briefly discussed along with an overview on the challenges ahead and future work.

Keywords: *modeling, simulation, abstraction, process, verification and validation, fidelity, ontology*

1. INTRODUCTION

Modeling & Simulation (M&S) is being widely used as a means to conceive, develop and test complex engineering systems. In using M&S as a means for the system Verification & Validation (V&V), often the difficulty is finding and implementing abstractions of the system being simulated with respect to the simulation requirements. Such difficulties gives rise to the problem of simulation fidelity i.e. the effectiveness of simulation in reproducing the reality. However in system validation through simulation, this fidelity requirement is seldom expressed even if the context of use is well known. The effectiveness of simulation in reproducing the reality i.e. realism of simulation, motivates an important question of how to quantify the distance between a system and its simulation with respect to its V&V objectives along the product development cycle? This Paper briefly addresses this problem of fidelity in simulation for system V&V in the industrial context.

The paper is structured as follows; the concept of simulation fidelity is explained in the context of system V&V followed by a brief description of simulation product development in industry. A process oriented view on improving the syntactic fidelity of simulation by using meta-modeling techniques and semantic web principles with some illustrative concepts is presented. The relation with the study of formal techniques on semantic or behavioral fidelity is briefly presented along with a discussion on challenges ahead and future work.

2. SIMULATION IN SYSTEM V&V

In the context of systems engineering, Verification and Validation determines the compliance of simulation products with their specifications and fitness for their intended use respectively. V&V activities are usually illustrated in the classical V cycle as seen in figure 1 and this cycle can be broadly classified into two parts. The left branch of the cycle corresponds to design V&V where the system is virtual i.e. under construction and the right branch corresponds to product V&V where the system is physical i.e. built. Simulation is used to perform V&V of the specification and the design of the System Under Test (SUT) in the design verification phase, and of the integrated configuration and the SUT operational environment in extreme conditions, such as failure, in the product verification phase.

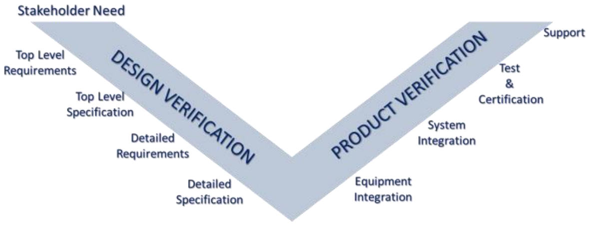

Figure 1 : System V cycle

Simulation is being increasingly used in complex system development due to its significant advantages in cost, time, safety, design tradeoff etc. However, as the systems are getting more complex so do the M&S activities. Even with the advent of powerful computing resources, the sheer complexity of phenomena to be modeled in addition to non-technical factors such as lack of rigorous and standardized process makes M&S activities challenging. There is neither an agreed standard to define or measure this complexity of model, nor a methodology for model developer to choose it [Brooks,1996].

The confluence of control, communication and computing results in cyber physical systems which are becoming ubiquitous especially in transportation systems. In V&V of avionics systems, a subclass of cyber physical systems, different modeling paradigms are being used and it is important to incorporate a multimodal approach in M&S of such systems. In addition, there is a problem of heterogeneity due to different modeling formalisms used by different stakeholders. It leads to interoperability issues especially the during model integration phase. Since simulation itself is a complex product whose development involves multiple stakeholders, resources such as IT, Platform etc., a rigorous Model Based System Engineering (MBSE) approach is needed to seamlessly develop and deploy simulation products for system V&V. The current paper is focused on an engineering process perspective on modeling and it serves as a compliment to [Ponnusamy,2014], where an MBSE approach in model assembly, integration and simulation was discussed in the context of avionic system V&V. In [Ponnusamy,2014], meta-modeling techniques were presented to develop a standard framework for information interchange and for making the domain assumptions explicit through the use of ontologies.

2.1. Simulation Fidelity

A general overview of this fidelity problem and a proposition for its formal assessment based on the structural and behavioral aspects is addressed in [Ponnusamy,2014] & [Ponnusamy,2015]. Ascribing a distance notion to the effectiveness of model in reproducing the required reality, fidelity is defined as ‘distance to reality’. It has been long acknowledged in the M&S community that models are usually verified but seldom validated rigorously. In other words, the context of usage is not explicitly taken into account during the modeling process. Consider figure 2, where system V&V through simulation process is illustrated with associated stakeholders.

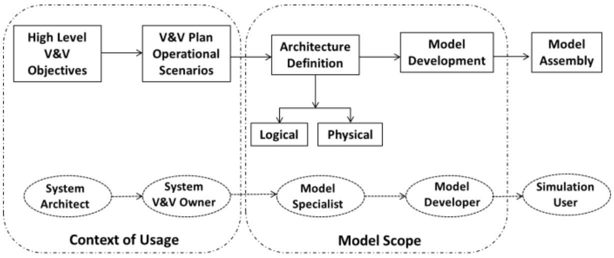

Figure 2 : Simulation Model Development Overview

A top down development of system commences with requirement collection from customers and refined to a system development and its V&V schedule by the programme management. System architect defines overall architecture and high level V&V objectives for the integrated system i.e. System of System (SoS). This drives the individual system development and the corresponding V&V plan definition i.e. operational scenario. This system definition by system designer and its V&V plan by simulation user i.e. system V&V owner serves as input for model specialist who in turn defines the simulation architecture, both physical and logical. The model functional and performance requirements drive the model development which when developed will be assembled and simulated according to the V&V plan by the simulation user. It can be seen clearly that despite the obvious need to integrate the context of usage into model development such that the model scope includes the intended usage, this proves to be a challenging task in both technical and non-technical perspectives. The distance between the model scope and its intended usage gives rise to fidelity and this phenomenon is further classified [Ponnusamy, 2014] and explained below.

2.1.1. Fidelity Classification

Fidelity can be classified in a myriad ways [Roza,1999] and in this section it is given from a process oriented view. It is classified into designed and measured fidelity which is illustrated in the following figure,

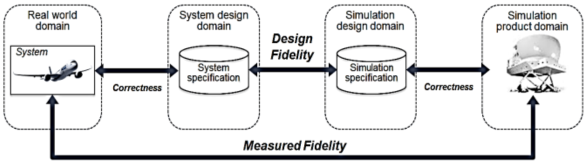

Figure 3: Design & Measured Fidelity

The classical model development process is essentially an iterative process based on measured fidelity approach due to the challenges in complexity, methodology and continuous evolution of product requirements. A paradigm shift to a design fidelity approach where the modeling process is driven by the associated validity requirements will help in better managing the fidelity.

In discussing model or simulation fidelity, the challenges are broadly classified into four groups namely, define fidelity, capture fidelity needs, manage and implement fidelity. The challenges are illustrated on the simulation product development process.

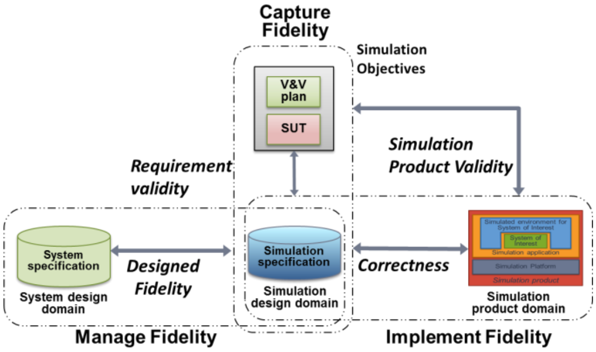

Figure 4: Fidelity Challenges

It can be seen that the requirement validity is defined between the simulation objectives given by the V&V plan over the SUT and the simulation specification, whereas the simulation product validity is defined with respect to simulation product. Similarly the concept of designed fidelity can be seen. The focus of this paper is on capture and manages fidelity aspects as fidelity definitions are already discussed in the preceding section and implement fidelity is arguably a verification problem. In the following section the simulation product [Thebault,2014] and its development process is explained in detail.

3. V&V BY SIMULATION: A PROCESS ORIENTED VIEW

A brief description of the simulation product is given followed by the development process and its relation with the problem of fidelity.

3.1. Simulation Product

A *simulation product* is generally described as a simulation application deployed on a simulation platform, and interfaced with the system of interest. In other words, a simulation product is akin to an Experimental Frame (EF) notion proposed by Zeigler [Zeigler,2000]. The EF defines the controllability and the observability means to stimulate and observe the model behavior in addition to the conditions of experimentation [Traore,2006]. The application of this standard M&S notion in the context of modeling abstractions were discussed in [Ponnusamy,2014] and [Albert,2009].

In general, a simulation product is illustrated in the following figure 5. The interface with system of interest is shown in green.

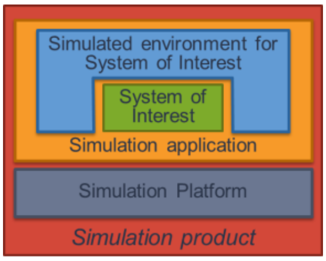

Figure 5: Simulation product architecture

In order to enable such an architecture representation, an internal standard commonly exists in the industry to define a common understanding on how the simulator platform shall execute the simulation application. The simulation application development is based on the knowledge of the operational environment of the system of interest, which is, in the avionics context, composed of equipment whose behaviour is governed by physical laws such as aircraft natural dynamics and other avionic systems.

The *simulation application* comprises a set of standard simulation models and associated configuration files which specify the connections between models, and their scheduling properties.

The *simulation platform* usually consists of an IT infrastructure and the simulation software. The platform schedules and monitors the execution of the models with respect to time constraints of logical or real time simulation. It enables communication between the models and provides the end user with control and observation facilities to operate the simulation [Thebault,2014].

3.2. Simulation Product Development

A simulation product needs to be updated continuously to follow each high level design change and also new simulation capabilities for V&V objectives to the end user. In general, this simulation application development process is performed by simulation platform teams, who consistently interact with the component system developers and simulation users. The simulation application development process is briefly illustrated in the following figure,

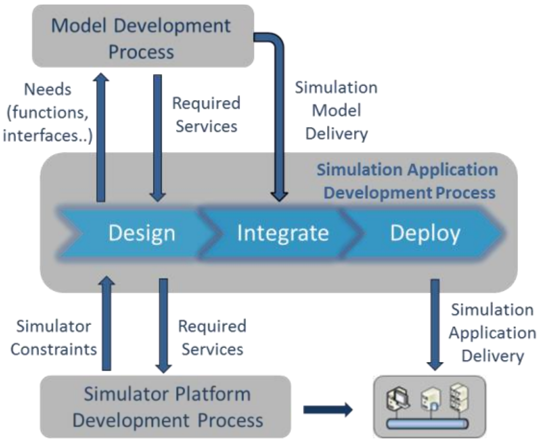

Figure 6: Simulation product development process

It can be seen that the process can be broadly classified into design, integrate and deploy. In the 'design' phase, functional and performance objectives of the simulation models are defined in addition to their interface definition. The second phase, 'Integrate', is model assembly phase to ensure the consistency for its 'deployment' on the simulation platform.

In [Thebault,2014], in a Model Driven Engineering (MDE) framework using SysML, this consistency in 'integrate' and 'deploy' phase are discussed. However, owing to the complex nature of this process, the context of usage is not always captured in accordance with modeling abstraction employed in the 'design' phase. This paper deals with consistency in the 'design' phase using similar such domain model techniques. In the design phase i.e. modeling, models are developed using system knowledge and its context of usage by model developers. This model development usually involves three stakeholders namely model developer, system designer and simulation user. The simulation user is usually the V&V task owner who defines the simulation requirements derived in turn from the high level V&V objectives in terms of functional, non-functional and behavioral requirements. In practice, there is a model specialist who translates simulation requirements and system specification into functional and behavioral requirements of the model to be built. The model developer builds the model based on this requirement using knowledge from existing library of abstractions. The built model assembled and then verified against their requirements by simulation according to the V&V plan. The following section briefly outlines the challenges in selecting modeling abstractions employed in the process which gives rise to the fidelity problem.

3.2.1. Challenges in Modeling Abstractions

A model is essentially an abstraction of reality it is intended to represent and formally it is defined by Brade [Brade,2004] as follows, A model is an abstract and idealized representation of a real system, which reflects all the relevant properties with sufficient accuracy with respect to its intended purpose. The key element in this definition is abstraction with respect to its intended purpose. A model must be built such that it is fit for the intended usage, in other words, it must be valid [Traoré,2006]. Owing to the fact that most of the models are rigorously verified but seldom validated, the onus must be on inclusion on validation objections a priori in model building process. However, there exists no agreed standard or a guideline [Brooks,1996] to choose the level of model complexity owing to the innate nature of problem in quantifying this complexity i.e. abstraction level vis à vis model performance. Some of the other challenges in modeling abstractions are lack of common understanding between the stakeholders, semantic inconsistency, and interoperability [Benjamin,2009].

In addition to the inherent technical complexity of modeling, there exists non-technical complexity in the development of complex systems such as constraints on the time, cost, human resources and infrastructure. In an industrial context, each component systems are developed by different teams often working transversely and transnationally. These component systems interact with each other to perform a Multi System Function (MSF) in an integrated system. For example, '*calculate and display aircraft position*' function is performed by GPS and inertial data system and communicated to Cockpit Display System (CDS) for the pilot's view. However, identification of functional contribution of each such system to MSF could be difficult and this equally true for identification of simulation requirements. Thus, formalization of such system functions and test objectives is often a tedious task for the system designer and simulation user respectively.

This is compounded due to the lack of a consistent derivation of low level V&V requirements from high level V&V objectives as illustrated in the figure 2. The requirements traceability between these two domains is seldom one-to-one and the inclusions of low level requirements in the high level requirements are traditionally managed by heuristics, domain expertise, margins and experience. This issue permeates down to all phases of the V cycle and often the model architect who defines abstraction rules to be implemented by the model developer faces a difficult choice of selecting abstractions consistent with its V&V objectives. This not only leads to model validity problems at the simulation runtime but also to over specification and sub optimal design and development. These challenges necessitates a domain model approach which mitigates such problems and enable a common understanding by making domain assumptions explicit and separate domain knowledge from the operational knowledge. Ontologies, in addition to classical MBSE tool such as SysML, serve as a good candidate due to their standardization in terms of OWL language, scalability, query capability and availability of tools such as Protégé[1]. However, ontologies have limitations in capturing the dynamics of reactive systems and a fidelity approach will only be complete if the fidelity requirements usually expressed as tolerances over desired behavior are adequately captured in modeling and this *semantic* i.e. behavioral perspective [Ponnusamy,2014] & [Ponnusamy,2015] is given by approximate bisimulation [Girard,2007]. Such a multimodal approach is discussed in the following section with emphasis on model teleological view in terms of operating modes ontology.

4. A MULTIMODAL APPROACH TO MODELING

A simulation product development involves requirement collection, conceptual modeling, model formulation, model construction, assembly and deployment on the platform. The simulation involves experimentation according to V&V plan, data collection, analysis and conclusion. All such activities involve multiple levels of abstraction, stakeholders, formalisms and tools. A single approach to tackle this abstraction consistency problem is neither feasible nor practical and a multi modal approach is needed. This problem is broadly classified on structural and behavioral aspects and methodologies are discussed in [Ponnusamy,2015]. In [Fishwick,1993], a multimodal approach to simulation is discussed in terms of reasoning, functional modeling, qualitative modeling and visuo-spatial reasoning. However in the current paper, the focus is on simulation domain ontology spanning all steps of simulation product development in the context of capture and manages fidelity as described in section 2.1.1. The ontologies based on the model teleological and theory of M&S concepts developed in OWL using the standard Protégé tool is presented in the following section. This is used for collecting and exploitation of system knowledge and context of usage by the model architect to formalize structural consistency aspects of models such as architecture, interface, data type, quantities, units etc.

A significant advantage of such an approach besides providing a standardized information exchange

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[1] http://protege.stanford.edu/

platform is its reasoning and query ability [Jenkins,2012]. They could be important in the industrial context as the information is incrementally and simultaneously being updated by different stakeholders; many linked concepts could be identified, classified and checked upon to ensure consistency all along the product development.

4.1. M&S Ontology: Operational view

In an industrial setting an essential prerequisite for any method proposed to improve the model fidelity is that it must be amenable for integration into the system development process and also need to be user friendly for the practicing engineers. It is thus important to illustrate how the proposed method will be operated and quantify its effect on the ‘as is’ process. In this context, the operational perspective of the proposed domain model is presented in the figure 7.

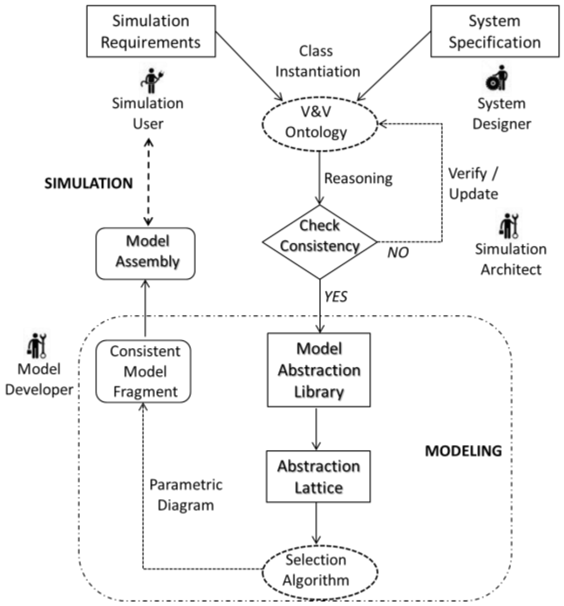

Figure 7: Operational View of M&S domain model

It may be seen that a single ontology is instantiated by the user and designer separately whose consistency and inclusion relations are ascertained by the model specialist. Here consistency refers to classical consistency checks such as incorrect instantiation, constraint violation etc. Inclusions relations are better understood through partial order relations defining a finite lattice [Lickly,2011]. The consistent lattice is input to the selection algorithm [Levy,1997], which selects the consistent yet simplest model abstraction. This selection through a parametric diagram is built in a classical simulation tool such as Modelica or Matlab SIMULINK. All such consistent models are assembled by the user into one integrated simulation application deployable on a platform and then simulated. The reasoning capabilities of ontology are exploited in conjunction with query capabilities to perform theses activities. It may be noted that the classical but often tedious document and discussion centric process used by model specialist as discussed in section 3.2 is being replaced by the domain model approach. Some of the important concepts of this domain model approach are briefly discussed in the following section for better understanding of this process vis à vis V&V activities.

4.2. M&S Domain Model – A Syntactic View

There have been various studies on the need for a domain model approach in system development [Zayas,2010], [Jenkins,2012] and the need for shared domain knowledge, i.e. ontologies, which is usually mastered by the engineers but not formalized. In addition, modeling as a reasoning problem was posed by et al in [Levy,1997] since a model developer reasons about a given physical system at different levels of abstraction. In the field of Artificial Intelligence (AI), qualitative simulation has been proposed by Kuipers et al which is based on qualitative reasoning about systems [Kuipers,2001]. Similarly, in the state of the art ontology document [CRYSTAL,2014] of the CRYSTAL project, five different levels of abstraction levels are proposed namely, operational, functional or non-functional, logical, physical and implementation and discussed in the context of engineering phases and viewpoints.

A domain model for M&S needs to incorporate all such possible paradigms of modeling concepts and in [Ponnusamy,2015], a domain model of modeling abstractions is proposed on four axes of scope, computation, data and time in and instantiated with model fragments data. This ontology was built using Protégé and the reasoning capabilities of ontology were exploited to build and fill the model abstraction library. An algorithm based on [Levy,1997], has been implemented as SysML activity diagram to select an abstraction consistent with requirements from this library. In discussing this preliminary attempt at an automated model selection approach, the need to be coherent with behavioral modeling and fidelity needs capture has been emphasized in it. This paper attempts to address this problem from the context of industry. In the following section, the initial version of ontology based on Structure, Behavior, Function (SBF) framework of [Gero,2004] is extended with Operational modes concept and discussed. This operational modes ontology proposed here corresponds to operational abstraction and is linked with behavioral and functional abstraction.

4.2.1. SBFIO Framework

The notion of Structure, Behavior & Function, originally proposed in the context of design studies has been used in system engineering studies as well for better understanding and decomposition of complex systems [Gero,2004]. In broader terms, Structure refers to the architectural notion of the system whereas Behavior refers to dynamic response of the system under input stimuli. Function in our context is the purpose or goal of the system i.e. availability of a service. In addition to SBF, the notation of interface (I) and Operating mode (O) are more pertinent for interconnected system description and different ways of operation respectively. Interfaces can be interpreted as ports of exchange, energy and data, between physical and cyber systems respectively. The following section briefly illustrates the Operating mode concept of the SBFIO framework. For fidelity approach for other concepts the readers are encouraged to refer to [Ponnusamy,2015].

The mapping of SBFIO framework is given as follows,

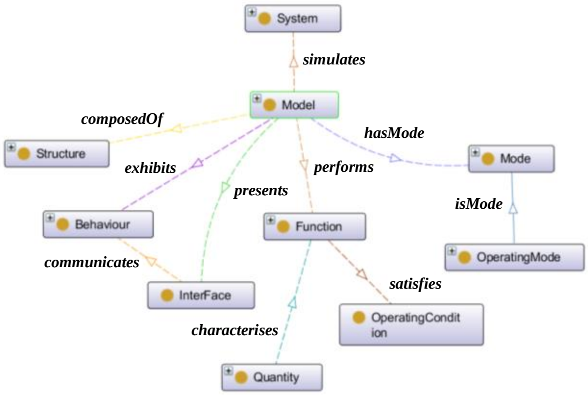

Figure 8: SBFIO Framework

It must be noted that not all the concepts and relations are explicitly given in the figure and this ontology is only a teleological view on models and it does not discuss ontology of modeling formalism, class of abstractions etc. [Albert, 2009], [Ponnusamy,2015].

4.3. Operating Modes &Transitions

A system may exhibit different ways of operation called *mode* and operating mode typically refers to such a phenomenon in the context of interconnected systems where one mode causally affect the other. A simple example would be light switch which could be either 'on' or 'off' connected to a light bulb which could be 'glow' or 'dark' depending on the mode of the switch. This mode definition could be physical or logical and it can be ascribed to logical architecture i.e. system or physical architecture i.e. equipment. Denoting such architecture constituents by a generic notion called '*block*', an operating mode could be associated to a block's modes of operation. In general, a block can function in different modes and for each mode and their combination, there exists an associated functionality and behavior. Two interconnected blocks essentially implies interconnection of their respective modes. The mode of the source component is called guard and the destination component is called mode. Together, the pair of causative and resulting mode, along with their blocks forms an operational mode. The interest of such a description is the correspondence with their functionality and behavior. It helps to envisage the modes of operation, its complexity causality, and inter dependencies.

This definition of mode as a control information of the system operation is similar to the concept of mode charts proposed in [Jahanian,1994]. Mode charts is a specification language for real time systems whose semantics are given by Real Time Logic (RTL) [Jahanian,1994], a logic for reasoning about the absolute timing of events. Our definition of operational mode is akin to series and parallel mode classification proposed by Jahanian et al, however, in our approach the parent-child modes given by guard-state are formalized as a single mode. This definition is based on simple causality relation i.e. mode A causes mode B and is amenable to ascribe functional behavior or a semantic behavior. A similar notion is mode automata proposed in [Maraninchi,1998], which is essentially an automaton whose states are labeled by dataflow programs. However, in our case, the modes refer to operational manifestation of a block under a given scenario. An analogy with state transition diagram [Jahanian,1994] is when mode could be interpreted as a grouping of states.

Definition 1: Let us denote a block, B_i where i is an identifier, exhibiting modes, M_j^i where j refers to the numbers of modes. An interconnection between blocks B_i and B_{i+1} and their modes are represented by an operating mode which is defined by the following tuple,

$$OM_n =< M_j^i \rightarrow M_j^{i+1} > \qquad (1)$$

where M_j^i, M_j^{i+1} are the connected modes of B_i and B_{i+1} respectively.

The direction arrow defines the causality connection, here it means when B_i is at mode M_j^i then B_{i+1} is at M_j^{i+1}. The tuple <B_i,M_j^i> is called the guard (i.e. source) and <B_{i+1},M_j^{i+1}> is called the state (i.e. destination).

The transition $T_{n\rightarrow n+1}$ defines transition from one operating mode, OM_n to another, $OM_{n+1}$when the guard conditions changes i.e. becomes true denoted by $\vdash$ symbol. Interpreting OM_n as source operating mode and OM_{n+1} as destination operating mode, then transition occurs when the guard mode of the destination operating mode becomes true i.e. enabled. It is defined by,

$$T_n\colon M_j^i \times \tau \rightarrow \; M_{j'}^i \,\Big|\, \tau : \; M_{j'}^i \vdash \qquad (2)$$

where $M_j^i \in OM_n$ and $M_{j'}^i \in OM_{n+1}$

The mode description and its transition is represented in the following figure,

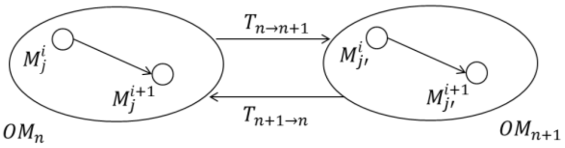

Figure 9: Operating Mode

These modes can be interpreted as reachability space where each state is a possible operating mode of the block and preceding state is the guard operating mode. In other words, when the guard condition is true the entailment relation between these two modes result in final mode. The evolution from guard to the mode involves dynamics and at each mode too there could be an associated behavior. In the next section, a brief discussion on how these concepts are useful in developing an abstraction library is discussed.

4.3.1. Operational Modes Inclusion & Abstraction

An important use of this definition is organizing such operational information of systems into interconnected modes which not only renders a lucid description but also yields information about independent modes which could be abstracted. Modes which have no transition relation with a particular mode i.e. unreachable are independent modes. Such enumeration of transition based on mode definition helps in determining necessary abstractions.

Thus depending on the user requirement on the operational mode of the system, a model specialist can navigate through the mode description given by the system designer to identify and segregate the necessary modes and thereby the associated sub systems or equipment (refer Fig 7). Only the system and the corresponding modes matching with user requirements will be retained. This also enables more autonomy for the modeler, who often has to rely on system designer to identify these mode transitions. A semi-automated way to extract such information will make operational modeling more lean and coherent with simulation objectives

This is akin to an automaton but the only difference being that the concept of time is abstracted. The modes are operational modes with causality relation between them and the detailed semantics of this approach is being formalized. However, for systems based approach, an abstract notion such as in Eq (1) & (2) may suffice and this definition should be seen from the operational context by the user and designer.

An ontology instantiation will help analyze the consistency through inclusion relations [Ponnusamy, 2015] and SPARQL[2] queries identify and extract desired information. For example, the model architect queries states having same guards, in other words, this state could be reached by two different sources and based on the simulation objectives any one branch and its associated block definition can be abstracted. Similar such extensions and analyses are possible and are not discussed here. An analogy for this approach would be fork-join definitions in reachability tree of petri net. In other words, there exists two ways to reach this mode and these two guards can be combined as follows. The semantics and its transformation to other formalism is being formalized and will be subject of other paper whereas the current objective is to illustrate this concept in a process based context of V&V by simulation. An application of these formalism on the V&V of aircraft nacelle anti ice system failure case has been discussed in [Ponnusamy,2016].

4.3.2. Mapping to Behavior – A Semantic View

In a SBFIO framework, these operational modes can be mapped to automata which model the system behavior and this is applicable to hybrid automata defined by invariants, guards and resets as well [Tomlin,2003]. Such behavior can be formally verified by reachability analysis and significant progress has been made in the control community in developing various geometric abstractions such as zonotopes [Girard,2007], polyhedrons etc. to perform reachability analysis over dynamic systems [Stursberg,2003]. In addition to verification, syntheses of abstractions are also studied with the help of approximate bisimulation techniques in [Girard,2007] & [Pappas,2003]. Alternatively, such a model can be executed using a discrete event system (DEVS) simulator such as ProDEVS for which there exists a meta model of execution semantics in SysML [Hung,2015]. This domain model for model execution complements the domain model for model building. Such an integrated domain model approach helps in standardizing M&S activities and thereby improves the overall fidelity. Another approach would be using such definition as a language for a formal system specification.

4.4. A Unified framework

A syntactic approach based on domain modeling and a semantic approach based on bisimulation and its approximations could lead to a unified framework encompassing high level fidelity needs capture to low level implementation. It may be noted that as the simulation product development process progresses, the method and tool used will become more formal and this multi modal approach of using a combination of formal and semiformal techniques will help managing the fidelity of models better. In addition, creation of such repository due to incremental addition of knowledge on modeling, systems and their usage will be a significant value addition for enterprise in terms of knowledge capitalization and reuse.

5. OUTLOOK & CONCLUSION

The preliminary process described above needs to be further developed, automated and integrated with the engineering process with user friendly GUI for instantiations by different actors. The SBFIO ontology is being improved with additional concepts based on naïve and basic physics and other domain specific concepts. The preliminary results demonstrate the flexibility of this approach in archival and exploitation of domain knowledge [Ponnusamy,2016]. However future challenges include integration, management and deployment of this process in the industry. Currently studies are being carried out to demonstrate the

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[2] http://www.w3.org/TR/rdf-sparql-query/

feasibility and industrial readiness of this approach through a real aircraft system application case.

Another axis of future work is tool development for integration of SysML and OWL. As remarked by [Greves,2009] and [Jenkins,2012], mutual transformation between SysML and ontology will help engineers to capitalise on their graphical syntax and reasoning capabilities respectively and thereby ensuring seamless design and product V&V activities. In the semantic approach, further work is needed in synthesis of abstractions with respect to fidelity requirements. In [Ponnusamy,2015], a preliminary approach based on bisimilarity preserving surjection maps is presented in the context of experimental frame. However, significant work needs to be done in this direction especially due to the increasing usage of cyber physical systems which exhibit hybrid dynamics where choice of abstraction is crucial in representing their dynamics to sufficient accuracy.

An important area to be addressed in the overall V&V process is the synthesis of requirements. Requirements are usually written in natural language text and unless they are managed by tools such as DOORS, it becomes a tedious task to consistently update, trace or modify the requirement database. An active area of research is to move from informal natural language description to a more semi-formal MBSE approach and in some cases formal description in some temporal logic such as Linear Temporal Logic (LTL) or Signal temporal Logic (STL) etc. In [Ponnusamy,2014], Ponnusamy et al discusses inclusion of simulation objectives described in LTL in modeling. The need to parse requirements into various classes has also been of considerable interest and NLP tools such as TXM[3] aids in some text analysis. However, automated transition from natural text to a class description is far from being done though there have been some initial attempts [Ileiva,2005]. A more formal definition of requirements would enable better rapid prototyping of systems. Such a method will help in coherent model development and deployment from top level requirements capture to low level behavioral modeling by mapping the related concepts at each intermediary step.

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AUGMENTED REALITY TO SUPPORT 3D VISUALIZATION OF GEOMETRIC ELEMENTS IN CLASSROOM WITH AR TEACHER TOOLS

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ABSTRACT

The augmented reality technology has too many direct applications for different areas. However, some contexts are more likely have particular possibilities to improve teaching techniques, and consequently, improving the quality of learning. Our approach consider a specific scene, where a teacher exposes visual content to his class, thus, the model itself helps not only understanding the 3D objects, but also the teacher's analysis. Aiming to bring an alternative concept in teaching people based on a tri-dimensional environment analysis, the teacher applies this idea of learning to classroom context, through the use of portable devices such as tablets and smartphones.Superimposing augmented reality content previously built from drawings may help improving the students understanding in migrating from 3D augmented environment to the real 2D environment.

Keywords: Classroom Learning; 2D and 3D Augmented Environment; Augmented Reality.

1. INTRODUCTION

This article describes a method of improving learning process with use the augmented reality in the classroom. The technology evolution made possible the use of new techniques and tools to support development and understanding inside classroom. The 3D view capability is the main skill of basic perception to recognize and understand objects of the physical world (Salkind 1976).

This work aims to help and stimulate the spatial view learning of students of elementary school. The geometric thinking is an ability that must be practiced during academic course. The previous researches indicate that students young in the most different thinking levels, they perceive geometric shapes differently (Clement and Sarama, 2000; HO, 2003; Wu and Ma, 2006). Some people has difficulty in transfer geometric figures from 2D plan-to-plan 3D and they needs get more domain of 3D geometry, inside classroom. The augmented reality models works dynamically, approximate the student to understand the solid, perspective and their projections.

The traditional method to learn spatial view is to do the elementary students to analyze and compare points from bidimentional views (2D) and design to tridimentional plan (3D). Furthermore, those methods has limited use to the conceptual struct due the interaction shortage between the reader and visual images, such as images, during the formation. Moreover, the elementary students cannot meet customers satisfactory acquiring spatial ability to the learning and representation of object volums. In this case, many students had difficulty to conceptualizing 2D images to 3D design for plan, still in the graduation. The teachers must provide a learning experience, which stimulate an ability and understanding of the geometric shapes by childrens in classroom.

The research presented in this paper makes use of Augmented Reality (AR) to develop ability the spatial view of students in the classroom. Through of Augmented Reality, students can analyze object in details, thus him can rotate the object and inspect your different angles. The virtual model stimulates multiple senses the student and provides a connection to understanding between the 2D representation and their spatial representation. Thus, there is great potential to build teaching models that incorporate this technology into the classroom (Kaufmann, 2003; Weghorst 2003).

The research was experimented by elementariness students group. Initially, the students were submitted to perception and capacitation tests without using aids tool. After, making use our support tool, AR Teacher Tools, students were able to measure and understand the purpose of the tests faster. Through this analysis, we evaluate the results generated by the students, and de-emphasize the significant improvement by adopting the support tool. From the developed models and the application of the tests, it was possible to measure the the degree of improvement, to its ability to display 3D objects.

Our research is in an AR tool, developed by our team in LAMCE/GRVA Laboratory in COPPE, which aggregate the lot area from knowledgement until actually. We will mapping the children group for two scenarios, before without our tool, and after making use our tool, and measuring an improve them and their capacity to view 3D objects. This tool can be used in many areas as the visualization can help understanding and interpretation. Our goal is to achieve undergraduate peoples for the scenarios with and without the use of **AR Teacher Tools.**

2. METHOD-TANGRAM

Our study deals with the use a Chinese puzzle consisting of seven pieces, which can form many different figures. The pieces of the puzzle were modeled in 3Ds Max and placed in the library of AR Teacher Tools. The tool provides the seven volumetrically modeled parts and encourages the construction of figures helping the development of logic, intelligence and imagination. The intention is to stimulate and sharpen the development of spatial vision.

3. METODOLOGY

The research investigates the process of evolution and effectiveness of learning using the AR is teaching and developing space vision. Within the classroom environment, students were tested in two steps; (1) Use only the traditional 2D images study and (2) use of the AR with the 3D object. To validate our study developed an intuitive and interactive tool to assist the representation of 3D models.

4. TOOLS

The support tool is an application for mobile devices, such as Tablet, Smartphones, and so on, that has some models divided into levels of difficulty, as shown in Figure 6. The idea is to provide a simple interface to be handled and practice to promote the understanding by anyone on their level of cognition. The interaction between the user and the tool is, basically, the touch screen of the device.

The tool has experimentally fifteen simulations Tangram. Fourteen of these simulations have a silhouette to be mounted by the Tangram pieces and a simulation that has no silhouette, i.e. this is the simulation of freestyle.

4.1. DEVELOPMENT

The application was developed using the Unity 3D Game Engine version 5.0.1, with working scripts written in c # (C-Sharp). For the inclusion of the augmented reality (AR), we use the framework of the Vuforia. Tangram parts were modeled in 3Ds Max program.

The application was tested on three mobile devices, a Tablet Galaxy S3, with 4 GB RAM and Android version 4.2.2 (Jelly Bean) in a Galaxy Tablet Note 12.1 with 8 GB RAM, 4.4.3 and Android on a Smartphone Z3 Compact Sony, Android version 4.4.4 (Kit Kat). Application performance was excellent in all devices, that is, different capacities of Hardware does not interfere in the proper operation of the program. Besides the production of the tool and your goals, we had even the concern about the minimum hardware requirements, to use in devices that have greater compatibility.

4.2. REPRODUCIBILITY

Initially it is necessary to install the application AR Teacher, downloaded by clicking the icon. After that, any model must be chosen from those listed in the menu on the left. To be chosen, and after the recognition of the marker by the camera, the pieces that make up the template along with your silhouette appear arranged on the screen in order to be moved to its correct position, i.e. on the silhouette. The Assembly ends when all pieces form the figure of the model chosen, when that happens a message will automatically be displayed to inform the user.

The application can be replicated and validated by anyone, to do so, simply send us an email requesting the test kit. The kit is composed of the validation tool AR Teacher, a marker and the questionnaire applied. In this way, just install the application on an Android device with version 4.2.2 or higher, codenamed Jelly Bean, run it and test the models embedded in the tool.

4.3. DESCRIPTION TOOL

This section describes the screens and the features of the support tool. Highlighting the clickable areas and parts, in addition to the interaction events that may occur.

4.3.1. MAIN SCREEN

Figure 1 shows the main screen of the tool, it has a scrollable menu left aligned with the thumbnails of the Tangram. Next to this menu, is the Tangram model chosen to be mounted. In the lower right corner, there is an icon that opens the tool settings screen figure 2. If the user press the "back" button of the device, the application is terminated.

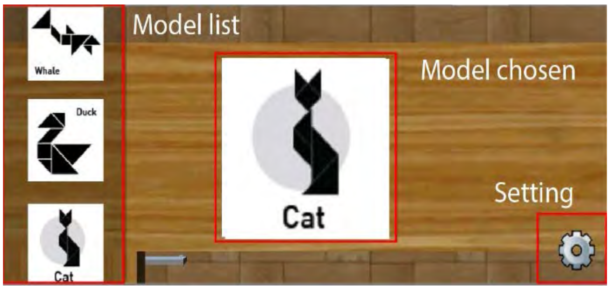


Figure 1-the AR tool main screen Teacher

4.3.2. SETTING

Figure 2 illustrates the settings screen of the tool, it contains a text field that must be filled with the location that the user wants to save the photos that can be captured when the last model of the list was selected, this is the free style, i.e. no silhouette to be filled. If the user press the "back" button of the device settings screen closes and the main screen will open.

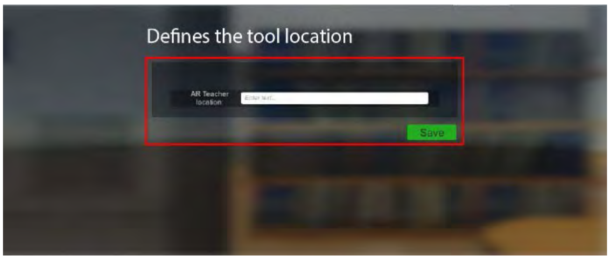


Figure 2-AR Teacher tool settings screen.

4.3.3. ASSEMBLY OF THE TANGRAM

Figure 3 represents the most important screen of the tool where students must move the pieces and fit them on the correct position in silhouette. The parts can be moved simply by simple drag n ' drop, i.e., simply click and drag the pieces around the screen, three-dimensional behavior is natural and always will exist in this environment. Another functionality is the rotation for the vertical axis (y-axis), for this, the user must hold down the desired piece and with a second touch, another finger, perform vertical movements, up or down, that gives the rotation of the piece. The two images below, Figure 3 and 4, were captured during the same simulation, however, the image 3, the device was on the marker, i.e. at an angle close to 0° (0π rad), in Figure 4, the device was almost vertical position, with close to 75° (5π /12 rad), so it can be observed the perspective view. If the user press the "back" button, then the main screen of the application device opens, and the simulation is terminated.

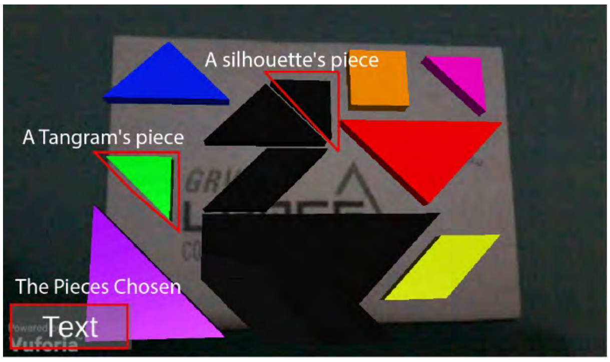


Figure 3 – mounting a screen model, top view.

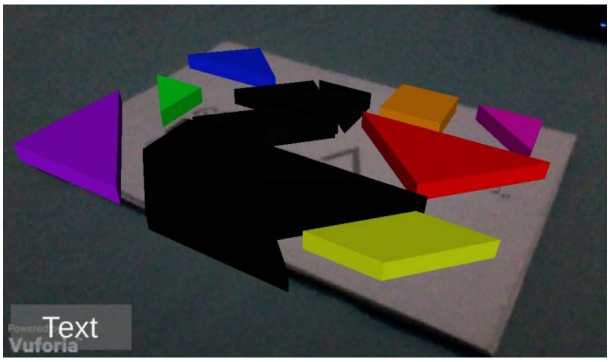


Figure 4-mounting a screen model, perspective view.

Figure 5 shows the mounting screen in free style, i.e. in this simulation, the student is free to assemble the figure of his imagination. In this section shall be measured the dexterity and creative capacity of students.

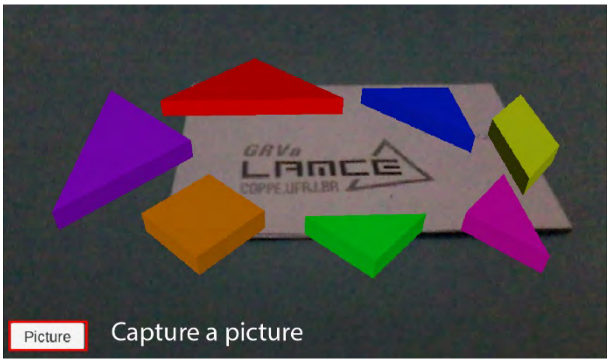


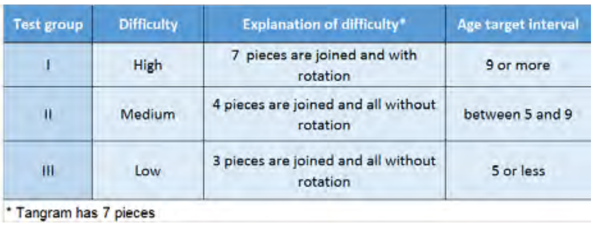
Figure 5- free mounting screen.

5. TESTS

In this section, we have divided into three topics to facilitate understanding; the first comes in a clear planning that we follow for the application of the tests in the field. The second topic – questionnaire – explains the structure of the questionnaires applied; finally, the last topic discusses the implementation itself of tests on students.

5.1. PLANNING

Our evaluation method classifies three groups, according to age group, which makes it possible to analyze the performance of each group modularly. The Group I is composed of students who are ages above 9 years. The Group II has students aged between 5 and 9 years. Finally, the Group III consists of children up to 5 years. Figure 6 presents the classification of groups, along with the distinction between each group.



Test group	Difficulty	Explanation of difficulty*	Age target interval
I	High	7 pieces are joined and with rotation	9 or more
II	Medium	4 pieces are joined and all without rotation	between 5 and 9
III	Low	3 pieces are joined and all without rotation	5 or less

* Tangram has 7 pieces

Figure 6-Table of classification among the groups.

5.2. QUESTIONNAIRE

We worked out a questionnaire as part of our analysis. Each questionnaire was composed of four questions with two alternatives, a correct and not correct. These questions are designed to assess four geometric skills and understanding 3D of the students, who are 1- shadow projection, 2- notion of perspective, 3-projection of faces and hidden edges and 4-volume perception. So, turn each of these skills in a matter illustrated. Figure 7 presents the illustrations used in the questionnaires to evaluate the four skills.

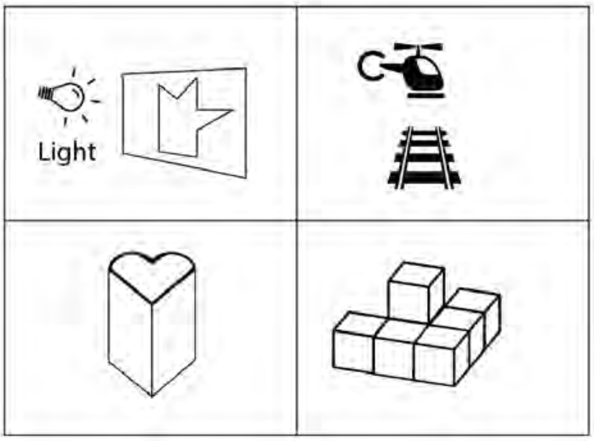


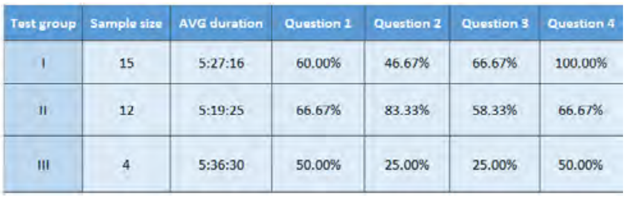
Figure 7-Illustration used for the issues.

The first question uses the image top left of Figure 7, it is about projection of shadows, for this, we ask students to imagine what it would be like a drop shadow behind the punched paper and explained that the lighting was applied to the front of the paper. The second point about perspective, upper right figure, we ask students to imagine what it would be like to see the train tracks by the pilot of the helicopter. In the third issue, which we hope to assess the understanding of the hidden edges, we ask students to select the option that represents the vision behind the pillar, this is the back of the piece. Finally, the bottom-right image in Figure 7, we ask for students scoring option that displays the number of blocks that could exist in the figure, for that, it might in the case of blocks of ice that can fall without support.

5.3. APLICATION

The tests were applied as follows: 1. Application of the analysis tool and 2-Application of the questionnaire. Initially, we ask the children that used the tool to compose the Tangram figure, set to their level. We then apply the evaluative questionnaires and ending with the exercise of abstraction, which consisted of students assemble some figure in freestyle with the Tangram pieces to the analysis tool. During the assessments, reap the duration of the test, the age and the child-mounted model.

We interviewed 31 children aged between 5 and 13 years of age of a primary school in public schools. Data from each group are shown in Figure 8, along with the sample size and the average duration of the exam. Figure 8 shows a table with statistical data, then Figure 9 illustrates the graph outlining the percentage of correct answers between the groups for the four questions answered in the questionnaires.



Test group	Sample size	AVG duration	Question 1	Question 2	Question 3	Question 4
I	15	5:27:16	60.00%	46.67%	66.67%	100.00%
II	12	5:19:25	66.67%	83.33%	58.33%	66.67%
III	4	5:36:30	50.00%	25.00%	25.00%	50.00%

Figure 8- Table of group stats.

From figure 9, we realize that questions 1 and 2, that deal projection of shadows and perspective were better understood in group II, central ages, in contrast, questions 3 and 4, which deal with the notion of hidden faces and volumetric space were better understood gradually, from Group III to the Group I, that is, from younger students understood unless their elders.

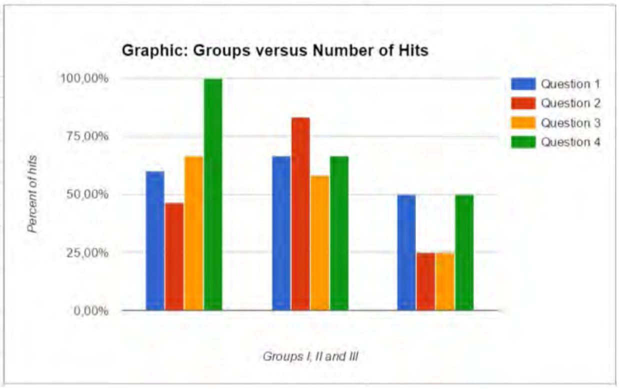


Figure 9-Percentage graph of hits between groups.

6. RESULTS

We observed that children in group III took longer to adjust to the analysis tool and who owned more difficult to imagine the perspective projections-Question 2-and visualization capabilities of the hidden faces-Question 3. We realize that while implementing the testing children in group III used the equipment in the horizontal position, top view, as shown in figure 10. While children in groups I and II were able to interact better with the equipment changing the angle of vision.

Figure 10-Figure obtained during the application running on the child in group III.

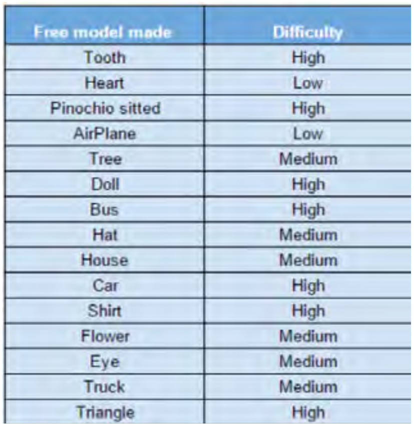
We realize that children from all groups in the first contact with the application struggled to handle in the first exercise, which is assembling the parts on the silhouette. In the exercise that the student should freely assemble the Tangram figure, they were already more adapted to handle the application. However, they were as yet felt difficulty understanding the geometry of the parts, synchronize them with silhouettes of models, and needed some aid.

At the end of the tests, we talked with three teachers in charge of classes to evaluate, both have worked with Tangram activities on paper, 2D. The application made by us was very well received by teachers who were very interested in continuing with the material developed by our research.

The insertion of our method to support routine activities of students in class will contribute to further progress and generated returns may be more efficient.

Our review of the figures of low, medium and high difficulties are illustrated in Figure 11. The table of Figure 11 was generated with from our empirical criteria making use of **difficulty explanation** of column constant of Figure 6, Figure mounted to each free the students assessed by those criteria and classify the figure in the levels of difficulty low, medium or high. Note that there is no link between the free figure mounted to the age group I, II or III, of the child, this is exactly what we seek to measure, i.e. the relation between the most complex figures with the group of students, so we can have students in Group I, older, less complicated free figures, or students of the group III setting free more complicated figures, noting that the evaluation criteria between low, medium and high difficulties figures are in Figure 6.

From the models created by students, reap the random sample of fifteen models and put in Table 11. Table 11 was generated based on the classification criteria we use to divide the groups.



Free model made	Difficulty
Tooth	High
Heart	Low
Pinochio sitted	High
AirPlane	Low
Tree	Medium
Doll	High
Bus	High
Hat	Medium
House	Medium
Car	High
Shirt	High
Flower	Medium
Eye	Medium
Truck	Medium
Triangle	High

Figure 11-Table of the relationship between the free model and your complexity.

Figure 12 is a graph generated by the same sample of fifteen students, the horizontal axis represents the percentage of correct answers the student obtained the questionnaires, there are four questions in the questionnaire and the possible percentages are 0%, 25%, 50%, 75% or 100%. In turn, the vertical axis shows the free model assembled by the student.

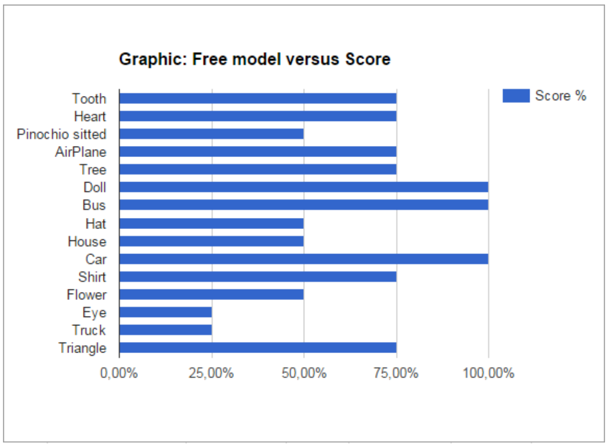


Figure 12-Graph of the relationship between the free model and the score obtained by the student.

The most complex figures assembled by the students were classified as those with high difficulty. Similarly, the figures with the least complex parts are the low difficulty. Based on Figures 11 and 12 we realize that the models with greater complexity were assembled by students who have higher scores in response to the questionnaires.

CONCLUSION

We conclude that the use of the tool to support the class helps in the formation of spatial understanding of the student. Additionally, with the results of the tests, we realized that in fact, the perception of three-dimensional space already reside in each individual, however, the critical view is three-dimensional environments can be worked more efficiently with support tools and activities that explores spatial vision. Thereby, we consider important the contribution of this research in academic and indispensable means to improve the method of capabilities and spatial skills, providing a base for guided each student in its first study classes.

FUTURE WORKS

A range of other studies that can be added in this research, however, shed in the segment of education and spatial vision in the classroom was chosen by us as the main activity subsequent to this study. It would be composed of more parameters vary in order to obtain more representative results. Thus variations would expand the body tests applied on larger samples of children select a larger number of different schools, towards the public and private schools, economically different regions and finally the results of measuring tests is applied in children with mental disabilities, such as people with Down syndrome, dyslexics, autistics, cognitive inhibited, and so on.

ACKNOWLEDGMENTS

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A POSITIONAL STUDY FOR NETWORK MODELING USING ZIGBEE PROTOCOL

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ABSTRACT

Zigbee technology makes possible to design a high distance network with low cost, and low communication rate. Mapping and locating of objects is one of the possible approaches of zigbee networks. Our research is based on the intrinsic intelligence of a zigbee network with low rates of transmission however, high efficiency in mapping objects. Our study focused in basic uses cases, for example, tracing certain trajectories. This work is also focused in the location of mobile objects from a fixed device, used for reference sectors within a determined area. Other example shows the location of the objects in the sector that this objects belongs to. Our proposal is to use the prototype tool developed for this study, named TinyBee, in order to validate the tests applied using zigbee nodes and to present their results.

Keywords: Zigbee, Mapping, Smart Grid.

1. INTRODUCTION

By making use the methodology exposed in the article [1], this work makes use of a specific algorithm, Signal Strength indicator (RSSI), and another algorithm uses the Quality Indicator (LQI). Both works in parallel mapping the different intensity of such indicators, obtained from the signals of the network nodes.

Due to the nature of the zigbee network it is not necessary the use of an access point for connecting nodes, as it happens in a Wi-Fi networks. On the other hand, routers nodes are used to compose a network. This way a longer distance can be achieved, then, the nodes naturally contribute to compose the network and those same nodes could be used for mapping [2]. However, the zigbee technology is the indicate one for this kind of study.

The zigbee technology was not developed to attend precision criteria, but, in this case it can be used to find the right point in the network. Once the points create the networks, these nodes are fundamental piece in the integrity of such network. However, the replacement of a node by another one not will affect the functioning of the network. The case of reference mapping, such as networks with mobile nodes and fixed nodes as described in the research [3] the not need high precision due to a such mobile node be connected to a one or more fixed nodes, that is possible to find out the locations of this node. In another words, from static nodes distributed in a space with many sectors, the zigbee network itself with no other coupled equipment is capable to yield the location of a mobile object with is in one of those sectors.

1.1. THE DIFFERENTIAL

Our goal is to propose a solution to large mapping and harsh environments aiming use a technical system with low cost, high distance of range and high precision. The other options of transponders (RFID - Radio Frequency Identification) or global positioning (GPS – Global positioning System) are enough for this assignment, mostly considering their range. However, in order to add network performance (active transponders) the investment of the project might be over expensive. Added to this, for those cases where it is necessary find devices in indoor places, the GPS could not be applied due the satellite poor functioning with no direct sight.

In conclusion, thinking on the study's relevance, the modernity walks to the point where the basic smart services in environment can be dissociated from the human operability. Therefore, we judge important such study that can to base complex control systems in big operational ambit.

2. RELATED WORKS

We have looking for based on inclusion criteria such as "Corporate smart grid", "Enterprise smart grid", in database from IEEEXplore, after, with pre-selected results, we filter searching for, first complete similar words in the articles, how our research proposal has focus in the corporative smart grid, maybe some application must be inside full text it, by citing it, and not in title, abstract or, still, key words, explicitly, 73 papers already have returned. In second moment, we take only researches which are "Conference publication", "Early Access Articles", resulting in 10 papers from there. Therefore, we find 10 related works that use themes like our work. For them results, is important say the time period is from 2011 to 2014, or actually, and for any authors and institutes were considered.

3. THEORICAL BASIS – THE NETWORK TOPOLOGY

Due the application design we used the mesh topology, to know, each node could connect itself with any other node within their operation radius. That network's organization leads the natural group making (clusters), where connector's nodes link with neighbors groups [5].

The multiple access protocol used by the network's nodes is the CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance), in other words, before a node send some date it has to "heard" the channel and check if the path is free, then, send a broadcast message to advise all to wait the transmission during a determinate period and does not send any message in the same time, avoiding signal collisions.

According to [5], the most important attribute of the IEEE 802.15.4 standard is its potential to create self-organizing networks capable of adapting to different topologies, connectivity nodes and traffic conditions, thus, its application as well as less costly , allows the network to cover a large area, something up to 65,535 nodes per network. In fact, this pattern contemplates the possibility of being used in real-time applications (real time). The spread of this technology is the quotient between coverage area versus amount invested, so for the same demand, wired networks (Ethernet) or wireless (Wifi, RFID or Bluetooth) have higher costs and lower accuracy.

ZigBee network presents the possibility of multiple links between nodes, function known as multi-hop, due to its training mesh network capability. This configuration allows the quickly removal and addition of other nodes in the network, because each router node has a table which is updated at the lowest cost from this to the destination nodes, with your internal algorithms, Modified Ad Hoc on Demand Distance Vector Z-AODV (Distance Vector) and Hierarchical Routing [6] and [7].

4. CONCEPTION AND DEVELOPMENT OF THE PROTOTYPE TOOL

The present proposal was validated by developing and use of a prototype tool. Three different applications were testing in the same zigbee mesh. Such test were splitted in two conception classes, the first one with two steps was classified as Positioning, and subdivided in 1- mapping and 2- location. These tests were pictorially positioned, that is, they measure the location of the target object and its eventual path relative to the network.

By knowing the object it is possible to send data to the fixed devices. Within this context, the second class is denominated by Bi-directional communication, which makes reference to the device communication function. For those tests, the mobile device named by coordinator, could send signal to another node that being part of the mesh creating a communication on both sides.

Were used for these tests some development Texas Instruments kits ZDK (Zigbee Development Kit).

We had tested the CC2530ZNP review 1.0 both for the fixed nodes and the mobile nodes. We had developed a functioning algorithm for each node according their function in the network. The root node is responsible to send commands to the destination nodes and receive data from the fixed nodes. Although, zigbee nodes have different denomination classified between end-points and routers, we decided to work with the roots nodes even to the fixed and mobile nodes. Our focus is to obtain more flexibility in those cases when occur a signal fault of a bridge fixed node some other node could works similar.

4.1 ALGORITHM

A. Fixed Node

The algorithm bellow integrates the fixed nodes on the mapping, are essential to set the network and intermediate the transmissions between the mobile nodes and the root. At first, the algorithm verifies if there is any message of type 0xA0, if it is positive, sends a message to root that composed by their MAC address and the MAC address of the mobile node.

In addition, this message occurs when some fixed nodes that are in the coverage area of a mobile node received a positioning message. Thus, in the case of it received a message 0xC1 address to this node, so it runs the action. As experimental proposes we just have created an action that works with the device's input and output pin (GPIO – General Purpose Input/Output).

Finally, if the fixed node received any message that exists in the neighborhood, i.e. on their coverage, forward to this interface, if not, sends the message to all interfaces (Method known as Flood).

```
Forever
        If
        has received some message 0 x A0, then
        It sends the address vector to root (0 X C0).
        Else if has received any message 0 X C1, then
        If
        address is the same of the message address,
        then
        Execute the message action.
        Else
        if the address is on the address vector
        then
        forward the message for the relative address.
        Else
        forward the message for all nodes of the
        address vectors.
        End If
End forever
```

B. Mobile Nodes

The algorithm bellow runs in the mobile nodes and constantly sends positioning messages (0XA0) to their neighbors, i.e., only those fixed nodes that are within its coverage area. Ignore any other incoming messages. To avoid consuming too much energy we set the ten-second interval for this node send a new position message.

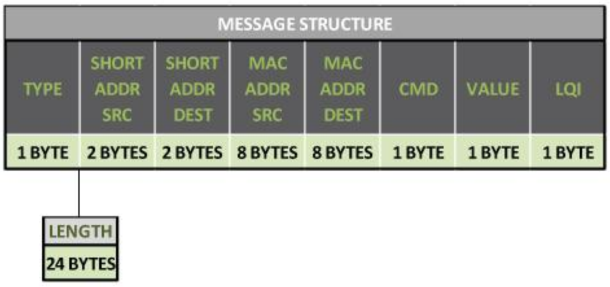
```
Forever
    It sends the message 0XA0 in Broadcast with HOP
    equal 1, i.e. neighbors.
    If
    has received some message then
    Discard message.
    End if.
End forever
```

C. Root

This algorithm is essential for network data collection and to interfere in the behavior of the network thus, as in zigbee networks there is only one root node, this algorithm is of paramount importance to mediate the network due to the task that includes: Setting the network unique identifier (PanID), control the access on network by nodes and to restrict non-certified, among others.
On its operation if it receives a message of type 0xC0, i.e. a positioning message from a mobile node forwarded by a fixed node it just writes into COM port (USB) the message to our analysis tool (Tiny Bee) aiming get that message. Conversely, if it receives a message of type 0xC1 - A message of action, it rides a message filling the CMD field, which is the command to be executed, and VALUE for the value to be set, see Figures 3 and 4. After this, sends this message in Unicast to the destination fixed node.

```
Forever
    If
    has received some message 0XC0
    then
    It sends the address vector of the message to the
    USB port.
    Else
    if has received some data from USB Port
    then
    set up header 0XC1.
    Understand the type of action and adds necessary
    information into message.
    Sends message to the relative address.
    End if.
End forever
```

Figure 1 shows the header protocol developed and used for communication on the zigbee network. It consists of seven fields, the first to indicate the type of message referred to the used types are shown in Figure 3. The two and three fields are the relative addresses for the network to the sender and receiver, that is, each new configuration of a network these addresses are modified, thereby functioning like IP address, i.e dynamic address. The following fields, four and five uniquely identify interfaces of the devices these addresses are static and are not modified at any time so those came from the factory. These addresses works as SSN (Social Security Number) addresses. The CMD and VALUE fields are exclusive of bi-directional communication, i.e., for transmissions in the direction from the root to the nodes, the figure 4 illustrates the variables defined for these fields. Finally, the LQI field is only filled in communications from mobile to fixed and fixed to the root, which is the signal quality indicator which the message was transmitted.

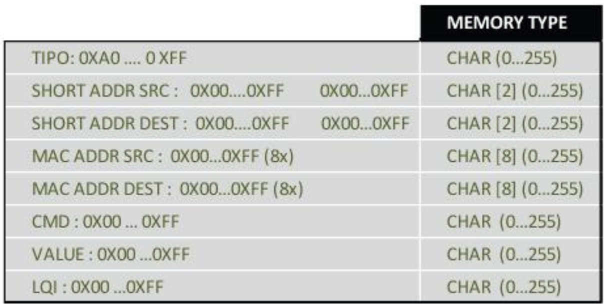


MESSAGE STRUCTURE							
TYPE	SHORT ADDR SRC	SHORT ADDR DEST	MAC ADDR SRC	MAC ADDR DEST	CMD	VALUE	LQI
1 BYTE	2 BYTES	2 BYTES	8 BYTES	8 BYTES	1 BYTE	1 BYTE	1 BYTE

LENGTH
24 BYTES

Figure 1 – Structure of the message exchanged between the nodes.

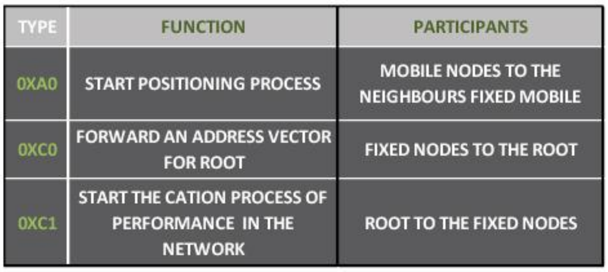
The figure 2 describes the fields of the protocol used in the messages. The column "Memory Type" indicates what type of variable used for this purpose, CHAR type variables store only one byte, with its range of values ranging from 0 to 255 in decimal. The CHAR notation (size) indicates an array of CHARs with the defined size, this way is possible store sequences of CHARs.



	MEMORY TYPE
TIPO: 0XA0 .... 0 XFF	CHAR (0...255)
SHORT ADDR SRC : 0X00....0XFF 0X00...0XFF	CHAR [2] (0...255)
SHORT ADDR DEST : 0X00....0XFF 0X00...0XFF	CHAR [2] (0...255)
MAC ADDR SRC : 0X00...0XFF (8x)	CHAR [8] (0...255)
MAC ADDR DEST : 0X00...0XFF (8x)	CHAR [8] (0...255)
CMD : 0X00 ... 0XFF	CHAR (0...255)
VALUE : 0X00 ...0XFF	CHAR (0...255)
LQI : 0X00 ...0XFF	CHAR (0...255)

Figure 2 – Data types of the message

The figure 3 sets out the types of messages that travel over the network, to the functioning of all parts of the network only use three messages, the first to start positioning, from a mobile node to the fixed nodes of their coverage, so it sends the message 0xA0 in broadcast message with the prescription set time for a node at most, and ensures that only the first level of neighbors, direct neighbors, receive the message, so we use the number of hops equal to one.



TYPE	FUNCTION	PARTICIPANTS
0XA0	START POSITIONING PROCESS	MOBILE NODES TO THE NEIGHBOURS FIXED MOBILE
0XC0	FORWARD AN ADDRESS VECTOR FOR ROOT	FIXED NODES TO THE ROOT
0XC1	START THE CATION PROCESS OF PERFORMANCE IN THE NETWORK	ROOT TO THE FIXED NODES

Figure 3 – Description of the types of messages.

The second type of message is the one used by fixed nodes, identified by 0xC0, and is used to forward the message 0xA0, that is sent by mobile node. Finally, messages of type 0xC1 depart from the root node in order to perform some action defined by the user at some fixed network node.

Thus, dependent on the fill of the fields six and seven of the message by the user, details on possible commands are present in the figure 4.

CMD	VALUE INTERVAL	FUNCTION
0X01	0X00 (OFF) / 0X01 (ON) / 0X02 (BLINK)	TURN ON/OFF THE GPI/O-1
0X02	0X001 / 0X01 / 0X02	TURN ON/OFF THE GPI/O-2
0X03	0X001 / 0X01 / 0X02	TURN ON/OFF THE GPI/O-3

Figure 4 – Description of the activities of the messages commands.

The figure 4 shows the commands determined to meet the demands of research. However, we include in this step only a small amount of possible commands of the commands. Experimentally we used three GPIO pins on each device that allow only two logical states, on or off, that could control a door, electronic equipment or any other sensors.

However, there is a possibility of entering commands to input signals from external sensors, for example temperature sensors, light, altitude, among others. Or, gradual manipulation of outputs as can be observed in the application of gradually turning on a lamp or control the speed of a rotary engine and so on.

We use the codes 0x01, 0x02 and 0x03 to control signal outputs, in order to activate or deactivate leds (light-emitting diodes) to light declare the code 0x01 and 0x00 to delete the code.

5. TESTS

Tests were split in three categories in order to evaluate possible solutions provided by zigbee grid and managed by zigbee. In all tests we made use of our prototype. Tests were organized to balance both sides: the side of the grid itself, and the user side. The first test evaluates the passive capability of the network, that is, the grid informs the user its state. The second one evaluates the active capability of the network, that is, the user has the power to change the behavior of the network by sending commands. The last test evaluates mesh "intelligence", by verifying if users stimulus (actuation logic) change mesh behavior after any action. The first test stores only the answers of trajectory points of the object. The second test adds the knowledge of object location inside the mesh, registering the last information.

Three different configurations were tested involving mapped objects that should be tested and zigbee devices.

Our proposal was validated by the use of our prototype. Tests executed using real sceneries and the developed tool are the following: location of portable objects using fixed objects as reference, mapping routes of portable objects using fixed objects as reference, modeling smart grids zigbee with actuators and physical sensors. For each one of these tests a certain sequence of steps was performed in order to evaluate points of interest and achieve expected results. In each of the tests performed, the composition of results, efficiency and accuracy was enough to measure the applicability of such proposition, i.e., our goal was reached when apply the real tests.

All of the fixed nodes were physically positioned and located by the tool before the beginning of the tests in order to optimize them. This is not a required step once the grid is adaptable to new node inputs and outputs, a characteristic which is a factory guarantee defined a priori in zigbee devices.

The figures 5 and 6 show devices and sensors used for tests and validation of our proposal. Devices used in the tests include: 15 Target Board CC2530ZNP devices from Texas Instruments, 13 of them set with fixed node, 1 with portable node and 1 with root node, 1 notebook and TinyBee validation tool.

Figure 5 - Devices used for field tests.

Figure 6– One of the fixed nodes used in the field tests.

Test 1 – Passive Capability: capture or track the position of a portable node, that is, the places the node passed by.

Figure 7 was captured from the analysis tool as a result of a test with three fixed nodes and 1 portable, by moving the portable node through the coverage area of the static nodes.

Figures 8 and 9 shows the result of mapping a portable node that moved from FF299-BF4DE-854CC to north. It was detected that as the portable node leaves the coverage area of fixed points BF4DE and 854CC, the node was connected only to FF299 node, later it belonged to 64FF0-B14DC-FF299.

Figure 7 – Passive test with three fixed nodes.

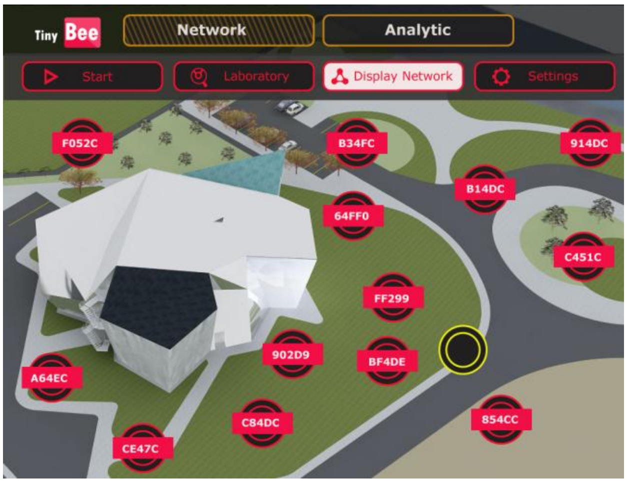


Figure 8– Passive test with thirteen fixed nodes.

Figure 9 – Passive test with thirteen fixed nodes.

Test 2 – Active Capability: Choose any node and send a signal to it, when the chosen node receive the signal, it should lights its own led (light emitting diode), as shown in the figure 10.

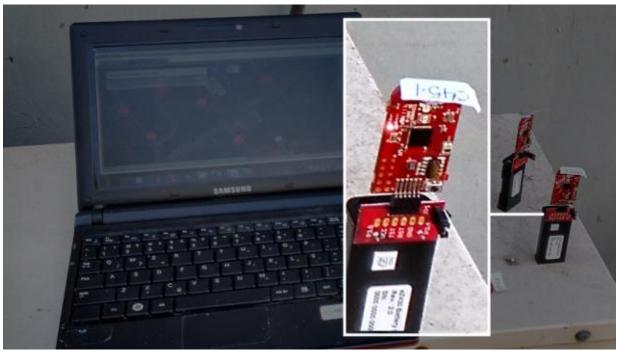


Figure 10 – Active test to one fixed node

Test 3 - Cognitive Capability: Choose any fixed node and inject the logic to recognize the proximity of a portable node and lights up the led. (Figure11)

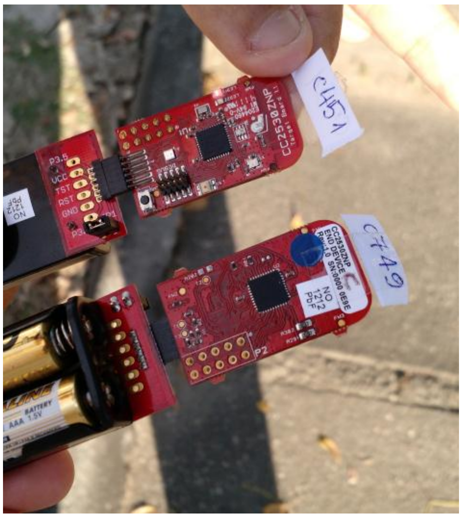


Figure 11– Actuators on fixed node test.

All the tests can be repeated and verified by users. For this purpose it is necessary to have three zigbee devices, model CC2530ZNP and our tool, containing source codes related to internal nodes functioning (low level information) and the validation prototype that can be obtained by sending us an e-mail.

6. RESULTS – PERFORMANCE ANALYSIS

We based our evaluation in three techniques of system performance, modeling, simulation and measure [7]. By the use of these techniques we built hybrid models that assures higher confidence in evaluation results pointed by virtual maps that represents individual positioning of physical nodes. For modeling, we designed a support tool that allows understanding and projection of dynamic grids, considering aspects of mapping dimension, coverage area, and efficiency.

Simulation was conducted using this tool and some mobile and fixed nodes, in order to evaluate the integration of our tool with the devices simulating a high scale mesh. Last but not least, we ran some tests to verify nodes capabilities of mapping and positioning, for which we use our tool to validate tests.

In order to improve confidence in conclusions obtained this sample should represent the observed system. The

bigger is the sample, the better the representatively. However, if the sample becomes too big, it will demand increasing resources and effort.
The equation (I) describes the minimum size of the sample (number of tests or experiments).

$$n = \frac{Z^2 . \alpha^2}{E^2} \qquad (I)$$

Z = Confidence level
α = Sampling average
E = Possible sampling error arbitrated by the analyst

We use the value 70% for confidence level, even in laboratory tests, there are obtained the effects of interference. The sample average chose the number five to map the desired land, something about 1200 m^2 (one thousand two hundred square meters) that are 30m by 40m wide, as each zigbee node covers about 7 meters radius, the average can be 13 us fixed, i.e., the total area ($13 \times 49 \times \Pi = 2.001m^2$) is sufficient to map the target area. For sampling error, we consider only one node in the worst case at most one node can be lost. Thus, we have the minimum number of experiments that must run in the field to validate our tests, according to equation (II):

$$n = \frac{0,7^2 . 5^2}{1^2} \qquad (II)$$

$$n = 13 \text{ tests on network}$$

7. FUTURE WORKS

Complementarily, we realized that this research offers some extra features that could be added. For example, in order to manage the date collected, three diagrams should be generated. The first one is to get the overview of the fixed nodes frequency on the indicated zones. Thus the accesses numbers of the mobile nodes are delivered by the fixed nodes. A layout suggestion could be seen on the figure 12.

The figure 13 is the visual demonstration using graphic elements of the figure 12 and let us easily observes the movement of the mobile nodes by the fixed nodes zone, i.e. such zones that presents more population of mobile nodes. This diagram could be used as a tool to analyze such POS (point of sale) that attracted more consumers.

The figure 14 shows a tracking proposal of a specific mobile node in the fixed zones. It leads us to observe the temporal displacement of the node and should be applied to optimize the internal process of the companies as FedEx and telegraph.

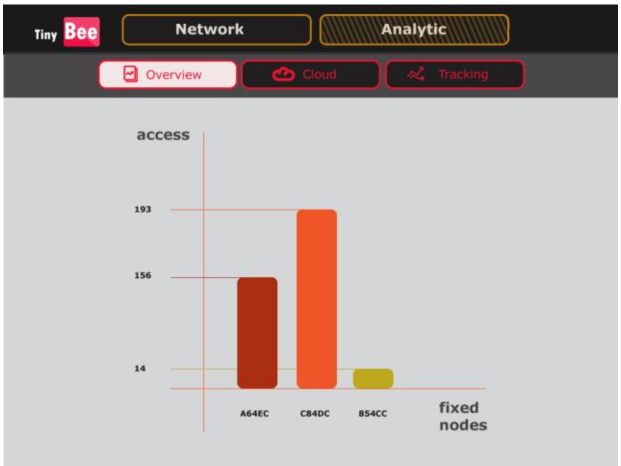


Figure 12– Mobile access for fixed areas.

Figure 13– Mobile access distribution for fixed areas.

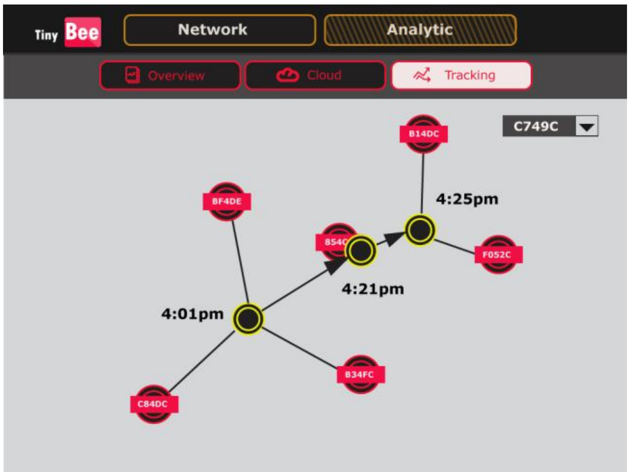


Figure 14– time tracking of mobile nodes for fixed areas.

8. CONCLUSION

The prototype tool plus the algorithm developed to operate in nodes of a zigbee network drove the field tests aiming to evaluate their functioning above uncontrolled situations. As well, we aimed to test the capability of the zigbee network of work in a mesh grid providing more robustness and a great range of functions which could be adapted to current situations of a company. As a result of these tests we could verify the zigbee network adequacy of providing services control and assets management by inputting automatic settings.

In addition, we could note it will not face difficulties to adapt to different scales of network's design since the zigbee network makes the reach higher due their great scalability. Finally, we intend that this study could support future research as a base content.

Consequently, the composition of results and efficiency were sufficient to measure the applicability of proposition, which the use cases are based on bias of theoretical study.

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POWERS CONTROLS OF A DOUBLY- FED INDUCTION GENERATOR USED IN A CHAIN OF WIND POWER CONVERSION

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ABSTRACT

This paper deals with a study of some controls applied on a Doubly-Fed Induction generator (DFIG) dedicate in a chain of wind power conversion. Two methods are proposed: using a PI controller which synthesis is done by a new method called generalized method (GM) and using a polynomial controller RST one. The object is to apply these techniques to control the active and reactive powers generated by the DFIG. Simulations show that these controllers lead good results on tracking behavior, load disturbance rejection and show robustness following of variation parameters.

Keywords: wind power, Doubly-Fed Induction generator, PI controller, RST controller, vector control

1. INTRODUCTION

The development and the exploitation of renewable energies met a great growth these last years. Among these sources of energies, the windmills represent a significant potential to give solution for the demand, which always increase (Allam, Dehiba, Abid, Djeriri and Adjoudj 2014). The wind power can contribute with a significant part for the new sources of energy not emitting a gas for purpose of greenhouse (Ardjoun, Abid Aissaoui, Ramdani and Bounoua 2010)

In this paper, a DFIG modeling and its vector control are showed. Several methods are been already studied (Adjoudj and Abid 2012, Benbouzid, Beltran and Mangel 2013) for the DFIG which give good performances. Here, the controls of the active and reactive powers generated by the DFIG are given. For this purpose, a generalized method (GM) for PI controller synthesis is proposed. A polynomial RST controller is also applied. It may be noted that these two methods need the function transfer of the system. This paper is organized as follows: first, a presentation of the wind power conversion is given. The DFIG modeling follows this generality. For PI controller synthesis, a generalized method is presented. The application of the polynomial controller RST is then showed. Discussions from various results and a conclusion will finish the paper.

2. WIND POWER CONVERSION SYSTEM

The system, showed by figure 1 is composed of a turbine, multiplier, the DFIG and two converters (Ardjoun, Abid, Aissaoui and Naciri 2012, Meroufel, Massoum and Hammoumi 2010). The turbine transforms the kinetic wind power in mechanical energy. The total kinetic power of the wind is:

$$P = \frac{1}{2} \rho \pi R_T^2 V^3 C_p \tag{1}$$

For windmills, the coefficient of energy extraction Cp which depends both of the wind velocity and the turbine speed is usually defined in the interval [0,35÷ 0,59] (Adjoudj, Abid, Aissaoui, Ramdani and Bouboua 2010). The DFIG transforms this latest in electrical energy. The converters are used to transfer the maximal energy delivered by the windmill to the grid according the wind velocity.

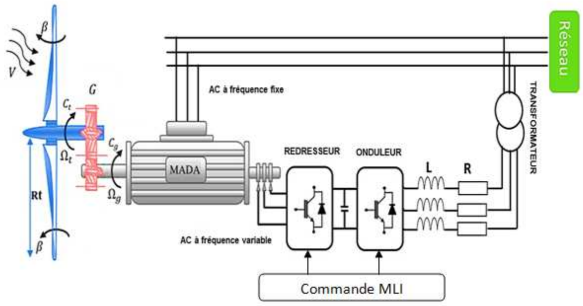


Figure 1: General scheme of a windmill based on DFIG

3. DFIG MODELING AND VECTOR CONTROL

The model of the DFIG is described in Park referential. The different equations give the global modeling of the machine.

3.1. Electrical equations

Te electrical equations give the voltage expressions.

$$\begin{cases} V_{sd} = R_s i_{sd} + \dfrac{d\phi_{sd}}{dt} - \omega_{coor}\phi_{sq} \\ V_{sq} = R_s i_{sq} + \dfrac{d\phi_{sq}}{dt} + \omega_{coor}\phi_{sd} \\ V_{rd} = R_r i_{rd} + \dfrac{d\phi_{rd}}{dt} - (\omega_{coor} - \omega)\phi_{rq} \\ V_{rq} = R_r i_{rq} + \dfrac{d\phi_{rq}}{dt} + (\omega_{coor} - \omega)\phi_{rd} \end{cases} \quad (2)$$

3.2. Magnetic equations

Relation (3) gives the expressions of different flux.

$$\begin{cases} \phi_{sd} = L_s.i_{sd} + M.i_{rd} \\ \phi_{sq} = L_s.i_{sq} + M.i_{rq} \\ \phi_{rd} = L_r.i_{rd} + M.i_{sd} \\ \phi_{rq} = L_r.i_{rq} + Mi_{sq} \end{cases} \quad (3)$$

With Ls, Lr, M design respectively the stator inductance, the rotor inductance and the mutual.

3.3. Torque and powers equations

The electromagnetic torque is expressed as according to current and fluxes by:

$$C_{em} = -p\frac{M}{L_s}(\phi_{sq} i_{rd} - \phi_{sd} i_{rq}) \quad (4)$$

The expressions of the active and reactive powers are:
By stator side,

$$\begin{aligned} P_s &= V_{sd} I_{sd} + V_{sq} I_{sq} \\ Q_s &= V_{sq} I_{sd} - V_{sd} I_{sq} \end{aligned} \quad (5)$$

By rotor side,

$$\begin{aligned} P_r &= V_{rd} I_{rd} + V_{rq} I_{rq} \\ Q_r &= V_{rq} I_{rd} - V_{rd} I_{rq} \end{aligned} \quad (6)$$

3.4. Vector control of the DFIG

In order to control the electricity production, a method, which not depends of the active and reactive powers, is proposed. It consists to establish relations between rotor voltages delivered by the converter with active and reactive stator powers (Ardjoun, Abid, Aissaoui and Naciri 2012, Meroufel, Djeriri, Massoum and Hammoumi 2010).

Referential **d-q** related of spinning field and a stator flux aligned on the axis **d** is adopted. So:

$$\begin{cases} \phi_{sd} = \phi_s \\ \phi_{sq} = 0 \end{cases} \quad (7)$$

Flux equations become:

$$\begin{cases} \phi_{sd} = \phi_s = L_s.i_{sd} + M.i_{rd} \\ 0 = L_s.i_{sq} + M.i_{rq} \\ \phi_{rd} = L_r.i_{rd} + M.i_{sd} \\ \phi_{rq} = L_r.i_{rq} + Mi_{sq} \end{cases} \quad (8)$$

If the grid is supposed stable, the stator flux ϕs is constant. Moreover, the stator resistor may be neglected; it is a realist hypothesis for a generator used in windmill. Taking into account all these considerations:

$$\begin{aligned} V_{sd} &= 0 \\ V_{sq} &= V_s = \omega_s\phi_s \end{aligned} \quad (9)$$

By the equation (8), a relation between stator and rotor currents can be established:

$$i_{sd} = \frac{\phi_s}{L_s} - \frac{M.i_{rd}}{L_s} \quad (10)$$

$$i_{sq} = -\frac{M}{L_s} i_{rq} \quad (11)$$

Using simplifying hypothesis, the equations of powers give:

$$\begin{cases} P_s = -V_s.\dfrac{M}{L_s} i_{rq} \\ Q_s = -V_s.\dfrac{M}{L_s} i_{rd} + \dfrac{V_s^2}{L_s.\omega_s} \end{cases} \quad (12)$$

In order to control the generator, expressions showing the relation between rotor voltages and rotor currents are:

$$\begin{cases} V_{rd} = R_r i_{rd} + L_r\sigma\dfrac{di_{rd}}{dt} - g\omega_s L_r\sigma i_{rq} \\ V_{rq} = R_r i_{rq} + L_r\sigma\dfrac{di_{rq}}{dt} + g\omega_s\left(L_r\sigma i_{rd} + \dfrac{MV_s}{\omega_s L_s}\right) \end{cases} \quad (13)$$

With g, σ denoting respectively the slip and the leakage coefficient.

Using relations (9),(10),(11) and (12), figure 2 shows a diagram where the rotor voltages like input and active and reactive powers like output.

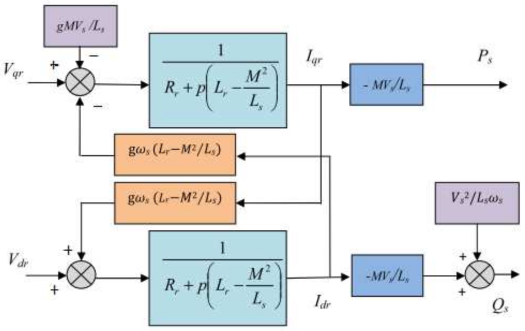


Figure 2: Diagram of the system to be controlled

There are generally two methods to do an independent regulation for the active and reactive powers:

- Direct method, which consists to neglect the coupling terms and to put a controller on each axe to control active and reactive powers. In this case, the controllers command directly the rotor voltages of the machine

- The second method, which takes into account the coupling terms and to compensate them by using two loops permitting to control the powers and the currents of the rotor. It is based on the relations (12) and (13). The diagram is given by figure 3.

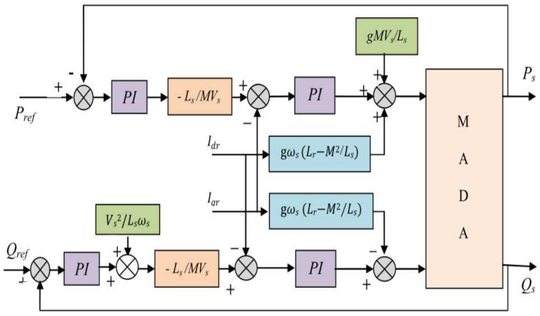


Figure 3 : Indirect vector control diagram

4. PI CONTROLLER

The synthesis is based on the simplified model of the DFIG. A PI controller is a simple one but can offer good performances. Different documentations show several methods (Allam, Dehiba, Abid, Djeriri and Ardjoun 2014, Bühler 1998) for its synthesis. Here, a generalized method (GM) is proposed to determine the parameters of the PI controller. Usually, there are two kinds of function transfer:

$$G_R(p) = \frac{1+pT_n}{pT_i} \qquad G_R(p) = K_p + \frac{K_i}{p} \tag{14}$$

It is easy to find relations between different parameters:

$$\begin{cases} K_p = \dfrac{T_n}{T_i} \\ K_i = \dfrac{1}{T_i} \end{cases} \tag{15}$$

For each loop, the function transfer of first order can be used for the system.

$$G(p) = \frac{K}{1+pT} \tag{16}$$

Usually, the second kind of function transfer is used. The method consists to:

- Impose a response time at ± 5%
- Choose a frequency for closed loop.

Here, the GM method using the first expression of the function transfer is chosen (Razafinjaka N.J. and Andrianantenaina T. 2015). Therefore, the function transfer of opened loop is:

$$G_o(p) = \frac{1+pT_n}{pT_i} \cdot \frac{K}{1+pT} \tag{17}$$

Relation (18) resumes the method:

$$\begin{cases} T_n = a.T & a \geq 0 \\ T_i = b.K.T & b > 0 \end{cases} \tag{18}$$

Example:

1/ **a =1** (the time constant T is cancelled)

$$G_o(p) = \frac{1+pT}{pbKT} \cdot \frac{K}{(1+pT)} = \frac{1}{pbT} \tag{19}$$

The function transfer for the closed loop is then

$$H(p) = \frac{G_o(p)}{1+G_o(p)} = \frac{1}{1+pbT} \tag{20}$$

The function transfer is yet a first order one with the time-constant $T_f = b.T$ *(0<b<1, here)*

2/ **a = 0**

$$G_o(p) = \frac{1}{pbKT} \cdot \frac{K}{1+pT} = \frac{1}{pbT.(1+pT)} \tag{21}$$

The closed loop transfer function is

$$H(p) = \frac{G_o(p)}{1+G_o(p)} = \frac{1}{pbT.(1+pT)} = \frac{1}{p^2bT^2+pbT+1} \tag{22}$$

By comparing with the canonical form,

$$\begin{cases} H_o = 1 \\ 2\zeta\omega_n = \dfrac{1}{T} \\ \omega_n^2 = \dfrac{1}{bT^2} \end{cases} \tag{23}$$

Imposing b gives ζ and vice versa. (b = 2 ⇒ ζ = $\frac{\sqrt{2}}{2}$).

Figure 4 shows the powers loop,

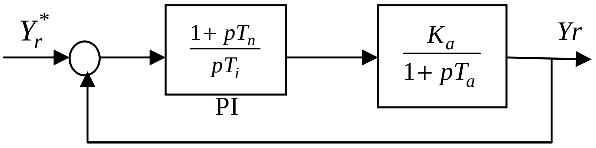


Figure 4: Power loop diagram

Here,

$$\begin{cases} K_a = \dfrac{M.V_s}{L_s.R_r} \\ T_a = \dfrac{L_s.L_r - M^2}{L_s.R_r} \end{cases} \tag{22}$$

For the current loop,

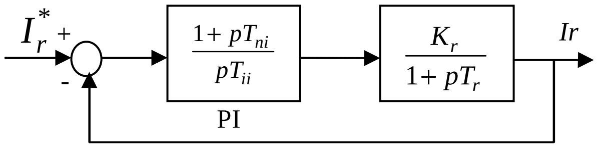


Figure 5: Current loop diagram

With,

$$\begin{cases} K_r = \dfrac{1}{R_r} \\ T_r = \dfrac{\sigma.L_r}{R_r} \end{cases} \qquad (23)$$

4.1. Simulation and results

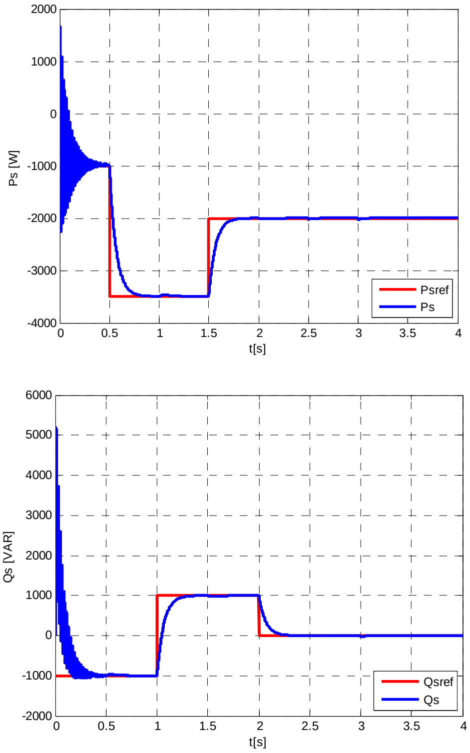
Tracking test, disturbance rejection and robustness compared to the variation parametric, especially variation of the rotorique resistance *Rr* are used.
All simulations have the same conditions:

$$\begin{cases} \text{Variation of the power references, } P_{sref} \text{ and } Q_{ref} \\ t = 2{,}5[s],\ \ \Omega\ :167{,}5\ [rd.s^{-1}] \longrightarrow 178\ \ [rd.s^{-1}] \\ t = 3[s],\ \ Rr\ \rightarrow\ 2{*}Rr \end{cases}$$

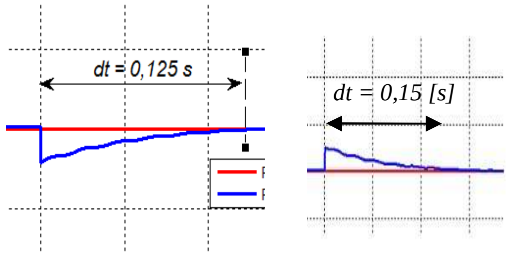
All the parameters of the PI controller are determined by the MG method.

$$\begin{cases} Powers : a = 0 \quad b = 0{,}058 \\ currents : a = 1 \quad b = 1 \end{cases}$$

Figures 6 present the simulation results.

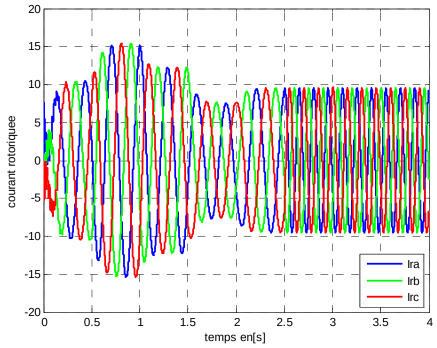


(a) : Active and reactive powers curves

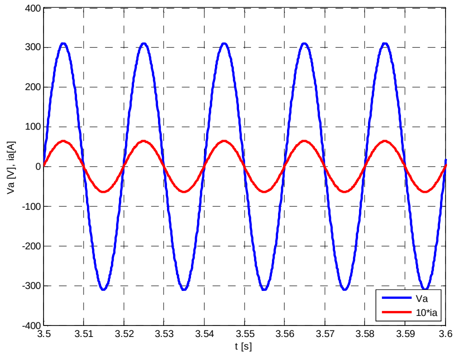


(b) (c)

(b) Active power (Ω:167,5 [rd.s^{-1}] $\longrightarrow$ 178 [rd.s^{-1}])
(c) Active power (Rr: Rr$\rightarrow$2*Rr)



(d) Rotorique currents



(e) Statorique Voltage and current when Q_s =0

Figure 6: Simulation results with PI controller

It is clear here to note that PI controller determined by the MG method allows good performances: tracking, disturbance rejection and robustness from parameters. Figures 6 (b)-(c) shows that steady state is reached after Δt= 0,125 ÷ 0,15 [s]. The peak value is: ΔP = 20 [W].

5. RST CONTROLLER

This controller is primarily a digital controller. It generalizes the standard PID controller.. It owes its appellation by the three polynomials R(z), S(z) and T(z) which define it. The command law is :

$$R(z).U(z) = T(z).Y_c(z) - S(z).Y(z) \qquad (24)$$

Where Yc(z), Y(z) are respectively the set point and the output.

The difference between T(z) and S(z) offers more possibility and it is the reason that RST controller is called controller with two degrees of freedom.

5.1. RST synthesis

The RST synthesis is based on poles placement when a desired model $H_m(z)$ in close loop is given. Figure 7 shows the basic idea. Usually, the desired model is with non-high order. Its poles must satisfy absolute and relative conditions of damping.

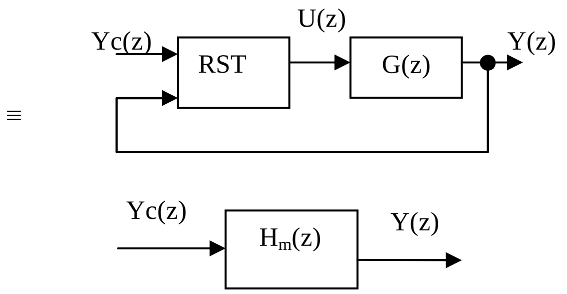


Figure 7: Basic scheme for RST synthesis

The relation (16) shows that power loop and rotorique current loop may be presented by first order transfer function.

$$G(p)=\frac{K}{1+pT}$$

Relation (25) permits to calculate the discrete transfer function G(z) when G(p) is given.

$$G(z)=(1-z^{-1})Z\left\{L^{-1}[\frac{G(p)}{p}]\right\} \tag{25}$$

So,

$$G(z)=\frac{B(z)}{A(z)}=\frac{b_0}{z-z_0} \tag{26}$$

With

$$\begin{cases} b_0=K.(1-z_0) \\ z_0=e^{-\frac{h}{T}} \end{cases} \tag{27}$$

Here ***h*** is the sampling time.

The desired model in close loop is as follows:

$$H_m(z)=\frac{B_m(z)}{A_m(z)} \tag{28}$$

Using the relations (24), (26) and (28), the followed equality can be established:

$$\frac{T(z).B(z)}{A(z).R(z)+B(z).S(z)}=\frac{B_m(z)}{A_m(z)} \tag{29}$$

Here, R(z), S(z) and T(z) are to be calculated. Usually R(z) is chosen as a normalized polynomial. Resolving the equation (29) needs zero simplifications. For $H_m(z)$, some considerations must be taken into account.

- To eliminate the position error:
  $e_p=0 \Leftrightarrow H_m(1)=1$
- The denominator is:
  $A_m(z)=z^d.P(z)$

Where d°P = 1 or d°P =2. For the last condition,

$$P(z)=z^2+c_1z+c_2$$
$$\begin{cases} c_1=-2.e^{-\zeta\omega_n h}.\cos(\omega_n h.\sqrt{1-\zeta^2} \\ c_2=e^{-2\zeta\omega_n h} \end{cases} \tag{29}$$

Because of the expression of G(z), no zero can be cancelled.

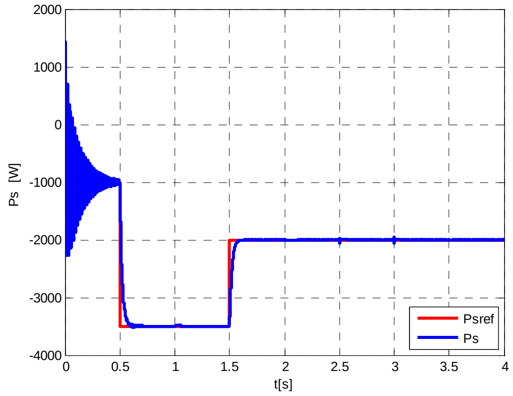
All steps to determine the polynomial RST are resumed in (Longchamp 1991, Razafinjaka 1991). In this paper, a polynomial P(z) with degree 2 and a perturbation compensator (m=1) are used. The results of computation are:

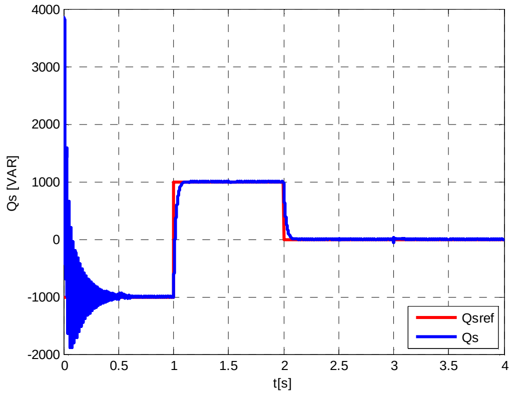
$$\text{Power}\begin{cases} h=10[ms]\ \ \zeta=0,707\ \ \omega_n=400\left[\frac{rd}{s}\right] \\ R(z)=z-1 \\ S(z)=0,0089z-0,0039 \\ T(z)=0,005 \end{cases}$$

$$\text{Current}\begin{cases} h=10[ms]\ \ \zeta=0,707\ \ \omega_n=400\left[\frac{rd}{s}\right] \\ R(z)=z-1 \\ S(z)=30,6z-13,48 \\ T(z)=17,12 \end{cases}$$

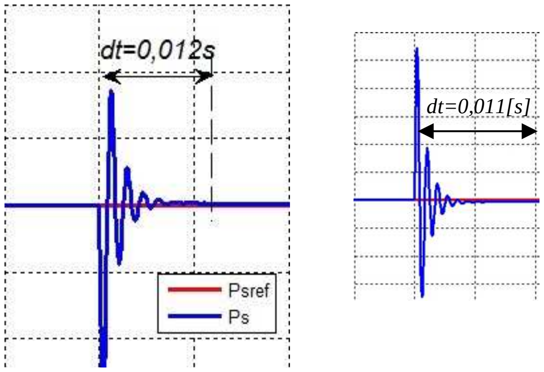
5.2. Simulation results

All conditions for tracking, disturbance rejection and robustness tests are the same like with the PI controller. Figures 8 show different curves.



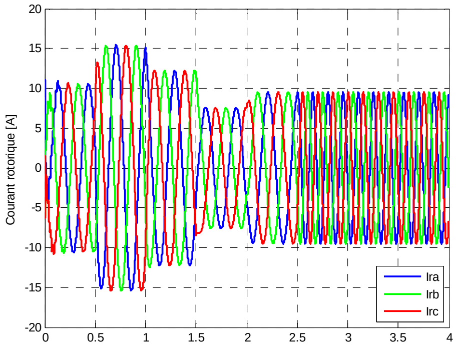


(a) Active and reactive power curves

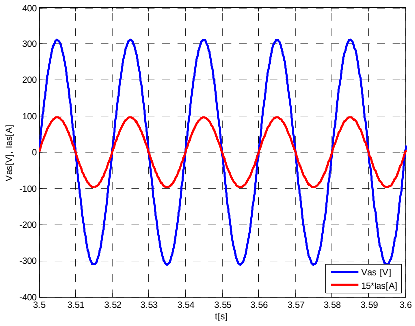


(b) (c)

(b) Active power (Ω:167,5 [rd.s^{-1}] ⟶ 178 [rd.s^{-1}]
(c) Active power (Rr: Rr⟶2*Rr)



(d) Rotorique currents



(e) Statorique voltage and current when Qs =0

Figure 8: Simulation results with RST controller

Figures 8 (b) –(c) shows that the system with RST controller (h = 10 [ms]) is faster but the peak power is higher (ΔP=80 [W]) in comparison with the PI controller one. However, it should be noted that this peak value and the oscillations decrease as the sampling time decreases. In the two cases, the reactive power Qs is null when statorique voltage and current are purely are sinusoidal and in phase ensuring good quality of the energy injected to the grid. The static error is null. At least, good performances are obtained.

CONCLUSION

In this paper, PI and RST controllers are used to control the active and reactive powers generated by a DFIG used in a chain of wind power conversion. A new method called generalized method (GM) is proposed and applied. The results show the effectiveness of this new method. It must be also noted that the RST controller may be inserted in adaptive control.

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OPTIMAL CROP SELECTION AND SCHEDULING USING A GENERIC CROP GROWTH MODEL AND INTEGER PROGRAMMING MODEL

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ABSTRACT

Crop growth programs and crop optimizers act as important decision support tools in selecting crops and influencing farmer decision process. However the crop optimizers do not always include the crop growth models while selecting the best possible crops. In this paper we will present the equations used to model a generic crop growth model and couple it with an optimal crop scheduler, to select the best possible sequence of crops. The scheduler aims to achieve various objectives like maximizing performance, maximizing economic gain and minimizing environmental impact. Each objective has three different configurations with regards to the crop rotation and crop growth period. The results will be visualized using a Gantt chart to show the scheduling of the crops.

Keywords: crop growth program, optimal crop scheduling, decision support system, integer programming

1. INTRODUCTION

The definition of sustainability in agriculture has been subject to multiple revisions. Various interpretations and objectives have been prescribed to define sustainability. Since, the conditions dictating agricultural activities vary between different regions, varying evaluation criteria are required to judge sustainability. This definition has progressed from a purely economic objective to now include ecological and social considerations. Sustainable agriculture is now considered as, methods or practices that facilitate the development of social, economic and environmental objectives by finding a common ground between the various conflicting options that these objectives present.

It is now necessary for policy makers and farmers to understand the decisions being made at farm level, and their consequences on the immediate environment, in order to create long-term plans for sustainable agriculture.

This need for modeling various scenarios and decisions at farm level, and analyzing their impact, has resulted in the demand for expert systems that can aid farmers and decision makers in making decisions that meet the objective of sustainability. Such a system would need to combine the various aspects of farm level procedures from crop growth dynamics to community based decision models. It would require quantifying various decision alternatives and scenarios through data analysis and a review of previous work. The designers of such a system would also need to identify those areas of farm processes that have a significant impact on the farm level decision process, and eliminate excessive complexity in the system. In order to give decision makers access to all these various aspects of decision making, we first need to understand the various socioeconomic and environmental issues faced by farmers, and derive the criteria to measure sustainability.

Typically farmers are profit maximizers. Their primary objective is to maximize their profits for each cropping season. Social and environmental welfare are generally treated as secondary objectives that are contingent upon the completion of the primary objective. The farmers often face various issues in achieving their primary objective. Additionally, the actions taken during the pursuit of the primary objective can cause a significant impact on the secondary objectives.

A tool, which is aimed at helping farmers make decisions, needs to be able to present the problem to the user from multiple perspectives and provide solutions for each of those perspectives. It should also be able to help the decision makers compare the results of the different perspectives, and provide a measure for computing the best decision, or sequence of decisions.

Decision support systems for farmers, fall under this category of expert systems. Due to the multiple methods of formulation of a farming problem, no single modeling methodology can answer all the questions a decision maker might ask. The various decision modeling methods can only address specific sets of scenarios. For example, Bazzani et al., 2005, Berentsen, 2003, El-Nazer & McCarl, 1986 treat farming problems as resource and policy optimization problems. They do not address the motivations behind decision making processes explicitly.

On the other hand, Bosma, Kaymak, van den Berg, Udo, & Verreth, 2011, Fairweather, 1999, Rehman & Romero, 1993 address farming problems as purely theoretical decision making problems. This causes the models to over stress the importance of some variables, which might not have an actual impact in real world scenarios.

Additional problems arise when most models do not integrate crop growth models into their decision support systems. This problem stems from research groups, which concentrate on specific problems of specific areas. Though this gives the research groups the flexibility to use historic yield data while formulating their problem, it becomes hard to apply their conclusions to other regions and crops.

Our research effort stems from this need to design a decision support system that integrates multiple modeling methodologies into a single system. Such a system should not require unrealistic amount of inputs from users, who have a limited knowledge of the various methodologies. Fig. 1 is a conceptual model of the architecture of the proposed system.

The crop growth model is the base component of the architecture. It consists of the necessary equations to model the growth of crops. It is capable of simulating the yield and also the height of a set of crops. The output of this layer is used in both the optimizer and the individual decision model. The optimizer is the second model of the architecture. Its purpose is to compute the optimum crop/combination of crops that the farmer can plant in order to maximize his profits, while maintaining a certain level of environmental friendliness.

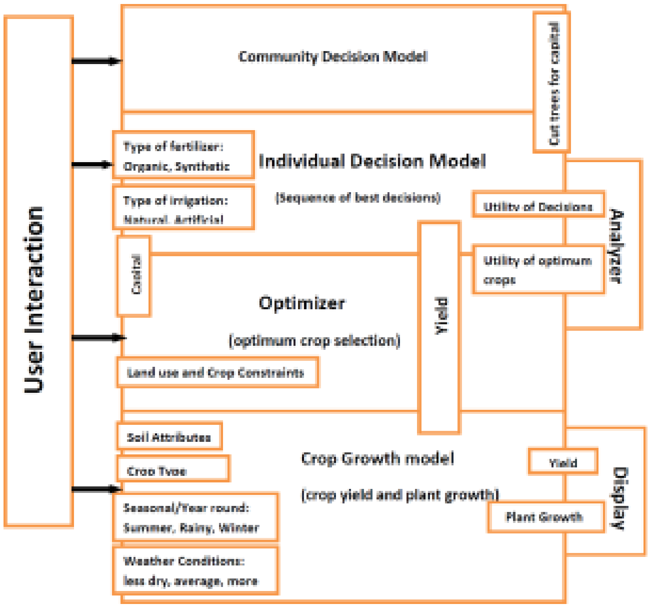

Figure 1: Multi layered decision support system for farmers

The individual and community decision models are used to simulate individual and collective farmer decision making process. These layers can show the impact of farmer decisions on their economic standing and the environment.

A generic crop growth model was analyzed by the authors, Vegesana & McKenzie, 2013, to determine the important variables affecting crop growth. A mathematical programming model was also implemented by Collins et al., 2013 to determine optimal crop selection and rotations for a small set of crops. An agent based decision models was explored by Vegesana & McKenzie, 2014 for use in the individual and community layers.

In this paper we will couple the crop growth model with the optimizer layer to evaluate the optimum scheduling of crops for a given set of weather data. The simulation results will be presented using a Gantt chart for various configurations and objectives. In the next section we will present the various equations used to model the crop growth and the applications of this model. In section 3 the mathematical programming model for optimum selection and scheduling of the crops will be presented. Section 4 contains the results for the simulation, and we conclude with some observations for future work in section 5.

2. CROP GROWTH MODEL

The mathematical model necessary for crop growth has been developed from existing resources. Several mathematical models are available to simulate the growth pattern of various crops McCown, (2002), Teh, (2006). The drawback of these models is that they are crop specific. Since our project did not need the complexity of the various crop specific models, we have attempted to use a generic crop growth model to simulate the crop bio mass yields and plant height. In this section, we will look at a form of the crop biomass equation. The individual variables in the equation will be explored, to see how we have arrived at the final form of the equation.

2.1. Generic Crop Growth Equation

A generic equation for plant biomass growth(Teh, 2006) can be written as:

$$\frac{dW}{dt_i} = \varepsilon * 0.5\ Q_0 [1 - e^{(-k * LAI_{i-1})}] * 0.0001 \qquad (1)$$

$\frac{dW}{dt_i}$ is the daily increment in biomass weight for the crops, in tonnes/hectare (ta/ha). Q_0 is the daily solar radiation in MJ m^{-2} d^{-1}. ε is the radiation use efficiency that converts the daily radiation into photosynthetically active radiation that is used by the plants. This co-efficient is crop specific. k is the extinction co-efficient. It is generally assumed to have a value of 0.65 for all crops.

LAI_{i-1} is the leaf area index for the previous day. LAI is a dimensional quantity that represents the one sided green leaf area per unit ground surface. In order to evaluate LAI, we need to calculate heat units, heat unit index, and heat unit factor for each day. A crop starts growing once the daily average temperature exceeds the base temperature for the crop. Daily heat unit is the difference between the daily average temperature and the base temperature required for germination. Heat unit HU is given by Williams, Izaurralde, & Steglich, 2008 as:

$$HU = T_{Avg} - T_{base} \tag{2}$$

Each day, if the value of the heat unit is greater than zero, it is accumulated as part of the total heat units HU_{tot}. These accumulated heat units are divided by the potential heat units for a crop to arrive at the heat unit index HUI

$$HU_{tot} = HU_{tot} + HU \quad \text{for } HU > 0 \tag{3}$$

$$HUI = \frac{HU_{tot}}{HU_{pot}} \tag{4}$$

The potential heat units for a crop are calculated by multiplying the difference between the optimal and base temperatures for a crop with the total number of growing days.

$$HU_{pot} = Planting\ duration * (T_{opt} - T_{base}) \tag{5}$$

HUI is a value between 0 and 1 that is used to measure the progress of a crops growth as a function of the daily temperature. It is also used to calculate the heat unit factor HUF, which indicates the fraction of the maximum leaf area index for the current heat unit index.

$$HUF_i = \frac{HUI}{HUI + \exp(ah_1 - ah_2 * HUI)} \tag{6}$$

$$ah_2 = \frac{\ln\left(\frac{frp_1}{frl_1} - frp_1\right) - \ln\left(\frac{frp_2}{frl_2} - frp_2\right)}{frp_2 - frp_1} \tag{7}$$

$$ah_1 = \ln\left(\frac{frp_1}{frl_1} - frp_1\right) + ah_2 * frp_1 \tag{8}$$

frp_1, frl_1, frp_2, frl_2 are crop specific parameters that provide the fraction of the maximum leaf area index reached for a specific period in the growing stages. These values are regression co-efficients that researchers have determined experimentally to fit the leaf development curve.

Finally, the leaf area index for each day is given by Neitsch, Arnold, Kiniry, & Williams., 2005 as:

$$LAI_i = \begin{cases} LAI_{i-1} + dH_{F,i} * LAI_{max} * (1 - \exp(5 * (LAI_{i-1} - LAI_{max}))), & i < decline\ period \\ LAI_{i-1} * \dfrac{1 - HUI}{1 - HUI_{sen}}, & i \geq decline\ period \end{cases} \tag{9}$$

$$dH_{F,i} = HUF_i - HUF_{i-1} \tag{10}$$

$\mathrm{HUI}_{\mathrm{sen}}$ is the heat unit index when the crop enters its decline stage. During the growth stages the LAI is an exponential function of the LAI from the previous day and the maximum leaf area index LAI_{max}. Once the crop starts declining, the leaf area also starts declining as a function of the heat unit index.

2.2. Evapotranspiration

Evapotranspiration is the combined process of plant transpiration and soil evaporation. Plants lose almost 99% of the water they take up due to evaporation. This process is called transpiration. Simultaneously, the soil surface also undergoes evaporation and loses water to the atmosphere.

Evapotranspiration is used as a means to calculate the water requirement of a crop for each day during its life cycle. Evapotranspiration is heavily influenced by the climate conditions. It is high in hot and dry conditions, and low in cloudy and cool areas. Crop evapotranspiration for each day is calculated by first calculating the potential evapotranspiration. Potential evapotranspiration is defined as the evapotranspiration that would occur from a large area uniformly covered with green vegetation with an unconstrained access to water.

Various methods have been developed to calculate the potential evapotranspiration on any given day. The Penman model, the Penman-Monteith model, the Priestly-Taylor model, and the Hargreaves model have all been successfully used to calculate daily evapotranspiration. The current crop growth model implements the Penman model to calculate the evapotranspiration. The Penman model calculates the evapotranspiration for a short green crop, like grass, that uniformly covers the surface of the land and has unconstrained water supply.

Table 1: Crop Coefficients and growth stages

Crop	**kcini**	**kcmid**	**kclate**	**Initial duration**	**Development duration**	**Mid-stage duration**	**Decline duration**
Broccoli	0.15	0.95	0.85	135	35	45	40
Lettuce	0.15	0.9	0.9	140	25	30	65
Onions	0.15	0.95	0.65	150	30	40	60

The equation for the penman model is given by Williams et al., 2008 as:

$$E_O = \frac{\Delta * R_N + psychro * FWV * VPD}{H_V * (\Delta + psychro)} \qquad (11)$$

E_O is the potential evapotranspiration for any given day, measured in mm/day. Δ is the slope of the saturation vapor pressure curve in kPa/^{o}C. Vapor pressure is the amount of pressure exerted by vapor in a closed container. It is an indication of the rate of evaporation of water from the soil surface. The slope of the vapor pressure curve indicates the speed with which the surface water content of the soil is evaporating. It is an exponential function of the daily average temperature in ^{o}C, given by the formula:

$$\Delta = 25029.4 * \frac{exp\left(\frac{T_{Avg}*17.269}{T_{Avg}+237.3}\right)}{(T_{Avg}+237.3)^2} \qquad (12)$$

FWV is a function of the wind speed W_S in m/s, that calculates the aerodynamic conductance of air in mm/kPa*day. It is calculated using the formula:

$$FWV = 2.7 + 1.63 * W_S \qquad (13)$$

VPD is the vapor pressure deficit in kPa. It is used to measure the difference in the actual water vapor pressure E_a, and the vapor pressure at saturation E_s, for the daily average temperature T_{Avg} and relative humidity R_h expressed as a fraction.

$$VPD = E_s - E_a \qquad (14)$$

$$E_s = 6.1078 * exp\left(\frac{T_{Avg}*17.269}{T_{Avg}+237.3}\right) \qquad (15)$$

$$E_a = E_s * R_h \qquad (16)$$

$psychro$ is a psychrometric constant. It is useful in relating pressure P_B, in kPa/^{o}C, of water in air to a specific temperature. It is given by the formula:

$$psychro = P_B * 7.2063 * 10^{-4} \qquad (17)$$

H_V is the latent heat of vaporization of water at the daily average temperature T_{Avg}.

$$H_V = 2.501 - 0.0022 * T_{Avg} \qquad (18)$$

The potential evapotranspiration calculated in the previous step is for a reference crop like grass or alfalfa. To scale this value to a specific crop, and to calculate its daily water use, we need to multiply the potential evapotranspiration, E_O, value with the crop co-efficient K_C.

$$E_S = E_O * K_C \qquad (19)$$

The crop co-efficient K_C depends upon the crop type, the growth stages of the crop, and the climate. The general crop co-efficient encompasses the evaporation from both the crop and the soil. General values of the co-efficient are available, and can be used to calculate the daily water requirement. If we need to calculate the daily crop co-efficient by taking the soil type into account, we will need to split the co-efficient into the crop specific co-efficient, and the soil co-efficient. The crop co-efficient K_C is given by Allen, Pereira, Raes, & Smith, 1998 :

$$K_C = K_s * K_{cb} + K_e \qquad (20)$$

K_{cb} is the basal crop co-efficient. For every crop, this value is defined for the different crop growth stages: initial, development, middle, and decline. It is important to know the duration of each of these stages for each crop, and the respective co-efficient. Table 1 shows a sample of the basal crop co-efficient for different crops, at the different growth stages.

The soil co-efficient K_e is calculated using the formula:

$$K_e = K_r * (1.21 - K_{cb}) \qquad (21)$$

The values K_r, K_s are evaporation reduction co-efficients that are dependent on the depth of the water depleted from the top soil for the crops. These co-efficients are given by the following formulae:

$$K_r = \begin{cases} \frac{TEW - D_{e,i-1}}{TEW - REW}, & D_{e,i-1} > REW \\ 1, & D_{e,i-1} < REW \end{cases} \qquad (22)$$

$$K_s = \begin{cases} \frac{TAW - D_{e,i-1}}{TAW - RAW}, & D_{e,i-1} > RAW \\ 1, & D_{e,i-1} < RAW \end{cases} \qquad (23)$$

TEW and REW are the total and readily evaporable water levels respectively, in mm, for different soils. TAW and RAW are total and readily available water levels each day, in mm, for a given crop-soil combination. TEW, and REW values are readily available for major soil types. TAW, and RAW are given by:

$$TAW = 1000(\theta_{FC} - 0.5 * \theta_{WP}) * Z_r \tag{24}$$

$$RAW = p * TAW \tag{25}$$

θ_{FC}, and θ_{WP} are the water content of each soil at field capacity and wilting point respectively. These values are constants for each soil. Z_r is the root depth of the crop at each day. p is a crop specific constant that is used to calculate RAW from TAW. The following table lists θ_{FC} and θ_{WP} values for all the major soil types.

Table 2: Coefficients for various soils

Soil type	θ_{FC}	θ_{WP}	**REW**	**TEW**
Sand	0.12	0.04	5	10
Loamy sand	0.16	0.06	6	13
Sandy loam	0.24	0.11	8	18.5
Loam	0.26	0.12	9	20
Silt loam	0.3	0.14	10	23
Silt	0.33	0.17	10	24.5
Silt clayloam	0.32	0.2	10	22
Silty clay	0.37	0.23	11	25.5
Clay	0.37	0.22	11	26

2.3. Nutrient Requirements

Crops require nitrogen and phosphorous for proper growth. The model calculates the potential nitrogen and phosphorous content of the crop for each day. The nutrient demand is then calculated by subtracting the actual content from the potential content. This nutrient demand is the amount of fertilizer required for a stress free growth. The potential content for each day is given by the formula:

$$N_{pot} = W_i * (bn_1 + bn_2 * \exp(-bn_3 * HUI) \tag{26}$$

$$P_{pot} = W_i * (bp_1 + bp_2 * \exp(-bp_3 * HUI) \tag{27}$$

N_{pot}, and P_{pot} are the potential content for a given day. bn_1, bn_2, bn_3, bp_1, bp_2 and bp_3 are crop specific parameters that express the optimal N and P concentrations as a function of the heat unit index.

2.4. Stress factors

Under ideal conditions the crop growth is stress free and the crop is able to achieve its maximum possible growth for each day. However, actual crop growth suffers from multiple forms of stress. Lack of sufficient water, sub-optimal temperature, and a lack of nutrients inhibit daily crop growth. This is modeled in the equations by multiplying the daily biomass with a stress factor. The new daily biomass is given by

$$\frac{dW}{dt_i} = \text{Stress}* \frac{dW}{dt_i} \tag{28}$$

Stress is a value between 0 and 1 that scales down the daily biomass to actual values. There are various kinds of stress acting on the crop. These are water stress, temperature stress, nitrogen stress and phosphorous stress. Stress is given by

$$Stress = \min(water, temperature, nitrogen, phosphorous\ stress) \tag{29}$$

Water stress is the ratio of the available water content to the actual water necessary. It is given by:

$$Water\ Stress = \frac{RAW}{Required\ water\ content} \tag{30}$$

Temperature stress is a sinusoidal function of the daily average temperature, optimal temperature and the base temperature of the crop.

$$Temp\ Stress = \sin(1.5707 * \frac{(T_{Avg} - T_{base})}{(T_{Opt} - T_{base})}) \tag{31}$$

Nutrient stress for both phosphorous and nitrogen is expressed as a function of the ratio of the actual nutrient content to the optimal nutrient content.

$$Nitrogen\ stresss = 200 * \frac{\frac{Actual\ nitrogen\ content}{Optimal\ Nitrogen\ content}}{(\frac{Actual\ nitrogen\ content}{Optimal\ Nitrogen\ content} + \exp\left(4.065 - 0.0535 * \frac{Actual\ nitrogen\ content}{Optimal\ Nitrogen\ content}\right))} \tag{32}$$

$$Phosphorous\ stresss = 200 * \frac{\frac{Actual\ phosphorous\ content}{Optimal\ phosphorous\ content}}{(\frac{Actual\ phosphorous\ content}{Optimal\ phosphorous\ content} + \exp\left(4.065 - 0.0535 * \frac{Actual\ phosphorous\ content}{Optimal\ phosphorous\ content}\right))} \tag{33}$$

2.5. Calculating Yield, Water and Nutrient Requirements

The equations from the previous sections have been implemented in in MATLAB®. The following figure shows a graph of the progression of daily biomass for different crops over their growing period.

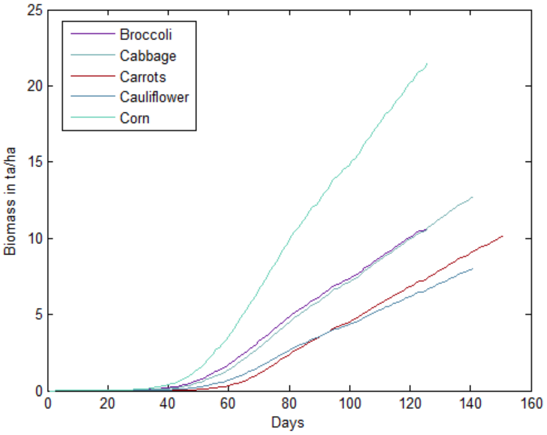

Figure 2: Biomass accumulation

The model can also be used to calculate the daily irrigation requirements for different crops. The daily water requirement is the volume of water necessary per hectare to keep the water stress value to 1. The evapotranspiration model calculates the amount of water lost by the crop each day. Daily precipitation is responsible for making up for this lost water. In the absence of precipitation there needs to be water supplied through irrigation to make up for this water deficit. The model calculates the amount of water required each day, in liters, to make sure there is a stress free growth.

Figure 3 shows the amount of water required for different amounts of rainfall. The model calculates the water required to make sure that there is no water stress. The graph shows that the water required decreases as the amount of rainfall increases. A similar analysis can be done to show the water requirements for different soil types under the same weather conditions.

Similar to water use, the model also calculates the required fertilizer, in tonnes, to make sure that there is no nitrogen and phosphorous stress on the crops. Fertilizers are defined by their rating, which is the percentage of nitrogen and phosphorous content in the given fertilizer. For example, a fertilizer with a 35-40 rating contains 35% of nitrogen and 40% of P2O5. For a 100 pound bag, this would mean a nitrogen content of 35 pounds, and 40 pounds of P2O5. To calculate the amount of fertilizer required, we simply have to divide the amount of nitrogen, or phosphorous required by the percentage rating. If a crop requires 10 pounds of phosphorous per day, the farmer would need to apply 10/0.4 = 25 pounds of fertilizer. Figure 4 shows the fertilizer required for broccoli for, in kg/ha, for the various planting start dates.

3. OPTIMAL CROP SCHEDULER

The objective of this model is to select the list of crops and their planting dates to maximize the potential yield. Since each crop has a yield on a different scale, we will need to use a more normalized measure to measure the yield. For example, a yield of 10 tonnes/ha might be a poor return for a potato crop, while a yield of 5 tonnes/ha might be very good for an eggplant crop. This problem can be overcome by first simulating the crop yields for all the possible planting dates. The yield at each planting date is then divided by the maximum yield for that crop. This serves to provide an accurate measure of performance for the crop by showing its proximity to the maximum potential yield.

The only constraint on the model is to ensure that at any given time more than one crop cannot be planted. The model is also setup to ensure that there is a 1 month fallow period after planting each crop.

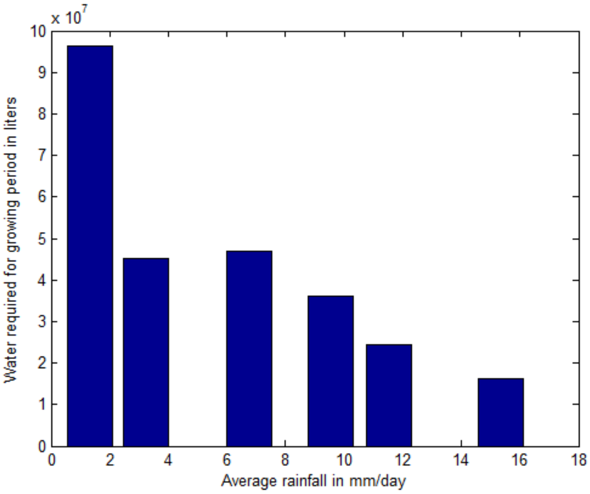

Figure 3: Water requirements for different average rainfall levels

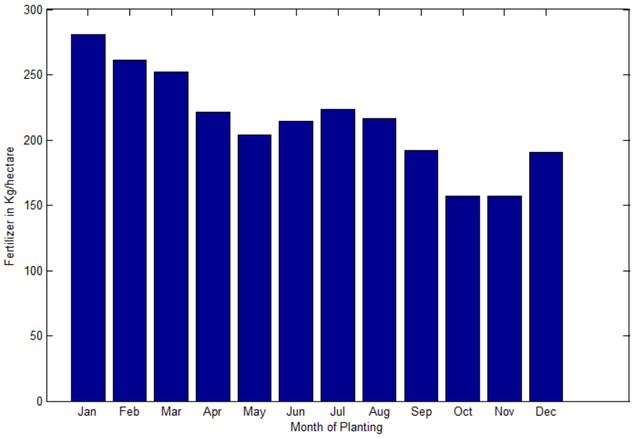

Figure 4: Fertilizer required in Kg/hectare for various planting dates

There is no crop rotation constraint, and the same crop can be planted in succession. The model is written as a binary integer program, where each decision variable can only take the values 0 or 1. The yields have been calculated for the beginning of each month during a 4 year simulation cycle. The list of variables is as follows:

- Y_{ij} : Normalized yield of crop j when planted on planting date i.
- x_{ij} : Decision variable for crop j on planting date i. It is a binary decision variable with 0 and 1 as the only possible variables.
- totaltime : Length of the simulation in months.
- numcrops : Total number of crops available for simulation.
- cropduration_j : Duration of crop cycle for crop j

$$maximize \sum_{i=1}^{totaltime} Y_{ij}x_{ij} \quad \forall j = 1,2, \ldots .number\ of\ crops \tag{34}$$

$$\sum_{i=1}^{totaltime}\left(x_{ij} + \sum_{k=1}^{numcrops}\sum_{l=1}^{cropduration_j} x_{k(i-l-1)}\right) \leq 1$$

$$\forall j = \ 1,2, \ldots .number\ of\ crops \tag{35}$$

The model was simulated for 48 months using weather data from http://globalweather.tamu.edu/. The weather data was for a tropical region with average temperatures of around 25^0C, and an average rainfall of 13cm. The model can currently optimize 28 crops. To visualize the results of the simulation a Gantt chart has been used. This chart is useful to display the start date and the duration of the crops. An initial run for all the 28 crops was made to determine the most optimal sequence of crops. Figure 5 displays the results from this simulation. The figure shows that broccoli, potatoes, barley, oats and millet produced the most optimal yield.

This model can now be extended to account for crop rotation. Since the decision variables are months, it is not possible to explicitly implement crop rotation for the crops. Crop rotation is implemented by specifying that the same crop not be re-planted for a minimum of three months. If the other crops do not fit the solution, the same crop can be planted again after waiting for 3 months. A new variable called $rotation$ is added to the model. This variable specifies the duration for which a crop cannot be reused on the same field. This value can take a value between 1-3 months.

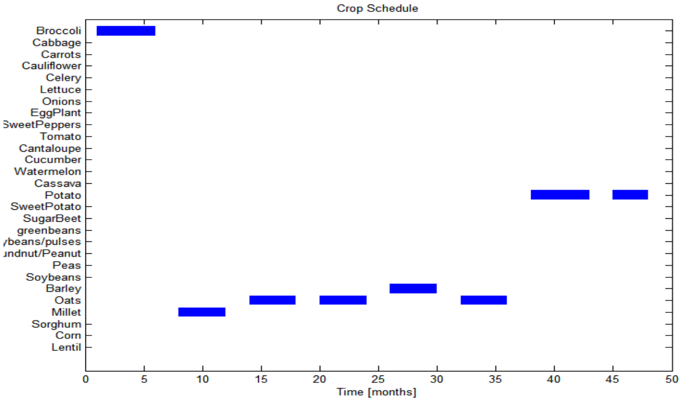

Figure 5: Crop scheduling for no crop rotation constraints for the full set of crops.

Using the same objective function as eq. 34, the new model constraint can be written as:

$$\sum_{i=1}^{totaltime}\left(x_{ij} + \sum_{m=i+cropduration_j}^{i+cropduration_j+rotation} x_{mj}\right.$$
$$\left. + \sum_{k=1}^{numcrops}\sum_{l=1}^{cropduration_j} x_{k(i-l)}]\right)$$
$$\leq 1$$
$$\forall j = 1,2, \ldots .number\ of\ crops \tag{36}$$

The objective function used in all these models has been aimed at selecting crops that have the best performance. In addition to this objective we can introduce three new objectives. The first objective is aimed at increasing economic output. To do this we will need to multiply the prices of the various crops to the yield. These prices have been obtained from the USDA website. The data covers a range of 48 months from the beginning of 2009 to the end of 2012. Figure 6 shows the price($)/pound of three crops overs this range.

The objective function for maximizing the economic impact for regular planting duration and truncated duration is given as:

$$maximize \sum_{i=1}^{totaltime} C_{ij}Y_{ij}x_{ij}$$
$$\forall j = 1,2, \ldots .number\ of\ crops \tag{37}$$

$$maximize \sum_{i=1}^{totaltime} C_{ij}\left(Y_{ij}x_{ij} + Y'_{ij}x'_{ij}\right)$$
$$\forall j = 1,2, \ldots .number\ of\ crops \tag{38}$$

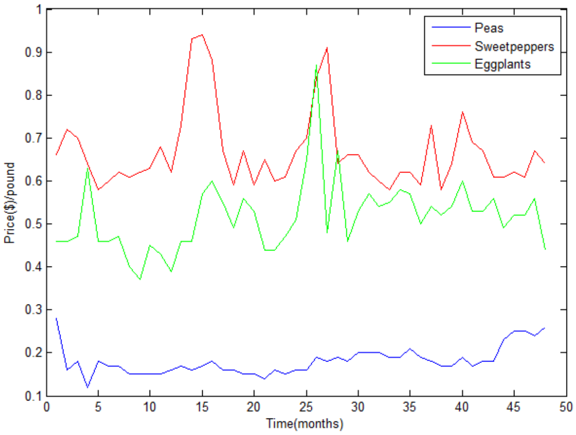

Figure 6: Price($)/pound for 48 month period

C_{ij} is the price/pound of crop i in the month j. The constraints for the three configurations are the same as the previous model. The next objective is decreasing the environmental impact of the vegetables selected. The model aims to select those crops that consume the least amount of water. The crop growth model gives us an estimate for the amount of water required for a certain crop for its growth period. Figure 7 shows the water requirements for three crops over a 48 month duration.

The objective function for minimizing the environmental impact for regular growing period and truncated period is given as:

$$minimize \sum_{i=1}^{totaltime} W_{ij}x_{ij}$$

$$\forall j = 1,2, \ldots .number\ of\ crops \qquad (39)$$

$$minimize \sum_{i=1}^{totaltime} \left(W_{ij}x_{ij} + W'_{ij}x'_{ij}\right)$$

$$\forall j = 1,2, \ldots .number\ of\ crops \qquad (40)$$

W_{ij} and W'_{ij} are the water requirements for crop i when planted in month j for a full growing period and a truncated growing period respectively. The constraints for the three configurations are the same as before.

Finally, we also have a combined objective of maximizing the economic output while minimizing the environmental impact. To achieve this we will multiply the water quantity requirements of the crops with a monetary value P_j and subtract it from the economic objective. The objective functions for the regular and truncated growing periods are given as:

$$maximize \sum_{i=1}^{totaltime} \left(C_{ij}Y_{ij}x_{ij} - P_jW_{ij}x_{ij}\right)$$

$$\forall j = 1,2, \ldots .number\ of\ crops \qquad (41)$$

$$maximize \sum_{i=1}^{totaltime} \left(C_{ij}Y_{ij}x_{ij} - P_jW_{ij}x_{ij}\right) + \left(C_{ij}Y'_{ij}x'_{ij} - P_jW'_{ij}x'_{ij}\right)$$

$$\forall j = 1,2, \ldots .number\ of\ crops \qquad (42)$$

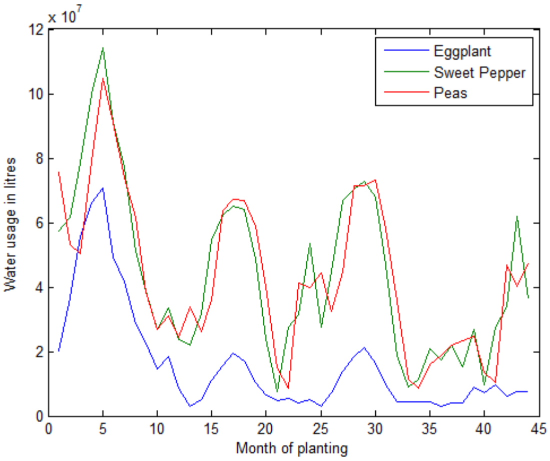

Figure 7: Water requirements in litres for a 48 month period

The values for the water price P_j are uniformly distributed between $0.0005-0.001 per liter.

4. RESULTS

This section presents the results for the 4 objectives discussed in the previous section. Each objective has 2 configurations; no crop rotation and explicit crop rotation of 3 months. Figure 8 present the results for a set of three crops: peas, sweet peppers and egg plants. These crops were chosen because they had yields in comparable ranges. From the figure we can see the change in schedules for the different objectives and configurations.

Sweet peppers and eggplant are dominant for economic and environmental objectives respectively. Peas are dominant for the performance objective. In a multi objective scenario we can see a healthy mix of all three crops being selected. We can also observe the change in scheduling for the various configurations across the different objectives.

5. CONCLUSIONS AND FUTURE WORK

In this paper we have studied the behavior of mathematical programming models for selecting and scheduling the planting of crops to fulfill various objectives. These objectives cover issues like performance, economic viability, and environmental impact but are not exhaustive. The decision variables in the developed model only simulate crop selection and scheduling. Decisions like resource utilization, borrowing money, farming practices and abandonment of farms need to be implemented to simulate real world situations.

The economic viability objective needs to include real world features like risk, market fluctuations and resource contentions. Similarly, the environmental impact objective only considers water usage. Future iterations of these models should also model impact of fertilizers, condition of soil and contamination of immediate environment. The models used in this chapter are binary integer programming models. This makes the model very time consuming to run. When we modeled the performance objective using all the crops, the model ran for over five hours to produce a solution. This issue can be addressed by turning the problem into a quadratic objective programming, or using alternative algorithms to find a solution. We can also use linear programming models to implement mixed cropping schemes.

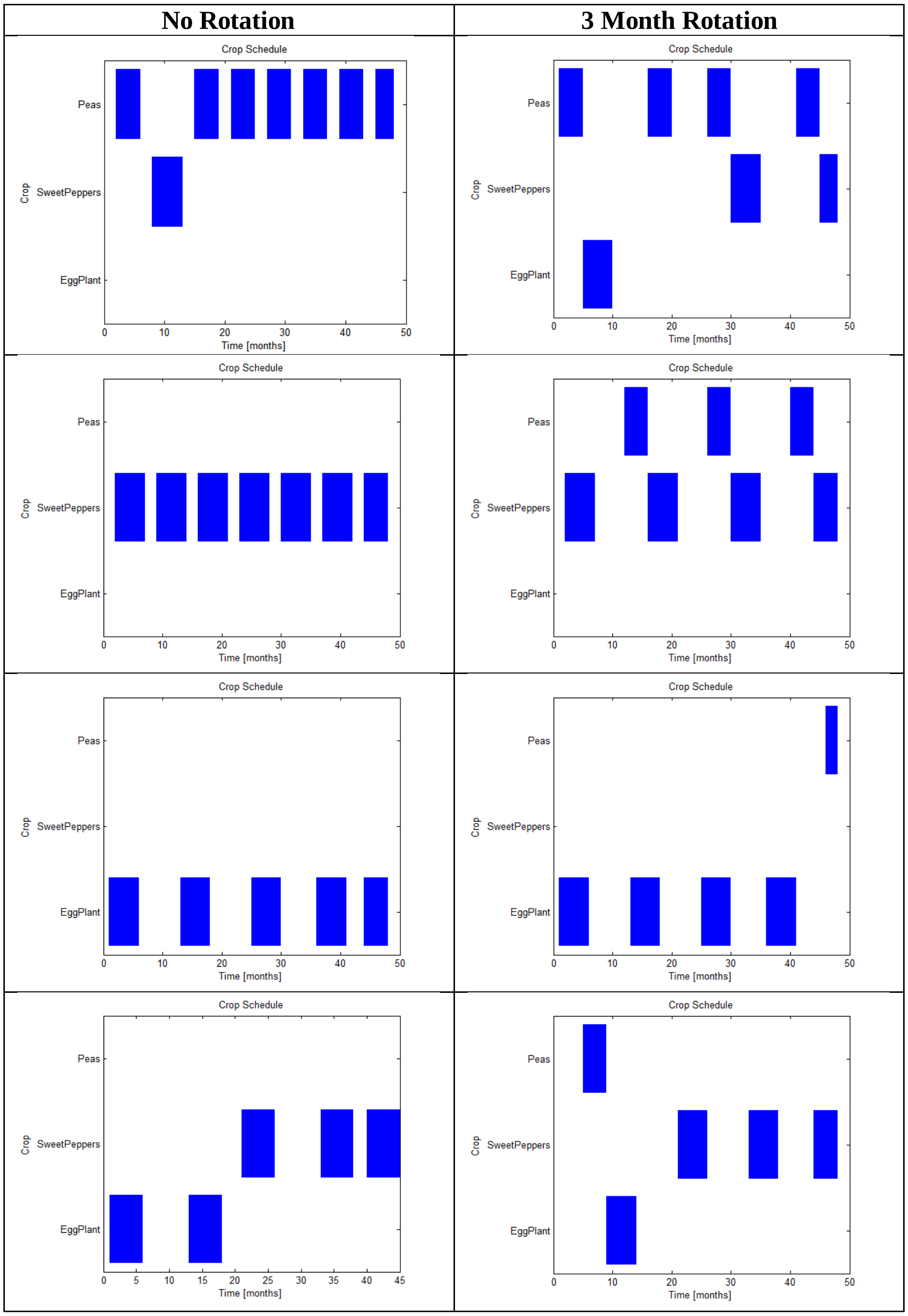

Figure 8: Scheduling of crops for different objectives. Row1-performance. Row2-Economic output. Row3-Environmental impact. Row4-Multi objective.

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INTERNET OF THINGS (IoT) APPLICATIONS STUDY USING BIG DATA AND VIRTUALIZATION PROCESS TECHNOLOGY.

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ABSTRACT

This paper is about the study about the Internet of things (IoT) applications using Big Data (or "data analytics ") and the virtualization process. The Internet of things is at the beginning, but is expected that in the near future will transform the world, creating a giant network of devices and machines globally connected, aggressively increasing communication and data exchange, the IoT is still seen as fiction, but in reality this world already exists through numerous devices present in our daily lives: the "wearables" (term meaning technologies to wear) like tablets, smartphones, smart watches and bracelets. With the use of IoT comes the solution of various problems, but through this intense communication another problem is created, the huge volume of collected data. This problem is being solved by Big Data, that handles structured and unstructured data.

Keywords: Automation, Security & Intelligence, Industrial Engineering, Internet Of Things

1. INTRODUCTION

The Internet of Things covers several technologies that have been developed in recent years, according to Ayres and Sales (2010), this is an expression used from the 90s relating the network connections between objects to the Internet, Figure 01. Technologies that guarantee much of its development are RFID[1] (Radio Frequency Identification) sensors, ubiquitous[2] wireless networks and the Internet Protocol change for IPv6 version.

Nowadays, the IPv4 protocol is the most used, and capable of generating up to 4 billion IP (Internet Protocol) addresses. In this case, different addresses can only be given to a limited number of computers, mobile phones and devices connected to the network. With Internet of Things, each object must have its own address. The solution to this obstacle is on IPv6. Through Ipv6 an almost unlimited amount of codes can be generated to a lot of objects, more precisely 340 undecillion objects.

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[1] RFID technology (radio frequency identification) is nothing more than a generic term for technologies that use radio frequency for data capture. Therefore there are several methods of identification, but the most common is to store a serial number that identifies a person or object, or other information, in a microchip. Such technology allows automatic data capture, to identify objects using electronic devices, known as electronic labels, tags, RF tags or transponders that emit radio frequency signals to readers that capture this information. It exists since the 40s and came to complement bar code technology, widespread in the world.

[2] The term "Ubiquotous Computing" was originally stated by Mark Weiser in 1991, on his article "The Computer for XXI Century", to refer to devices conetcted everywhere so transparently to the human being, we will end up not realizing they are there.

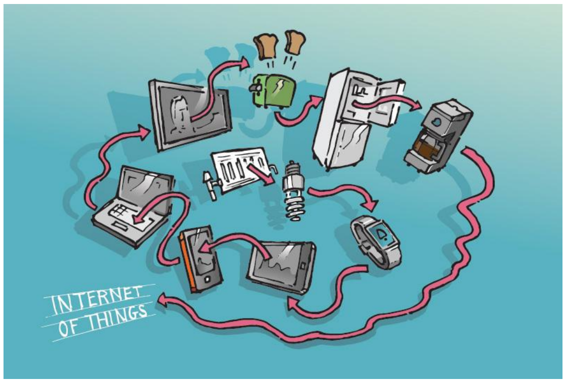

Figure 01 – Internet of Things (IoT)

In general, the Internet of Things (IoT) is an extension of the internet to the real world (physical) where a great interaction with objects and their independent communication between them become possible, however, according to Singer (2012), define what actually is the Internet of Things (IoT) is complicated in the face of several studies and publications on the subject. A lot of information stored on computers around the world is used on the Internet. This is a totally virtual world where people browse and interact with pages accessed via hyperlinks. On the Internet of things, objects have their own identification and this can be read in an automated manner. Physical objects are now represented in a virtual environment.

2. IoT CONCEPTS:

- Internet access;

- AIDC[3] (Automatic Identification and Data Capture);

- Context perception.

These three concepts allow the development of a fairly complete model of technologies needed for the creation and deployment of IoT (Internet of Things) services. Interest in this area is very large due to the potential this concept has to be applied for idealizing new business models. IoT is a very representative technological revolution regarding the future of computing and communications, its development depends mainly on technological innovation of nanotechnology and new wireless sensors. Advances in miniaturization processes and nanotechnology enable small objects to connect and interact.

The advantage of this vast amount of information integrated between various industrial products and everyday items only become possible through sensors that are able to identify environmental physical changes. These modifications allow static objects to be transformed into dynamic, adapting intelligence and stimulating the development of several innovative products and new applications. RFID (Radio Frequency IDentification) is the most promising technology in this regard, Figure 02.

According to the analysis of Kranenburg, 2008, p.62, which states:

> “Cities across the world are about to enter the next phase of their development. A near invisible network of radio frequency identification tags (RFID) is being deployed on almost every type of consumer item. These tiny, traceable chips, which can be scanned wirelessly, are being produced in their billions and are capable of being connected to the internet in an instant.”

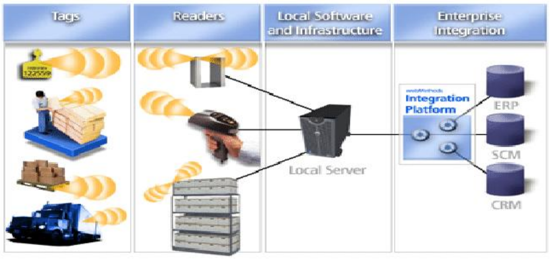

Figure 02 - Basic scheme of RFID use.

Most of these devices are already used in several countries including Brazil. Some of the benefits of the internet of things are:

- Identify and track assets and people;

- Check and improve process efficiency;

- Improve inventory control efficiency;

- Improve perishable products control;

- Reduce losses;

- Facilitate supply chain synchronization;

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[3] Automatic identification and data capture (AIDC) refers to the methods of automatically identifying objects, collecting data about them, and entering data directly into computer systems (i.e. without human involvement). Technologies typically considered the part of AIDC include bar codes, Radio Frequency Identification (RFID), biometrics, magnetic stripes, Optical Character Recognition (OCR), smart cards, and voice recognition. AIDC is also commonly referred to as "Automatic Identification", "Auto-ID" and "Automatic Data Capture”.

- Increase supply chain visibility;

- Reduce operational risks;

- Increase customer satisfaction and loyalty;

- Reduce theft and forgery;

- Get greater reliability in data management;

- Get accurate information for decision making;

- Meet the requirements for Retailers and Distributors;

- Check after-sales and warranty.

Through advanced nanotechnology development and internet penetration, the natural way is the connectivity of these RFID tags to the computer network and the information switching between them. IoT is an increasingly present reality.

Some applications that can be developed: subcutaneous health monitor warning your doctor or the nearest hospital of a heart attack risk; a product informing your health monitor of gluten, lactose or phenylalanine presence; smart refrigerators able to report the lack of food, find recipes on specialized sites and add products to the supermarket shopping list, and the user is able to approve and confirm it over the internet with a click. Objects themselves would be responsible for this interaction: a chip in the milk box, for example, warns the device of the proximity of expiration date; when the last beer is consumed, the device informs electronically it is necessary to buy more.

3. WEARABLES

There are devices called "Wearables"[4] (a term that refers to technologies to wear). This technology is being used mainly in “smart” watches and devices for sports practice, but there is much more about this technology. Manufacturers like Samsung, Intel, LG, Sony, Qualcomm and others, developed several wearable equipment, figure 03. The list of large companies that have developed innovations in this segment is quite representative. Also, a large portion of small industries have participated, desirous of finding even more specific purposes for developed microchips.

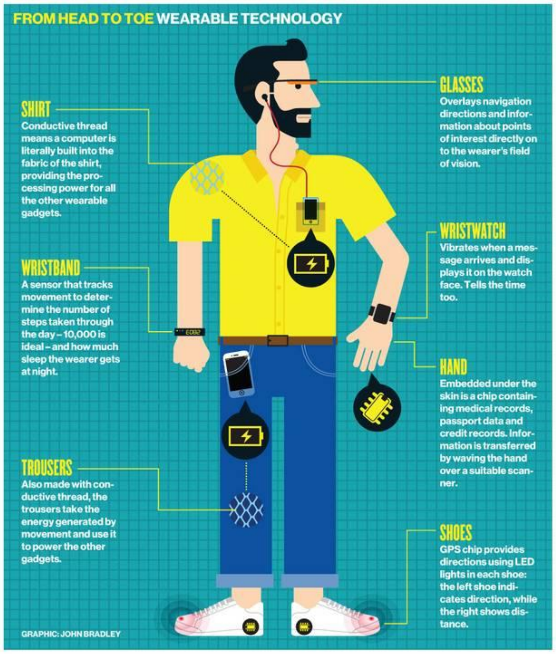

Figure 03 - Examples of Wearable devices.

Sony and Samsung went ahead placing on the market the “smart” watches SmartWatch 2, figure 4, and the Galaxy Gear, figure 5. Even though there is still a small share of users, these devices are increasing their use of technology possibilities, and more and more applications are developed for such equipment. Receive e-mail notifications, access Twitter[5] or even Facebook posts, remotely control the smartphone and start a car in the distance, figure 6, are just some of the possibilities.

The "smart" bracelets that have been released prior to the clocks found another way to help consumers monitoring their health. An example is the LG Life Band Touch, figure 7, which in addition to controlling smartphones can also monitor your heart rate. All collected data is transferred to the phone via Bluetooth, and through a specific application, it is possible to measure distances and even count steps, average speed and calories expended during use. This type of technology is increasingly diverse and present in our daily lives.

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[4] Wearable computers, also known as body-borne computers or wearables are miniature electronic devices that are worn by the bearer under, with or on top of clothing. This class of wearable technology has been developed for general or special purpose information technologies and media development. Wearable computers are especially useful for applications that require more complex computational support than just hardware coded logics.

[5] Twitter is a social network and server for microblogging, which allows users to send and receive personal updates from other contacts (texts up to 140 characters, known as "tweets") via the service website, via SMS and specific software management.

Figure 04 – Sony SmartWatch 2.

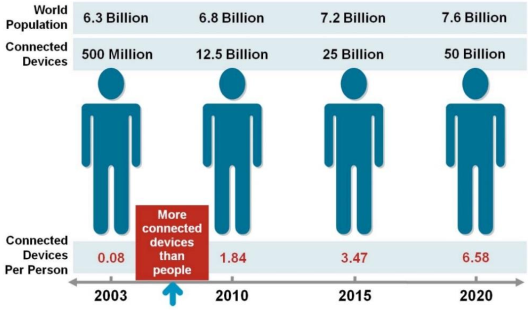
Figure 05 – Samsung SmartWatch Galaxy Gear.

Figure 06 – Starting the car with the SmartWatch.

Figura 07 - LG Life Band Touch.

4. FORECASTS FOR IoT

Cisco[6] made a preview about the growing number of devices per person, based on a study in China which came to the conclusion that in 5.36 years (2001-2006) the number of devices doubled. Thus it is estimated that in 2020 we will have a world population of about 7.6 billion people and 50 billion devices connected to the Internet, figure 08, this generates an average of about 6.58 devices per person. (Evans, 2011).



Source: Cisco IBSG, April 2011

Figura 08 - The Internet of things was "born" between 2008 and 2009.

The greatest effect of all this is a large increase in variety of devices, various possibilities that are unknown even to the industry. The most obvious items, not coincidentally, are the ones that are first delivered to the public: "smart" bracelets, watches and glasses now have their own processors and have the ability to integrate and interact easily to tablets and smartphones.

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[6] Cisco Systems, Inc. is an American multinational technology company headquartered in San Jose, California, that designs, manufactures, and sells networking equipment. The stock was added to the Dow Jones Industrial Average on June 8, 2009, and is also included in the S&P 500 Index, the Russell 1000 Index, NASDAQ-100 Index and the Russell 1000 Growth Stock Index.

The industry estimated sales projection is 171 million units by June 2016. Devices probably will enter the market in extremely different ways, reaching in several ways our personal lives, from health services to fitness, from well-being care to medicine, including sectors of entertainment and information.

Technological dimension is highly insufficient for understanding the world of IoT and to build roadmaps representing realistically and adequately how to forward efforts and investments in research and development to enable everyone, as soon as possible, to use the benefits IoT can provide.

Brazilian industry uses this system in several projects, mainly through application with the RFID technology. The most common segments in the market with troubleshooting focus are:

- Consumer Goods have more traditional solutions with technology use in supply chain;

- Logistics with focus on traceability solutions and urban mobility;

- Industry focused on productivity solutions;

- Services focused on quality solutions for providing services to clients;

- Entertainment focused on innovative solutions and integrated experiences for consumers;

- There are several initiatives which stand out in the areas of education, health, and safety, and the combination of safety with other technologies consists of high value-added projects.

5. USE OF BIG DATA IN IoT

The term Big Data[7] is fairly new, emerging around 2005 with Google and increased greatly in 2008 with Yahoo, who changed the Hadoop platform and to turn it into Open Source.

When someone hears the term Big Data, immediately comes to mind a literary translation of the text "Big data" related to the huge amount of data to be analyzed. But the term is much broader, Carlos Barbieri (2013) states that Big Data is commonly classified by 5V's, that identify its five premises:

- **Volume**, relates the large amount of data inside and outside the company;

- **Velocity**, every second a lot of new data is created on the Internet, and some of this data may be of interest to one´s company;

- **Variety**, the data may be a blog post sharing, a text in a social network, an e-commerce review, etc.

- **Veracity**, collected and mined data should have authenticity;

- **Value**, as it is important to have return on investment.

With the evolution of IoT applications and the increasing need for information, more and more applications are being developed, continually increasing the amount of information. The growth of data in enterprise applications annually is of approximately 60%. It is estimated that a company with a thousand employees can generate annually about 1,000 terabytes, and this number tends to increase fifty times by 2020. With this significant increase in applications, information is generated exponentially, thereby manageability of these information becomes essential for these applications.

5.1 BIG DATA CHALLENGES

The biggest challenge of Big Data is to manage a large volume of data and mine this information in a shorter request. An excellent strategy is to make the application grow as it is required, using thus a vertical scale (the power of the hardware is increased by increasing memory and processing of a single machine) or horizontally (where the number of machines is increased). Although it is more complex, the horizontal scalability ends up being very cheap, and it is easier to grow or shrink resources according to demand.

An aspect rarely discussed in Big Data, is related to the speed in the software development and the speed of modeling. One example is Twitter where many users use the hashtag[8] ('#' added together with a word) and when searching for that hashtag will then present each message that has been tagged with it.

In conclusion, the concept of Big Data is extremely easy, even diverging from various sources, which is to carry out the management of a huge amount of memory extremely quickly.

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[7] Big data is a broad term for data sets so large or complex that traditional data processing applications are inadequate. Challenges include analysis, capture, data curation, search, sharing, storage, transfer, visualization, and information privacy. The term often refers simply to the use of predictive analytics or other certain advanced methods to extract value from data, and seldom to a particular size of data set. Accuracy in big data may lead to more confident decision making. And better decisions can mean greater operational efficiency, cost reductions and reduced risk.

6. FINAL CONSIDERATIONS

The Big Data technology is a modern tool of Predictive Management and Analysis, bringing great gains and benefits to different areas, whether private or public. The future will be much more challenging and productive by utilizing the Internet of Things, since this technology makes the Internet connection to everyday objects possible: household appliances, televisions, automobiles, etc. To provide smart environments, IoT will revolutionize our lives as consumers.

Big Data allows integrating high volume of data in IoT with data from companies' owners. This will allow a deep insight into customer behavior, especially regarding usage of a product. In the automobile industry, automakers will be able to learn about the real mileage of the vehicles, the driver´s driving style, if the drive more on the road or in urban areas heavy traffic. Thus, the returns will be much greater enabling a relationship that will attract the customer to do maintenance and reviews more effectively. The possibilities of joint action creation will be almost limitless among auto parts manufacturers and dealers, offering at the right time, replacement of the product with the right solution to the problem, helping the customer he is close to replace his vehicle and through the information obtained, offer a more appropriate model to his needs, and a bank loan plan according to the customer's financial conditions and thus increasing customer loyalty.

The conclusion is that without Big Data it will not be feasible to have the Internet of Things, as one depends intrinsically on the other. For Ayres and Sales (2010) the concept of the Internet of Things (IoT) had its beginning at MIT (Massachusetts Institute of Technology) at the 1999 AutoID Center program. Today the world's leading Internet of things research and development centers are the Massachusetts Institute of Technology (MIT), the precursor in the United States, and the University of Manchester in England, where the annual conference "The Future of Things " is hosted.

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IMPACT ANALYSIS OF A CROSS-CHANNEL RETAILING SYSTEM IN THE FASHION INDUSTRY BY A SIMULATION APPROACH

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ABSTRACT

In recent years, the wide spread of e-commerce and mobile channel purchasing has deeply changed retailing sector, leading to the unavoidable necessity of integrating them with the physical stores. In this context, main purpose of the present work is to analyse how the introduction of this new integrated strategy, called cross-channel retailing, can impact on the performances of a traditional supply chain. In order to analyze the change in trend of a defined set of KPIs, a simulation model has been developed. It uses, as case study, a Fashion and Apparel Retailing company that manages an extended network of both direct-operated and franchising mono-brand stores. Simulation results show that, despite a decrease in service level, the adoption of a cross-channel strategy may result in a significant cost reduction due to the better management of replenishments to stores.

Keywords: multi-channel retailing, fashion and apparel industry, supply chain management, simulation.

1. INTRODUCTION

In the fast changing environment of the retailing industry, adapting to always increasing customer requirements can make the difference in being a highly successful and profitable market leader. In the recent years, one of the main challenge to meet customers' needs is the integration of traditional stores with mobile channels in a new synchronized operating model called cross-channel retailing (Lanzilotto et al., 2014). It gives to customers the opportunity to have a seamless experience across all company's channels.

The last decades, in fact, have been characterized by the wide spread of e-commerce and mobile channel purchasing that have deeply changed retail business and management strategies leading to the birth and the development of e-commerce companies. Furthermore, the diffusion ICT based tools of retail supply chain has contributed to modify retail operations (Elia and Gnoni, 2013). In this context, traditional brick and mortar companies have attempted to increase sales and improve profitability by adding online retail channels for consumers (Bretthauer et al, 2010). Many small businesses, use platforms like eBay and Amazon Marketplace on one hand, and a self-managed online store on the other hand, as sales channels (Schneider and Klabjan, 2013). On the other side, "pure-play" Internet retailers are also opening physical stores or cooperating with traditional retailers (Agatz et al., 2007).

Nowadays, multi-channel retail systems have experienced increasing interest. The simultaneous and integrated management of all channels is not simple and assumes that the supply chain meets the requirements of visibility, accuracy and control of information, flexibility and efficiency. Furthermore, some processes such as inventory management and logistics become extremely critical by adopting a cross-channel retailing.

In this context, focusing the attention on the particular case of the Fashion and Apparel (F&A) industry, purpose of this paper is to analyze the impact on supply chain performance deriving from the introduction of a cross-channel strategy by a simulation approach. The focus on a real fashion supply chain means considering all its features and peculiarities: short product life cycles; unpredictable and volatile demand; impulsive purchasing behavior; wide product variety; demand-driven and long and complex supply chains (Iannone et al., 2015).

After a brief introduction on advantages due to the adoption of new integrated strategies (section 2), the conceptual framework is presented in section 3, defining all the processes, material and informative flows of a cross-channel fashion supply chain with two sale channels. Next, a set of Key Performance Indicators (KPIs) measuring system performance have been defined taking into account store and supply chain operations, service level, profitability and costs (section 4). The case study is the presented in section 5, while in section 6 we describe the logical process of the simulation model and the different operational scenarios. To conclude, in section 7, simulation results are shown and analyzed.

2. ADVANTAGES AND CRITICALITIES OF A MULTI-CHANNEL RETAILING SYSTEM

The multi-channel retailing can be defined as a synchronized operating model in which all of company's channels, i.e. traditional stores and mobile channels, are aligned and present a single face to the customer, allowing companies to meet customers' requirements and to be more competitive. From customer point of view, main benefit due to cross-channel application is to provide a seamless experience across all channels, translating benefits characterizing the online experience in physical stores and vice versa. Main advantages of the web channel can be observed in the reduction of buyer's search costs, in providing detailed information to the customer and offering a very large range of products. From traditional channel perspective, the proximity to the customer is considered the key element.

Combining the two sales modalities (in store and online) with delivery options, several channels comes out representing the logistic services offered to customers:

- *"buy in store, pick up in store"*: it is the traditional in store purchase and pick up;
- *"buy in store, home delivery"*: after buying the item in store, an additional home delivery service is provided by the retail firm;
- *"reserve in store, pick up in the same or another store"*: when the item required is not available in the store, the retailer verifies availability in another nearby store. In case of success, the product is booked and the customer can pick it up in the store where it is available or wait for the delivery to the first visited store;
- *"buy online, home delivery"*: it is the traditional e-commerce. The user buys the product online and it is delivered to its home.
- *"buy online, pick up in store"*: the customer buys the product online and then picks it up in a physical store or in a pick-up point, thus cancelling home delivery costs;
- *"reserve online, pick up in store"*: customer books product online, then pays and picks it up in the physical store; this model differs from the previous one just in the purchasing process which is not performed online in advance but in the physical store at the moment of the pick-up.

The analysis of different logistic paths highlights the processes that could become critical by adopting multi-channel retailing and several capabilities are required for a successful implementation (Mercier et al., 2014): (i) accurate and real-time inventory management; (ii) lean warehouse operations; (iii) reliable and quick distribution network; (iv) efficient return flows.

Information sharing and synchronization among channels is the distinctive element of the management strategies. Elia et al. (2014) proposed two management models of retailing systems with several sales channels:

- *multi-channel model*: the management of channels is separate, i.e. each channel manages independently information on its products, customers and distribution network;
- *cross-channel model*: the management of the channels is integrated and coordinated. This means a high level of integration in operations which implies the adoption of a single and shared information system containing real-time updated information on purchases and stock levels in each warehouse or store.

3. CROSS-CHANNEL IMPACT ON THE TRADITIONAL FASHION SUPPLY CHAIN

The conceptual framework developed by Lanzilotto et al. (2014), defines all the processes, material and informative flows of a cross-channel fashion supply chain with two sale channels: the physical channel (with the traditional sale in the physical stores) and the "buy online, pick up in store" channel (where the customer can buy the product online and pick it up in the preferred store). This framework is the starting point in this paper for the definition of the simulation model. We describe the particular case of a company that manages an extensive network of direct-operated and franchising mono-brand stores. Below the detailed description of the traditional supply chain and then the additional processes and flows due to the adoption of the cross-channel.

3.1 Traditional channel

Framework shown in Figure 1 with black colour represents processes, material and informative flows that underlie the complex SC in the F&A industry in case of adoption of the traditional channel strategy only (Iannone et al., 2013). Blocks and arrows coloured in red, instead, represent the additional processes and flow required for the adoption of a cross-channel strategy and will be better described in the following paragraph.

The process starts from the development of the *New Collection* by the styling office and the definition of the *Demand Forecasts*. While the *New Collection* is considered as a simple input for our framework, forecasting is one of the pillars on which all further planning activities are based. In the F&A industry this process is crucial and particularly complex due to high volatility and unpredictability of demand and is based on historical sales data and characteristics of the new collection and stores. Next step is the drafting of *Merchandise Orders* (*MO*), which define purchasing quantities for each item, and *Delivery Orders* (*DO*), which define time and place for products deliveries from suppliers. For simplicity, we suppose that the k-th supplier produces the k-th item and delivers it all to the area warehouses in quantity Q_{kj}. The supply process ends with the delivery of goods to the Area Warehouses according to the DOs. At this point, warehouse staff has the task of preparing personalized kits of items to send to the *Stores* (*S*) according to the *Replenishment Orders* (*RO*). The j-th warehouse supplies only a specific set of n_j stores pertaining to its area. The process described so far defines the material and informative flow that characterizes the PRE-SEASON phase that, as the name implies, is performed before the beginning of the selling season. The IN SEASON phase, instead, starts with the first sales recorded in the stores. We suppose that both deliveries form the suppliers and replenishments to the stores are also performed during the selling season even if they are scheduled before it.

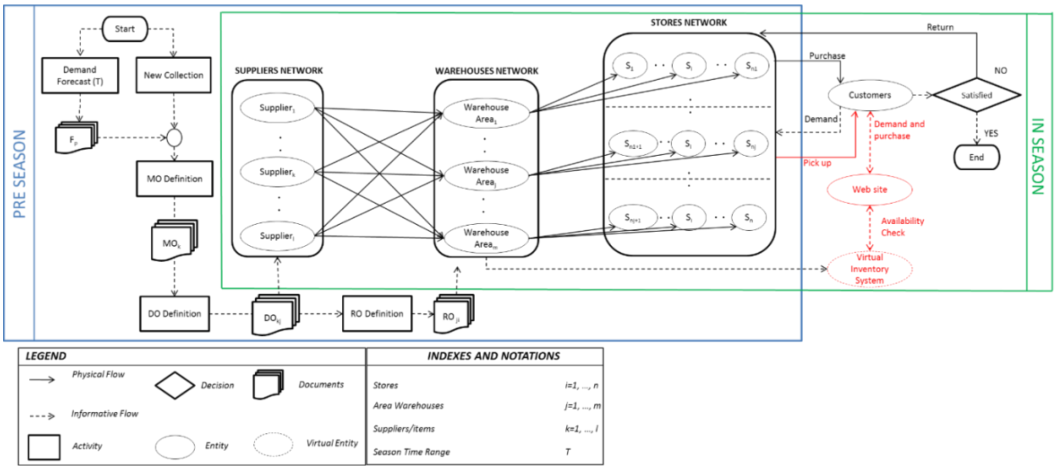

Figure 1: Supply Chain Of F&A Industry – Traditional And "Buy On Line, Pick Up In Store" Channels

3.2 Channel "buy online, pick up in store"

With the modality "buy online, pick up in store", also called "Click and Collect" strategy, the customer chooses products online and then picks them up in the physical store or dedicated facility. Management approach of this channel changes according to the retailing model applied. If a *multi-channel* model is implemented, the product bought online is shipped from a central warehouse to the store selected by the customer; no control is carried out at the store level to verify the product availability. On the contrary, if *cross-channel* model is implemented, central warehouses and stores' inventories are synchronized as a centralized inventory works. Thus, the customer chooses a product on the web site and if it is available in the selected store, he can buy it online and pick it up in short time (e.g. less than one hour). Otherwise, the information system verifies in which warehouses the product is available and plans a shipment from the nearest location to a specific store. The cornerstone of the system is the *Virtual Inventory System*: it contains data of all central warehouses and stores' inventories updated in real time.

4. KPIs

The set of KPIs used for our analysis were selected after a careful study. After a literature study we were able to find and analyse the indicators already used in retail field for the evaluation of supply chain performance. Some KPIs are focused on inventory management, particularly on inventory inaccuracy, i.e. the discrepancy in information between the real inventory and the information system, and the costs directly related to it (Fleisch et al., 2005). On the other hand, considering the order fulfilment process, the main parameters to be estimated concern the service level in store and the indicators express the accuracy of delivery in terms of lead time, quality and quantity of delivered goods (Amer et al., 2010). Mattila (1999) have analysed retail performance with special regard to product sourcing strategies, while, with reference to financial dimension, extensively investigated in literature, the standard financial indicators, e.g. Return On Investment, Return On Assets, Net Cash Flow, etc., have been applied also to retail supply chain (De Felice and Petrillo, 2013; Byoungho, 2006; Moore and Fairhurst, 2003). Therefore, the processes to be taken into account are several; a useful tool to monitor all of them is the SCOR Model. It is a reference model applied for performance measurement of supply chain processes (Caricato et al., 2014). Vlachos (2014) has chosen eight areas for the performance evaluation of retail supply chains: plan, forecasting, source, replenishment, ordering, distribution and delivery, store operations, sales and returns. Taking into account SCOR areas of interest and indicators, together with parameters deriving from business practices, a set of KPIs are defined for a traditional retail supply chain.

Their definition is reported in table 1.

5. INTRODUCTION TO THE CASE STUDY

As already mentioned, main purpose of this research work is to analyse the impact of the introduction of a new integrated strategy on Supply Chain performances through the definition of a simulation model. As case study we used an Italian Fashion Company which works in the national territory with hundreds of franchising and direct operated mono-brand stores and just a single central warehouse. The data collected from the abovementioned company concern characteristics of 10 selected clothing items and 10 selected point of sales (POS) and the related historical data on sales.

5.1 Characteristics of the Clothing Items

Clothing items can be grouped into:

- *Clothing:* products, such as jackets or coats, that can be quickly purchased without trying them on in the dressing room;
- *Clothing to Try on:* all the items that require the use of the dressing room;
- *Accessories:* handbags, scarves, jewelry, etc.;

And three price ranges: (i) *Cheap:* from 0 a 50 Euro; (ii) *Intermediate:* from 51 to 100 Euro; (iii) *Expensive:* more than 100 Euro.

Table 1: KPIs assessment after the introduction of the "buy online, pick up in store" channel

Category	KPI	Definition	Notes
Service Level	**Forecasting Error (*FE*)**	Percentage of errors in *sales forecasting* (*f*) compared to *actual sales* (*s*). $FE_{ik} = \frac{f_{ik} - s_{ik}}{f_{ik}} * 100$	FE has to be calculated for each sales channel since forecasts are estimated for each of them and not for the whole retail system. For forecasting purpose, in fact, the mobile channel could be treated as an additional store with its defined characteristics.
	Backlog Time	Time range during which the stock level is null.	Together with FE it can help assessing how much the demand was underestimated and it can be used to estimate the amount of possible lost sales.
	Sales Percentage (*%S*)	Ratio between sales and quantities delivered to the stores (*R*). $\%S_{ik} = {}^{s_{ik}}/_{R_{ik}}$	In this sector, it is meaningless to evaluate the pure data on actual sales since, given the impulsive purchasing behaviour of customers, sales will increase with the availability of product in stores.
	Service Level	Ratio between actual sales and demand (*d*): $SL_{ki} = {}^{s_{ki}}/_{d_{ki}}$	It is usually defined as the ratio between orders fulfilled and total orders received; which in this context are respectively represented by actuals sales and demand.
Profitability	**Inventory Turnover (*IT*)**	It measures how many times inventory is sold or used over a period. It is defined for centrale warehouse and POS by the ratio between *quantity outgoing* the warehouse and *average inventory*: $IT_{W,j} = {}^{R_j}/_{\overline{IW_j}}$; $IT_{POS,i} = {}^{s_i}/_{\overline{IS}_i}$	For the warehouses, quantities outgoing are defined by the items delivered to the stores (*R*) and $\overline{IW}$ represents the average inventory level. For the stores, quantities outgoing are defined by the actual sales (*s*) and $\overline{IS}$ represents the average inventory level.
	Store profitability (*SP*)	Ratio between turnover and store area. $SP_i = \frac{\sum_{k=1}^{l} s_{ik} * Pr_k}{dim_i}$.	Pr_k represents the price of the k-th item and dim_i is the dimension of the i-th store expressed in m^2.
Supply Chain Costs	**Warehouse management costs (*CW*)**	Fixed and variable costs for management of warehouse and for holding stocks. $CW_j = cfw_j + \sum_{k=1}^{n} \left(\overline{IW_{k,J}} * cu_k * cH_j\right)$	- cfw_j : fixed warehouse management cost; - cu_k: unitary purchase cost of the k-th item; - $cH_{j:}$ unitary holding cost in the warehouse expressed as a percentage of cu_k.
	Store Management Cost (CPOS)	Fixed and variable costs for management of stores and for holding products in stores. $CPOS_i = cfpos_i + \sum_{k=1}^{l} (\overline{IS_{\imath k}} * cu_k * ch \ \ )$	- $cfpos_{,i}$: fixed POS management cost; - ch: unitary holding cost in the store internal warehouse expressed as a percentage of the unitary purchase cost – it is higher than equivalent cost for the central warehouse.
	Primary transport cost (CTP)	Fixed and variable costs of transport from suppliers to central warehouses. $CTP = \sum_{k=1}^{l} \sum_{j=1}^{m} \left(DIST_{kj} * QD_{kj} * CV_{kj} + CF_k\right)$	For the k-th supplier and the j-th warehouse: - $DIST_{kj}$: distance expressed in Km; - QD_{kj}: quantity delivered; - CF_k and CV_{kj}: fixed and variable unitary transport cost.
	Secondary transport cost (CTS)	Fixed and variable costs of transport from central warehouses to stores. $CTS = \sum_{i=1}^{n} \sum_{j=1}^{m} \left[dist_{ij} * R_{ij} * cv_{ij} + cf_{ij}\right]$	For the i-th store and the j-th central warehouse: - $dist_{ij}$ is the distance expressed in Km; - cf_{ij} and cv_{ij} are fixed and unitary variable transport cost.

The selected items include all the product categories and all the price ranges and they are listed in Table 2.

Table 2 Clothing Items characteristics

	Category	Description	Price Range
1	Clothing to try on	Trousers	Cheap
2	Clothing to try on	Shirt	Cheap
3	Clothing to try on	Dress	Exp.
4	Clothing to try on	Denim Trousers	Interm.
5	Clothing to try on	Denim Trousers	Cheap
6	Clothing	Cotton Cardigan	Cheap
7	Clothing	Jacket	Interm.
8	Accessories	Necklace	Interm.
9	Accessories	Handbag	Interm.
10	Accessories	Foulard	Cheap

5.2 Characteristics of the Point of Sales (POS)

The 10 selected Stores represent a good mix of the whole store network and they are identified by:

- *Dimension* [m^2], including exhibition area and internal warehouse. Stores are "Small" if they are smaller than 100 m^2, "Large" if are larger than 200 m^2 and "Medium" in other cases;
- *Location:* it can be on the Street, in a Shopping Mall or in Airport. Depending on the store location, the three product categories record different sales levels. Accessories, for example, are highly sold in airports because customers are passing and purchases must be very quick, while in shopping malls and on the street, accessories have very little success. Opposite behaviour is showed for clothing to try on;
- *Geographical Area,* in which POS are located. Since we are referring to a company that works nationwide in Italy, we consider three different areas: North, Centre and South.

The 10 stores selected for the simulation represent a good mix of the whole company's network and their characteristics are shown in Table 3.

Table 3 POS characteristics

	Geographical Area	Location	Dimension	
			M^2	category
1	South	Airport	66	Small
2	South	Shopping Mall	113	Medium
3	South	Street	180	Medium
4	South	Street	58	Small
5	South	Shopping Mall	62	Small
6	Centre	Shopping Mall	343	Large
7	Centre	Street	82	Small
8	North	Shopping Mall	100	Small
9	North	Street	84	Small
10	North	Street	41	Small

5.3 Historical Data on Sales

Historical sales data were collected over a time range of 5 months (140 days) corresponding to the whole Fall/Winter season (from October to February), divided into four different periods:

I. Early Season (from day 0 to day 42)
II. Christmas Time (from day 43 to day 85)
III. Early Sales (from day 86 to day 114)
IV. Late Sales (from day 115 to day140)

The following table shows, for each of the 10 selected POS, the historical sales data (hs_i) and in particular the mean number of items sold per day. These numbers represents an aggregate value for all the 10 selected items. To obtain the number of pieces sold for each k-th item, this value must be multiplied for the “mix” value (m_k) which represents how the total value of the sales, reported in Table 4, is shared between the items. This mix is different for stores located in the South, Center or North of Italy and is reported in Table 5.

Table 4 Historical Salesa Data (hs_i)

Period / POS	I	II	III	IV
1	3,08	3,96	2,71	3,08
2	1,89	1,72	8,84	1,895
3	3,68	4,33	4,28	3,68
4	1,57	1,01	0,83	1,57
5	3,13	1,73	2,31	3,13
6	1,95	1,68	1,32	1,95
7	1,05	0,42	0,53	1,054
8	1,14	1,68	1,56	1,14
9	1,01	1,19	0,59	1,01
10	0,96	0,94	0,88	0,96

Then the number of pieces sold, for each of the four analysed periods, for each store and for each item is given by:

$$hs_{ki} = hs_i * m_k$$

6. DEFINITION OF THE SIMULATION MODEL

Main purpose of the developed simulation model was to analyse how performances of a fashion retail supply chain can change when introducing an integrated strategy between traditional physical stores and online sales.

Table 5 Mix Value (m) for the different Areas

Area / item	South	Center	North
1	8 %	22,2 %	6,9 %
2	19,6%	10,9 %	15,3 %
3	7 %	11,5 %	10 %
4	12,3 %	8,4 %	11,7 %
5	11 %	11,6 %	13,3 %
6	9,9 %	10,1 %	8,4 %
7	7,9 %	8 %	9,2 %
8	6 %	2,4 %	1,6 %
9	6,2%	6 %	8,9 %
10	12,2 %	8,9 %	14,7 %

The model developed with Rockwell Software Arena has the main purpose of simulating the supply, delivery and sales process and its general diagram is represented in Figure 3. It uses as input data:

1. *Sales Forecasts* for each item and for each POS (f_{ki}). This value is equal to historical sales data (hs_{ki}) recorded during previous selling seasons as defined in previous section;
2. *Merchandise Order*, which defines the total quantity to be purchased from suppliers for each item (Q_k);
3. *Delivery Order,* which defines quantity and time for deliveries from suppliers to the central warehouse ($D_k(t)$);
4. *Replenishment Order*, which defines quantity and time for deliveries from the central warehouse to the stores ($R_{ki}(t)$).

The model starts with the casual generation of the daily demand for each item and for each store both for the traditional channel ($d_{ki}(t)$) and for the online channel ($do_{ki}(t)$). Even though in current practice not always shop assistants record real demand (which means also recording missed sales) through Electronic Point of Sales (EPOS) devices, this information is highly important for always improving sales forecasts. Given demand, the model checks availability of the requested product by verifying that demand is lower or equal to the inventory level. While for the traditional channel we check availability in the store internal warehouses ($IS_{ki}(t)$), for the online purchases we have to distinguish the two logistics strategies:

- *Multi-channel:* the two channels – traditional and online – are separate, then purchases and deliveries are independently managed. The retailer does not satisfy on line purchases with stores’ on-hand inventory, but always ships the requested items from the warehouse, previously performing a check for availability in central warehouse stock ($IW_k(t)$).

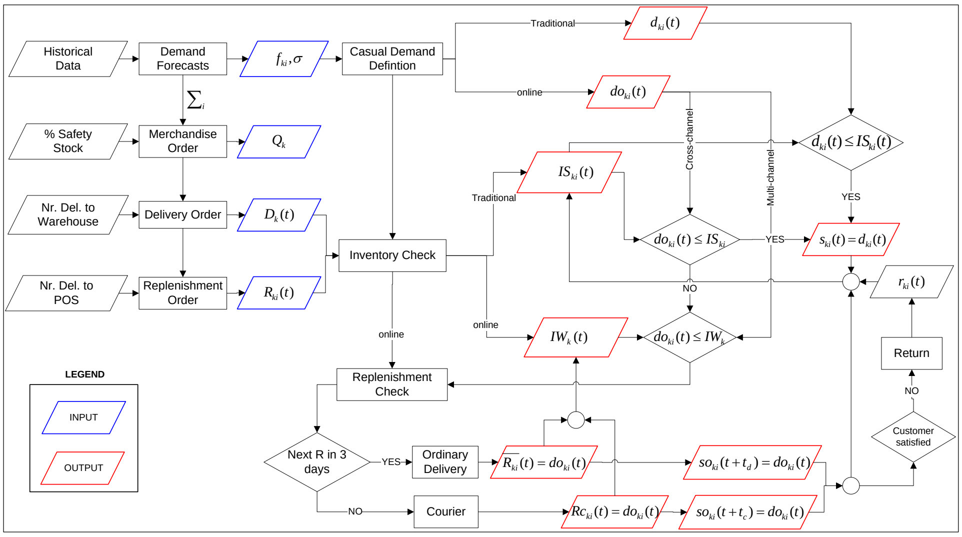

Figure 2 General Diagram of the Simulation model

- *Cross-channel:* in this actually integrated strategy the company has a single and shared information system containing real-time updated information on all stock levels. In this case, the model first performs an availability check in the store internal warehouse ($IS_{ki}(t)$), and then, only in case of unavailability, delivers the requested product from the central warehouse.

For online purchases which are shipped from the central warehouse, we need to perform a further check for replenishment schedule: if there is an ordinary shipment to store already scheduled in the next three days the requested item will be unified with the pre-defined shipment ($\overline{R_{k\iota}}(t)$) otherwise it will delivered through a dedicated courier ($Rc_{ki}(t)$).

Another crucial variable that has to be considered when dealing with online purchases are returns ($r_{ki}(t)$). While this phenomenon can be disregarded for physical stores, it becomes important in integrated strategies since customers do not physically see or try the item and may simply do not like or fit it. In our model the returned goods will stay in the store increasing stock level and will not be shipped back to warehouse for recovery since we disregard defective products return. The return rate is fixed as the 15% of the online total demand.

Then, output data given by the model are:

1. *Demand*, for the physical stores ($d_{ki}(t)$) and for the online market ($do_{ki}(t)$);
2. *Sales*, for the physical stores ($s_{ki}(t)$) and for the online market ($so_{ki}(t)$);
3. *Inventory levels*, for the stores internal warehouses ($IS_{ki}(t)$) and for the central warehouse ($IW_k(t)$);
4. *Ordinary additional shipments* for online purchases ($\overline{R_{k\iota}}(t)$);
5. *Courier shipments* ($Rc_{ki}(t)$).

All those outputs will be used to calculate KPIs reported in Table 1.

In the following sections we will better describe all the steps of the simulation model.

6.1 Merchandise and Delivery Order

This plan defines, for each clothing item, the quantities to be purchased from the suppliers. We suppose, for simplicity, that the k-th item is supplied entirely by the k-th supplier.

The purchase quantity is defined by:

$$Q_k = \sum_{i=1}^{n} f_{ki} * (1 + SS)$$

Where f_{ki} is sales forecast for both traditional and online channel and SS is the Safety Stock fixed as 40%.

This total quantity (Q_k) is delivered from the suppliers to the central warehouse in 3 different periods: (i) 80% at time 0 (Dk,0); (ii) 20% at time 50 (Dk,50); (iii) The remaining 10% at time 86 (Dk,86).

It is important to underline that the last deliver to the warehouse (at period 86) coincides with the beginning of the sales period.

6.2 Replenishment Order

Replenishments to the stores are weekly performed, for a total of 17 deliveries from day 1 to day 115 when the late sales period starts. In this last phase, in fact, from day 116 to day 140, the stores try and sell all the remaining goods out in order to reduce costs for the withdrawal of unsold goods. In addition, we suppose to deliver to the stores only the 80% of the total quantity purchased in order to absorb possible fluctuations in demand.

Then the quantity to be delivered to the i-th store is weighted in respect to the sales forecasts f_i and is defined as:

$$R_i = \frac{\frac{f_i}{f} * D_{k,t}}{n_{weeks}}$$

Where n_{weeks} is the number of weeks between two consecutive deliveries to the central warehouse.

The quantity supposed to be sold through mobile channel are not delivered to the stores but stays at the central warehouse waiting for the actual request.

6.3 Simulation scenarios

In order to assess the impact of the introduction of an online strategy on the performances of a traditional supply chain, we simulated 11 different scenarios, by keeping fixed the sales forecasts for the traditional channel (as per Table 4) and increasing the sales forecasts for the online channel.

Given the mean sales forecast for the traditional channel equal to 20.130 item/day, for each scenario we progressively increase the online forecasts of this quantity, except for scenario 0 that simply represents a traditional retailer without online market (Table 6).

Table 6 Simulated scenarios

Scenario	Online forecast [item/day]	Traditional mean forecast [item/day]
0	0	20.130
1	2.013	
2	4.026	
3	6.039	
4	8.052	
5	10.065	
6	12.078	
7	14.091	
8	16.104	
9	18.117	
10	20.130	

It is clear that, according to the sales forecasts, the quantity purchased from the suppliers and delivered to the central warehouse will increase while the replenishment plan remains unchanged. As already mentioned, in fact, items sold online will be shipped to stores with ordinary deliveries when possible; in this case the replenishment plan will be updated accordingly, otherwise they will be delivered by courier.

Each scenario is simulated both with a multi-channel and a cross channel strategy, for a total of 22 simulation.

The simulation time range covers 140 days, i.e. an entire selling season.

7. ANALYSIS OF RESULTS

In this section we show and analyse the trend of the selected KPIs in all the simulated scenarios.

7.1 Forecasting Error

As shown in Figure 3, the mean forecasting error grows with the online purchasing both for the items and POS.

This is clear since we have a return rate which contributes to increase deviation between forecasts and actual sales.

In addition, when introducing a cross-channel strategy, this deviation will further increase since all the items supposed to be purchased online are not delivered to the stores but stocked in the central warehouse and shipped only when requested. It implies that all stores on-hand stock are quickly consumed thus increasing the possibility of stock outs.

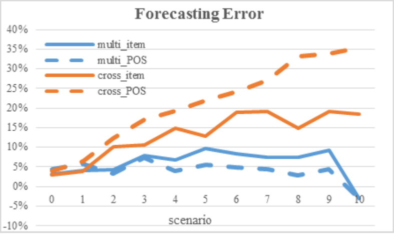

Figure 3 Forecasting Error for items and for POS

7.2 Backlog time

As shown in Figure 4, the backlog time increases when introducing the cross-channel strategy. This indicator is obviously strictly connected to the previous one (forecasting error) since it measures for how long the store is unable to satisfy customer request due to products unavailability.

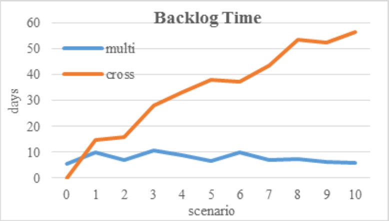

Figure 4 Backlog time

On the contrary, with the multi-channel strategy, online purchases are always satisfied with dedicated shipments from central warehouse.

7.3 Sales Percentage

As shown in Figure 5, in the multi-channel strategy the mean value is almost constant at more than 85% despite the increasing rate in returned goods.

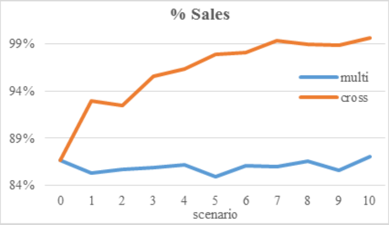

Figure 5 Sales Percentage

Whit this approach, in fact, both sales and deliveries to stores will increase. When introducing a cross-channel approach, additional items will be delivered only if necessary then this ratio will obviously increase.

7.4 Service Level

As shown in Figure 6, for both retailing strategies, service level of the online market does not significantly change. For the traditional POS, instead, this KPI drastically decreases when adopting a cross-channel approach. In this case, in fact, stores stocks are consumed by online purchases as well, then backlog time increases (ref. section 7.2) since scheduled delivered items are not able to satisfy traditional demand. This trend is due to a not optimized replenishment strategy, since quantity supposed to be sold online are not delivered to the stores but stays at the central warehouse waiting for the actual request.

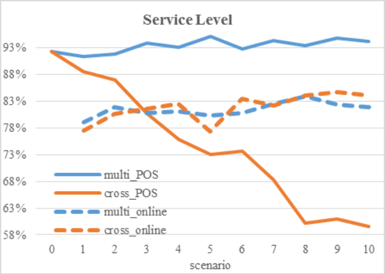

Figure 6 Service Level

7.5 Inventory Turnover

Figure 7 and 8 show an opposite trend of the inventory turnover in central warehouse and stores for the cross-channel strategy. This is due to the fact that, with this approach, before delivering an item from the central warehouse all stores stocks must be consumed. This obviously leads to an increase in inventory turnover for the stores and a decrease for the warehouse.

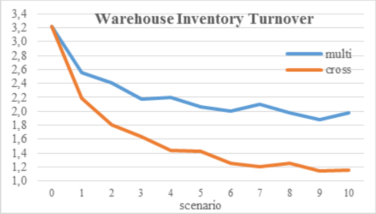

Figure 7 Warehouse Inventory Turnover

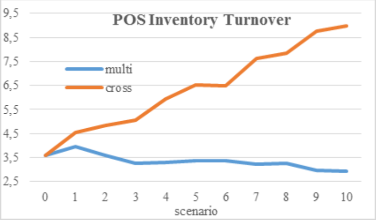

Figure 8 POS Inventory Turnover

7.6 Store profitability

As already mentioned in previous sections, in the 11 different simulated scenarios, sales forecasts and consequently demand, purchase quantity and items delivered to stores. Then, in order to appropriately compare these different conditions, Figure 9 shows the value of the store profitability compared to quantities delivered to stores.

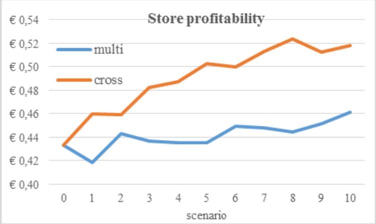

Figure 9 Store Profitability

When introducing a cross-channel approach, this KPI records an increasing trend slightly higher that the multi-channel case since quantities shipped to POS are reduced and, as shown in section 7.3, sales percentage increases.

7.7 Warehouse Management Cost

As for previous sections, in order to appropriately compare the different scenarios, Figure 10 shows the value of the warehouse management cost compared to quantities delivered to it, i.e. the total purchased quantity. It is clear that in the cross-channel strategy, items are delivered to stores only when they are actually requested resulting in a higher average level of stocks (ref. section 7.5); this implies a higher cost for their holding.

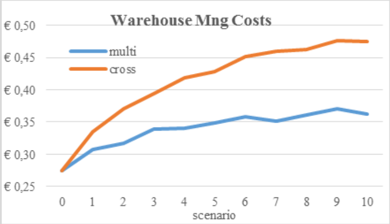

Figure 10 Warehouse Management Cost

7.8 Store Management Cost

Figure 11 shows the value of the store management cost compared to quantities delivered to them. This cost has an opposite trend than the previous one, since in the cross-channel strategy, replenishments to stores, considering both ordinary deliveries and courier shipments, increase and, at the same time, the average stock level in the stores' internal warehouses decreases. This results into a lower holding cost.

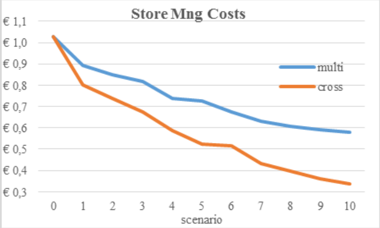

Figure 11 Store Management Cost

7.9 Primary Transport Cost

Parameters used to calculate the primary transport cost are reported in Table 7. These values are estimated according to real transports. Since we use same values for both logistics strategy, their actual value is not influencing global cost trend.

For the fixed transport cost (*CF*) cost we supposed to have a step function which reflects the need of using bigger or more than one means of transport, and is defined as:

$$\begin{cases} CF_k = CF_k & if\ Q_{D,k} < 50 \\ CF_k = CF_k * (1 + 25\%) & if\ 50 < Q_{D,k} < 100 \\ CF_k = CF_k * (1 + 50\%) & if\ 100 < Q_{D,k} < 200 \\ CF_k = CF_k * (1 + 70\%) & if\ Q_{D,ki} > 200 \end{cases}$$

Figure 12 shows the values of the unitary primary transport cost, i.e. the total transport cost compared to the quantities delivered to the central warehouse. This value is equal for multi- and cross-channel since we suppose that purchasing and delivery plans do not change for the two strategies. The slightly decreasing trends reflects the higher saturation of the transport means when quantities increase.

Table 7 Primary Transport parameters

Supplier	***DIST* [Km]**	***CF* [€/trip]**	***CV* [€/Km]**
1	400	30	0,04
2	1600	50	0,015
3	4500	130	0,005
4	2300	110	0,01
5	600	30	0,04
6	850	30	0,035
7	1200	50	0,015
8	1700	80	0,005
9	4700	130	0,002
10	800	30	0,03

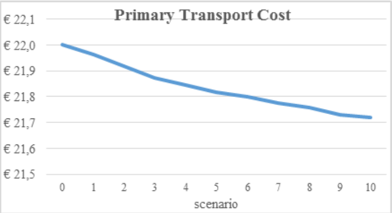

Figure 12 Primary Transport Cost.

7.10 Secondary Transport Cost

Parameters used to calculate the secondary transport cost are reported in Table 8. As per primary transport (section 7.9) these values are estimated according to real transports. For the fixed transport cost (*cf*) we suppose to have a step function which reflects the need of using bigger or more than one means of transport, and is:

$$\begin{cases} cf_i = cf_i & if\ R_i + \bar{R_i} < 50 \\ cf_i = cf_i * (1 + 50\%) & if\ R_i + \bar{R_i} > 50 \end{cases}$$

Table 8 Secondary Transport parameters

POS	***dist* [Km]**	***cf* [€/trip]**	***cv* [€/Km]**
1	50	23	0,1
2	90	22	0,1
3	70	24	0,1
4	30	20	0,1
5	60	25	0,1
6	120	44	0,1
7	150	45	0,1
8	400	52	0,1
9	450	50	0,1
10	500	55	0,1

Figure 13 shows the values of the unitary secondary transport cost, i.e. the total transport cost compared to the quantities delivered to the POS through ordinary weekly deliveries. This value decreases when online purchases increase, demonstrating a higher saturation of transport means.

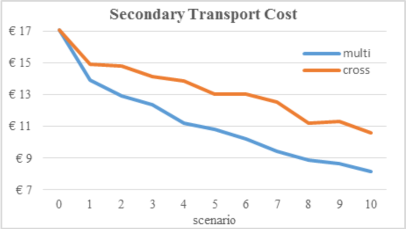

Figure 13 Secondary Transport Cost

On the other hand, this unitary costs remains higher in the cross-channel strategy since on average we deliver lower volumes. It is important to underline that, for online purchases, we need also to evaluate courier costs (Figure 14) since we need to guarantee deliveries within three days even if there I no scheduled ordinary delivery in this time range.

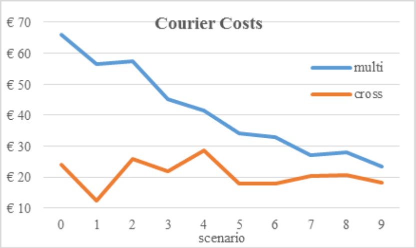

Figure 14 Courier Cost

We are supposing that the courier cost is independent from the quantity delivered in a single solution but it is only proportional to the number of deliveries. For this reason, this cost is decreasing when online purchases increase; in fact, only the quantity delivered through courier increases but not the number of deliveries.
In the cross-channel strategy this value always remains lower since courier deliveries are requested only in very few cases.

7.11 Total Cost

Figure 15 shows unitary total cost (including purchase cost), i.e. the total cost compared to total purchase quantity. It is clear that cross-channel strategy seems to be the most economically viable given that total costs always remains lower.

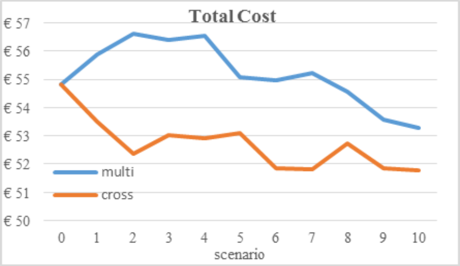

Figure 15 Total Cost

8. CONCLUSIONS AND PERSPECTIVES

The integration between physical stores and mobile channel is the new frontier for retail: customer expectations are always increasing, then operational requirements and supply chain configuration must be considered in the design and management of a cross-channel system.

This paper shows how the introduction of another fulfilment path, in addition to the traditional one, impacts on the SC of F&A industry. The first requirement for the implementation of this integrated strategy is coordination and proper management of the information flow which becomes an enabling factor. The role of the virtual inventory system is, in fact, crucial for the access to data on availability and location of products. In addition, the analysis of a defined set of KPIs which considers aspects connected to service level, profitability and costs, highlights that despite an increase in backlog, the cross-channel strategy can guarantee a significant cost reduction due to the better management of replenishments to stores. It is also important to underline that the replenishment policy is not optimized for the cross-channel approach, then by varying replenishment plans, in terms of frequencies and quantities, we may experience a further improvement both in cost and backlog reduction due to a better fulfillment of customers expectations.

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USING MULTI-POLE MODELING AND INTELLIGENT SIMULATION IN DESIGN OF A HYDRAULIC DRIVE

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ABSTRACT

An approach based on multi-pole modeling and intelligent simulation is proposed for design of fluid power systems. The method is explained on the example of modeling and simulation of a hydraulic drive with two-directional flow regulating valve. Multi-pole mathematical model of a hydraulic drive is presented. An intelligent visual simulation environment CoCoViLa supporting declarative programming in a high-level language and automatic program synthesis is used as a tool. Simulation examples of steady state conditions and dynamics of the hydraulic drive are presented and discussed.

Keywords: hydraulic drive, multi-pole model,
intelligent programming environment, simulation.

1. INTRODUCTION

Most of modeling and simulation tools in existence such as MATLAB/Simulink, SimHydraulics™, ITI SimulationX, DSHplus, Dymola, HOPSAN, VisSim, AmeSim, 20-Sim, DYNAST, MS1^{TM} referred in (Grossschmidt and Harf 2009a) and HYVOS 7.0 (Bosch Rexroth 2010), etc. used for simulation of fluid power systems, are object-oriented (systems are described as functional or component schemes) using equations with fixed causality or equations in non-causal form for each object. The obtained equation systems usually need checking and correcting to guarantee solvability. It is complicated to debug and solve large differential equation systems with a great number of variables. Special integration procedures must be used in case of large stiff differential equation systems. In analysis and system synthesis frequently simplified, 3rd…5th order differential equation systems are used.

In the current paper an approach is proposed, which is based on using multi-pole models with different oriented causalities (Grossschmidt and Harf 2009a) for describing components of different complexity. When modeling fluid power systems, elementary components are hydraulic resistors, tubes, hydraulic interface elements, valves, pumps, motors, pistons, etc. (Grossschmidt and Harf 2010). Hydraulic control valves of different types (Harf and Grossschmidt 2014) are described using elementary components.

During simulations calculations are performed in level of elementary components considering structure of the entire system. In such a way solving large equation systems can be avoided. Therefore, multi-pole models of large systems do not need considerable simplification.

Modeling and simulation of a hydraulic drive including a two-directional flow regulating valve is considered as an example of applying proposed methodology.

2. MULTI-POLE MODELS

In general a multi-pole model represents mathematical relations between several input and output variables (poles). The nearest to physical nature of various technical systems is using multi-pole mathematical models of their components and subsystems.

In hydraulic and mechanical systems variables are usually considered in pairs (effort and flow variable). Multi-pole models enable to express both direct actions and feedbacks.

Each component of the system is represented as a multi-pole model having its own structure including inner variables, outer variables (poles) and relations between variables.

Using multi-pole models allows describe models of required complexity for each component. For example, a component model can enclose nonlinear dependences, inner iterations, logic functions and own integration procedures. Multi-pole models of system components can be connected together using only poles. It is possible directly simulate statics or steady state conditions without using differential equation systems.

The multi-pole model concept enables us to describe mathematical models graphically which facilitates the model developing.

3. SIMULATION ENVIRONMENT

CoCoViLa is a flexible Java-based simulation environment that includes both continuous-time and discrete event simulation engines and is intended for applications in a variety of domains (Kotkas, Ojamaa, Grigorenko, Maigre, Harf and Tyugu 2011). The environment supports visual and model-based software development and uses structural synthesis of programs (Matskin and Tyugu 2001) for translating declarative specifications of simulation problems into executable code.

CoCoViLa (Figure 1) supports a language designer in the definition of visual languages, including the specification of graphical objects, syntax and semantics of the language. CoCoViLa provides the user with a visual programming environment, which is automatically generated from the visual language definition. When a visual scheme is composed by the user, the following steps – parsing, planning and code generation – are fully automatic. The compiled program then provides a solution for the problem specified in the scheme, and the results it provides can be feedback into the scheme, thus providing interactive properties.

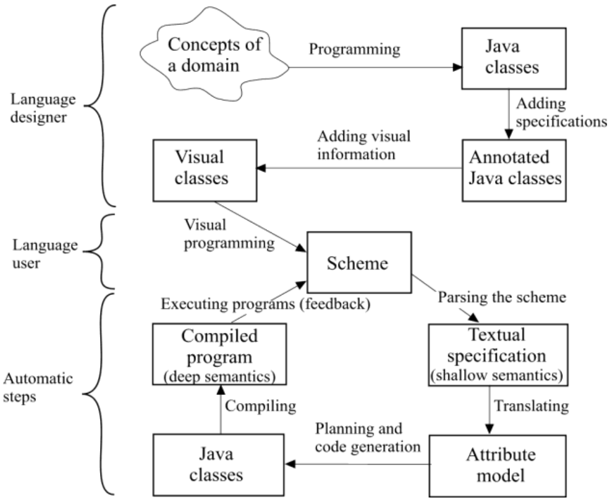

Figure 1. Technology of visual programming in CoCoViLa

Structural synthesis of programs is a technique for the automatic construction of programs from the knowledge available in specifications. The method is based on proof search in intuitionistic propositional logic.

The synthesizer (planner) determines computational paths from initial variables to required goal variables (i.e., tries to solve a given computational problem "find values of V from given values of U", where U and V are sets of input and output variables).

Designer do not need to deal with programming, he can use the models with prepared calculating codes. It is convenient to describe simulation tasks visually, using prepared images of multi-pole models with their input and output poles.

4. SIMULATION PROCESS ORGANIZATION

Using visual specifications of described multi-pole models of fluid power system components one can graphically compose models of various fluid power systems for simulating statics, steady state conditions and dynamic responses.

When simulating statics or steady state conditions fluid power system behavior is simulated depending on different values of input variables. Number of calculation points must be specified.

When simulating dynamic behavior, transient responses in certain points of the fluid power system caused by applied disturbances are calculated. Disturbances are considered as changes of input variables of the fluid power system (pressures, volumetric flows, load forces or moments, control signals, etc.). Time step length and number of steps are to be specified. For integrations in dynamic calculations the fourth-order classical Runge-Kutta method is used in component models.

Static, steady state and dynamic computing processes are organized by corresponding process classes (static Process, dynamic Process). To follow the system behavior, the concept of state is invoked. State variables are introduced for each component to characterize its behavior at the current simulation step.

A simulation task requires sequential computing states until some satisfying final state is reached. A final state can be computed from a given initial state if a function exists that calculates the next state from known previous states. This function is to be synthesized automatically by CoCoViLa planner.

A special technique is used for calculating variables in loop dependences that may appear when multi-pole models of components are connected together. One variable in each loop is split and iteratively recomputed to find it value satisfying the loop dependence.

State variables and split variables must be described in component models. When building a particular simulation task model and performing simulations state variables and split variables are used automatically.

5. HYDRAULIC DRIVE WITH TWO–DIRECTIONAL FLOW REGULATING VALVE

Functional scheme of a hydraulic drive with three-directional flow regulating valve in cylinder inlet is shown in Figure 2.

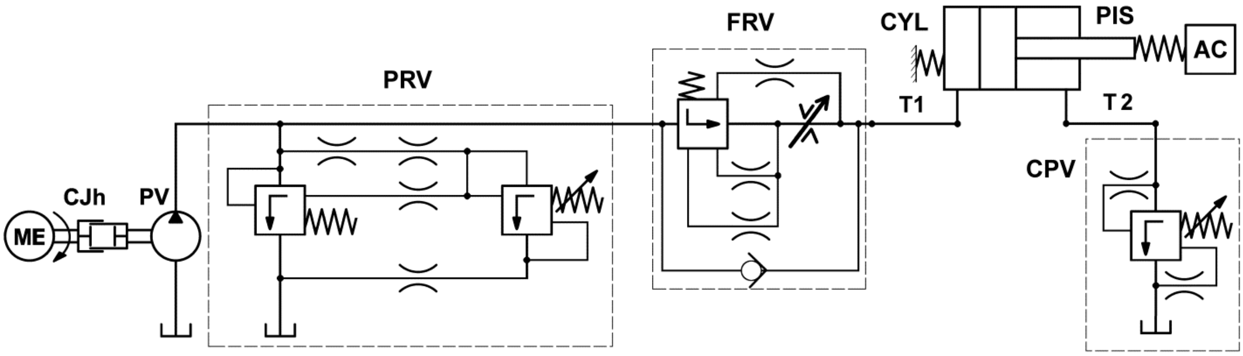

Figure 2: Functional scheme of a hydraulic drive with two-directional flow regulating valve

The pump **PV** is driven by electric motor **ME** through clutch **CJh**. The outlet of the pump is provided with pilot operated pressure relief valve **PRV** and two-directional flow regulating valve **FRV**.

Tubes **T1** and **T2** are located in inlet and outlet of hydraulic cylinder **CYL**. Piston and actuator are denoted respectively as **PIS** and **AC**. Constant pressure in outlet of the cylinder is ensured by pressure valve **CPV**.

In the next section two-directional flow regulating valve FRV is considered in detail to demonstrate how it is described by multi-pole and mathematical models.

6. TWO-DIRECTIONAL FLOW REGULATING VALVE

Flow regulating valves (Murrenhoff 2005, Gebhardt, Will and Nollau 2011) are used when the working speed of hydraulic drive should remain almost constant in case of different loads at the user.

Two-directional flow regulating valve FRV in Figure 2 contains adjustable throttle and connected in sequence pressure compensator ensuring constant pressure drop in the throttle.

In Figure 3 two-directional flow regulating valve of Mannesmann Rexroth is shown.

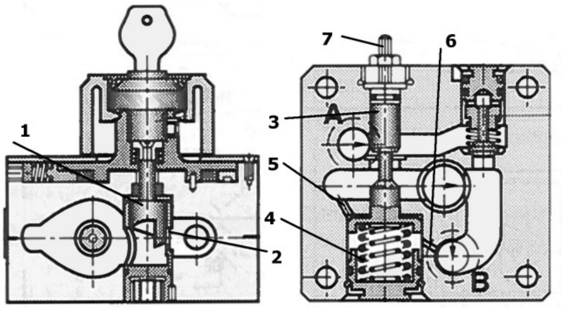

Figure 3: Two-directional flow regulating valve

The valve consists of throttle pin 1 with orifice 2, normally open pressure compensator spool 3 with two springs 4, bores 5, 6 to the spool surfaces and stroke limiter 7.

Multi-pole model for dynamics of a two-directional flow regulating valve FRV is shown in Figure 4.

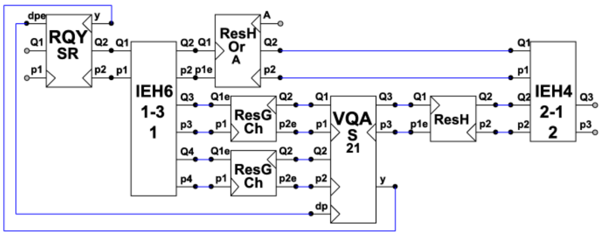

Figure 4: Multi-pole model of a two-directional flow regulating valve

Multi-pole models: **RQYSR** – pressure compensator slots, **ResHOrA** – regulating spool slot, **VQAS21** – pressure compensator spool, **ResGCh, ResH** – cushioning resistors, **IEH** – interface elements.

6.1. Mathematical Models

6.1.1. Regulating throttle orifice ResHOrA

Inputs: pressure $p2$, volumetric flow $Q1$, area of the regulating throttle orifice A.

Outputs: pressure $p1$e, volumetric flow $Q2$.

Output pressure

$$p1\mathrm{e} = p2 + \mathrm{RT} * \mathrm{abs}(Q1) * Q1.$$

Resistance at turbulent flow

$$\mathrm{RT} = \rho / (2 * \mu^2 * A^2),$$

where

ρ fluid density,

μ discharge coefficient.

Output volumetric flow

$$Q2 = Q1.$$

6.1.2. Pressure compensator spool VQAS21

Inputs: pressures $p1$, $p2$, $p3$, pressure drop dp in valve flow-through notches.

Outputs: volumetric flows $Q1$, $Q2$, $Q3$, displacement of valve y.

Pressure compensator spool areas:

$$\mathrm{A1} = \pi * \mathrm{d1}^2 / 4,$$

$$\mathrm{A2} = \pi * (\mathrm{d2}^2 - \mathrm{d1}^2) / 4,$$

$$\mathrm{A3} = \pi * \mathrm{d2}^2 / 4,$$

where

d1 diameter of the spool,

d2 diameter of the spool head.

Stiffness of springs:

$$\mathrm{c1} = \mathrm{G} * \mathrm{ds1}^4 / (\mathrm{Ds1}^3 * \mathrm{n1} * 8),$$

$$\mathrm{c2} = \mathrm{G} * \mathrm{ds2}^4 / (\mathrm{Ds2}^3 * \mathrm{n2} * 8),$$

where

G	shear modulus,
ds1, ds2	diameters of spring wires,
Ds1, Ds2	diameters of springs,
n1, n2	numbers of turns of springs.

Sum of spring stiffness

$$\mathrm{c} = \mathrm{c1} + \mathrm{c2}.$$

Force to pressure compensator spool

$$\mathrm{F} = \mathrm{A1}*p1 + \mathrm{A2}*p2 - \mathrm{A3}*p3.$$

Displacement of the pressure compensator spool:

$$\mathrm{y1} = 1 / (\mathrm{F} / \mathrm{c} - \mathrm{fV0}),$$

where

fV0 preliminary compressibility of spring.

Output pressure compensator spool slot width

$$y = \mathrm{y0} - \mathrm{y1},$$

where

y0 initial width of spool notches.

Difference of actuator velocity dv for integration used in Runge-Kutta method is calculated by formula

$$\mathrm{d}v=(\Delta\mathrm{t} /\mathrm{m})*(\mathrm{F} - (\mathrm{y1}+ \mathrm{fV0})*\mathrm{c} -$$

$$(\mathrm{Ff0} + \mathrm{kfr}*(\mathrm{p1} + \mathrm{p2}) /2)*\mathrm{sign(v)} - \mathrm{h*v}),$$

where

Δt time step,

m mass,
Ff0 constant part of friction force,
kfr coefficient of friction force,
v velocity of valve,
h damping coefficient.

Difference of spool displacement

$$dy = \Delta t * v.$$

Output volumetric flows:

$$Q1 = A1*v,\ Q2 = A2*v,\ Q3 = A3*v.$$

6.1.3. Pressure compensator slots RQYSR

Inputs: pressures $p1$, $p2e$, displacement y of the pressure compensator spool.
Outputs: volumetric flows $Q1$, $Q2$.

Initially, pressure compensator model strictly followed the build-up of the flow regulating valve (Fig. 3). Simulation results showed some instability in behaviour of the valve. To achieve more precise and smoother control over flow, pressure compensator slot of changed shape was invoked. The conical poppet of the compensator spool was replaced by inclined triangular notches.

Pressure compensator slots area

$$A \approx n * (y * \sin(\beta * \pi / 180) - h/2)*y,$$

$$h = [d/2 - (d^2/4 - y^2/4)^{1/2}] *\cos(\beta * \pi / 180),$$

where
n number of notches.
β inclined angle of triangular notches,
h height of segment-shaped portion of slot,
d diameter of spool.

Output volumetric flows:

$$Q1 = \mu *A* (2 * \mathrm{abs}(p1 - p2e) / \rho) * \mathrm{sign}(p1 - p2e),$$

$$Q2 = Q1,$$

where
μ discharge coefficient,
ρ fluid density.

7. SIMULATION OF STEADY STATE CONDITIONS

Simulation task for steady state conditions of a hydraulic drive with two-directional flow regulating valve is shown in Figure 5.

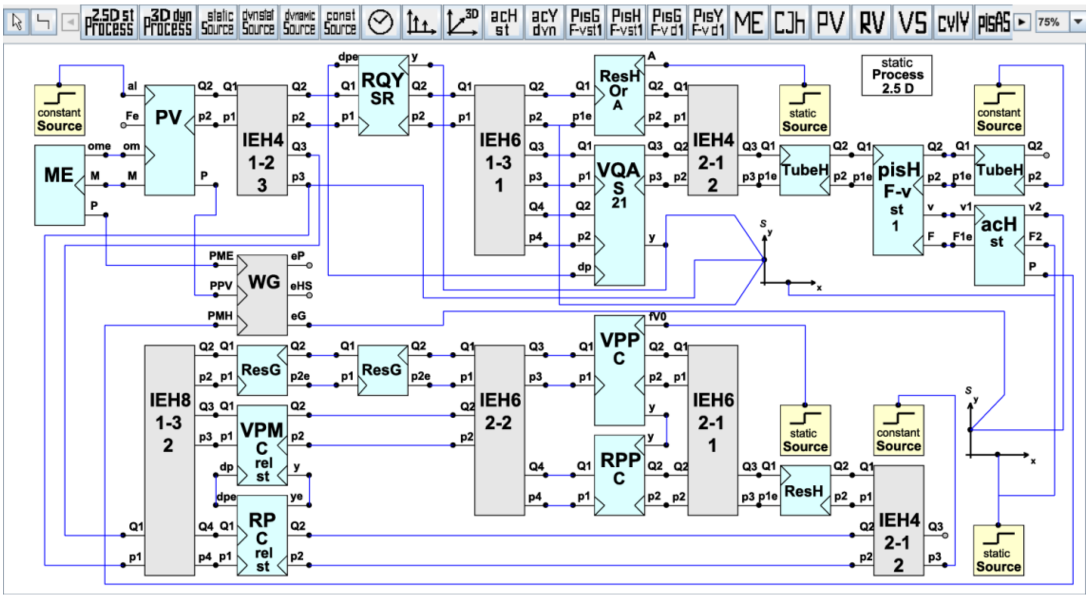

Figure 5: Simulation task of a hydraulic drive with two-directional flow regulating valve for steady state conditions

Multi-pole models: **ME-** electric motor, **PV -** axial-piston pump, **RQYSR** – pressure compensator slots, **ResHOrA –** regulating throttle orifice, **VQAS21** – pressure compensator spool, **VPPC –** pilot poppet valve with spring, **RPPC** – pilot poppet valve slot, **VPMCrelst –** main poppet valve with spring, **RPCrelst –** main poppet valve slot, **pisH_F-v_st1** – piston, **acHst** – actuator, **TubeH** – tubes, **ResG, ResH** – resistors, **IEH –** interface elements, **WG** – efficiency coefficient calculator (Grossschmidt and Harf 2009b, Grossschmidt and Harf 2014).

Inputs: outlet pressures $p2$, regulating orifice area A, constant position angle al of the pump regulating swash plate.

Outputs: actuator velocity $v2$, efficiency coefficient eG of the entire hydraulic drive.

Simulation manager*:* static Process 2.5D.

The following parameter values are used for steady state simulations.

For pilot operated pressure control valve the parameter values are shown in (Harf and Grossschmidt 2014).

For flow regulating valve:

for **ResHOrA:** μ=0.7;

for **VQAS21:** d1=0.01 m, d2=0.03 m, ds1=0.0024 m, Ds1=0.022 m, n1=5, ds2=0.0024 m, Ds2=0.014 m, n2=4, G=8e11 N/m, fV0=0.004 m, kfr=2e-9 N/Pa, Ff0=3 N;
for **RQYSR:** n=3, β=30 deg, d=0,01 m, μ=0.8.

For tubes, piston and actuator:

for **TubeH:** d=0.019 m, l=2 m;

for **pisH_F-v_st1:** piston diameter dpi = 0.10 m, diameters of rods dr1=0 m, dr2=0.056 m, piston friction force Ffpi=100 N, rod friction force Ffr=50 N;

for **acHst:** Ffr=100 N, h=3e4 Ns/m.

Results of simulation of steady state conditions depending on the pressure compensator slots area for three different values of the load force F = (0.1, 0.6, 1.1) e5 N are shown in Figure 6 and Figure 7.

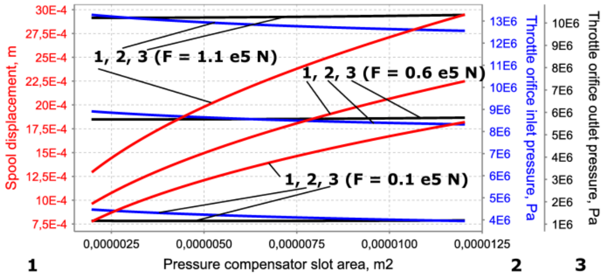

Figure 6: Graphs of simulations of steady state conditions

Pressure compensator spool displacement (graphs 1) is bigger in both cases pressure compensator slot area and load force values are bigger. Throttle orifice inlet and outlet pressures (graphs 2 and 3) depend only on the load force.

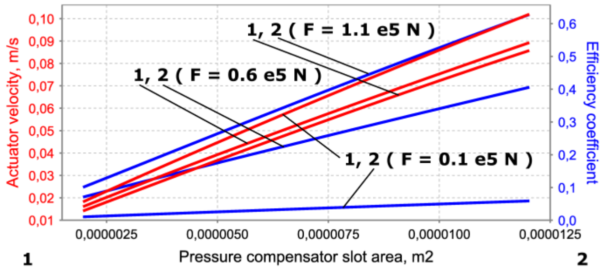

Figure 7: Graphs of simulations of steady state conditions

Actuator velocity (graphs 1) linearly depends on the pressure compensator slot area. Dependence on the load force is marginal. Efficiency coefficient (graphs 2) depends on both pressure compensator slot area and load force. Efficiency coefficient is higher in case of bigger actuator velocity and load force.

Results of simulation of steady state conditions depending on the load force for three different values of the regulating orifice area A = (12, 7, 2) e-6 m^2 are shown in Figure 8 and Figure 9.

In Figure 8 pressure compensator spool displacement (graphs 1) is bigger in both cases pressure compensator slot area and load force values are bigger. Feeding pressure (graphs 2) is slightly lower in case of higher load force. Throttle orifice inlet pressure (graphs 3) linearly depends on the load force.

In Figure 9 actuator velocity (graphs 1) is kept almost constant on load forces lower 80 kN. Efficiency coefficient (graphs 2) is maximal on load force 110 kN.

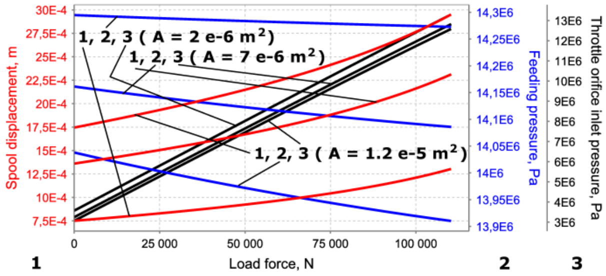

Figure 8: Graphs of simulations of steady state conditions

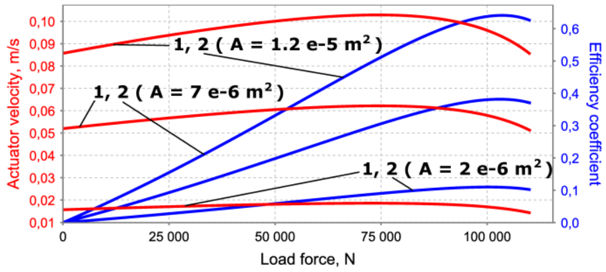

Figure 9: Graphs of simulations of steady state conditions

8. SIMULATION OF DYNAMICS

Simulation task of a hydraulic drive with three-directional flow regulating valve for dynamics is shown in Figure 10.

Additional and different multi-pole models from steady state conditions: **CJh** – clutch, **VPMC –** main poppet valve with spring, **RPCreldyn –** main poppet valve slot, **TubeH**, **TubeY –** inlet and outlet tube, **pisY–** piston, **cylY** – cylinder, **veZ1**, **veZ2 –** volume elasticities of cylinder chambers, **acY** – actuator, **ResGCh** – resistors.

Inputs: constant outlet pressures *p*2, load force *Fac*2, regulating orifice area *A,* constant position angle *al* of the pump regulating swash plate.

Outputs: actuator velocity *v*2, outlet volumetric flows *Q*2, cylinder position *xfi*.

Simulation manager*:* dynamic Process3D.

The following additional parameter values are used in dynamic simulations.

For flow regulating valve:

for **VQAS21:** m=0.04 kg, h=20 Ns/m;
for **ResYOrA:** A=1e-5 m^2;
for **ResGCh1:** d= 0.0012 m, l=0.02 m;
for **ResGCh2:** d= 0.0015 m, l=0.01 m;
for **ResH:** d= 0.0012 m, l=0.03 m.
For tubes, cylinder, piston and actuator:

for **TubeH**, **TubeY:** d=0.019 m, l=2 m;
for **cylY:** fixing elasticity efi= 1e-8 m/N, m=20 kg, hfi=5e5 Ns/m, Fffi= 20 N;
for **veZ1**, **veZ2:** lengths of chambers l1=l2=0.2 m;
for **pisY:** elasticity of piston rod er2=1e-10 m/N;
For **acYdyn:** m=20 kg, h= 3e3 Ns/m.

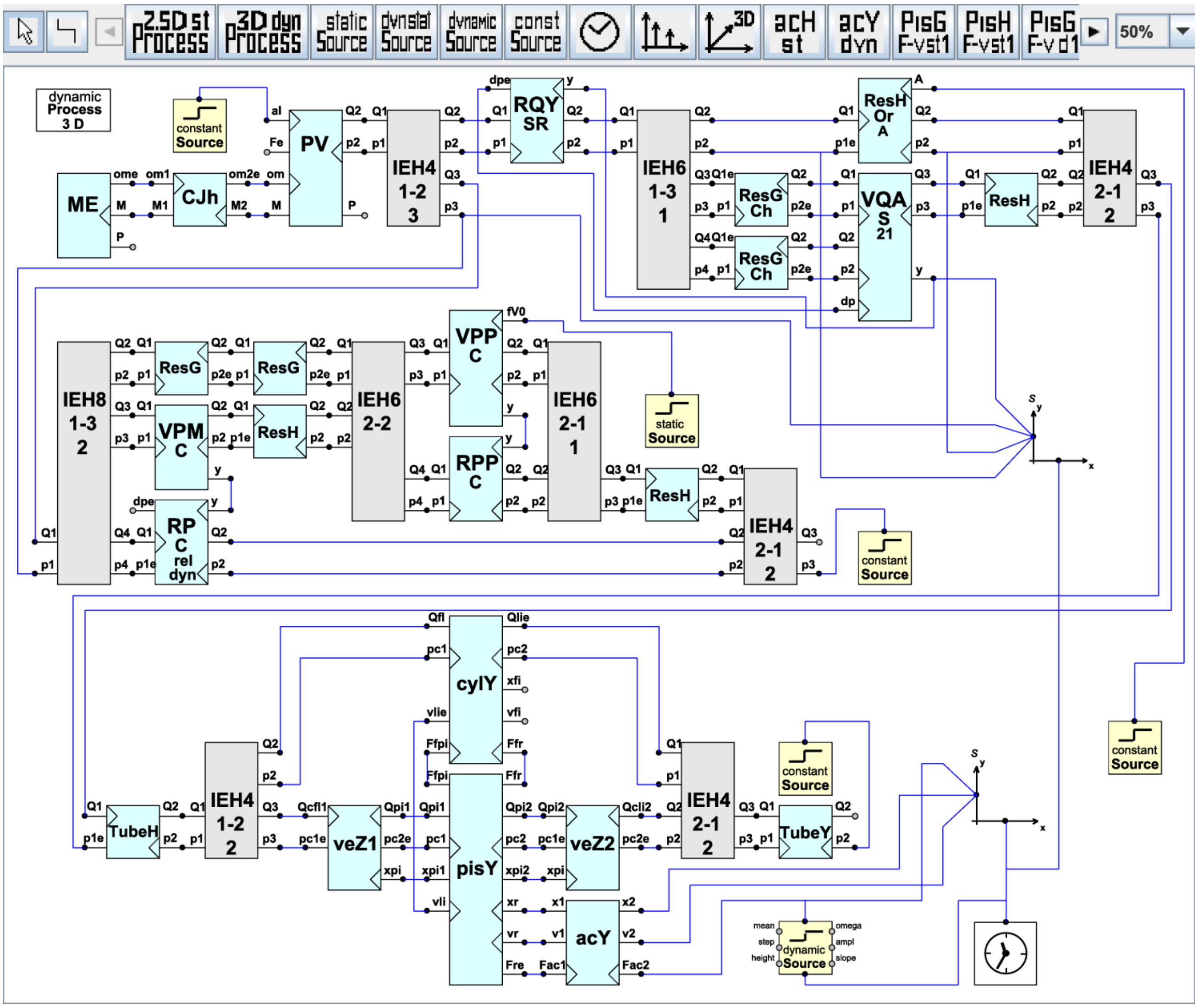

Figure 10: Simulation task of dynamics of a hydraulic drive

Results of simulation of dynamic responses caused by step change of regulating throttle orifice area *A* from 1e-5 m^2 to 1.1e-5 m^2 (step time 0.01 s) (graph 1 in Figure 11) as input disturbance are shown in Figure 11 and Figure 12. Load force *Fac2* is taken of constant value 1e4 N.

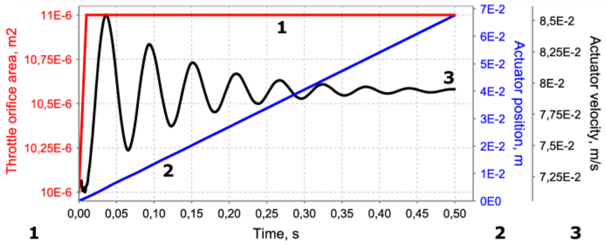

Figure 11: Graphs of actuator

Actuator moves linearly (graph 2), actuator velocity (graph 3) reacts by damped oscillation. The process lasts 0.5 s.

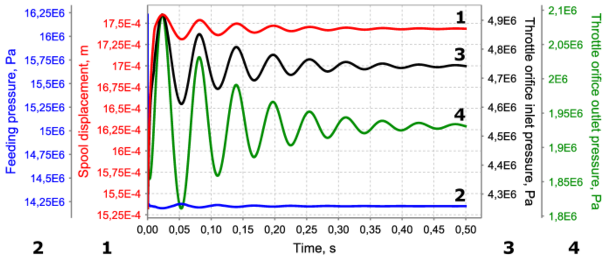

Figure 12: Graphs of flow regulating valve

Pressure compensator spool (graph 1) takes a new position after damped oscillations. Feeding pressure (graph 2) remains almost constant. Throttle orifice inlet and outlet pressures (graphs 3 and 4) oscillate synchronously and are damped in 0.5 s. Pressure drop in throttle orifice remains almost constant.

Results of simulation of dynamic responses caused by applying the hydraulic drive actuator step load force *Fac2* from 0 to 5E3 N (step time 0.01 s) (graph 1 in Figure 13) as input disturbance are shown in Figure 13 and Figure 14. Regulating throttle orifice area *A* is taken of constant value 1e-5 m^2.

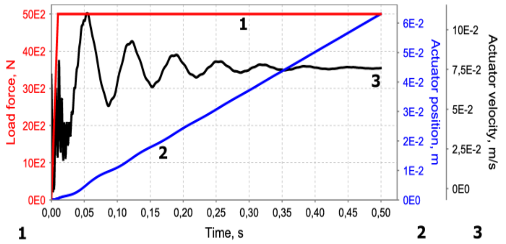

Figure 13: Graphs of actuator

Actuator moves linearly (graph 2), actuator velocity (graph 3) reacts by damped oscillation of two different frequencies. The process lasts 0.5 s.

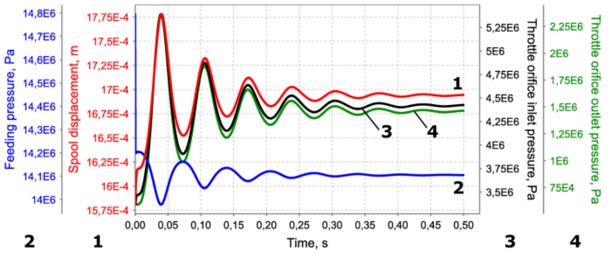

Figure 14: Graphs of flow regulating valve

Pressure compensator spool (graph 1) takes a new position after damped oscillations. Feeding pressure (graph 2) remains almost constant. Throttle orifice inlet and outlet pressures (graphs 3 and 4) oscillate synchronously and are damped in 0.5 s. Pressure drop in throttle orifice remains almost constant.

CONCLUSION

A simulation methodology for design of fluid power systems based on multi-pole modeling and intelligent simulation has been discussed in the paper. Modeling and simulation of a hydraulic drive with two-directional flow regulating valve was considered as an example.

As a result of the experiments initially used two-directional flow regulating valve of Mannesmann Rexroth was modified. The conical poppet of the compensator spool was replaced by several inclined triangular notches. Also, it was noticed that parameters of control valves such as stiffness and preliminary compressibility of springs, values of hydraulic resistors and damping coefficients required precise adjustment for each particular case to attain the best performance of the hydraulic drive.

Control valve models e.g. those we described and used in the paper can be used when composing models of fluid power systems whatever type.

The methodology described and applied for modeling and simulation of hydraulic drive is meant to be used at the first stage of design of fluid power systems. This enables to try out different configurations and find first approximate parameters in development of fluid power systems. Results of simulations are meant to be as basis for the further experimental stages of the design process.

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AN IMPROVED CONVERSIVE HIDDEN NON-MARKOVIAN MODEL-BASED TOUCH GESTURE RECOGNITION SYSTEM WITH AUTOMATIC MODEL CREATION

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ABSTRACT

Mobile devices like smartphones and tablets that are controlled via a multi-touch interface have become ubiquitous. In previous work a touch gesture recognition system based on Conversive Hidden non-Markovian models has been proposed that is able to recognize similar gestures with different execution speeds based on recorded examples. With this work, we improved the system by eliminating the major drawback of manually and tediously creating models for every gesture from recorded training data. To achieve this, the gesture model design has been adapted to include an additional structure that represents a map of all known gesture examples. Experiments conducted on two different datasets show that the new system can distinguish gestures with different speeds with good accuracy and fast detection times. Ideas to further improve the system are discussed and we believe that such a system could be the basis for a new gesture authentication system in the future.

Keywords: touch, gesture recognition, CHnMM, mobile

1. INTRODUCTION

The presence of mobile touch devices has become ubiquitous, especially due to the success of smartphone and tablet devices, which are primarily operated via the multi-touch interface they provide. This way of interaction and these device classes became popular with the introduction of the Apple iPhone in 2007 and the Apple iPad in 2010. Due to this development touch devices and interaction play an important role nowadays. Two facts that reinforce this are that Microsoft optimized their Windows Desktop operating system for touch input and Google adapted their web page ranking algorithms to consider the mobile (touch) quality of websites.

Many internet services are accessed from these mobile touch devices and the user authentication almost always requires the user to enter his or her username and a password, which takes significantly more time on a glass surface than on a physical keyboard (Findlater 2011), especially when it is a long and secure password with capital letters and special characters. An alternative authentication method for touch devices that has been mentioned already is the verification of users by touch gestures (Sae-Bae 2011, Sherman 2014) which have the potential to be far more convenient to enter by the user. But to our knowledge these methods do not consider differences in temporal dynamics of a gesture execution and only validate the shape, although the discrimination of gestures with different temporal dynamics would add an additional factor of entropy and therefore be more secure.

With this work, a first step towards such a touch gesture authentication system that considers temporal dynamics is taken. Our previous experiments (Bosse 2011, Dittmar 2015) have shown that Hidden non-Markovian Models (HnMM) and their subclass Conversive Hidden non-Markovian Models (CHnMM) are able to distinguish similar gestures also by their temporal dynamics. But the models in these papers had to be manually and tediously created by an expert from a set of training examples, which render these approaches infeasible for applications in practice. A system that is feasible in practice would be required to automatically generate its gesture models from given example executions, which is currently not efficiently possible for HnMMs and CHnMMs. While it is possible with HMMs, these have another weakness. HMMs do not explicitly incorporate timing information, hence, they are dependent on a periodic symbol emission that implicitly adds this information, which is difficult to achieve if the system is required to support a large set of different touch devices.

Consequently, we propose a new CHnMM-based hybrid model for touch gestures that also considers temporal dynamics. By introducing a new data structure, the *StrokeMap*, an automatic creation of the CHnMM from a set of given examples is facilitated. Additionally, a prototype gesture recognition and authentication system is created to evaluate our proposal.

2. BACKGROUND

In the following sections our previous work, a formal CHnMM definition and related work are presented to put this paper into context and to increase the understanding of its contents.

2.1. Previous Work

In this section a short overview of previous work that this paper relies on is presented to explain some basic methods and models needed to understand this paper and our approach. Furthermore, a formal definition of a CHnMM is given at the end of this section.

In Krull et al. (2009) an extension to the popular Hidden Markov Model (HMM) (e.g. used in speech-, gesture- and handwriting recognition (Fink 2014)), has been presented: the so-called Hidden non-Markovian models that are more powerful regarding their modelling capabilities. For example, they incorporate arbitrary distributions for state sojourn times instead of only geometric distributions like HMMs do implicitly by utilizing fixed probabilities and a fixed time step for state changes. Due to their complex modelling capabilities the solution algorithms of HnMMs are complicated and computationally very demanding and that is why the subclass of CHnMMs was defined and thoroughly analysed by Buchholz (2012) in his dissertation. This subclass only slightly limits the modelling capabilities of HnMMs by requiring an output symbol for every state change, but this small change allows much more efficient solution algorithms. These algorithms (one is utilized in this paper) employ the Proxel method, which is not further explained in this paper, but the dissertation by Lazarova-Molnar (2005) covers this method thoroughly.

In 2011, Bosse et al. (2011) successfully showed that HnMMs can be used to create a Wiimote gesture recognition system that is also able to distinguish between similar gestures with different execution speeds. Similarly, Dittmar et al. (2015) utilized CHnMMs to create a touch gesture recognition system for a multi-touch tabletop, and showed in experiments the ability of the recognition system to distinguish touch gestures by their temporal dynamics.

In both experiments the systems have been compared to an HMM-based recognition system. While these performed slightly worse than the HnMM- and CHnMM-system, they also were able to distinguish the gestures with different execution speeds in most cases, even though HMMs do not incorporate explicit timing information. The ability comes from the fact that implicit timing information is provided due to the periodic emission of symbols that is used for HMM-based systems.

Another problem of both approaches is the fact that the models for the gestures were created and parameterized manually. A circumstance that renders the system infeasible in practice, because no user would be able to create the models on their own and even an expert needs a long time to create it. With the new approach presented in this paper we especially want to eliminate this problem by trying to employ a supervised learning approach as proposed by Bosse (2012) for CHnMM-based gesture recognition systems.

2.2. CHnMM – Formal Definition

A CHnMM contains the following elements that are similar to the elements of HMMs:

- a set of states S of length N
- a set of output symbols V of length M
- an initial probability vector $\Pi=(\pi_1,\ldots,\pi_N)$
- an NxN matrix A containing the state change behaviour, but with more complex elements a_{ij}.

Additionally, a CHnMM contains the set $TR=\{tr_1,tr_2,\ldots,tr_K\}$ of K transitions that define the model behaviour. Each transition tr_i is a tuple consisting of the following three elements:

- *dist* represents the continuous probability distribution that specifies the duration of the transition which causes a discrete state change on completion.
- *b(v)* is a function that returns the output probability of symbol v when the transition causes a state change. It is the semantic equivalent of the output probabilities in B for HMMs, but associated to transitions for CHnMMs instead of states as in HMMs.
- *aging* is a boolean value that determines if the time that the transition has been active is saved (*aging=true*) or reset to 0 (*aging=false*) if there is a state change deactivating it caused by another transition, i.e. if the current active transition is interrupted by the triggering of another one.

All elements a_{ij} in A are either elements of TR or empty if no transition between states s_i and s_j exist. A CHnMM model λ is fully defined as a tuple $\lambda=(S,V,A,TR,\Pi)$ that contains all previously described elements.

In addition to the output symbol o_t of the observations, CHnMMs have a *time* property p_t, containing the point in time of symbol emission. This valuable time information is not needed for HMMs which only get it implicitly by a periodic symbol emission. An ordered sequence of these observations is called a trace O. The path Q also contains a sequence of states q_t with associated time stamps.

2.3. Related Work

The idea to use gestures for authentication is not completely new. A basic and widespread approach that is similar is the so-called “Pattern Lock” used in the Android mobile operating system (Shabtai 2010). Further research that focuses on authentication for unlocking a certain device includes Sae-Bae et al. (2012) and Sherman et al. (2014), but none of them considers temporal dynamics.

The application of HMMs for gesture recognition in general is very common but quite rare for touch gesture recognition systems. Two systems that employ

HMMs to learn touch gestures by example are presented by Damaraju et al. (2008) and Joselli et al. (2009). The first system is able to learn and recognise multi-touch gestures performed on a tabletop, while the latter learns and detects single stroke gestures on mobile touch devices. But in both cases different execution speeds are not tested or even considered.

To our knowledge the recognition of similar gestures that differ only in execution speeds has never been further investigated (except in our previous work), although there exist many HMM-based gesture recognition systems that incorporate temporal features like the velocity into the output symbols, for example (Chen 2003). On the contrary, most papers concentrate on tolerating the time variances in gesture executions, for example (Hong 2000), and do not try to exploit them.

3. THE MODEL

Our new method employs a single model per gesture, which is also the case for most HMM-based gesture recognition systems (for example (Damaraju 2008)). Unlike our previous work (Dittmar 2015), we do not solely use a CHnMM to represent a gesture but combine it with what we call a *StrokeMap*, a structure that holds all the information about the shape of a gesture stroke. The creation of this structure based on example gestures is explained in detail in the following section.

The reason for introducing this new structure is to enable supervised learning by separating a gesture into known and clearly defined sections. It is also driven by the idea that for a gesture authentication system mainly the shape and the temporal dynamics of a gesture are relevant and the new structure helps to add valuable information about the shape to the output symbols.

The CHnMM represents the temporal dynamics of the gesture and is explained in Section 3.2 after the *StrokeMap*.

3.1. Creating the StrokeMap

As already mentioned and as the name suggests the *StrokeMap* holds all the information about the shape of a gesture stroke in the form of circular areas representing expected locations of successive points of the trace. It is created from all training examples of the gesture.

In Figure 1 all steps involved in creating a StrokeMap from training data are visualized with two example trials used as training data. The first part of the figure shows the recorded points of both examples (1.). In the first step of the *StrokeMap* generation process these points are interpolated linearly to get a continuous path (2.). The next step is to calculate *n* spatially equidistant points for each example gesture, i.e. a pair of adjacent points has the same length of interpolated stroke path between them. In the visualized example the value *n* is five but apart from that, *n* is a parameter or setting of the recognition system that is called *nArea* within this paper. In another step the calculated equidistant points are grouped together (all first, second, third, etc. points) to so called area points to create circle shapes around them containing all points of a group (4.). These circles represent the area where a gesture stroke is expected to be after a certain distance of the gesture has been executed. The centre of the circle is determined by determining the average of all points of a group while the radius is given by the distance from the circle centre to the point of the group with the maximum distance from the circle centre. As a result the created circle contains all the points of the group.

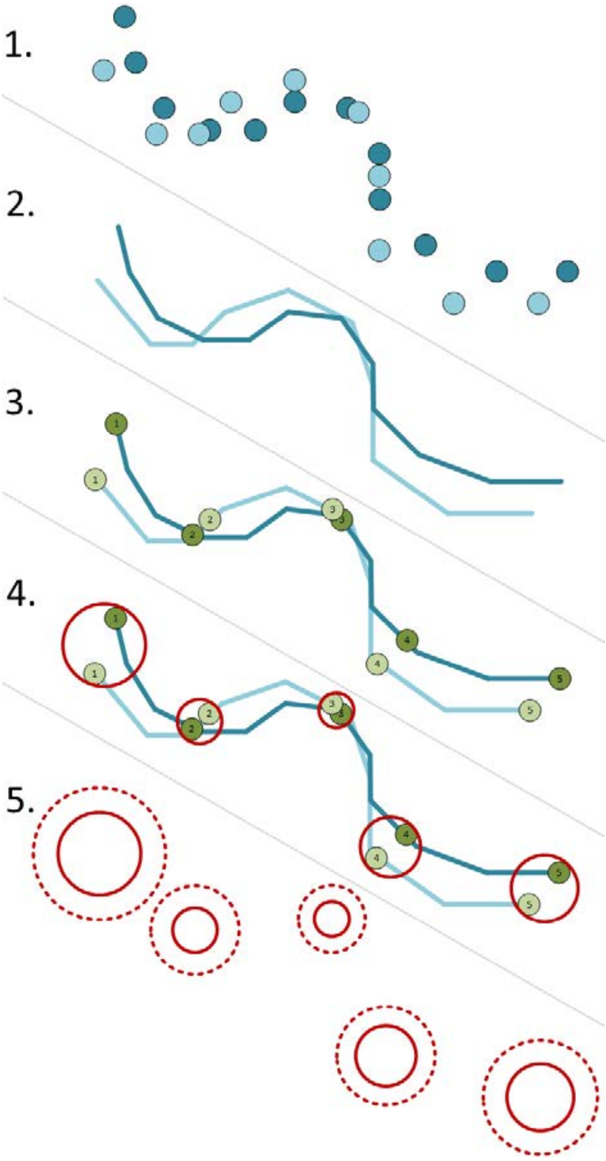

Figure 1: StrokeMap Generation Process Demonstration

As a last step, slightly larger circles are calculated for each circle representing a tolerance area, as it cannot be expected that new and unknown executions of the same gesture will go through the already calculated circles, especially if only a small number of example gestures is available. The radius of the tolerance circle is determined by multiplying the original circle radius with the factor *tolF* which is another parameter of the recognition system. Eventually, the final *StrokeMap* consists of the ordered set of circles and their tolerance radii (5.).

3.2. Creating the CHnMM

The design of the CHnMM for a gesture is closely connected to the *StrokeMap*. Each area (a circle and its tolerance circle are considered one area) of the *StrokeMap* is represented by a state of the CHnMM. Furthermore, a start state is added, hence the set of states is $S=\{Start,A1,A2,\ldots,An\}$. These states are linearly connected with transitions $TR=\{T1,T2,\ldots,Tn\}$ resulting in a layout that resembles the linear topology known from HMMs (Fink 2014). Consequently, the elements a_{ij} where $i=j+1$ are mapped to the elements of set *TR*, all other matrix elements are empty. A graphical representation of this design is given in Figure 2. Further visualized elements are the output symbols $V=\{A1\_Hit,A1\_Tol,\ldots,A2\_Hit,A2\_Tol,An\_Hit,An\_Tol\}$ and their output probabilities . In this first iteration of our new approach $b(A_i\_Hit)$ is set to 0.9 and $b(A_i\_Tol)$ is set to 0.1 to inflict a penalty for gestures that only go through the tolerance areas of the *StrokeMap*. Further details on the symbols and their creation and meaning are given in Section 3.3.

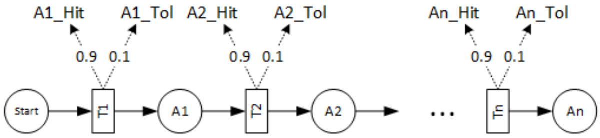

Figure 2: CHnMM Design for a Gesture

All the aforementioned CHnMM elements are already determined by the connected *StrokeMap*. Incidentally, the *aging* element of the transitions is not relevant for this design, because there are no competing transitions. The remaining *dist* element for each transition of the CHnMM is the part of the model that represents the temporal dynamics of the gesture. For *T1* the distribution is always the same as it is deterministic because the first symbol always occurs at the very beginning, hence, the state change from *Start* to *A1* happens in an instant. However, it is included in the model to incorporate the information of the first symbol which would be just a dummy symbol otherwise. For the remaining transitions, the calculated area points (3. section in Figure 1) are utilized to calculate the required time from area A_i to A_{i+1} for each training gesture, which is possible because every area point also contains a time value which is the linearly interpolated timestamp. As a result, a list of sample times is created for every transition (except *T1*) that can be utilized to estimate a probability distribution. In this paper, a uniform distribution was chosen using the minimum and maximum of the collected samples as parameters.

This new process makes it possible to automatically create a CHnMM-based gesture model from a set of examples, which is the main goal of this research.

3.3. Symbol Creation

The symbol creation process transforms the data of an executed gesture to a symbol trace *O*, which is used to classify the gesture. For the proposed system, the output symbols are connected to the *StrokeMap* and the chosen symbols (see Section 3.2) contain information about the shape of the gesture due to this connection. In detail, a given executed gesture is processed in an analogous manner to the process described in Section 3.1. Thus, area points are determined for the given single gesture execution and checked against the corresponding areas in the *StrokeMap*. If an area point lies within the inner circle area, the symbol A_i_Hit is emitted, if it lies within the tolerance circle it is symbol A_i_Tol and if it lies outside of the tolerance circle the trace generation is cancelled, as this already indicates that the gesture does not fit the *StrokeMap*. This way the processing of gestures that do not fit the gesture model shape-wise can be cancelled early.

3.4. Gesture Authentication and Classification

In a *gesture authentication scenario* or to be more precise in a gesture verification scenario, a user would identify himself first, for example with a unique username. The recognition system knows the gesture model (*StrokeMap* and CHnMM) that was created for this username at registration and to be authenticated, the user needs to recreate the gesture. For the inputted gesture the symbol creation process is conducted, and if all area points at least lie within their respective tolerance areas of the *StrokeMap* a symbol trace *O* is generated as described above. If no trace could be created the authentication fails. Otherwise, the so called evaluation task is performed on the CHnMM using the trace *O* to calculate $P(O|\lambda)$, employing the Proxel method. With an evaluation value greater than 0 the authentication succeeds for a given gesture and username.

For a *gesture recognition scenario* an executed gesture needs to be classified as a gesture from the set of trained or known gestures respectively. In this case, the newly developed system in this paper creates a trace *O* from the given gesture for each known gesture model. This is different to our previous work and most HMM-based systems, where only one trace is created. For each trace O that could be created, which should be the case for similarly shaped gestures only, the evaluation task is conducted and the gesture model that generated the highest value is used as classification result. In case that no trace could be generated or that no evaluation value was higher than 0, no classification result is returned and the inputted gesture is considered to be different from all known ones. This represents an important difference to most existing gesture recognition systems, where every input is classified to the best fitting gesture even if they are shaped completely different.

4. EXPERIMENTS & RESULTS

To evaluate the abilities and quality of our system different experiments have been conducted. These experiments are based on two different datasets.

4.1. Description of the Datasets

Dataset1 consists of touch gesture data from ten different persons. Each participant was told to think of a gesture that he or she could use as a gesture password and to perform it twenty times while attempting to use the same position, shape and speed. In Figure 3 these gestures are visualized by an example of each user.

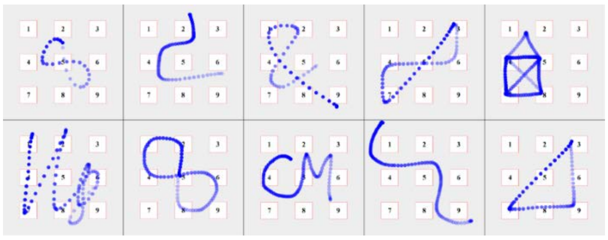

Figure 3: Gestures of Dataset1

Dataset2 has been created to evaluate the ability of the recognition system to distinguish gestures with different execution speeds and is illustrated in Figure 4. It consists of three different shapes namely a circle (C), a shape formed like the letter D (D), and a triangle (T), which are all performed counter-clockwise and starting at the top. These shapes are performed at two different speeds, fast (f) and slow (s) and consequently the dataset consists of six different gestures each performed thirty times. The similarity in shape C and D adds an additional challenge for the recognition system.

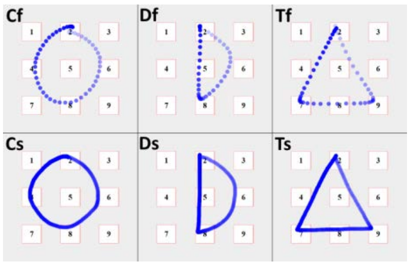

Figure 4: Gestures of Dataset2

Both datasets have been recorded on an iPad using the same user interface where the touch area has a numbered grid in the background (as seen in Figure 3 and Figure 4) to aid the user in performing the gestures at the same position. Furthermore, the touch data has been retrieved in the browser via JavaScript instead of an application to demonstrate that the recognition system could be employed in the web.

To increase the expressiveness of our experiments a cross validation approach is utilized, i.e. the dataset is split into *k* subsets of the same size and each subset is used as a test set while the *k-1* remaining subsets are used to train the recognition system. As a result, *k* tests can be conducted with one dataset and the test data will always be different from the training data.

Furthermore, a parameter variation is performed on each experiment to analyse the behaviour of the system for different parameter sets. The parameters and their ranges are as follows:

- *nArea* – The number of areas used in the StrokeMap (range: 10–20, step: 2)
- *tolF* – The tolerance factor used to determine the size of the tolerance area (range: 1.1–2.1, step: 0.1)
- *minRadius* – The minimal radius of each area (range: 0.01–0.19, step: 0.2)

As a result, 660 different parameter sets are created within the parameter variation. The unit used for the *minRadius* parameter is related to the employed interface and its coordinate system. The touch area is 600x600 pixels in size while the x and y values for the point coordinates range from zero to one. Thus, a *minRadius* value of 0.5 would create circles that are as wide as the touch area (diameter of 1.0).

The recognition system and the experiments were implemented in C# and all experiments were processed on a usual laptop with an Intel Core i5 processor (2410M @ 2.3GHz) and 6GB RAM.

4.2. Basic Gesture Recognition

First, a gesture recognition experiment was conducted to see if our new recognition system is able to classify different gestures based on training data. We conducted a parameter variation and cross validation with four subsets on Dataset1 and recorded the result of each gesture classification. With four subsets of twenty gestures, every gesture is trained with fifteen and tested with five other gesture examples per subset, resulting in twenty classification results per parameter set and gesture. With 660 parameter sets, ten gestures and 20 tests for each gesture, a total of 132000 classifications have to be processed, including 2640 times of training the recognition system.

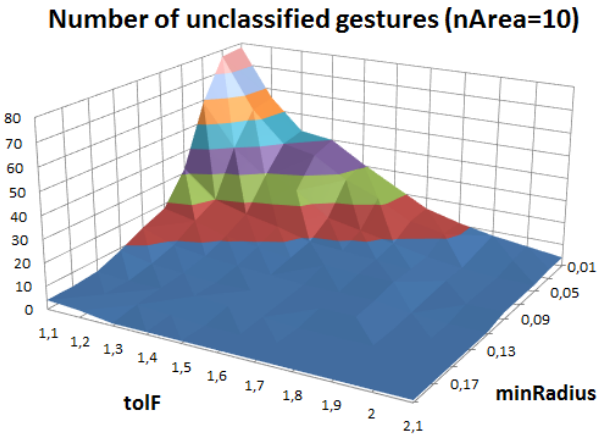

Figure 5: Number of Unclassified Gestures for Different Parameter Sets (*nArea*=10) using Dataset1 and 4 Subsets

The results of this experiment are very promising as they prove that our new approach does not fail the basic task of recognizing different gestures that were created from examples. The data reveals that not a single gesture has been classified as another gesture, but as Figure 5 shows there are cases where the tested gesture could not be classified at all. This number of unclassified gestures increases with stricter and more intolerant parameters and peaks at 78 unclassified gestures (of 200 executed gestures). But a nearly perfect result with only one unclassified gesture can be achieved by setting the parameters more tolerantly. Consequently, a good setting for this kind of gesture set would be *nArea*=10, *tolF* = 1.6 and *minRadius* = 0.17 which only had one unclassified gesture, probably because of a badly executed gesture example, as even more tolerant settings cannot avoid it. In Figure 6 the results for *nArea*=20 are visualized which suggest that this parameter has only little influence to the general behaviour but slightly decreases the tolerance as it raises the number of unclassified gestures which peak at 83 in this case.

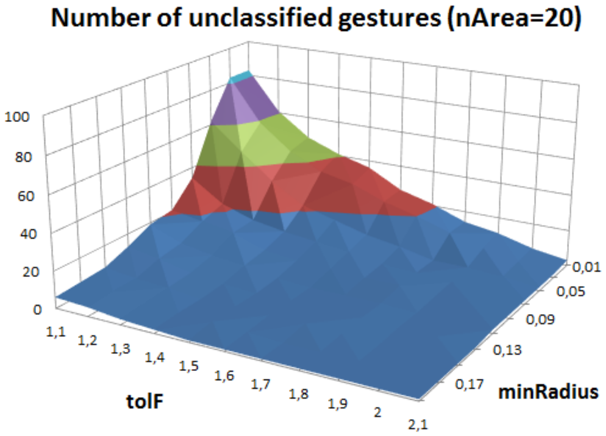

Figure 6: Number of Unclassified Gestures for different Parameter sets (*nArea*=20) using Dataset1 and four Subsets

The processing of this experiment (without writing results to file) was finished after 31 s, proving that the classification and even training is very fast, because the average classification time for a gesture is less than 0.24ms.

4.3. Temporal Gesture Recognition

For Dataset2 the same experiment approach as in the previous experiment has been used to evaluate the gesture recognition quality of the system if the gestures have different execution speeds. In this case, the dataset consists of six different gestures whose thirty examples are divided into five subsets, resulting in a total of 118800 classifications to be processed. Consequently, each gesture is trained with 24 training and tested with six gesture examples for each parameter set.

The calculation of the results took 44 s, which is around 13 seconds more than the first experiment, although fewer classifications had to be performed. The reason for this is probably the fact that more training processes had to be conducted due to the greater number of subsets. Additionally, the recognition system presumably cannot benefit from early cancelation as much as in the first experiment due to the similarity of most gestures. However, it is still very fast with less than 0.38ms per gesture on average.

For the recognition quality, the results for one parameter set (*nArea*=10, *tolF*=1.7, *minRadius*=0.01) are shown in Table 1, where a decent recognition quality could be achieved. Only one fast triangle execution was wrongly classified as slow and four executed gestures were not classified, leaving 175 out of 180 gestures that were correctly recognized. In Table 2 the same parameter set has been used but the number of subsets was reduced to two, resulting in a smaller training set of 15 gestures instead of 24, and a larger test set of 15 gestures instead of 6.

Interestingly, no gesture was wrongly classified this time, but the number of not classified gestures increased notably to 18 which is especially due to 12 slow circle gesture executions that were not classified. It is hard to tell why this particular gesture performed so much worse than the others, but it could be that there is more variation in the execution due to its length. Future investigations are necessary to verify this.

Table 1: Experiment Results with *nArea*=10, *tolF*=1.7, *minRadius*=0.01 and five Subsets

	Classified Gesture						
Executed Gesture	Cf	Cs	Df	Ds	Tf	Ts	None
Cf	30	-	-	-	-	-	-
Cs	-	29	-	-	-	-	1
Df	-	-	29	-	-	-	1
Ds	-	-	-	28	-	-	2
Tf	-	-	-	-	29	1	-
Ts	-	-	-	-	-	30	-

Table 2: Experiment Results with *nArea*=10, *tolF*=1.7, *minRadius*=0.01 and two Subsets

	Classified Gesture						
Executed Gesture	Cf	Cs	Df	Ds	Tf	Ts	None
Cf	29	-	-	-	-	-	1
Cs	-	18	-	-	-	-	12
Df	-	-	29	-	-	-	1
Ds	-	-	-	28	-	-	2
Tf	-	-	-	-	28	-	2
Ts	-	-	-	-	-	30	-

Another interesting fact is that these results could only be achieved using a *minRadius* of 0.01, because higher values were causing significantly more wrong classifications, as seen in Table 3 where *minRadius* is set to 0.05. Some fast gestures were falsely classified as slow while however the number of not classified gestures decreased to 0. The results suggest that the recognition system seems to prefer the slow variants of a gesture in some cases. The *tolF* parameter has a similar influence as in the first experiment as it slightly reduces the number of not classified gestures the higher its value and additionally has a slight influence on the number of false classifications, which is, however, minor compared to the influence of *minRadius*.

Table 3: Experiment Results with *nArea*=10, *tolF*=1.7, *minRadius*=0.05 and five subsets

	Classified Gesture						
Executed Gesture	Cf	Cs	Df	Ds	Tf	Ts	None
Cf	25	5	-	-	-	-	-
Cs	-	30	-	-	-	-	-
Df	-	-	27	3	-	-	-
Ds	-	-	-	30	-	-	-
Tf	-	-	-	-	23	7	-
Ts	-	-	-	-	-	30	-

Based on this experiment, we can conclude that the system can differentiate gestures that only differ in execution speed, at least with a *minRadius* of 0.01, as with higher values the slow gesture variants seem to be preferred as a classification result.

4.4. Authentication

Since this paper is motivated by the idea of a gesture authentication system, a suitable experiment for evaluating the authentication quality has been conducted. The approach is similar to the previous experiments, employing parameter variation and cross validation. For each gesture a training set is used to create the gesture model. The test set contains genuine gestures that should be accepted by the system as they represent the trained gesture. Furthermore the examples of all other gestures of the dataset are tested against the created model to analyse whether the system correctly rejects them. With this approach it is possible to calculate a False Acceptance Rate (FAR) and a False Rejection Rate (FRR) for each parameter set, gesture and subset.

The results of this experiment for Dataset1 are rather uninteresting as it performs analogously to the first experiment and therefore achieves an average FAR of 0 and an average FRR of 0.05 for the same parameter set as in the first experiment. Presumably, the FRR is again caused by the badly performed gesture.

The results for Dataset2 are shown in Figure 7 where five subsets were used for the cross validation. Consequently, 3088800 gesture examples were authenticated and 19800 times a gesture model has been generated from 24 examples, and the process finished after 68 s. Thus, the average time to process a gesture is below 0.02ms. However, it has to be noted that the majority of the authentication attempts were fraudulent ones that benefit from early cancellation.

A quite good parameter set (*nArea*=10, *tolF*=1.5, *minRadius*=0.03) achieved an average FAR of 2% and an average FRR of 4%, which is marked with a red circle in Figure 7. This is a very good result for a prototype but especially the FAR value could not be accepted in real world applications where sensitive data and information need to be protected from unauthorized persons. The influence of the parameters is as expected. A higher tolerance (*tolF* and/or *minRadius* is increased) causes improved (smaller) FRR values, because more variants of a gesture are accepted. Simultaneously, the FAR values get worse (increase), because also fraudulent inputs are more likely to be accepted. The reason that the FAR and FRR values are worse than for Dataset1 is due to the fact that Dataset2 has gestures that only differ in their execution speeds and their discrimination only seems to work well for rather intolerant parameter sets.

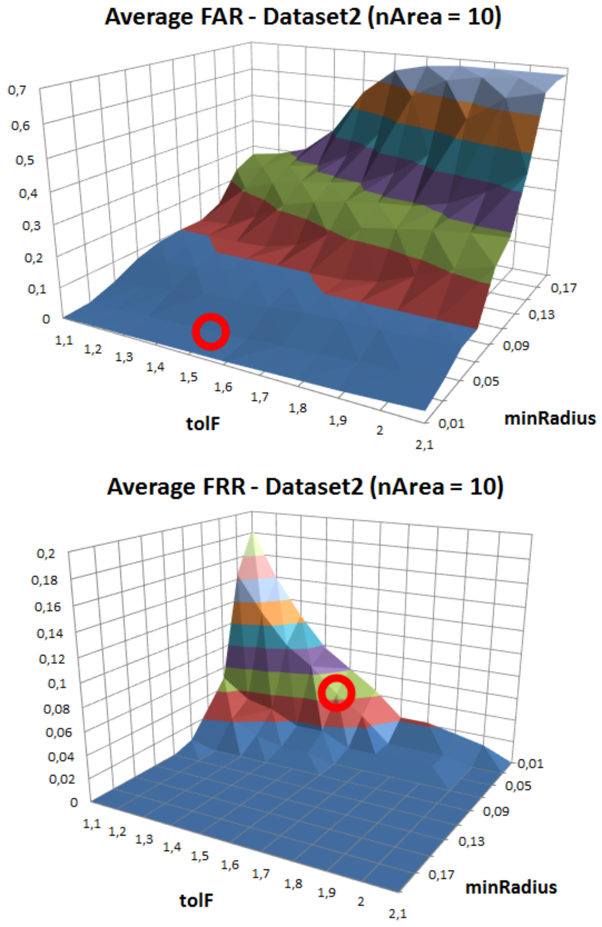

Figure 7: Average FAR & FRR for Dataset2 with Different Parameter Sets (NOTE: the *minRadius* scale has been reversed for a better visualization in the lower image)

The results show that the system can recognize different gestures by different users. The worse performance in the second experiment is due to the gesture examples being very simple (and similar) and therefore not a good choice for authentication gestures. This suggests that there should be rules for the choosing of secure gestures, as there are for secure passwords, such as for example a minimum length of the gesture stroke.

5. CONCLUSION

With this paper we presented a prototype of a new CHnMM-based gesture recognition system that unlike our previous systems is able to automatically generate touch gesture models from given gesture examples and that is able to perform gesture recognition and authentication tasks. Hence, the goal of removing the tedious and difficult manual creation and parameterization process for CHnMM based systems could be achieved. The results show that the system works very well in recognizing different gestures by different users. Even the discrimination of gestures that only differ in execution speed achieved respectable results.

As a summary, the following list gives an overview of some special properties of the new recognition system that could be advantageous for different application:

- Gestures are defined by examples
- The tolerance and accuracy of the recognition system is configurable with parameters
- The training and recognition processes are computationally very fast
- The gesture model creation and the recognition is independent of the touch data frequency and therefore independent of the device and platform used (unlike HMM-based systems)
- The system does not attempt to always classify an executed gesture, hence, only gestures that really are represented by a gesture model are detected
- Due to the early cancelation abilities of the system, it has the potential to work with good performance even on very large gesture sets

Of course, there are also some current limitations to the system, for example the current prototype is not translation, rotation or scaling invariant, although translation invariance could be easily achieved by using coordinates relative to the start of the gesture. However, it is not clear if these invariances are desirable in authentication scenarios.

Since the implementation of the system is only a prototype there are still many aspects that need to be investigated, for example:

- More sophisticated approaches to define the size of the tolerance areas should be employed that also consider the number of examples (more examples → smaller tolerance area)
- The circle generation could calculate the smallest circle enclosing all area points
- Different area shapes like a polygon could be employed
- More specific probability distributions depending on the use case
- Instead of a fixed number of areas, an area point could be generated every time a certain distance of the gesture trace is reached, to better cope with different lengths of the example gestures
- The output probabilities for symbols could be adapted according to the number of example gestures

The proposed idea of using a *StrokeMap* and a CHnMM to model touch gestures, which is presented in this paper, could be easily extended to a more general concept where paths and trajectories are modelled that are subject to variations in their execution and can differ in their temporal dynamics, which is the case for many human movements. Therefore, the presented approach could also be used for gestures that are performed with a stylus device or, in combination with image recognition techniques, it could also be applied for gesture recognition from camera-recorded movements. The concept is also easily extendable to three dimensional paths and trajectories (e.g. for Wiimote or Kinect gestures) and also multi-path abilities are a subject of future research, hence the applications could be manifold.

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MONTE CARLO SIMULATION USED FOR THE ELECTRICITY SUPPLIER SELECTION

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ABSTRACT

One of the very important commodities that affect our life is electricity. The costs related to the electricity consumption are significant and so each subject (e.g. household or company) has to consider carefully which electricity supplier is the most suitable with respect to the minimal costs. The electricity price is influenced by the region where the subject chooses the suppliers, by the amount of the electricity consumption and by the electricity prices given by the regulatory office. The transformation of the electricity market in the Czech Republic has led to the increasing number of suppliers offering this commodity to households and companies. The aim of this paper is to select such a supplier that minimizes total costs of the electricity for given household and given tariff rate. As a tool we use Monte Carlo simulation for the electricity consumption.

Keywords: Monte Carlo Simulation, electricity consumption, suppliers' selection

1. INTRODUCTION

Electricity belongs to the commodities that are essential for our lives and also for the economic development. The expansion of modern technologies and the increase of the electronic equipment usage to ease the work, to relax, to study, etc. causes the non-decreasing demand for electricity (Fig. 1).

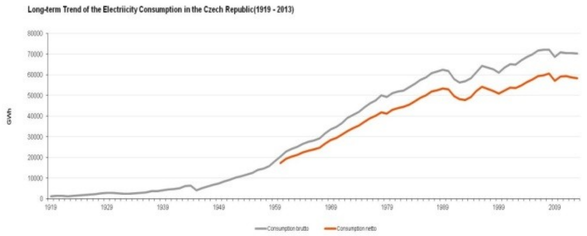


Figure 1: Long-term Trend of the Electricity Consumption in the Czech Republic. Source: CEZ (2015)

The transformation of the electricity market in the Czech Republic started in 2002 when the companies could choose its electricity supplier. For the households it started to be possible since 2006. After this process each household and company can choose the supplier of the electricity. This liberalization has led to the increasing number of suppliers entering the electricity market. Except of the suppliers, there are other subjects on this market in the Czech Republic: distributors, Energy Regulatory Office (ERU) and operator of the market (OTE) (www.eru.cz). The Czech Republic is divided into three network parts operated by three distributors (Fig. 2): PRE, CEZ, E.ON.

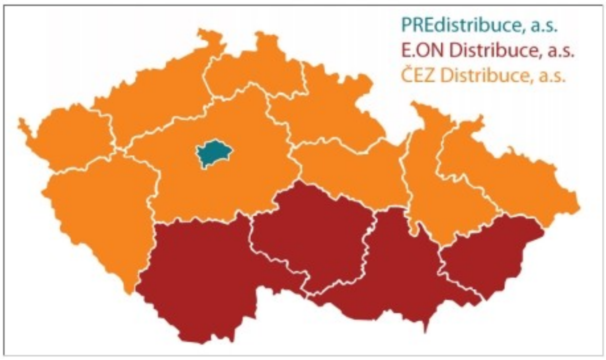


Figure 2: Distributors' regions in the Czech Republic (Source: www.penize.cz)

Each household cannot choose the distributor but only the supplier that sells the electricity. The tariff rate for each household is given according to the supplier's conditions. The complete list of the suppliers and their tariffs and prices is changing every year. The selection of the supplier depends on the contract conditions but mainly on the prices. With respect to all these facts it is a hard task to find the best supplier. Various techniques and methods can be used to model the situation on the market (Ventosa et al. 2005; Seknickova, Kuncova 2014). In this paper we use the simulation of the electricity consumption of one household (tariff rate D25d) to compare the final prices for all suppliers and their products in all regions in 2015 and we compare it with the results from the previous research (Kuncova, Seknickova 2014).

2. CZECH ELEKTRICITY MARKET

The electricity market in the Czech Republic was specific till 2002 when the transformation process oriented at the fully liberalization has started and so all the households and companies can choose its supplier. As it was mentioned above, there are other also other subjects on the electricity market, especially distributors, the Energy Regulatory Office (ERU) and the Operator of the market (OTE). OTE predicates the whole market consumption and analyses the differences, ERU regulates the prices of the transfer and distribution of the electricity. The high number of the suppliers and their products on the retail market (Fig. 3) embarrasses the position of the households. According to this situation it is hard to follow the rules and the price changes on the market and so it is hard to choose the best (cheapest) product.

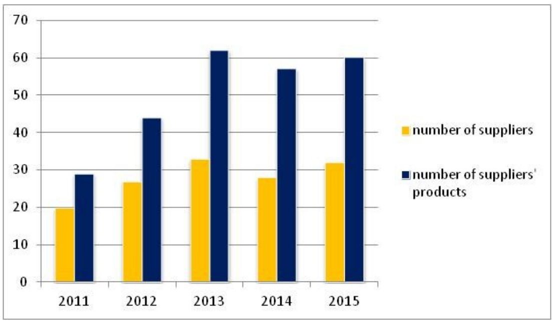


Figure 3: Number of suppliers and products (source: www.eru.cz)

The product selection is influenced mainly by the electricity take-off amount and by the prices for the electricity consumption. The final price is given by more factors such as consumption, fixed fees or taxes. Generally the price can be divided into two components. The first one is the controlled charge for services related to the electricity transport from the generator to the final customer. This charge is annually given by Energy Regulatory Office (ERU, 2015). It covers:

- monthly lease for the circuit breaker,
- price per megawatt hour (MWh) in high tariff (HT),
- price per megawatt hour in low tariff (LT),
- price per system services,
- price for the support of the renewable energy purchase,
- charges for the electricity market operator,
- electricity ecological tax (28,30 CZK per 1 MWh).

The second part of the total price is given by the electricity supplier. It covers:

- fixed monthly fee for the selected product,
- price per megawatt hour (MWh) in high tariff (HT),
- price per megawatt hour in low tariff (LT).

The final price is increased by VAT that was 20% till 2012 and 21% from 2013.

3. DATA AND METHODS

3.1. Data for the Analysis

According to the previous analysis (Kuncova, Seknickova 2014) we compare the offered products for the tariff rate D25d. This tariff rate is given to household when the electricity is used also for the accumulative heating and hot water heating for lower and middle yearly offtake with operative management of the validity period of the low tariff for 8 hours. It is so-called dual tariff rate as it covers 2 periods (high tariff, low tariff) during the day. The ranges for the electricity consumption were taken from the real data with the electricity consumption about 10 MWh anually, 45% energy in high tariff and 55% in low tariff and with the circuit breaker from 3x20A to 3x25A. According to the ERU calculator (2015) we use data for 60 products (offered by 32 suppliers) in all three distribution areas. All data display prices for year 2015. When we compare the average prices in 3 distribution areas (Fig. 4) we see that since 2012 they are decreasing but similar for all regions.

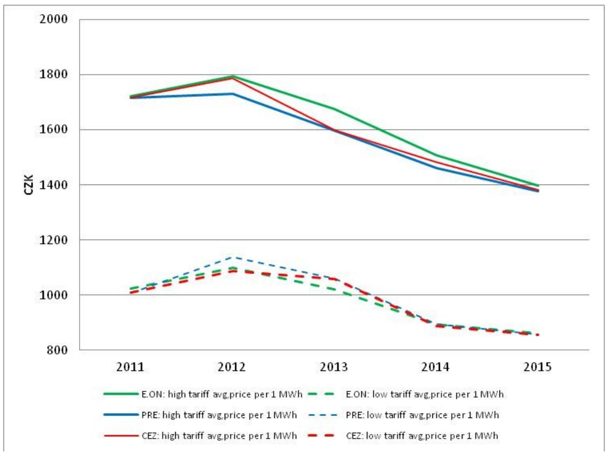


Figure 4: Suppliers' average prices for 3 regions

On the other hand when we compare the prices given by the distributor and ERU (Table 1), we see that the CEZ region is the most expensive one.

Table 1: Prices of distributors

year	distrib. region	circuit-breaker monthly fee	Distrib. HT price per 1 MWh	Distrib. LT price per 1 MWh	Distrib. Other services price per 1 MWh
2011	**E.ON**	105	1846.39	27.63	530.15
	PRE	98	1582.83	19.90	
	CEZ	120	1978.50	32.85	
2012	**E.ON**	98	1667.65	27.63	569.97
	PRE	98	1553.79	19.90	
	CEZ	120	1972.84	32.89	
2013	**E.ON**	98	1697.42	30.08	722.75
	PRE	105	1650.04	25.49	
	CEZ	120	1991.98	37.36	
2014	**E.ON**	90	1592.04	30.59	621.8
	PRE	98	1563.66	24.45	
	CEZ	105	1731.93	36.38	
2015	**E.ON**	95	1518.43	29.99	607.21
	PRE	102	1508.54	24.37	
	CEZ	110	1727.62	36.94	

3.2. Monte Carlo Simulation

To find the best product we can use various methods and techniques. One of them (that we also have used for the previous comparison – Kuncova, Seknickova 2014) is Monte Carlo simulation. Simulation models can be applied in situation when some variables of the model are uncertain. Simulation itself is a technique for imitation of some real situations, processes or activities that already exist in reality or that are in preparation – just to create a computer model (Banks 1998). Simulation models do not provide the solution of the problem but they show what can happen. They are used to study the system and see how it works, to find where the problems come from, to compare more model variants and to select the most suitable one, to show the eventual real effects of alternative conditions and courses of action, etc. (Dlouhý et al. 2011). Monte Carlo simulation repeats a lot of random experiments to find out the possible outcomes. This is typical situation for various decision-making processes in finance (Razgaitis 2003), banking (Kuncova, Lizalova 2012) and also in energetics to generate the whole demand for the distributed units (Hegazy et al. 2003) or to generate the annual electricity consumption (Kuncova, Seknickova 2014). The process of simulation involves a lot of experiments when random number generator and the transformation of the random numbers into random variables from the selected distribution must be used. The spreadsheet add-in package Crystal Ball is designed specifically for Monte Carlo simulation in MS Excel and it has been used also in this article.

For the calculations we use the same model as in (Kuncova, Seknickova 2014). The ranges for the electricity consumption in each month were set (at about 900 kWh per month on average), the high tariff is used in 45% from the whole consumption. Our simulated consumption has been generated for each month from the normal distribution with 20% of the average taken as the standard deviation. In all Monte Carlo simulations 1000 experiments have been tried to randomly select consumption for each month and afterwards the annual costs are calculated. The formula for the annual cost calculation for each supplier's product is following:

$$
\begin{aligned}
COST_{ij} = (1 + VAT)& \\
&\cdot \left[12 \cdot \left(mf_{ij} + mf_j\right) + 0.45 \cdot gc\right. \\
&\cdot \left(ph_{ij} + ph_j\right) + 0.55 \cdot gc \\
&\left.\cdot \left(pl_{ij} + pl_j\right) + gc \cdot (os + t)\right]
\end{aligned}
$$

where

i … product, $i = 1, \ldots, 60$,
j … distributor, $j = 1, \ldots, 3$,
VAT … value added tax (VAT = 0.21 in 2015),
mf … fix monthly fee,
gc … yearly generated consumption in MWh,
ph … price in high tariff per 1 MWh,
pl … price in low tariff per 1 MWh,
os … price for other services per 1 MWh,
t … electricity tax per 1 MWh (t = 28.3 CZK).

4. RESULTS

The comparison of suppliers is based on the 1000 simulation experiments created in the Crystal Ball software. We have found out that the difference among the distributors regions exists. The cheapest region is the area of the distributor PRE (Table 2). The order of the suppliers and their products in 2015 according to the average annual prices is nearly the same in all regions. On the first place there are 2 suppliers (that offer only one product each): CARBOUNION KOMODITY or ST Energy. The differences of the annual costs of the supplier CARBOUNION KOMODITY in all regions can be seen in Figure 5. The most expensive is the supplier Global Energy with its two products (Table 2). The difference between the lowest and highest annual average price is about 5400-5600 CZK which is about 20% of the average annual costs.

Table 2: Order in 2015 for all distributors and the average annual price

distr. area / order	E.ON	avg. annual price CZK	PRE	avg. annual price CZK	CEZ	avg. annual price CZK
1	CARB. KOMOD	28961	ST Energy	28850	ST Energy	30262
2	ST Energy	29040	CARB. KOMOD	28944	CARB. KOMOD	30390
3	Nano En.Trade	29063	Nano En.Trade	29062	Nano En.Trade	30474
4	Europe Easy Energy Com.aku	29385	Fonergy Premium	29179	Fonergy Premium	30591
5	Fonergy Premium	29462	Europe Easy Energy Com.aku	29231	Europe Easy Energy Com.aku	30643
58	E.ON elekt.	32927	E.ON elekt.	32925	E.ON elekt.	34342
59	Global Energy fix 2015 G aku	33241	Global Energy fix 2015 G aku	33075	Global Energy fix 2015 G aku	34503
60	Global Energy G aku	34564	Global Energy G aku	34339	Global Energy G aku	35693

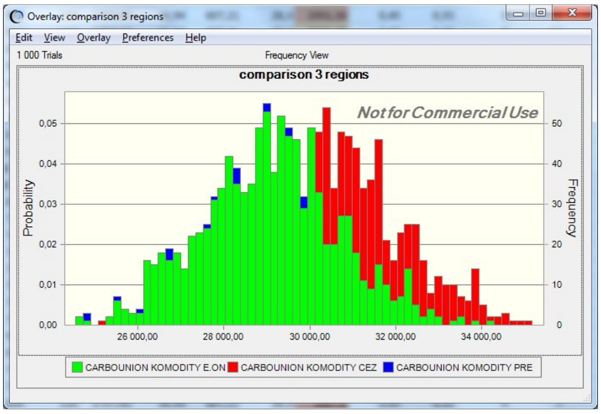
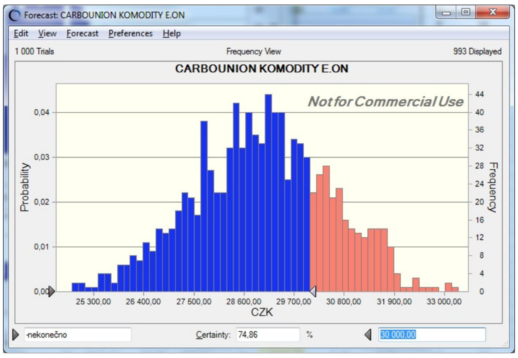


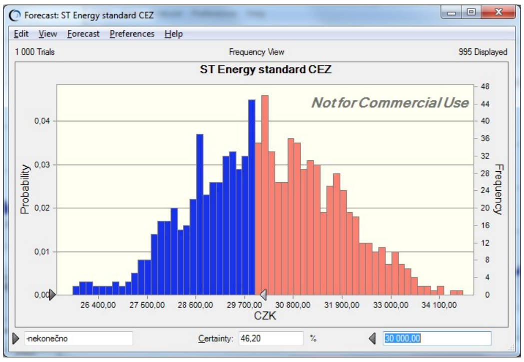
Figure 5: Histograms for the annual costs for the supplier CARBOUNION KOMODITY

As all the annual average costs oscillate around 30000 CZK, we have dealt with the probabilities that the annual costs will be lower than 30000 CZK. For the best products this probability is around 74-76% (region PRE, ST Energy; region E.ON CARBOUNION KOMODITY – Fig. 6), but only around 44% in CEZ area (Fig. 7). The worst products have this probability close to zero (Fig. 8) so there is very small chance to have the household annual electricity consumption costs lower than 30000 CZK (for D25d tariff rate with the selected circuit breaker, consumption around 9-10 MWh annually with 45% consumption in high tariff).



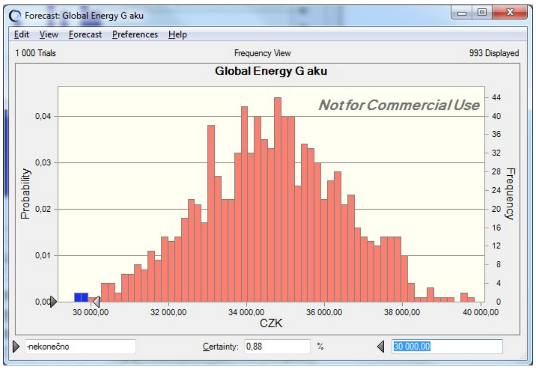
-nekonečno Certainty: 74,86 % 30 000,00

Figure 6: The probability of the annual costs lower than 30000 CZK – region E.ON, CARBOUNION KOMODITY



-nekonečno Certainty: 46,20 % 30 000,00

Figure 7: The probability of the annual costs lower than 30000 CZK – region CEZ, ST Energy



-nekonečno Certainty: 0,88 % 30 000,00

Figure 8: The probability of the annual costs lower than 30000 CZK – region E.ON, Global Energy G aku

When we compare the histograms of the best and worse products we can see the difference between the annual costs (Fig. 10).

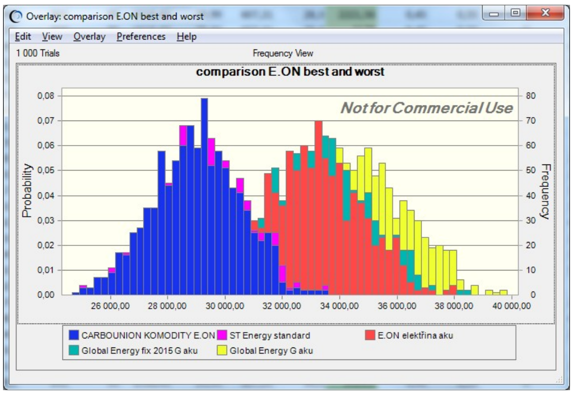


Figure 10: Comparison of the best and worst products – region E.ON

5. CONCLUSION

The situation on the electricity retail market in the Czech Republic is not clear because of the number of suppliers and its products. The formula of the annual cost calculation of the electricity consumption contains a lot of factors and so it is hard for the household to compare the costs and to choose the cheapest product. For all products the cheapest distributor is PRE. Monte Carlo simulation of the electricity consumption can be used as a good tool to compare the prices of the products as it covers the variability in the electricity consumption. Our analysis has showed that there are the big differences in annual cost for the electricity consumption and all suppliers in CEZ region have higher prices than in other regions. The selection of the cheapest product can save about 20% of the annual electricity consumption costs on average. The next research will be aimed at the optimization models minimizing the annual costs when looking for the limits of the annual consumption for each supplier and also at the comparison of other tariff rates.

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MODELLING THE EFFECT OF INDIVIDUAL DIFFERENCES IN PUNISHMENT SENSITIVITY ON BEHAVIOUR IN A PUBLIC GOODS GAME

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ABSTRACT

Previous research on social dilemmas demonstrated that various forms of punishment for free-riding can increase contribution levels in public goods games. The way individual group members react to the possibility of punishment can be also affected by individual differences in punishment sensitivity. Therefore, depending individual differences in punishment sensitivity of group members, different levels of punishment can be more or less effective to prevent free riding behaviour. This paper uses agent-based modelling to model the effect of punishment sensitivity on contribution levels in a public goods game. The paper then examines the correlation between punishment sensitivity and variability of free riding behaviour under different punishment conditions.

Keywords: agent-based modelling and simulation, behavioural game theory, public goods game, punishment

1. INTRODUCTION

Public Goods (PG) game is a standard experimental economics approach to study human cooperation. In this game each player faces a dilemma: to invest into PG and potentially get a higher return through cooperation in the future; or keep their endowment which essentially means free riding on other people's contributions. A standard finding using this paradigm is that there is variability in behaviour: some individuals cooperate while others free-ride (Fehr & Gächter 2002; Fischbacher et al. 2001). Since cooperation is a fundamental feature of human society, it is important to understand why people choose to free-ride, and what factors can decrease levels of free-riding. One mechanism to promote cooperation is monetary punishment for free riding. Previous research demonstrated that the way people are affected by the punishment in the PG game differs between individuals and the differences are explained by trait punishment sensitivity (Skatova & Ferguson 2013). In their experiment, participants played a series of standard PG game with varying punishment conditions. Individual punishment sensitivity of participants was assessed through Behavioural Inhibition Scale (BIS, Carver & White 1994). The results demonstrated that participants contribute more under threats of punishment compared to no threat of punishment, and that people with higher punishment sensitivity provide higher contributions (free ride less) even when punishment is not certain. This research suggests that varying probability of punishment could affect contribution levels of groups depending on individuals' levels of punishment sensitivity. However, the lab-based design of experiment with real participants limits opportunities to test how different levels of punishment threat in combination with different levels of sensitivity to punishment of group members, affects contribution levels of different groups. Current paper aims to fill this gap by modelling an experimental game using agent-based modelling and simulation. This will allow to capture group dynamic through varying parameters of punishment and sensitivity to punishment in a series of artificial experiments.

2. BACKGROUND

2.1. Public Goods Game and Punishment

In experimental economic, a laboratory PG experiment consists many participants, which are matched into groups (usually of four people). They will have an endowment of Money Unit (MUs) which they can keep for themselves or invest into a public account. The invested money is multiplied and distributed equally to all group members. This creates a dilemma: by investing something into PG, the player loses this money from their private account but potentially gains from future profits from public account. However, if the player contributed more than others, they will be worse off in the end, as the profits are distributed equally. Those who contribute less than there group members, therefore, free ride on the public good. Many researches attempted to explain the reason behind free-riding and how to maintain cooperation. One of the central mechanisms to sustain punishment in large groups is punishment. For example, Guillen et al. (2007) showed that central authority punishment increases the contribution comparing to the standard game.

2.2. Agent-based Modelling and Simulation

Agent-based Modelling and Simulation (ABMS) is a methodology that has been utilised recently by social scientists and economists to model social system. ABMS is individual-centric and decentralized approach, in which a system is modelled using fine-grained models with attention to dynamics. In economics, economies are complex dynamic systems, which are composed of many interacting units (individuals, organizations) and exhibit emergent properties. With ABMS, economic systems can be modelled from the bottom up, considering the global behaviours rooted in the local interactions (Tesfatsion 2006).

Agent-based Modelling and Simulation is suitable to model the PG game experiment, because the experiment is a human-centric system and an agent represents a human very well. An agent, same as a human, is heterogeneous (with its own goals, behaviours), autonomous (can adapt and modify their behaviour), and proactive (adjust action depending on internal state) (Wooldridge & Jennings 1995).

3. METHODOLOGY

3.1. The public goods game

The simulated game will be in the same format as the experiment of Skatova & Ferguson (2013). The game comprised four blocks with punishment conditions in the following order:

1. A non-punishment block (standard PG game)
2. A implemented punishment block
3. A non-implemented punishment block
4. A non-punishment block

Each block consisted of 10 trials (rounds). After each trial, participants were shuffled and put into group of four players they did not play before with. Each participant received the initial endowment of 20 MUs, which could be divided to the private and public account. After everyone made their investment decision, the payoff then calculated based on the following function:

$$\pi_i = 20 - g_i + 0.5 \sum_{j=1}^{4} g_j \qquad (1)$$

Where a pay-off (π) for a participant i is defined by their contribution (g) and the sum of contributions of other players in the group.

After the first block of a standard PG game, participants received additional instructions for the next three blocks, which introduced a punishment rule. In the non-implemented punishment block, the punishment never occurred. In the implemented punishment block, the punishment actually occurred in two out of 10 trials.

3.2. The agent-based model

The agent-based model is implemented in AnyLogic 7, (XJ Technologies 2015), a multi-method simulation modelling tool. In the model, agents representing the participants played a series of one-shot PG games with three different conditions: non-punishment, implemented and non-implemented punishment.

There were two types of agents: Main and Person. There was one Main agent, which acted as a game master, controled the game stage, and let Person agents know about the stage, and punishment condition of the game. There could be many Person agents, which represented the participants in the game. At the beginning of each game, each Person agent was assigned to a Group, which was implemented using a Java class. Group object managed the contribution and punishment of the group.

The behaviour of agents was modelled using statechart. Statechart diagrams described different states of an agent and the transitions between them, and could be used to visualize and model the reaction of agents by internal or external factors. The use of statechart to model agent behaviour is described in the sections 3.2.2 and 3.2.3.

3.2.1. Strategies of Person agents

For every Person, there was a variable: *Punishment_Sensitivity*, which represented punishment sensitivity value measured by BIS-anxiety score, a subscale of BIS (Skatova & Ferguson, 2013). *Punishment_Sensitivity* ranged from 1 to 4. Based on Skatova & Ferguson's work, there were differences in behaviours of people with high and low punishment sensitivity. Accordingly, we categorized Person agents based on its *Punishment_Sensitivity* variable. The agent were categorized as "high-anxiety" if *Punishment_Sensitivity* of a Person agent was greater than 3.13. Person agents with *Punishment_Sensitivity* less than 3.13 were "low-anxiety". People with different anxiety had the tendency to use different strategies. There were five available strategies for Person agents:

1. **Full Cooperation (FC)**: always contributed 20 MUs.
2. **Strong Conditional Cooperation (SCC)**: contributed 3-4 MUs more than average group investment in previous round.
3. **Normal Conditional Cooperation (NCC)**: contributed the same or difference of 1 MU with average group investment in previous round.
4. **Weak Conditional Cooperation (WCC)**: contributed 3-4 MUs less than average group investment in previous round.
5. **Full Defection (FD)**: always contributed 0 MU.

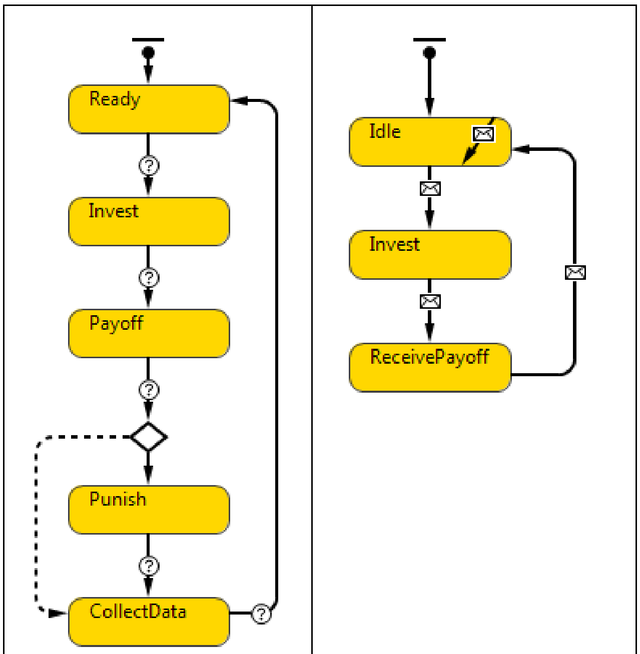
High-anxiety agents tended to contribute more; while low-anxiety agents tended to contribute less. Therefore, at the beginning, each Person agent was assigned with a strategy and a *Punishment_Sensitivity* value following the distribution in Table 1.

Table 1: Person agent initialization

Percentage of agents	**Strategy**	**Anxiety**
5%	FC	100% High
20%	SCC	80% High, 20% Low
50%	NCC	50% High, 50% Low
15%	WCC	20% High, 80% Low
10%	FD	100% Low

3.2.2. Modelling game play

The Main agent and Person agents used two statecharts (Figure 1) to coordinate and play the game. The game had several stages such as invest, payoff, punish. Each stage of the game was represented by a state in statechart of the Main agent. Based on the current state of the statechart, the Main agent sent messages to all Person agents to inform the current stage of the game. Based on the received message, the Person agents also made transition to the corresponding state.



(a) Main agent (b) Person agent

Figure 1: Gameplay statecharts of Main agent and Person agent

At the beginning, when in "Ready" state, the Main agent prepared for the game by setting up variables, shuffling Person agents, and assigning them to groups. Then the Main agent changed state to "Invest", in which messages were sent to all Person agents. Person agents were in "Idle" state would change to "Invest" state when they received the message, and made a decision on how much to invest based on their strategy. After all Person agents made investment decision, the Main agent went to "Payoff" state and sent messages to all Person agents. The Person agents changed to "ReceivePayoff" and asked the Group object to calculate the payoff and the average investment of the group. After receiving payoff, Person agents went to "Idle" state. In the Main agents, if punishment was implemented during that game round, Person agents went to "Punish" state, and sent messages to Person agents. There was a self-transition in "Idle" state of Person agents, which was triggered when they received message about punishment. When triggered, Person agents asked Group object whether they got punished. If punishment was not implemented, Main agent changed state from "Payoff" to "CollectData", and then went back to "Ready" state.

3.2.3. Modelling individual differences in punishment sensitivity

A representation of Punishment Sensitivity was implemented in each Person agent to represent individual differences related to BIS-anxiety value. People with higher punishment sensitivity would be more cautious and avoid free-riding behaviour in response to signals of punishment. In addition, people were only cautious for a period of time and then they forget about punihsment. Therefore, the agents were contributing more when there was threat of punishment, and only being cautious for several rounds after. The behaviours were modelled with a statechart (Figure 2), which had two states: "Normal" and "Cautious". The state change was controlled by two transitions:

- From "Normal" to "Cautious": This transition was triggered if (the agent was high-anxiety AND there was threat of punishment AND the agent had not been in cautious state) OR (the agent got punished).
- From "Cautious" to "Normal": This transition was triggered if (there was no threat of punishment) OR (a low-anxiety agent had been in "Cautious" state for 3 rounds) OR (a high-anxiety agent had been in "Cautious" state for 10 rounds).

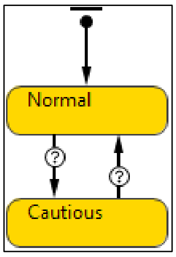
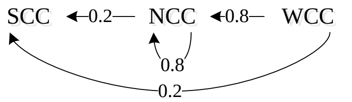
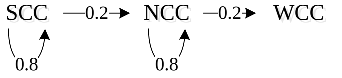
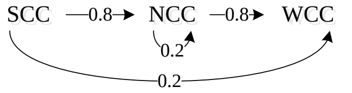


Figure 2: Punishment Sensitivity statechart of Person agent

Table 2: Strategy change of Conditional Cooperators

High Anxiety	
Normal to Cautious	
Cautious to Normal	
Low Anxiety	
Normal to Cautious	
Cautious to Normal	

When a Person agent changed state, the strategy of that agent would also be changed as well. The high-anxiety agent using FC strategy did not change strategy. The low-anxiety agent using FD strategy would change to WCC strategy when changing to "Cautious" state, and change back to FD strategy when changing to "Normal" state. For the agent who was using conditional cooperation strategies (SCC, NCC and WCC), the strategy change followed as described in the Table 2. When changing to "Cautious" state, agents would avoid free riding and stop using WCC strategy. Because agents with high anxiety contribute more under threat of punishment, when agents changed to "Cautious" state, high-anxiety agents were more likely to change to SCC than low-anxiety ones. For example, in the first graph of Table 2, 80% of high-anxiety agents using WCC strategy changed to NCC strategy, and the rest (20%) changed to SCC strategy. When agents changed to the "Normal" state, low-anxiety agents were more likely to use WCC strategy than the high-anxiety ones.

4. EXPERIMENTS AND RESULTS

4.1. Validation Experiment

In this experiment, the model was set up with the similar settings to Skatova & Ferguson (2013) to validate the simulation results and examine whether the model replicates the contribution level over different blocks as well as the correlation between punishment sensitivity and free riding behaviour of a real experiment. The simulation was set up with 1000 Person agents, initialized with different punishment sensitivity value and strategy based on Table 1. Person agents played four blocks (10 trials each block):

1. A non-punishment block
2. A implemented punishment block
3. A non-implemented punishment block
4. A non-punishment block

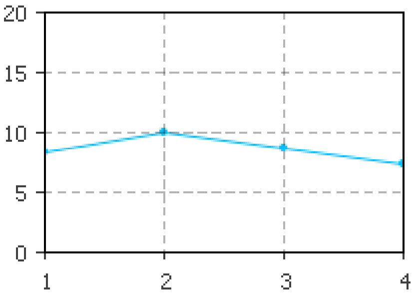


Figure 3: Average investment over four blocks

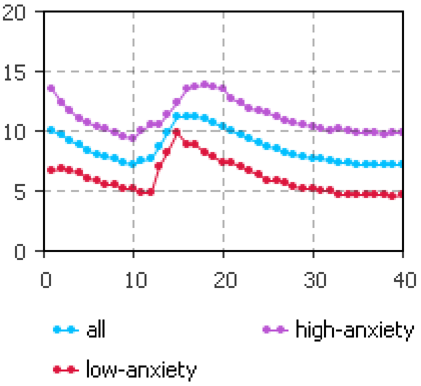


Figure 4: Average investment over 40 trials

Only the Main agent knew about the punishment conditions of the blocks. The Main agent just informed Person agents that there would be a threat of punishment in the second and third block. In the implemented punishment block, punishment was implemented in two out of ten trials.

The average group investments over four blocks, showed in Figure 3, replicated the trend in Skatova & Ferguson laboratory experiment. The average investment in the first block of standard PGG was 8.25. In the second block where punishment was implemented in two out of ten trials, the group investment increased to 9.77. In the third block where the punishment was expected but not implemented, the group investment decreased to 8.64. In the last block of standard PGG, the group investment dropped to 7.34.

In the second block of this particular experiment, the punishment was implemented at block 12 and 14. Figure 4 shows that the average investment had a sharp rise after block 12 and 14. In those two trials, it appeared that free-riding agents, especially low-anxiety agents, got punished, switched to more cooperative strategies, and contributed more in the next ground. If this was a lab experiment, we would not be able to investigate much further. But since we used an agent-based model, we could analyse the decision making process of agents better.

Figure 5 shows the states of punishment sensitivity statechart of all agents. In the first 10 rounds, all agents were in "Normal" state. When there was a threat of punishment, high-anxiety agents changed to "Cautious" state. In block 12 and 14, when the punishment was implemented, free-riding agents got punished and changed to “Cautious” state. The more agents were in “Cautions” state, the more contribution there was overall. The strategy change of conditional cooperators, who were the majority, played a crucial role to the contribution in the system. Figure 6 and 7 shows the strategy change of high and low anxiety agents. High-anxiety agents changed to more cooperative strategy when there was a threat of punishment then changed the strategy again after being cautious for 10 rounds. Low-anxiety agents still used the same strategy even when there was a threat of punishment. They only changed when punishment was implemented (trial 12 and 14): the more agents used SCC, the less agents used WCC. After 3 rounds of being cautious, low-anxiety agents changed back to Normal state, and used less cooperative strategies.

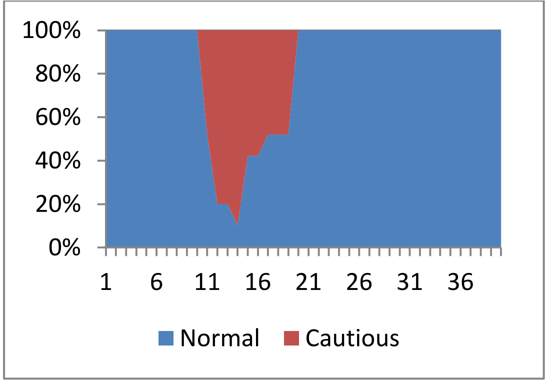


Figure 5: Agent states of punishment sensitivity statechart

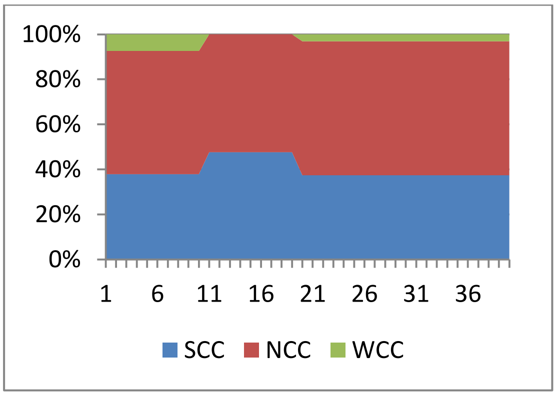


Figure 6: Strategy of high-anxiety agents

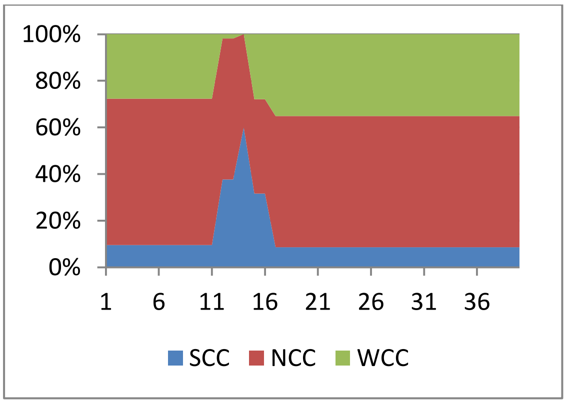


Figure 7: Strategy of low-anxiety agents

4.2. Experiments with different Punishment Conditions

One of the applications of this model is to use it for examination of the contribution levels under different levels of punishment. In this experiment, the model was set up with the same ratio of agents but under different punishment conditions. We then analysed the simulation results to understand more about free-riding behaviours in various punishment conditions.

Figure 8 shows an experiment where in every trial punishment was expected but only implemented periodically. If the punishment was implemented every trial, the contribution level increased gradually before stabilizing. The same trend occurred for implemented punishment every 3 trials, but the contribution level was lower. If the punishment was implemented every 5, 10 or 15 trials, the contribution levels oscillate, which meant contributions decreased over time and only increased in trials with implemented punishment. The greater the period between two implemented punishment trials, the lower was the contribution level.

Figure 9 and 10 show another experiment in which agents played in a series of non-punishment blocks of PG games, and the implemented punishment blocks occurred periodically. In the implemented punishment blocks of Figure 9, randomly on *two out of ten trials* individuals were punished. While in Figure 10, randomly on *five out of ten trials* punishment was implemented. The contribution level decreased and for certain number of trials became stable, to only increase when punishment was implemented. Comparing between Figure 9 and 10, the contribution level (overall as well as the peaks) was higher in Figure 10. This was because there were more trials where punishment was implemented in Figure 10 than in Figure 9.

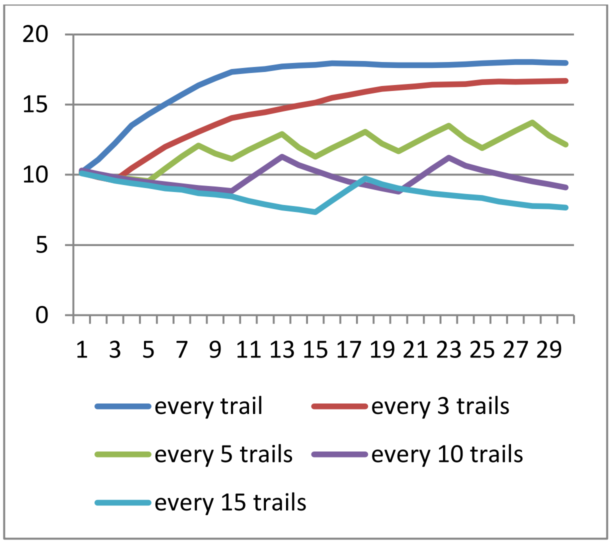


Figure 8: Punishment was periodically implemented on trials in an expected punishment condition

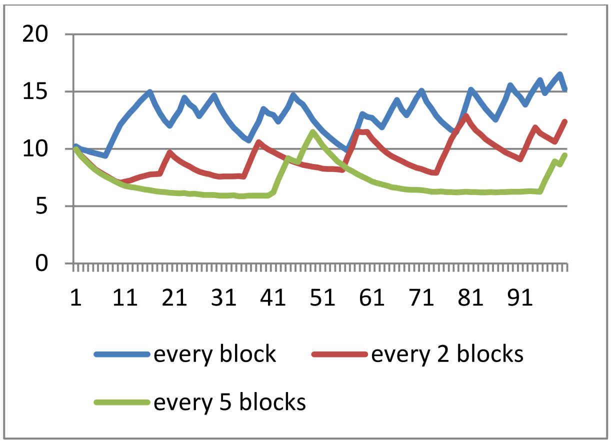


Figure 9: Punishment was periodically implemented in a block with *two out of ten* punishment games per block

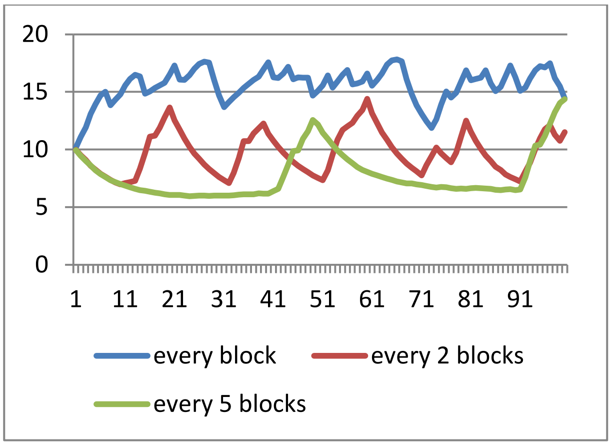


Figure 10: Punishment was periodically implemented in a block with *five out of ten* punishment games per block

The above experiments showed that contribution levels had different dynamic in different punishment conditions. Using the agent-based models as a decision support tools, policy maker could be able to decide on how to implement punishment in order to achieve a desired pattern of contributions in the real world public good scenario.

4.3. Experiments with different ratios of strategy

In this experiments, we investigated how the ratios of strategy used by agents are affected the total investment of four blocks. Figure 11 shows the results of six experiments. The total percentages of five strategies (FD, SCC, NCC, WCC, FD) were 100%. In all the experiments, the percentage of FC was fixed to 5%. There were three experiments with 10% of FD (solid line), and three experiments with 30% of FD (dotted line). So in each experiment, the percentages of FC, FD, and SCC were fixed, then percentage of NCC was varied from 0% to 100%, and the rest would be percentage of WCC. The percentage of NCC was represented by the x-axis, while the total invesment was represented by the y-axis. For example, the red solid line had 5% FC, 10% FD, 20% SCC; and as the percentage of NCC increased, the total investment increased as well.

How the ratios of strategy affect the total investment can be concluded by comparing between these experiments:

- Looking at one experiment, we noted the larger the percentage of NCC was, the more investment there was into PG.
- Comparing between the blue, red, green line, we saw that the larger the percentage of SCC was, the more investment there was into PG.
- Lastly, comparing between the solid line (FD 10%) and dotted line (FD 30%), the smaller the percentage FD was, the more investment there was into PG.
- With FD of 10%, the increase in percengate of SCC (from 0% to 20% to 50%) resulted in bigger raise of total invesment comparing with FD of 30%.

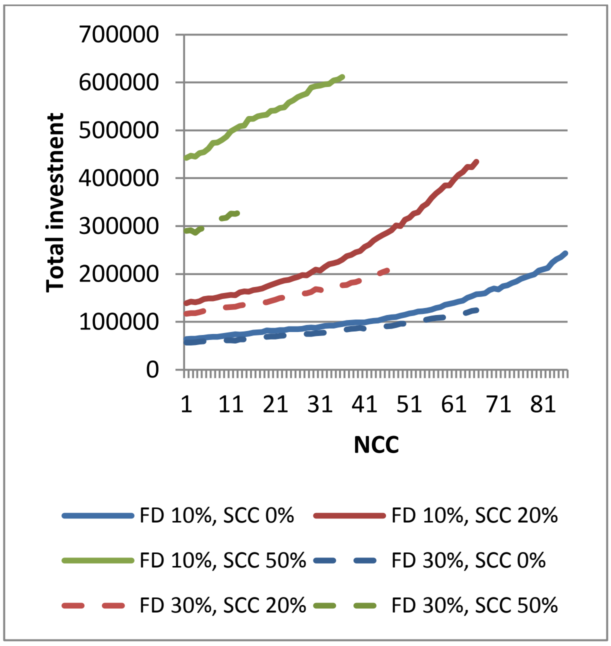


Figure 11: Total investment in different ratios of strategy

Table 3: Experiments with different ratios of anxiety

Strategy	Anxiety		
	Exp. 1 (baseline)	**Exp. 2**	**Exp. 3**
FC	100% High	100% High	100% High
SCC	80% High, 20% Low	*80% High,* *20% Low*	*20% High,* *80% Low*
NCC	50% High, 50% Low	*80% High,* *20% Low*	*20% High,* *80% Low*
WCC	20% High, 80% Low	*80% High,* *20% Low*	*20% High,* *80% Low*
FD	100% Low	100% Low	100% Low

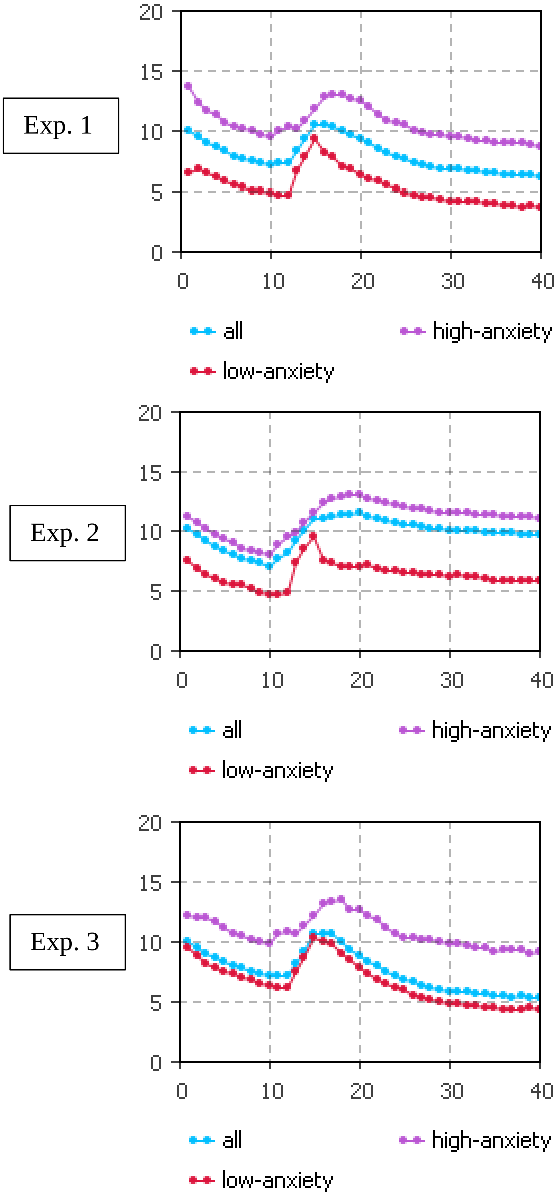


Figure 12: Investment over time in different ratios of anxiety

4.4. Experiments with different ratios of anxiety

The final experiments were to change the ratios of anxiety and examined the investment over time. Using the experiment in section 4.1 as the baseline, two more experiments were set up by changing the ratios of high and low anxiety of conditional cooperators (CSS, NCC, WCC). In the second experiment, 80% of conditional cooperators were high anxiety and 20% were low anxiety. In the third experiment, 20% of conditional cooperators were high anxiety and 80% were low anxiety. Table 3 shows the three experiments and corresponding percentages of anxiety levels.

The results of three experiments are shown in Figure 12. In the first block (first 10 trails) the investment trend was the same for the three experiments. This is because the investment in the standard PG game is only affected by the ratio of strategies used by agents, not by their anxiety.

For the last three blocks:

- In the second experiment, because there were more high-anxiety agents, the investment was increasing faster than the first experiment, and became stable at higher value.
- In the third experiment, because there were more low-anxiety agents, the investment was increasing to approximate the same value of the first experiment, but became stable at lower value.

5. CONCLUSION AND FUTURE WORK

Using agent-based modelling and simulation, this paper has modelled the effects of individual differences in punishment sensitivity in a Public Good Game. The simulation has validated the behaviours which observed in Skatova & Ferguson laboratory experiment. This agent-based model can be used as a decision support tool for policy makers to examine the free riding behaviours in varying punishment conditions in a real world scenario which resembles a public goods game (e.g., recycling, littering, energy use at home, etc).

This paper also demonstrated that agent-based modelling and simulation can be used to investigate different aspects of human decision-making which do not integrate with traditional economic models of behaviour. Researchers have been trying to extend the traditional approach by integrating other sciences (such as psychology and neuroscience) to add more layers into human decision-making models. Theoretical models can be validated by using the approach developed in this paper. Modeller can build an agent-based model in which the overall decision making process of agent is affected by the combination of many decision-making factors derived from models in different disciplines.

In future research, classification techniques can be used for analysing the change in the strategy of participants in the laboratory experiment with different punishment conditions, and developing a method to capture the change in contribution levels. It is also interesting to collect more data on the interaction between strategies and anxiety of people from different demographic groups.

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VIRTUAL PANEL SYSTEM WITH TACTILE FEEDBACK

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ABSTRACT:

This paper presents the work with the purpose of developing a search for creating a simulation and training system for the operation of control panels in various sectors of industrial sphere, having as main features the use of an immersive and interactive Virtual Reality system through the use of display equipment and a tactile feedback system composed of actual control devices.

The study also suggests the use of a numerical control system for controlling the movements of the tactile system in order to allow greater flexibility in the simulation, enabling the panels virtual training varied by modifying the system in accordance with the training needs.

Keywords: Virtual Reality, Tactile System, Augmented Reality, Simulation and Training.

1- INTRODUCTION:

Industrial activities, even the small-scale production, generally involve production processes with high costs and high operating precision levels, and very high risks of accidents. An example is the operating temperature control panels of industrial boilers, the auto industry panels, operations control panels in ports, hydroelectric plants panels, nuclear power plants, petrochemical plants, etc. Nevertheless many trainings are conducted in a theoretical way, a process which, although it represents gain, can be considered fragile and incomplete (Navarro, V et al 2009). These characteristics indicate the need for a well trained and skilled labor, creating the demand for training to provide a high quality learning.

Training is planned effort of an organization to facilitate the learning of behaviors required for the work (Lacerda and Abaad 2003), using training systems with a virtual simulation allows the learning of specific activities of operation and also has advantages such as do not interrupt the industrial activities and ensure safety to this learning, because it allows work on a fully controllable environment, and the flexibility to simulate different activities.

In many cases the virtual resources currently used in training are geared to experts and users - lay in many cases - expend a lot of time to learn the tools (Grave, L et al 2001). In this context the opportunity to create a realistic and interactive training environment, through visual immersion and even the tactile feel, is a more intuitive learning process where the user can absorb knowledge in an easily and directly way, looking at a very close activity with the real work situation. Furthermore, the use of a virtual simulation has the advantage of not interrupting the industrial activities and ensure safe training, because allows working in a fully controllable environment and flexibility to simulate different activities.

Advances in training systems, in addition to assist in the improvement of work processes and the current professionals, also allow the formation of new better skilled workers to enter the labor market.

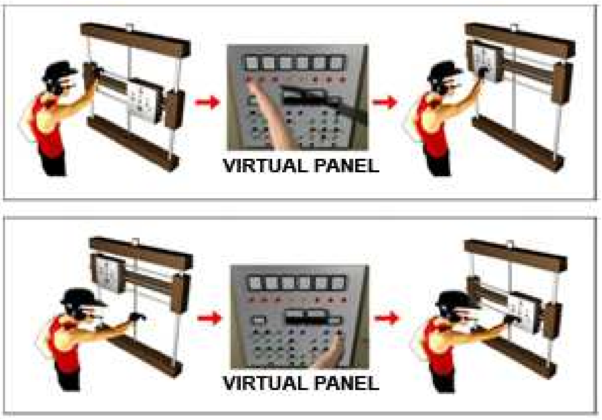
2- THE PURPOSE:

Develop a simulation system able to provide a tactile response with low cost of implementation, using techniques of virtual reality and augmented reality combined with a positioning system controlled by computer(CNC) to simulate different industrial control panels with order to provide training and education to professionals of this field of activity. It is also proposed to present possible solutions and resources incorporated into the system to ensure greater immersion and better interaction, enabling the use of a virtual environment with a high level simulation of reality.

3- PROJECT CONCEPT:

The degree of a user's interaction within a virtual environment depends on the class of the virtual reality system used, as well as devices used (De Mello 2009). In this way the project was conceived in order to develop a simulation system that allows greater reality in control panels operation. For both defined, besides the use of a virtual environment, the use also of a low cost tactile response - which allows the operator the feeling of touching the panel, and also a computer-controlled drive system (CNC) - which allows the displacement of the tactile system as the simulation, enabling a wide variety of simulated panels, and also the use of an immersive display device (Picture 01). The methodological process of project design started from identification of project needs and research relating to its individual parts. The components of the proposed system were as follows:

. Interactive virtual environment;
. The tracking and interaction system;
. The tactile system;
. The CNC system;
. The immersion.



Picutre 01-The elements and the operation of the system

3.1- The virtual and interactive Environment:

The features indicated the need to use an interactive virtual environment that allows the tracking position, locating with some precision real and virtual objects, and the integration of some devices and features such as tactile CNC system, camera, viewing glasses and Augmented Reality resources. For the production of the virtual environment the following steps were followed: three-dimensional modeling and construction of the interactive environment.

3.1.1- The 3d modeling:

The construction of the virtual environment was initiated by the construction of a digital model that can simulate with good reality a comand panel of industrial activities. The model was based on a generic control panel with simple functions and controls, but the proposed system allows the flexibility to create simulations with different panels, that is, you can use 3d models in different ways by modifying system settings for different simulations.

To produce the digital model can be used any kind of CAD software that can generate a 3d mesh file having the ability to export the template for insertion in other applications to create an interactive virtual environment.

3.1.2- The Virtual Environment and the Augmented Reality:

Following the aim of developing a high-fidelity simulation project we were oriented interaction in first person. As an experiment in 1st person can consider situations where the user knows the virtual world through interacting directly with it, featuring a direct learning, subjective and often unconscious (Botega and Cruvinel 2009).

For this purpose at this step was necessary to use a software which, besides being able to produce an interactive scenario, could also incorporate augmented reality resources, and also could enable integration with other devices and software. In this way it was possible to generate an integrated simulation system where the devices and system interfaces communicate directly with the simulated environment. For this we used a software able to incorporate into your own environment other applications designed specifically for the job, as the system that transmits the user tracking data to the control system of the movement of the tactile system.

Application of Augmented Reality at work consisted not only in the use of its typical features for referencing the virtual images within the scene through the optical tracking camera and fiducial markers, but also in the use of these resources as tracking system of movement of the user and also as an important part of the motion system control of the touch system developed, so the augmented reality resources have been used as part of various system elements, being adapted to create a virtual reality system of simulation and training.

Therefore the interactive virtual environment production process was conducted in two stages: the import of 3D model and the introduction of other elements, such as fiducial tracking system and the external application developed to control the CNC system.

3.2- Tracking and interaction:

The function of tracking systems is to define the position and orientation of the virtual objects should be placed in relation to the actual scene. Therefore, it is necessary to relate the coordinates of virtual objects with the real scene (Silva 2006).

Motion tracking systems can be configured through several capture techniques, among them we can highlight the sitemas magnetic, optical, inertial, mechanical and acoustic (Ramon 2007).

For the study we used an optical system of low cost, designed from the use of Augmented Reality features built to work.It used a software which already has these features embedded in their work environment, which provided the direct use of a tracking system consists of the capture camera and the fiducial markers, without the need to use programming tools for the implementation of reference system between the real and the virtual scene.

The fiducial marker is a visual reference captured by the camera, through it the virtual 3D object is positioned relative to the scene, considering their perspective and creating a system that inserts the virtual model in the scene in real time.

This tracking system was used in this work for inserting the virtual panel, fixing its position relative to the user, and also for referencing the user interaction avatar. Furthermore, the markers were also used in adapted form to send commands to the CNC system, connecting the AR system with the tracking system of the user hand position.

The solution to the use of this system was the interpretation markers as tracking devices, taking his position captured in real time by camera and interpreted by the system. For that was set a marker in the user's hand with the dual function of positioning the avatar in the virtual environment and have captured, in real time, its position during the simulation, through the camera. This placement is transferred in real time to the CNC system for positioning the tactile system by using a second marker attached to this system, that is the device mounted near real-time two marker coordinates, with the second marker always following the the user's hand.

3.3- The tactile System:

Virtual reality is, above all, an advanced user interface for accessing applications running on the computer, with the features to view and movement in three-dimensional environments in real time and interaction with elements of that environment, and may be characterized by stimulation of other senses such as touch and hearing (Tori, R et al 2006). So the use of a tactile system is intended to increase the sense of immersion and therefore the system simulation quality. Nevertheless systems that allow the tactile sensation are uncommon in simulations, in general this is due to the high market value they have. In the work the proposal was to use a real panel commands to create a tactile response with low cost of implementation, as actual buttons operation would be able to provide to the user the perfect sense of feel for the simulation. For this purpose would suffice combinations of these actual commands using a system that limits the visual perception of the virtual environment to the user.

The assembly of a panel with various buttons limit the system to certain types of control panels. From this problem occurred the need for greater flexibility to the system, enabling a greater variety of panel configurations, adapting its shape and size according to the needs of the simulation. The solution was to use a system that can move a group of real buttons (touch system) to track user's hand movement through a system of coordinates, the CNC system. The use of this technique permitted the flexibility of the system to adapt to a great variety of control panels, modifying the virtual environment according to the specific needs of each training.

3.4- The CNC System:

The technology CNC (Computer Numeric Control) started in the 50s, it was many years limited to large companies and became popular from the 90s (Fagali and Coelho 2003). Even today the most advanced features of this technology are used in greater quantities by large industries, however, with the spread of this system, you can find small machines being used widely in smaller items productions, and you can build them with low cost and simpler production processes.

Based on the research on CNC technology work was directed to the development of a small system. From the search and definition of the available resources has been developed a low-cost CNC machine prototype, adapted to the characteristics of this work. Taking advantage of some elements of a "traditional" setting for this type of machine, including the structure, mechanical and electronics system, the prototype was assembled. Moreover, it was dispensed using the third axis of motion, using only two axes of displacement. Thus the information found about the production of CNC systems have been adapted to the characteristics of the job. To this set was coupled the tactile system.

It is noteworthy that for the design of the prototype were analyzed the basic needs of the project and defined solutions with lower cost and ease of acquisition and implementation. This process involved from the determination of materials and processes used for the production of the structure, the setting of the mechanical system easier acquisition and the specification of the motors used. Defined solutions are not configured as definitive, being able to change them as needed, or you can create similar systems with higher capacities depending on the project needs.

Besides the construction of CNC set would require a solution to connect this system to trace, it was necessary that the tactile system accompany the user's hand movement and position itself as the virtual environment. To that end, it developed an application that works inside the software environment used to generate the virtual scenario. This was possible because the software used, as previously mentioned, has the capacity to extend its capabilities by incorporating external applications produced with a particular programming language. This feature allowed the creation of an extension application that interprets the coordinates of the markers and sends them to the CNC system to position the tactile system. So, the coordinates of the tracking system are utilized as reference for the positioning system, converting them into commands that are passed on to the electronic control of the CNC system, which orders the movements of the mechanical system. So you can position the tactile system as the user's hand moves during the interaction with the virtual environment.

3.4- The Immersion:

The purpose of providing to the user an immersive sensory experience in an artificial environment largely depends on the hardware used, it is through it that influences his senses (Cruz, M et al 2005). The need for complete visual immersion was the determining factor in defining the use of a display device as the Hmd type. Using this feature allows the users to a maximum level of immersion by limiting the visual field to the generated images from the virtual environment, allowing the experience to realize in real-time the environment which they interact from his own point of view and not an external point as in the case of using a common display screen. In the case of virtual panel system with tactile feedback, the user only sees the virtual representative panel of the panel to be simulated and your avatar, realizing the moves in a direct way through their own movement.

HMD used in the proposed system was adapted settling it a capture camera. It is through this camera that the virtual scene is positioned in relation to actual scene, locating the user and the tactile system CNC. The need of the camera is directly related to the use of AR resources and the tracking system employees and already mentioned.

3.5- The final configuration of the system:

The system was set with five basic elements:

. The interactive virtual environment where you can view the virtual panel and interacting with an avatar;

. The motion tracking system, which allows the user direct interaction creating a reference between the real and the virtual scene;

. The tactile system which consists of a panel with actual commands of an operation panel;

. The CNC system, using the user's hand tracking system information, positions the tactile system;

. The immersive system composed of the display device.

4- SYSTEM IMPLEMENTATION:

After all the system design were carried out the assembly of parts and testd to the implementation and validation, in which it was possible to observe the operation of the parties and the final integration of the full set.

The tests were as follows:

. Augmented Reality Test
. CNC system test
. AR and CNC integration tests
. Initial tests of interaction
. Final test

4.1- Augmented Reality Test:

The main objective of this test was to implement the features of Augmented Reality employees and analyze their behavior. In this initial test it was possible to realize the operation of the marker system and the characteristics of the software environment and AR tools.

The results showed a relative simplicity of operation of these features because the tools used allowed flexibility in the augmented reality implementation process, enabling the placement of 3D objects as the scene, including the two markers action, which would be indispensable for use that system for tracking the user's movements and positioning of the tactile system through numerical control (CNC).

The system responded as expected. Because the difficulties have not gone beyond the expected for this type of tool. The instability in the positioning of virtual objects, which sometimes lost the reference and out of the correct position was a difficulty found. The tests indicated that this problem is associated with the marker image occlusions, capture camera shake or by the possibility of confusion over the marker reference, that is the software sometimes confuses the position and direction of the captured image, reversing the position of the virtual object. All these options are considered characteristics common to the tracking system used. This type of problem can be reduced by using larger markers, increasing its area within the captured image.

4.2- CNC System Test:

The test consisted on an initial set of resources employed in order to control the mechanical assembly by the electronics assembly, performing the vertical and horizontal movements in the two axes by commands on a computer keyboard.

The first results demonstrated a lower speed than necessary for the training system, suggesting a review of the mechanical system, using techniques that ensure greater speed in the movements. Were also carried out modifications to the command code of the electronic control software CNC system, which contributed to a considerable improvement in system speed.

Despite the speed reached by the prototype was not ideal, but still the tests proved the feasibility of constructing this type of control system. Because research to the assembly of the prototype demonstrated the possibility of incorporating different improvements depending on the requirements of the job. In other words, you can build the system with different techniques and devices, including their transmission to the mechanical assembly, different specifications of stepper motors, and even different electronic settings via software. These modifications are capable of providing a higher speed to the system according to its specifications.

4.3- AR and CNC integration tests:

They were carried out in the three steps listed below:

4.3.1- Testing the extra application for CNC:

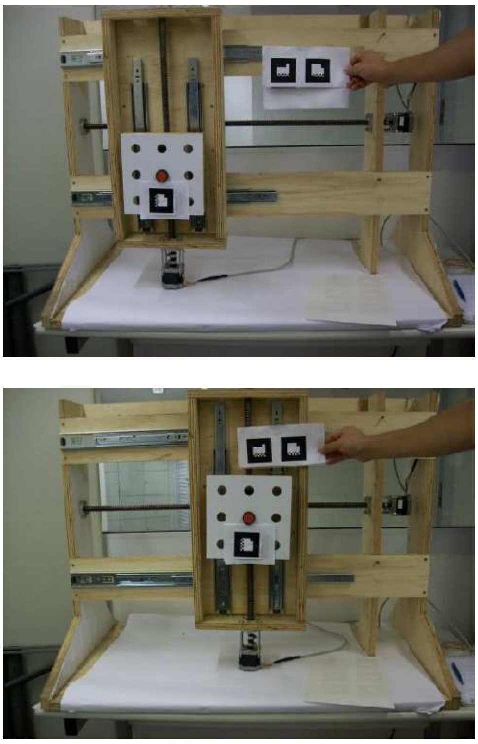
The incorporation of extra application developed for communication between CNC system and the interaction software development was tested. The purpose was to carry out an initial test using only keyboard commands. The work done was create commands within the interaction software development, through its specific programming language, to turn the keyboard commands on command interpreted by the electronic control software of CNC system. At this stage there was complete success, with complete control of movement through the use of the keyboard as the final result.

4.3.2- Testing the extra application by mouse:

In the next step, changing the code in the interaction software development, the keyboard movement controls were associated with the movement of the mouse, that is the mouse position coordinates were converted to commands sent through the serial communication the control board. Thus, it was carried out within the software development environment, programming with commands associating a limit of mouse performance space to a square visual reference, that is, within the area specified the movement of mouse was converted into command positioning system. This test step has been implemented with the purpose of preparation for next step and also showed a very good result, since the movements performed within the defined area were readily accompanied by the CNC tactile response panel.

4.3.2- Test with two markers:

In the last stage has been implemented using two markers, utilizing an initial marker, which provides the reference data, and a secondary one that tries to follow the first. That is, when the first marker is moved, the camera captures in real-time his position which is interpreted by the AR system, then the extra application incorporated in the system captures these coordinates and passes them to the CNC system that moves the second marker to the same position (Picture 02). The objective of this test was to evaluate the efficiency of this system to be implemented as tracking position, where the first marker would be set in the user's hand and the second set in the tactile system, which is associated with the CNC system drive.



Picture 02 - Tracking position

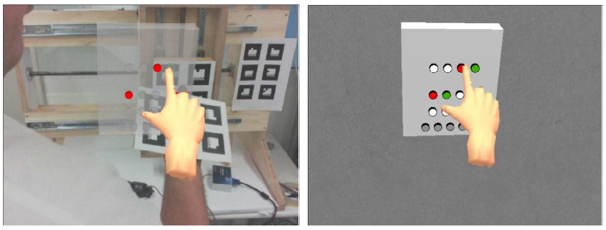
4.4- Inicial tests of interaction:

For the validation of the virtual panel system with tactile feedback was used an interaction system based on the use of an avatar that simulates the hand of the operator (Figure 03). That is, we used a digital model that represents the user's hand in the virtual environment. In this test the aim was to analyze the use of the marker system to position this avatar by checking the process of interaction with the real environment. For that was set a marker on the user's hand.

An important point to highlight regarding the use of fiducial markers is that in general there is a depth of reference problem as the virtual image is always inserted ahead of the actual image, that is real objects placed the lead appear behind the virtual image. In the case of this work this problem did not occur because there is no mix between real and virtual images, since the aim is that the user only sees the virtual scenario, utilizing an avatar to interact with it.

The results, as in previous tests also demonstrated the ease of implementation of marker system. The positioning of the avatar, as well as the connection to the user's movements, presented itself as a low-complexity task. This was due to the use of augmented reality tools for easy access and with the features to be made available ready for use.

The problems are also the same as the previous tests, low accuracy and occlusion problems, as mentioned, are common in the use of fiducial systems, and able to be amortized. As in the previous test is still possible to conclude that the system settings open possibilities for implementation of other types of devices for positioning the avatar depending on the required level simulation, but it is possible to conclude that for the work proposed devices used provided the enough to support the survey.



Picture 03 - The avatar and the Interactive and virtual environment

4.5- Final Test:

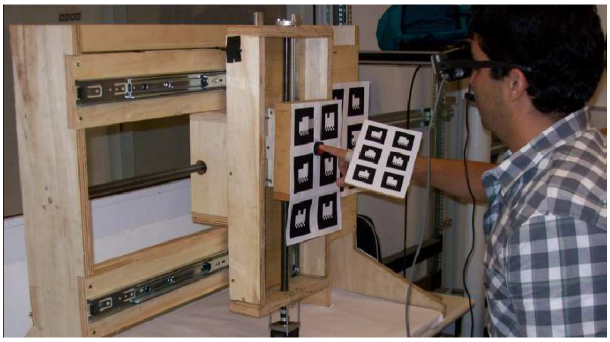
In the final test (Picture 04) the aim was to analyze the functioning of the complete set, integrating all elements of the system. They are: the virtual environment with AR devices implemented for tracking, tactile CNC system and the visual device, included in this final stage of testing.

For the visual device, as already mentioned, we used a Hmd equipment in order to provide greater immersion to the user, displaying only the images of the simulated environment for training. Coupled to the display system was used the capture camera, with which is performed the tracking of the markers. The use of this camera is also necessary to reference movements of the CNC system, and also to position the entire virtual environment, that is through the camera is still positioned the avatar and the virtual panel.

The results demonstrated as the greatest challenge positioning of the training objects, since the accuracy difficulties of using markers was multiplied when testing all elements simultaneously. Another factor that influenced the process was the establishment of capture camera on the user's head, for the camera steady movement hindered the setting position of the scene objects. Another difficulty was the small field of view of the camera used, because since it is a simulation where the object is very close to the user, it was difficult to frame in the picture the virtual objects and markers simultaneously.

Possible solutions to these problems are: the use of multiple reference markers for each object, the use of more than one camera - a movable for positioning the fixed virtual objects and other static to track the user's hand - and the use of a camera model with wider field of view.

Despite the difficulties encountered the tests demonstrated the feasibility of implementing a low-cost training system, integrating the different features and techniques employed at work.



Picture 04 - The final test

5- CONCLUSIONS:

The entire work process involved knowledge from different fields associated with the common goal of this work. The tests demonstrated the feasibility of implementing the proposed system and also highlighted some points for improvement work.

Regarding the perceived qualities in the system can be highlighted:

. The easy implementation of the individual parts, especially the application of the Augmented Reality resources employed;

. The CNC system production process used different areas of expertise, from project of the structure, the mechanical system and assembly of electronics and programming. These features demanded a long process of research, but the results have demonstrated the feasibility of implementing this type of system. The construction of the mechanical system aiming at the use of more accessible resources for the production of a prototype validation lived up to expectations, as well as resources used for the control of this system;

. The resources used for the production of interactive virtual environment through AR tools have shown to be efficient, especially when considering the ease of work and the relative simplicity of implementation of this system with the employed tools;

. The integration of CNC system with interactive virtual environment also proved to be satisfactory and process control through this interface was also presented as a good deployment solution, since the resources used have not demanded large programming projects, enabling the integration of elements with the use of command lines low complexity.

Among the problems encountered during the work process can highlight mostly:

. Difficulties in the production of CNC prototype to achieve optimum speed of movement for the tactile simulation. The end results did not meet this requirement completely, but the experience of work proved the viability of the system, as research has shown the possibility of solutions that allow higher speed to the system, such as different techniques and devices for use in the assembly of mechanical system prototype for example;

. The challenges encountered in the use of fiducial markers affected the stability of the positioning of virtual objects. This difficulty is related to interference in the interpretation of the captured image (visual confusion between markers) and also the factor of occlusion of the markers in the scene (very common in optical systems in general). This was an effect already foreseen in the project, because it is a characteristic of fiducial systems.

Among the possible solutions we can consider using different types of markers for each specific function - reducing the risk of visual clutter - the use of larger markers or fixation with greater distances between the markers, increasing its area within the captured image.

. The same problems were perceived in the use of fiducial markers as user movement tracking system. However, besides the solutions already presented, it is still possible to incorporate the system several other forms of tracking, like other optical systems with infra-red reflective dots capture or as use of LEDs, or the use of inertial devices, etc.

. Especially in the assembly process of parts of the system other difficulties were encountered. Among them we can mention those found during the integrated use of the camera attached to the visual device, and tracking and positioning system.

One of the perceived effects has been occlusion of the markers occurred during the user's head movement, causing the loss of reference for the positioning of virtual objects and tracking movements. As a solution to these problems, we can mention the use of two capture cameras, one fixed on the user's head and the other used only for tracking the movements of his hands. We can also consider using a capture camera with a wider viewing angle, reducing the risk of occlusion during the simulation.

Another possibility of improvement that we can quote is the use of a more appropriate visual device for use Augmented Reality, wich already has an attached capture camera.

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ECONOMIES OF SCALE AND SCOPE IN MANUFACTURING SYSTEMS - A BENCHMARKING APPROACH

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ABSTRACT

The main purpose of this study is to benchmark the economics of scale and scope (EoSS) for three different manufacturing systems layouts namely; functional, cellular and fractal layouts. The effect of setup reduction factor (SRF) on the EoSS of the mentioned layouts is also included in this study. Firstly, simulation modelling is employed to model and generate the necessary performance measures of these proposed layouts and then, EoSS levels are generated using mathematical programming. This study revealed that, fractal layout (FrL) showed the highest level of EoSS followed by cellular layout (CL) and then functional layout (FL). Additionally the findings of this study are in line with previous studies about the effect of SRF on the CL and the relative level of EoSS in the FL and CL. While majority of previous research focused on the comparison of functional and cellular layouts, it is clear that evaluating the EoSS attracted little attention in the past; therefore, the originality of this research work is threefold. Firstly, the evaluation of EoSS, secondly, the consideration of the FrL in the comparison as one of the 21st century manufacturing systems and lastly the development of the parts routing for the FrL is intelligently defined in the simulation model.

Keywords: Economies of scale and scope, Functional, Cellular, Fractal, Manufacturing layout

1. INTRODUCTION

It has been a while that manufacturing systems face complexity and decrease in productivity as a result of increase in plant size , machine production rates, part complexity and most importantly volume and mix of parts. In order to overcome such mentioned issues the layout of manufacturing systems has been under great attention. Since the middle of the past century this concern has led to emergence of the cellular layout (CL) and apparition of its expansion, a fractal layout (FrL) as a substitute of the traditional functional layout (FL) (Askin, et al., 1999). In the FL, same types of machines are physically groups into machine centres. This indicates that the number of work centres is equal to the number of machine types. Parts can be processed by any machine in a machine centre and there might be as many queues as the number of machine centres in this type of layout. In contrast with FL, machines of CL are grouped to serve families of products. Moreover machines within each cell are dedicated to process certain parts, and each cell of CL may consist of different machine types. Then queues may be made in front of every machine in CL (Co & Araar, 1988). Most importantly, in the factory with fractal design, the layout is divided into smaller cells or fractals which are very similar in that they are autonomous and products are well distributed between them. This similarity enables each fractal to produce all type of products. Also the moving distances between operations within each fractal are minimised. Contrary to CL in which cells were specialised to the particular product types, in the FrL each fractal is able to produce wide range of parts (Askin, et al., 1999).

Firms in any industry may achieve two types of production economies namely; economies of scale and economies of scope. While the first is associated with the firm size the latter relates to the joint production of two or more firms (Clark, 1988). Measures of EoSS can be obtained through the study of relationship between inputs and outputs by means of best practice production frontier. Therefore, the data envelopment analysis (DEA) which uses mathematical programing method is used to evaluate the relative efficiency of different firms to the best frontier (Bogetoft, 2012).

The comparison of different manufacturing systems has been the subject of numerous researches recently. While these studies have conflict in their results, they were comprehensively categorised and reviewed by some researchers such as; (Chtourou, et al., 2008), (Agarwal & Sarkis, 1998) and (Negahban & Smith, 2014). Study of these revision articles showed that the comparison studies mainly revolved around functional and cellular layouts. Moreover, while researchers rigorously have considered the most important performance factors of these two layouts, the economical evaluation is still the missing element of these studies. The author's research also showed that the literature lacks any comparison study consisting new generation layouts, like FrL.

The main purpose of this research is to compare the relative level of EoSS between three manufacturing layouts including functional, cellular and fractal. This goal is sought to accomplish by two methods of simulation modelling and then efficiency analysis by mathematical programming. The reminder of this paper is organised as follows; the next section, two, consists of the methods, based on which, this study was constructed. Section three exclusively presents the configuration and layout features of the modelled manufacturing layouts in this study. In section four the important and complicated components of simulation models are explained. Then followed by the models verification and validation using different techniques. Experimental design is also developed and lastly the results of the simulation study are presented and analysed. The paper ends with the conclusion section.

2. METHODOLOGY

2.1. Simulation Modelling

In order to generate the necessary values of performance measures, simulation is utilised in this research work. Computer simulation is one of the most popular research methodologies implemented in the operation management (Shafer & Smunt, 2004). Due to competition to improve productivity and quality, simulation is used to study the real behaviours of manufacturing systems in order to identify underlying issues. Because of high cost of complex systems, equipment and facilities, simulation model of such systems can reduce the cost of failure. Simulation analysis of production plan and control, product chain management and logistics, and production scheduling can represent real scenarios to pinpoint system issues and improve key performance indicators of systems (Shahin & Poormostafa, 2011).

Kelton, et al. (2015) observed the simulation from practical point of view and explained that; simulation is the process of designing and creating the computerised model of the real or suggested system, in order to analyse and evaluate the conditioned behaviour of that real system by numerical experiment. Also these authors claimed that the advantage of the simulation model over other modelling methods is that; simulation can produce the desirable model and can even make a more complex model than other modelling methods which may need simplifying assumptions to allow analysis.

2.2. Efficiency Analysis:

Most of economic measure of efficiency can be defined as ratios of measure of total productivity factor (*TPF*). *TPF* of multi-output multi-input firm is the ratio of an aggregate output to an aggregate input. If $x_{it} = (x_{1it}, \dots, x_{Kit})'$ and $q_{it} = \left(q_{1it}, \dots, q_{Jit}\right)'$ denote the input and output quantity vectors of firm i in period t, then the TPF of the firm i is defined by (O'Donnell, 2011) and can be calculated using equation (1):

$$TPF \equiv {}^{Q_{it}}/_{X_{it}} \qquad (1)$$

Where:

- $Q_{it} = Q(q_{it})$ is an aggregate output,
- $X_{it} = X(x_{it})$ is an aggregate input.
-

Then measures of residual scale and mix efficiency which are the measures of productivity related to economies of scale and scope, can be calculated by the following equations (O'Donnell, 2011);

$$RISE_{it} = \frac{Q_{it}/\hat{X}_{it}}{TFP_t^*} \leq 1 \qquad (2)$$

$$ROSE_{it} = \frac{\hat{Q}_{it}/X_{it}}{TFP_t^*} \leq 1 \qquad (3)$$

$$RME_{it} = \frac{\tilde{Q}_{it}/\tilde{X}_{it}}{TFP_t^*} \leq 1 \qquad (4)$$

The following notation describes equations 2 to 4.

- $ROSE_{it}$: residual output-oriented scale efficiency of firm i in period t,
- $RISE_{it}$: residual input-oriented scale efficiency of firm i in period t,
- RME_{it}: residual mix efficiency of firm i in period t,
- TPF^*: maximum *TPF* that is possible using the technology available in period *t*,
- $\hat{Q}_{it}$: maximum aggregate output possible when using x_{it} to produce any output vector,
- $\tilde{Q}_{it}$: aggregate output achieved when *TPF* is maximised subject to the constraint that the output and input vectors are scalar multiplies of q_{it},
- $\tilde{X}_{it}$: aggregate input achieved when *TPF* is maximised subject to the constraint that input vectors are scalar multiplies of x_{it},

3. SYSTEMS DESCRIPTION

The research showed that the only case study for which functional and cellular layouts are designed is the one that represented by (Co & Araar, 1988). This case study was originally a job shop which consists of 10 different machine types. Moreover, the system is fed with 15 different product types that totally require 95 operations. Table 1 shows the routings, processing times and the distribution of the different product types. Overall this job shop system consists of 67 machines with different capacity. Table 2 displays the number of machines for each machine type as well as capacity of each machine. For example, for machine type 1, there are four copies with number of hours available per week 20, 15, 10 and 30 in turn.

Table 1: Job routing and processing times (minutes) (Co & Araar, 1988)

	Machine type										
Jobs	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Job Distribution**
1	10	-	15	7	-	-	20	17	-	8	0.10
2	-	15	10	-	10	5	-	15	15	-	0.15
3	-	11	13	20	15	-	-	-	12	10	0.07
4	9	10	20	-	-	-	17	9	-	8	0.06
5	15	-	-	15	9	7	12	7	9	-	0.05
6	8	6	-	10	7	13	8	-	-	-	0.06
7	-	-	-	13	12	7	19	-	13	14	0.08
8	12	-	11	-	18	11	-	13	-	10	0.07
9	17	8	6	9	20	-	-	-	12	13	0.06
10	-	7	-	5	-	6	-	12	-	18	0.07
11	12	-	13	-	8	-	11	-	9	-	0.05
12	7	6	5	-	-	-	11	12	13	17	0.04
13	-	15	20	13	-	17	-	12	-	5	0.04
14	18	12	-	7	9	8	-	20	-	-	0.04
15	20	13	5	7	12	13	20	13	7	5	0.06
											1.00

Table 2: Machines' capacity per week (Co & Araar, 1988)

	Units (Number of copies of each machine)									
Machine type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	20	15	10	30						
2	16	29	15	25	30	20	28			
3	17	15	40	30	10					
4	18	19	17	28						
5	15	20	30	20	20	20	30			
6	18	20	15	15	10	15				
7	10	20	20	10	15	20	15	15	15	10
8	20	20	15	15	10	10	10			
9	18	17	20	30	40	30	20	17		
10	20	10	10	10	30	30	30	15	15	

Presentation of parts' sequences is graphically illustrated by (Co & Araar, 1988). However, table, 3 was adapted from (Montreuil, 1999) who inferred part's sequences from the original paper.

However, fractal layout configuration used in this study is adapted from (Venkatadri, et al., 1997). This fractal layout is generated based on the same data in the case study of (Co & Araar, 1988). In order to design the fractal layout, (Venkatadri, et al., 1997) implemented an integrated design approach.

Table 3: Processing sequences (Montreuil, 1999)

Product types	**Processing sequences**
1	1, 4, 7, 3, 10, 8
2	3, 9, 2, 8, 5, 6
3	2, 3, 4, 5, 9, 10
4	1, 7, 8, 10, 2, 3
5	5, 6, 8, 1, 4, 7, 9
6	5, 2, 6, 4, 1, 7
7	6, 4, 5, 7, 10, 9
8	1, 3, 5, 6, 8, 10
9	3, 4, 2, 1, 5, 9, 10
10	8, 10, 2, 4, 6
11	3, 1, 9, 5, 7
12	1, 9, 10, 2, 7, 8, 3
13	4, 3, 10, 2, 8, 6
14	4, 2, 8, 5, 1, 6
15	1, 5, 2, 6, 8, 3, 4,

4. THE PROPOSED SIMULATION MODELS

The proposed layouts were modelled using Arena software.

In the simulation model of functional layout, jobs arrive in the system randomly by the Create module. Then using the Assign module part types as well as parts sequences are determined. Part types are defined with general discrete distribution, DISC, which allows certain values with given probabilities. The part type assignment has two purposes; first is to define which part is arrived, and then part type value can be associated with the parts' sequences which were defined with Advanced Set and Sequences data modules.

Using the Leave module, different parts are transferred to their first work centre. The Leave module allows seizing the transportation resource, as well as considering the proper transfer time between different departments or workstations. Figure 1 shows the arrival logic.

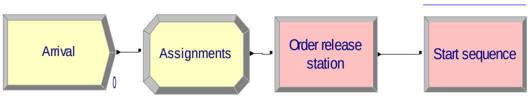

Figure 1: Arrival logic

Different departments possess different number of machine types although machine types are the same in each department or machine centre. When the jobs enter the appropriate department, based on the part sequence, first the transportation resource is released, and then they enter the department queue in case all the machine resources are busy. Next, because the entity can seize every each machine units in its current department, the Select Block module uses Preferred Ordered Rule (POR) to select and guide the entity to the first Seize

Block for which the required resource units, namely; operator and machine, are available. After the job receives the required service at the first department, in the Delay module, it runs through next department until it receives all the required processes and then it leaves the system. Figure 2 shows department four with four similar machines which are named as Process 1 to 4.

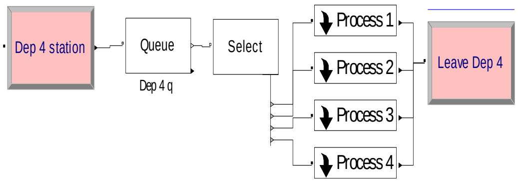

Figure 2: Machine centre logic in the FL

Regarding the setup reduction factor (SRF) logic, in each department, Process Submodels that represent work centre can intelligently diagnose if the two consecutive parts are similar or not. More precisely, after the part enters the Process Submodel, it enters the Seize Block module to grab the machine and operator resources. Then before it enters the Delay Module, the Decide Module checks and compares the part type of current entity with the last part type that left the existing Process Submodel. When any entity goes through any Process modules, Assign modules allocate its part type value to the multi-dimensional Last Part variable which allows comparison of two consecutive entities' attributes by the successive Decide Module. Then, if two consecutive parts are similar, the setup reduction factor can be assigned to the entity by the successive Assign modules. In other words, if the machine has already been setup for that similar part type, setup time can be reduced by setup reduction factor at the Delay Module. Finally, the entity releases the seized resources at the Release Module and proceeds to its next location on the basis of its predefined sequence. Figure 3 illustrates the component of a Process Submodel.

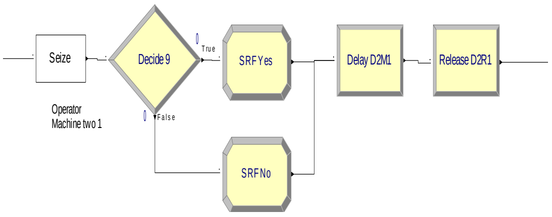

Figure 3: The Process submodel logic

The simulation models in this study only assume unidirectional flow of materials and backtracking is not allowed. Also because setup times are not provided in the case study of (Co & Araar, 1988), setup times are supposed to be 10 percent of the parts' processing times in the Delay Modules. The delay times that are defined by equation 5, includes SRF, setup and processing times. Obviously, this equation states that the pure value of process time is 10 percent less than the values presented in the table 1 in order to consider this 10 percent as the setup time. Then, again the actual processing time is added to the setup time which is multiplied by the value of SRF.

$$Delay\ time = (\ Process\ time\ -\ (\ Process\ time\ *\ .1)\ ) + \ (\ Process\ time\ *\ .1\ *\ SRF\ ) \qquad (5)$$

Similar to functional layout, cellular layout model consists of three main parts: jobs arrival, cells and exit logics. The cellular model consists of 64, machines which are distributed unevenly between 6 cells. Like functional layout, part types go through different machines based on their defined processing plan by the Sequence Data module. In the CL, part travel within and between cells which necessitates consideration of inter-cell and intra-cell travel time definition .

In contrast with the functional layout in which each department had one queue, in the cellular simulation model, each machine centre has its own queue. All of CL's queues are governed by the same priority rule of first in first out (FIFO). In the FL the travel time only included inter-cell travel time, however, in the CL, parts can travel within and between cells which requires the definition of both inter-cell and intra-cell travel time.

Some features of the cellular simulation model are almost similar to functional layout. Therefore, to be brief the explanations of these features are not repeated here. For example, the similar logics include job arrival; exit the system, transfer logic and process submodel.

Simulation model of Fractal layout is more complicated than last two models. The part routing information of FrL was not presented in the original design of FrL, therefore, the responsibility of determining parts' sequences are creatively assigned to the developed simulation model of this layout. This must be expressed so that this logic is based on the capability of each fractal to process all part types. In order to achieve this purpose, parts sequences are not assigned to entities in the arrival logic; however, it is allocated when jobs arrive in a chosen fractal with lowest number of entities in its queues. In other words, when initially jobs arrive into the system, their part types are allocated to them and then they seize the transportation resource to travel to the fractal cell which has the lowest number of parts in its queue, see Figure 4.

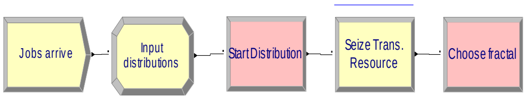

Figure 4: Arrival logic in the fractal layout

Selection of the proper fractal cell is carried out by the PickStation Advanced module. This module is used to choose a fractal cell with the lowest number of entities in its queues and then send the job to that chosen fractal.

Equation 6, which calculates the total number of entities in the queues of each fractal, is used in the Pickstation module.

$$\sum_{i=1}^{n} NQ\ (QM(i)) \qquad (6)$$

Where

- NQ is the number of entities variable, in a queue
- QM (Queue machine) denotes the queue name of machine i.

When the parts are sent to any particular cell, their sequences are assigned to them firstly. Then they are guided to their first work centre by the Route transfer module. Afterwards they follow their sequence until they receive all the necessary services by the Enter and Leave transfer modules in that particular fractal. Figure 5 shows the station of fractal one and necessary modules to route parts based on their sequences.

Figure 5: Fractal station

Due to the fact that each fractal can process all part types, inter-cell movement is not allowed. Also each part types process plan follows the shortest distance travel rule within each fractal. Other logics of fractal model like machine centres and exit are similar to models of last layout types.

4.1. Models Verification

The three developed models were comprehensively verified by using numerous Arena verification techniques. These techniques include;

1 using the Check Model Command
2 overcrowding the systems for a large period of time and observing some performance measures like; queue length and output quantities
3 Most importantly, using the Command window and the trace command while only one entity was allowed to enter the system.

4.2. Experimental Design

The variable input factors or experimental factors include SRF and the three proposed layouts. While layout factor consists of three levels, SRF includes two levels of high and low. Table 4 shows the experimental factors and their description.

Fixed factor elements of this simulation study are also summarised in table 5.

In this case this simulation study consists of 6 different alternatives (Scenarios) as shown in table 6.

As the quantities of inputs and outputs can be the variables of economies of scale and scope measures. Table 7 represents the chosen performance measures of this simulation study.

Table 4: Summary of experimental factors

Factors	**Levels**	**Description**
Layout type	Functional	Three layouts were explained and depicted in previous section.
	Cellular	
	fractal	
Setup Reduction Factor (SRF)	Low	SRF= .8
	High	SRF= .2

Table 5: Fixed factors of the simulation study

Characteristics	**Value**
No. of Part types	15
No. of machine operators	67 in FL 64 in CL 33 in FrL
No. of transportation resource	infinite
Job inter-arrival times (minute)	Expo (3)
Transfer times (minute)	
Inter-cell	UNIF (1,15)
Intra-cell	UNIF (1,5)
Process times	Shown in the table 3
Queue ranking rule	FIFO
Replication length	1920 hours (one year)
No. of replication	100

Table 6: Features of different scenarios

Scenario	**Layout type**	**SRF**
1	Functional	0.8
2	Cellular	0.8
3	Fractal	0.8
4	Functional	0.2
5	Cellular	0.2
6	Fractal	0.2

Table 7: Performance measures

Performance measures	**Input / Output**
Operator working time	Input
Transportation working time	Input
Machine working time	Input
Material quantity	Input
Product types Produced	Output

4.3. Results and Analysis

There was a huge results generated from this research work which will be presented in the conference. However, Figure 6 shows the output quantity of different part types in the six different scenarios under investigation. The most striking feature of the obtained results is that the outputs of all scenarios follow the same pattern and this is due to the part mix probability distribution used in the three layouts. Additionally, the recorded highest output quantity was belongs to FrL with high SRF. Then the figure indicates that at same value of SRF allocated to the three layouts, FL and FrL had the lowest and the highest output values respectively. Finally, it is obvious that the output values of FrL with low SRF is considerably close to the output values of FL with high SRF. This can be interpreted as a higher efficiency of FrL compared to other layout types. Due to space limitation, the other four performance measures under investigation in this research work will be presented in the conference.

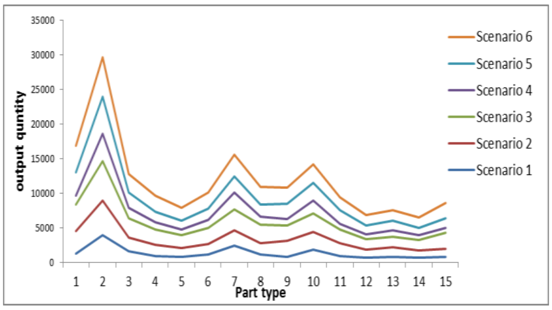

Figure 6: Output values of different scenarios

There were five performance measures considered in the analysis, it was clear that the FrL layout outweigh the other two layouts in transportation time, operator working time and output values. While FL performed better than FrL and CL in terms of machine working time. On the other hand, it has been found that the fifth performance measure, materials quantity that arrives to the system, was at same level for all the three layouts.

5. EFFICIENCY ANALYSIS

"DPIN™ software is used for decomposing Productivity Index Numbers into measures of technical change and various measures of efficiency change" (O'Donnell, 2011). This software can analyse the productivity of any multiple-input multiple output firm working in any market environment (O'Donnell, 2011). According to (O'Donnell, 2011) DPIN can generate measures of numerous efficiencies, including; residual output-oriented scale efficiency (ROSE), residual input-oriented scale efficiency (RISE) and residual mix efficiency (RME) which are measures of productive performance associated with economies of scale and scope (EoSS).

After inserting the performance measures (input and output values), which were resulted from simulation study, into the DPIN software, scores of various efficiencies were generated. This efficiency analysis was conducted based on Constant Returns to scale (CRS) assumption. Also regarding the orientation of the efficiency analysis, input-oriented approach was chosen for this analysis.

As mentioned before, the RISE and RME values of DPIN output file can be used to represent scores of scale and scope economies, respectively. The score of scale and scope economies of different scenarios as well as the maximum efficient scenario under CRS assumption is clearly illustrated in table 8.

Table 8: Results of efficiency analysis under CRS

Scenario	level of scale economies	level of scope economies	Max
1	0.8893	0.8893	
2	0.9181	0.9181	
3	0.9952	0.9952	
4	0.8888	0.8888	
5	0.9679	0.9679	
6	1	1	✓

Therefore, from table 8 the followings can be concluded;

1. The highest degree of productivity, due to EoSS, is achieved by the FrL with high SRF. This indicates that when FrL's input is increased, the output will also increase by same rate.
2. Even FrL with low SRF shows a higher level of scale and scope efficiency than the bests of FL and CL. The quantity of this difference is approximately 11 and 3 percent in relation to FL and CL respectively.
3. Different values of SRF influenced the EoSS of FL, CL and FrL by almost 0.1, 5 and 0.5 percent respectively. This finding complies with the previous studies which mentioned the SRF as the main advantage of group technology (Chtourou, et al., 2008).
4. All in all, it was observed that the FrL showed higher level of EoSS related efficiency than that of CL; similarly CL had higher degree of such efficiency than FL.

6. CONCLUSION

This study focused on benchmarking of the Economies of scale and scope (EoSS) of three different layouts which was functional, cellular and fractal layouts. In order to achieve this goal, detailed simulation models of these three manufacturing layouts were developed. Although layouts' configurations of this simulation study were adapted from the valid designed layouts available in the literature, the part routings of designed FrL was not available in its original paper. Therefore, based on the characteristic of FrL, the assignment of part sequences was creatively defined by advanced modules of Arena. Then simulation models of this study were comprehensively verified. In addition, consideration of statistical concepts in the experimental design has led to the generation of statistical reliable performance measures with short interval values at 95% confidence level. These statistical valid performance measures were used in the efficiency analysis of the mentioned layouts included in the benchmarking.

The generated performance measures from simulation study have shown different superiority-inferiority results in different layouts. While FrL with high SRF could produce the highest output production, CL and FL possessed the second and third highest values of the output production. Operator and transportation working time were at their lowest level in the case of FrL while CL and FL stood in the second and third positions, respectively. Moreover, SRF did not dramatically influence the value of machine working time within same layouts configuration. The results also showed that for same number of parts produced using FrL, we need almost 17% extra in machine working time if FL used.

Measures of scale and scope economies were calculated by DEA LPs and Constant Returns to scale (CRS) assumption. Regarding different models of DEA; input oriented CRS was found appropriate for the purpose of this study. Nevertheless, the efficiency analysis under CRS model identified the FrL with high SRF as the most efficient firm, in comparison with FL and CL. This efficiency analysis also proved that FrL outperformed both CL and FL in terms of EoSS efficiency score, regardless of SRF.

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MODELLING AND SIMULATION OF RAIL PASSENGERS TO EVALUATE METHODS TO REDUCE DWELL TIMES

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ABSTRACT

The paper outlines a feasibility study using modelling and simulation to reduce dwell times and increase rail network capacity. We use agent based modelling, where passengers are treated as a separate entities, basing their movements on rules from the Social Force Model (SFM), proposed by Helbing to model pedestrian dynamics. Implementing this SFM, together with a novel decision making system for passengers' door choices, a mesoscopic model is produced of the platform, train and passengers. An outline of the modelling process is presented, along with a critical analysis of the final model. Analyses are conducted to evaluate novel concepts in train and platform design, to reduce loading times, using passengers with a range of attributes. In a simulation experiment, four concepts (wider doors, designated boarding/alighting doors, and an active passenger information system) are assessed, with the latter two giving reductions in loading times of 7.0% and 7.3%.

Keywords: agent-based modelling, simulation, rail passengers, dwell time reduction.

1. INTRODUCTION

The rail network in the UK is fast approaching maximum capacity and passenger numbers are growing 6-7% per year. The current transport secretary, The Rt Hon Justine Greening has even said expressly "without investment in new capacity, our main rail arteries will grind to a halt during the 2020s, with disruption, overcrowding and damage to our economy" (Department for Transport 2012). It is stated in the Rail Technical Strategy (RTS 2012), an outline of a plan for the next 30 years of the rail industry, that even before 2020, East Croydon station would be too crowded to function successfully. This is one of many examples within a network approaching its capacity.

One relatively simple (and therefore cheap) way to increase capacity of the rail network is to reduce loading/unloading times (dwell time); this allows more frequent services while not requiring additional rolling stock. In their study on international dwell times, Harris and Anderson (2007) proposed examples to reduce dwell times. These included wider platforms, separate boarding and alighting platforms and "step aside" signs in front of doors. They found that "function time", where doors are closing and the train is preparing for departure is equally important as boarding/alighting time; however this varied widely between stations and countries. The study also identified that some of these dwell time reducing methods succeeded, but failed to quantify by how much. When displaying results, they did not identify the stations and reasons for their relative success or failure. Harris (2000) also performed a study on station capacity at Norreport, Denmark, which interestingly found that military style music helped speed up the boarding/alighting process.

Our project tests the ability of simulation to assess a number of these and other novel methods for reducing dwell times, as well as the impact each method would have across a number of different scenarios.

While there have been many studies into crowd and pedestrian dynamics, they tend to be focused on stadia and crowds at events. There are a few studies looking at modelling and simulation in a rail context, however there seems to be a lack of studies performed on reducing loading times, particularly focusing on the train-platform interface. In the Academic Response to the Rail Technical Strategy (RRUKA 2013), it was highlighted that there were no projects in the area of "Modelling to optimise seating/loading capacity and speed" listed on the research database of the Rail Safety and Standards Board (RSSB), though there is a demand for this type of research. There have been attempts to simulate train stations before, but on two different scales. Macroscopically, there have been a number of publications (Grontmij and Carl Bro n.d.; Thompson et al. 2013) using Legion SpaceWorks software package in order to model the station as a whole. The focus of the analysis was on ticketing barriers and halls and not on the train-platform interface, where there is likely to be greater impact on dwell time. Microscopically, Zhang et al. (2008) performed a simulation study on the relative sizes of boarding and alighting groups and the effect this has on dwell times. The Pedestrian Accessibility Movement Environment Laboratory (PAMELA) at UCL investigated the effects of factors such as platform humps (Fujiyama, et al. 2014) and stairs on walking speeds in physical mock-ups (Fujiyama and Tyler

2010). This research group has also produced a report for the Department for Transport (DfT) on train dwell times (Fujiyama et al. 2008). This type of study is carried out at great expense in both time and money, and can only hope to study a small section of the platform or train at any one time, ignoring any interactions between sections. This is acknowledged in the DfT report, and suggests that the train and the platform should be "considered as one connected system".

In order to test strategies to reduce train dwell time, it is proposed that modelling and simulation of the platform-train interface as a holistic system would provide a relatively cheap, easy and extremely flexible solution to assess strategies and concepts in reducing dwell times, also with opportunities to take account of the attributes of different types of passengers. The following strategies to reduce dwell times were assessed:

- Wider doors (1.5x and 2x the standard size)
- Designated boarding and alighting doors
- Novel passenger information systems, such as those proposed by Network Rail and Thameslink, and currently in a limited trial in a Dutch station (Fast Co. Design 2014).

While we acknowledge that there are several simulation tools that enable similar studies (e.g. Sourd et al. 2011; Nash et al. 2007; Zhang et al. 2008), the novelty of our approach lies in the application of the Extended Social Force Model (ESFM) (Xi et al. 2011) in the context of dwell time optimisation, as well as the fact that we are able to define a specific heterogeneous population when we develop our scenarios. The aim of this paper is to introduce our novel Agent-Based Modelling (ABM) approach and to demonstrate the feasibility of it for assessing potential methods of reducing rail passenger dwell times for different passenger populations.

2. MODELLING THEORY

ABM is the current state of the art in modelling and simulation for pedestrian dynamics (Castle and Crooks 2006) and is based on treating each pedestrian as an individual "Agent" that bases its decisions on a set of predetermined rules. This naturally lends itself to modelling of pedestrians in a heterogeneous crowd. ABM was first used extensively in the Social Sciences (Dowie and Schelling 1980; Axelrod 1997) to show emergent collective behaviour; how a number of microscopic decisions lead to much larger macroscopic level emergent behaviour of a crowd. It was in the Social Sciences that the Social Force Model (SFM) was first proposed (Helbing 1991). The SFM treats each agent as if it had an electrical charge, and so as two agents move towards each other they feel a repulsive effect. They also receive an attractive force from their destination point (usually an area). The resultant force acts on the agent, and gives it an acceleration (or deceleration), adjusting the speed of each agent. In addition to these psychological forces, when agents are physically touching two physiological forces are produced, based on granular interaction forces: a tangential force, and a frictional force. The same combination of psychological and physiological forces is produced with interactions with walls and barriers (boundaries).

While the SFM ABMs act on a continuous space it is possible to abstract things further, so that entities act on a discrete grid. This can be achieved by using Cellular Automata (CA). CA are mathematical idealisations of physical systems in which space and time are discrete, and physical quantities take on a finite set of states (e.g. on and off) (Wolfram 1983). In the beginning of a simulation run an initial state is assigned to each cell. A new generation of cells is then created within each time step, according to a fixed rule (usually a mathematical function). This determines the new state of each cell, in terms of the current state of the cell and the states of the cells in its neighbourhood. Running the simulation in this way for some time often leads to the emergence of recurring patterns on the grid. Legion software was first built as a CA model (Still 2000) but seems now to be an ABM on a continuous space, although this is not made clear due to its proprietary nature (Berrou et al. 2007). It uses a "least effort" principle of deciding each pedestrian's movement. It goes through a number of iterations in order to find the path of least effort, and so could be viewed as computationally inefficient. Nevertheless, Legion is the most commonly used software and there is a set of Network Rail capacity assessment guidelines (Network Rail 2011) and a London Underground best practice guide (Transport for London 2006), which outline the expected procedure for simulation, using this software. There has also been an effort to calibrate and validate Legion against empirical evidence (Berrou et al. 2007). For a larger scope, whole-station model it would seem very appropriate. Due to its expense, its proprietary nature and therefore its lack of adaptability, it is deemed inappropriate for this project, in relation to the train-platform interface.

For our project we decided to use ABM together with the SFM to determine agent movement. On this scope it is more appropriate than a CA model (which would be better for a microscopic look at the doors alone), or a "least effort" principle as used by Legion for a macroscopic, whole-station perspective. To add some novelty, we decided to incorporate the ESFM proposed by Xi et al. (2010), who used this to study the movement of shoppers within a shopping mall. We did not find any evidence suggesting that it had been used in the rail context before. The ESFM adds "vision" to the SFM. A simple way of considering vision is to use a "form factor" coefficient which modifies the psychological force felt by a passenger. We also developed a novel decision making algorithm which is based on a passenger's knowledge of the station. The ESFM also includes a socially attractive force between members of a group, but due to time constraints this could not be developed for use in our model.

3. MODEL DEVELOPMENT

For the model design and implementation we used AnyLogic 7.1.2 (University Edition). AnyLogic is a multi-paradigm Eclipse-based commercial drag and drop modelling and simulation IDE. It can be programmed and extended using Java and supports GUI design.

3.1. Base Model

In starting to create a computational model, it was important to start with a small scale, simple model to test the SFM. The SFM was implemented by computing the force on an agent at each time step, using the Equations 1-3, provided by Xi et al. (2010).

$$m_i \frac{d\boldsymbol{v}_i}{dt} = m_i \frac{v_i^0(t)\boldsymbol{e}_i^0(t) - \boldsymbol{v}_i(t)}{\tau_i} + \sum_{j(\neq i)} \boldsymbol{f}_{ij} + \sum_W \boldsymbol{f}_{iW} \qquad (1)$$

$$\boldsymbol{f}_{ij} = \boldsymbol{f}_{ij}^{psy} + \boldsymbol{f}_{ij}^{phy}, \quad \boldsymbol{f}_{ij}^{psy} = A_i \exp\left(\frac{r_{ij} - d_{ij}}{B_i}\right)\boldsymbol{n}_{ij} \qquad (2)$$

$$\boldsymbol{f}_{ij}^{phy} = kg\left(r_{ij} - d_{ij}\right)\boldsymbol{n}_{ij} + \kappa g(r_{ij} - d_{ij})\Delta v_{ji}^t \boldsymbol{t}_{ij} \qquad (3)$$

Using this force, it is possible to update the velocity, and position of the agent at each time step. From this the parameters used in the SFM could be calibrated in order to produce realistic behaviour. The four behaviours that are to be expected were outlined in Helbing's papers (Helbing and Molnar 1995; Helbing et al. 2000). These are:

- Clogging at bottlenecks
- Lane formation
- Oscillations at doorways
- Freezing by heating

The "Freezing by Heating" behaviour refers to pedestrians' high desired velocities resulting in slower overall movements. For the calibration we used a trial and error approach. All four behaviours were visible once parameters were set to the values shown in Table 1; column 1. Most of these are quite different to the ones from Helbing shown in Table 1; column 2. In our implementation the diameter of each agent is set by a uniform distribution between 0.45 and 0.75m, and their mass related to this, with a range of 60-100kg.

Table 1: Parameters Used in Both Models

	Initial values	Helbing's values	Final values
A [N]	200	2000	30000
B [m]	1.5 x combined radii (approx. 1.5)	0.08	0.6
k [kgm^{-1}s^{-1})]	390	2500000	9500
K [kgs^{-2}]	300	1200000	30000
τ [s]	0.5	0.5	0.5

It was also necessary to consider another set of parameters for the interactions with the walls or other boundaries. This is due firstly, to the large amount of agents and the nature of waiting for doors to open and secondly, because of agents near to the walls of the train or the closed doors, which feel a large force from the passengers behind them. A large reactionary force is then needed from the wall to counteract this and stop passengers "jumping through walls". This required larger parameter values, particularly for the physical forces. Even after these changes some passengers do not stop at the walls but we decided to leave this as further work. The final parameter values are shown in Table 1; column 3.

3.2. Passenger Types

We used attributes that influence behaviour to distinguish between the different types of passengers. A passenger decision-making process was developed which depends on the values of these attributes. One of these attributes is "knowledge" of the station. If a passenger has this attribute set to true, they base their decision on the least crowded door. In a real-life situation, this tends to be a certain door or number of doors that are usually under-utilised. A passenger with knowledge of the station would be able to identify this. These passengers are shown in GREEN in the output animation of the platform visualisation within AnyLogic. If a passenger does not have knowledge of the station, then there are two different decision-making processes, depending on their arrival time relative to the train's arrival time. First of all, if a passenger arrives well before the train arrival time (before the simulation start time), they move towards the nearest anticipated door area. This is a prediction, and so therefore in the simulation they aim for a random point in a wide area. If a passenger arrives in this time period, they are initialised at the beginning of the simulation in one of two areas, "nearPlatform" (shown in RED) and "farPlatform" (shown in BLUE), either at the front edge of the platform or at the rear. These locations are based on areas outlined in the Network Rail Station Design Principles (Network Rail 2015). If a passenger in this time frame has knowledge of the station, they aim for a narrower, more accurate area of where they anticipate the door to be. If a passenger arrives near to the train arrival time, when crowds are already forming (after the simulation start time) and does not have knowledge of the station, they pass by each door in turn, starting at the nearest to the platform entrance they arrived from, to the furthest. If the crowd at a door is under a specified threshold, the passenger will choose that door to enter. If not, then they pass to the next door. The threshold differs depending on the total amount of passengers on, or crowdedness of, the platform. For this simulation it is set as a sixth of the total number of passengers (with six doors). These passengers are shown in progressively darker BLUE the later they arrive. For alighting passengers (shown in YELLOW), the nearest door is chosen. Then the nearest exit from the station is chosen once they are on the platform. In this simple feasibility test, once boarding passengers are on the train they are ignored (disappear from view in the simulation – this is also the case for other passengers on the train at this station). For simplicity, it was also assumed that

boarders do not wait for alighters before they start moving. Instead it is left to the social force model to decide which group moves, hopefully oscillating, depending on relative group sizes.
After the passengers' movements and decision making were modelled, tested, calibrated and de-bugged, the AnyLogic 3D engine was employed to give a more realistic visualisation. One significant bug fixed was agents getting "trapped" in corners. When an agent has to go through a door, a temporary waypoint or target had to be added in the doorway, to ensure they went through the door before heading towards their overall target.

3.3. Passenger States

During the simulation a passenger can be in different states. This was captured by producing a UML state machine diagram which is then translated into source code by AnyLogic. In this kind of diagram states are represented by ovals and transitions between states are represented by arrows (Siebers and Onggo 2014). Events will trigger state changes. There are different types of events, the key ones are: timeouts (triggered when a specific time has elapsed), rates (triggered at a certain rate which usually depends on a distribution), and conditions (a condition has become true). Such a state chart is embedded in every passenger object so that each passenger has its own current state depending on their type (i.e. the current settings of his attributes) and their environment. The passenger state machine diagram is shown in Figure 1. This sets the variables and targets for each passenger in the beginning of a simulation run, and provides information about the state they are in during the simulation run (on platform, deciding door, exiting etc.).

4. MODEL IMPLEMENTATION

4.1. Simulation Platform

The model has been implemented using the AnyLogic IDE. The complete model is available for download at http://www.cs.nott.ac.uk/~pos/publications/mas2015model.zip. Although AnyLogic comes with a pedestrian library which uses the SFM and could be used to build simple models, we found this library to be limited and inflexible. Therefore we developed our own SFM implementation, considering the form factor coefficient and our novel decision making algorithm within our agent template. In the end we only used the library for providing the 3D animation of the passenger agents.

4.2. Simulation Execution Algorithm

The overall simulation runs in time steps. Throughout the time horizon at each time step a certain algorithm is executed. The pseudo code for this algorithm is provided in Figure 2.

4.3. Verification and Validation

Six model verification and validation techniques, originally described by Law and Kelton (1982), have been applied to validate the model. These included continuous debugging, independent review, reasonable output, trace, model run with known characteristics, and animation. At each stage of building the model any bugs were identified and debugged. At various points throughout the project experts in human factors and agent-based simulation were consulted to verify any assumptions and observations made and to assess the state of the model. The base case outputs of the simulation model were compared both qualitatively and quantitatively to previously observed and expected outputs. Decision making processes, scenarios and strategies were all derived from observation and assumptions of real stations. Real data were used for input parameters, for both agents and the environment. The simulation has both 2D and 3D animations to provide a visualised output, in both static images and video which could lead to further analysis. After applying all these verification and validation techniques we are confident that our simulation model is sufficiently accurate for the purpose at hand.

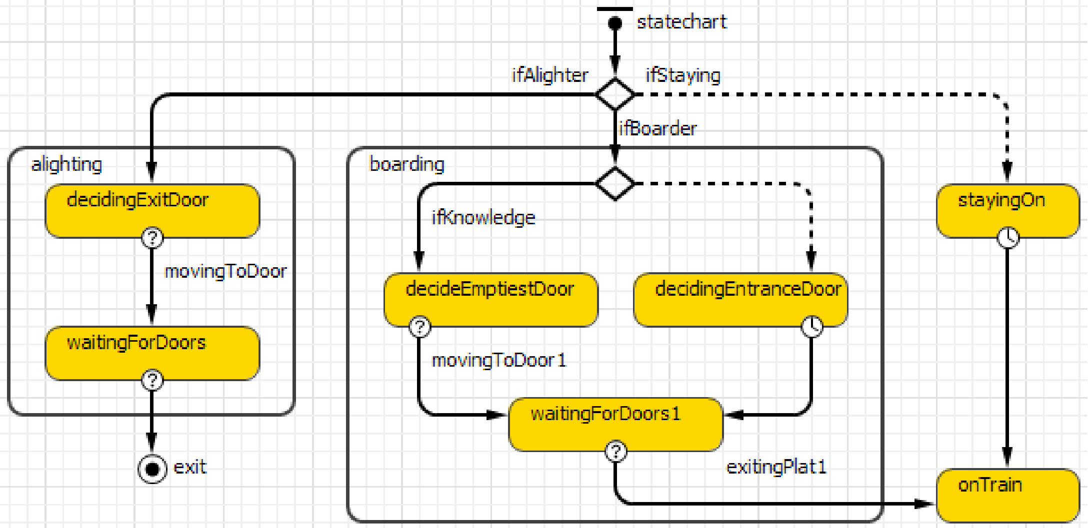

Figure 1: The Passenger State Machine Diagram which Updates a Passenger's Targets and Variables Throughout the Simulation

```
Find mass of agent, update the current and target coordinates, and reset forces
Calculate the attractive force to the destination
For each passenger:
    If not the current passenger:
        Check distance
        If in connection range:
            Calculate physical and psychological forces
Check whether doors are open or closed:
    Set relevant boundaries
        Calculate distance
        If in connection range:
            Calculate physical and psychological forces
Repeat above for boundaries which are constant
Update position and velocity based on the sum of the above forces
Check passenger type (boarder, boarder with knowledge, alighter)
    Check whether near relevant destination
        If so set target reached variable to true
        Else move to new position in time step
```

Figure 2: Pseudo Code for Each Simulation Time Step

5. EXPERIMENTATION

5.1. Scenarios

There are four different scenarios which are examined in the experimentation. In all scenarios a three carriage train was used, with carriages based on the British Rail Class 456, deemed to be a fairly generic train design. Each carriage is 20m long, and has two doors facing the platform, as well as the opposing side (however these are ignored in the model as they do not have an influence on the boarding and alighting). The platform is also modelled to be fairly generic, with no particular features such as barriers or narrow areas. It was modelled to be 90m long and approximately 15m wide, perhaps wider than the average. In each simulation 100 boarding passengers are distributed randomly in two areas of the platform (near to the track awaiting the train and in a waiting area at the rear of the platform) at the beginning of the simulation, with additional passengers arriving from two entrances during the run time of the simulation. Boarders base their door decision on where they predict the nearest door to be. Images of the simulation in both 2D and 3D can be seen in Figure 3 and Figure 4.

The attributes for the different scenarios are as follows:

- Scenario 1: The "standard" generic scenario: 600 passengers (2/3 capacity, split evenly between boarders, alighters, and 200 ignored in the simulation but assumed to be staying on train); Normal Distribution (ND) of desired walking speeds, with Mean (M) 1.3m/s and Standard Deviation (SD) 0.2m/s (Fitzpatrick et al. 2006); 10% of passengers have "knowledge" of the emptiest door
- Scenario 2: The "rush hour" scenario in which the majority of the passengers are expected to be middle-aged commuters: 1200 passengers (4/3 capacity, deemed to be "overcrowded" (Rail Technical Web Pages 2011), and split equally between boarders, alighters and 400 staying on the train); ND, with M 1.47m/s (Fitzpatrick et al. 2006) and SD 0.2m/s; 50% of passengers have "knowledge" of the emptiest door
- Scenario 3: "OAP day out" in which a large number of passengers are elderly passengers. This may somewhat represent a daytime situation, but is mainly for curiosity, as to the effects of a number of slower passengers on the system as a whole: 600 passengers (same even split as the "standard" situation, at 2/3 of capacity); ND, with M 1m/s and SD 0.5m/s (Oxley et al. 2004); 10% of passengers have "knowledge"
- Scenario 4: The "Emergency" scenario, to assess how well the train and platform can be cleared, including a higher desired velocity representing panic: 400 passengers, 44% of capacity, and all of which being alighters; ND, with M 3m/s and SD 1m/s; 10% of passengers have "knowledge".

5.2. Strategies

In each of the four scenarios, the standard strategy (as currently used) is compared to four alternative strategies in order to reduce dwell time. The standard strategy uses the standard doors, 1600mm in width (Rail Technical Web Pages 2011). Doors are used for both boarding and alighting, and it is assumed that boarders do not wait for all alighters to exit the train before entering. The direction of crowd movement through doors is left to the SFM.

The first alternative strategy for reducing dwell time is a slightly wider door, at 2400mm (1.5x standard door width). If a standard door is classed as a double door, this would be a triple width. It is chosen so that we can have some insight as to whether this allows for more "lanes" of traffic through the door (e.g. three lanes), or whether people avoid an additional middle lane, for example, due to social forces.

The second alternative strategy used is "quadruple" width doors, or 2x the standard, at 3200mm. Similar to the above, it is interesting to see whether this allows four "lanes" of traffic, or double the flowrate of a standard sized door, or whether there is a diminishing return effect.

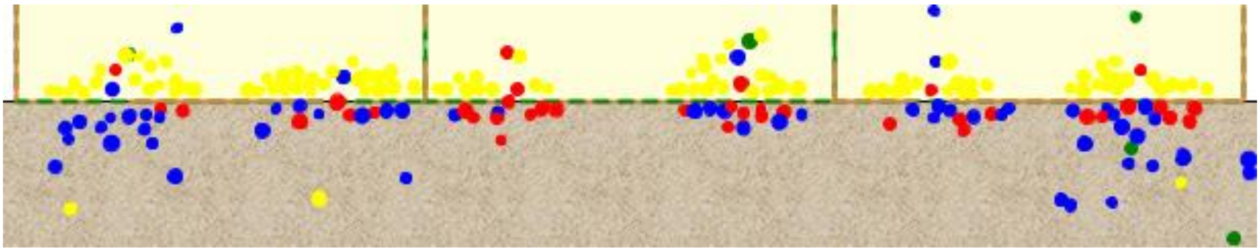

Figure 3: 2D Visualisation of the Simulation

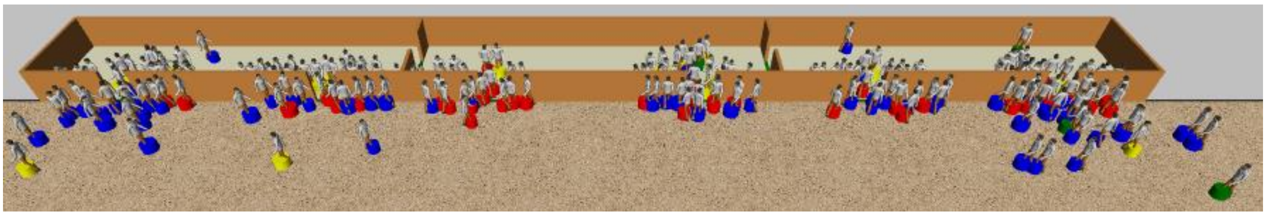

Figure 4: 3D Visualisation of the Simulation

The third alternative strategy used is a dedicated boarding and alighting door system. This is developed from insight given by Harris and Anderson (2007). It was found that stations with dedicated boarding and alighting platforms had significantly smaller dwell times. Unfortunately, as stations and results were kept anonymous, it is impossible to give a quantitative percentage decrease from this paper. They do acknowledge the weakness in dedicated platforms (i.e. the large amounts of infrastructure needed to have two platforms on every track). This would be almost impossible to achieve on the current British rail network (either increasing the numbers of platforms per track, or the number of tracks would need to be reduced). This would not give the network capacity increase that is needed. Thus dedicated doors for boarding and alighting on the same platform are proposed. These allow the separation of passenger flows, similar to dedicated platforms, but without the costly infrastructure changes. This strategy is modelled by adapting the execution algorithm presented in Figure 2, to only allow boarding and alighting at their designated doors. The fourth alternative strategy is used to represent a novel passenger information system. This was first proposed by a Dutch design company, and is a long LED screen, placed above the edge of the platform. By using infrared sensors, the screen is updated with real-time information on the number of passengers in each carriage and the locations of the waiting points for the doors for the less crowded carriages. An image of this in a small-scale test at a single station is shown in Figure 5. This information system is modelled computationally by every passenger in the scenario having "knowledge" of the station and the least busy door.

5.3. Experiment execution

Each of the strategies and scenarios were tested (four factors with five levels respectively). Each combination was tested three times and means for loading times for three repetitions were then calculated.

Figure 5: The Novel Passenger Information System (Above the Train) during a Pilot Test at the Den Bosch Rail Station (Fast Co. Design 2014)

5.4. Results and Discussion

The quantitative output in this particular experiment was total loading time, taken when 90% of passengers had either alighted or boarded. 90% was chosen to overcome some of the bugs still in the model, ignoring those passengers who became stuck within the simulation. Despite the main focus on loading time in this experiment, there are a number of other numerical outputs that could be available from this simulation. Boarding and alighting times could be measured separately. Within the simulation window a plot of the door utilisation is shown in real time. This information could be noted at a number of time steps, producing a plot of each door use against time to provide an insight as to when each door is fully, over, or underutilized, as in the example from the standard simulation in Figure 6.

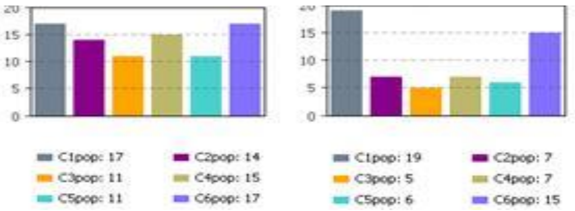

Figure 6: Number of People (Utilisation) at each of the Six Doors at the Time of Doors Opening (left) and 60 Seconds After (right)

When the doors are first opened, all doors are similarly utilised (11 to 17 passengers), whereas 60 seconds after this, the end doors have on average 172% more passengers than the inner doors, with a range of 5 to 19 passengers at each door.

The average loading times for each strategy in each scenario is shown in Figure 7. From this, analysis can be performed on the effectiveness of each strategy. In the standard scenario, with no loading strategy, an average loading time was 70 seconds, and other strategies are compared to this standard. For the 400 boarding and alighting passengers this seems realistic. Wiggenraad (2001) found that each alighting passenger going through any one door takes 1.1s, while each boarding passenger takes 0.85s. For this standard scenario with 200 boarders and 200 alighters, this would amount to 65s.

Using a mean reduction in total loading time as the measure of a strategy's efficiency, the best strategy seems to be the novel passenger information system, with a reduction of 7.3%. The dedicated boarding and alighting doors also performed well, with a 7.0% reduction. However, these were less efficient during the emergency scenario, due to a modelling assumption that would likely be ignored in a real emergency (i.e. that only the designated alighting doors could be used, despite the emergency). This effectively halved the number of exit doors available, and it would be hoped that common sense would prevail and this would not apply in an actual emergency.

The information system did not seem to be effective in the rush hour scenario. This could also be due to a ruling made during the modelling stage. By assuming boarding passengers do not allow alighting passengers to get off the train first, pressure builds up around the doors, particularly with the high passenger numbers seen in rush hour. When doors are less well used by boarding passengers, a release of this pressure is triggered as the alighting passengers have a clear exit door. When all doors are used more equally, as with the passenger information system, there are few opportunities for this social pressure to be released. One suggestion would then be to use a combination of the designated boarding/alighting doors and this passenger information system.

Wider doors led to a 1.5% and 3.5% reduction respectively. This is less than perhaps could be expected. Wiggenraad (2001) found an 11.8% reduction with 18% wider doors. He also found a diminishing returns effect that is not seen in this simulation; a 72.7% wider door only gave a 13.7% reduction. Part of the reason for this may be the differing definitions of "standard" width. When Wiggenraad performed his experiment the standard was 1100mm, whereas now, in this model it was taken as 1600mm. This means the same percentage increase is now a larger actual increase in width, potentially allowing a whole additional lane of traffic through the door.

Qualitatively, the model performed well. Within each simulation there were a number of expected behaviours shown. Crowding around doors, lane formation and oscillations in the direction of movement through doors can all be viewed in Figure 8 (see the expected behaviours from Helbing's papers 1995, 2000).

6. LIMITATIONS AND FURTHER WORK

6.1. Limitations

While the results above show that the model, in its current state, can give very useful and direct real-world outputs, some weaknesses remain. One potential weakness of multi agent simulation is the time taken to run large simulations with many agents. In the "rush hour" scenarios, it took approximately 20 minutes to run a 4 minute simulation, using an Intel Pentium 2.1GHz with 1GB RAM. However, while this is a long time period for a short simulation, when added to the development and modelling time, this would still be quicker than developing and building a physical experiment. There is also a compounding issue with higher numbers of agents. Higher forces are seen and therefore smaller time steps are needed to maintain realistic movement, adding to the slow performance.

One remaining bug, agents "bouncing" unrealistically long distances in short spaces of time, also becomes a greater issue with larger numbers of agents. When this occurs, agents initialise overlapping other agents, causing their repulsive forces to be unnaturally high. These are not physically possible or realistically expected. This also tends to occur in the first few seconds of the simulation starting, for the same reason of agents overlapping when initialising. It also occurs when the alighters initialise in the confined space of the train, forcing some to get stuck in the train. These have to be ignored in the results and outputs, but still produce a computational strain. This also limited the emergency simulation to 400 alighters, as adding more caused most of the agents to be forced out through the walls of the train, producing unnatural results.

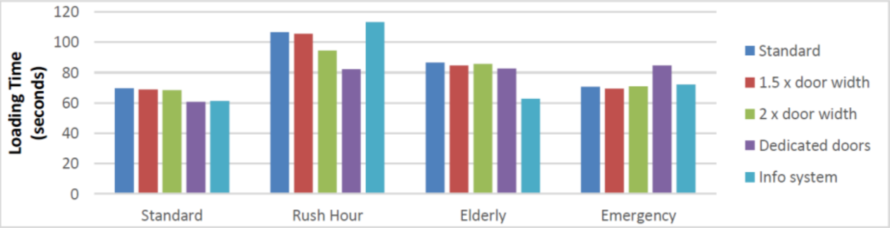

Figure 7: Loading Time Results for the Various Strategies (in legend) and Scenarios (along x axis)

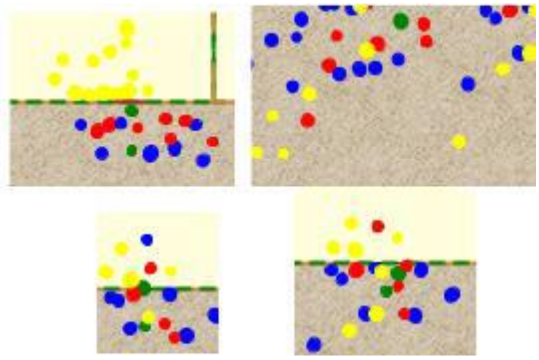

Figure 8: Clockwise from Top Left: Crowding Around Doors/Bottlenecks; Lane Formation and Oscillations Through Doorways; Alighters Going Out in YELLOW; Boarders Going Through in GREEN, BLUE and RED)

6.2. Further work

In this project we have conducted a feasibility study. There is much further work that could be done with this model in order to give it better real-world application.

The first, and perhaps most important potential improvement, is to iron out more of the issues and bugs affecting the current iteration. In particular a rule should be applied so that no agent can be initialised within touching distance of an existing agent, in order to avoid the unnatural "bouncing". This seems to also be the major cause of passengers "jumping through walls".

The next potential step is applying the model to the interior of the train. This has a large effect on flow through the doors and therefore on boarding and alighting times. Currently, there are no known studies into modelling this aspect. This would also fit with the philosophy of looking at the holistic train-platform system. It remains to be seen if the social force model would be applicable in this situation. Having so many obstacles in such a confined space, the forces related to these may sum to be so great as to produce unrealistic behaviour, forcing passengers to bounce around, or to be pushed backwards or through walls. This could be avoided by incorporating another set or parameters for internal obstacles, or a smaller connection range, ignoring all but the closest of obstacles in social force calculations. It would also require an additional state for sitting, though sitting passengers would take up a different floor area than those standing or walking. New concepts in the design of this could also be evaluated. This could also be applied to the environments on the platform (e.g. in relation to benches or seats for waiting at the rear of the platform). Some of the passengers that are randomly distributed at the rear of the platform at the beginning of the simulation would be assumed to be sitting.

Another potential improvement could be through more detailed input data, with particular use in validation and calibration. Input data from a specific platform, train, or scenario (a train dwell) at a station, including the numbers and the characteristics of passengers, could be compared to a simulation of the scenario. This could be used to produce a wider range of outputs and results, such as a passenger density map as a direct qualitative output, and flows at doors or entrances/exits. These could also be compared to outputs from similar simulations (e.g. Legion SpaceWorks). Once the agent-based model and simulation outputs are empirically validated against a number of real-world scenarios, we can be confident that the outputs with the differing dwell-time reducing strategies are sufficiently accurate for the purpose at hand.

Groups have been proposed and implemented before as part of the social force model (Xi et al. 2010). This requires a socially attractive force between group members, as opposed to the socially repulsive forces between unrelated agents. This is relatively simple mathematically, with one additional term in the social force equation. However, the difficulty comes in keeping track computationally of group members, and initialising them within these groups.

In this model, it was not assumed that all alighters are allowed off the train before boarders start getting on. In Britain, in particular, this is expected in most occasions, and so further tests could be performed with this social rule assumed. In many other countries (e.g. Germany or China) this is not the case, and it would be useful to have an option that allows parallel alighting and boarding at different levels.

7. CONCLUSIONS

The study presented in this paper has demonstrated the potential for using ABM, incorporating the Extended SFM, to assess methods of reducing dwell time at stations. A train / platform environment has been created that is capable of being adapted to represent new design ideas (e.g. providing wider doors or train carriages with different door configurations). A set of scenarios have been developed that reflect a range of real world situations, including different densities and attributes of people that interact with the station environment. These scenarios have been tested, producing some preliminary findings on boarding and alighting time. For example, from this model, it has been highlighted that using dedicated boarding and alighting doors and a novel passenger information system are promising strategies for reducing dwell times. Further work could be performed to see if this can give similar physical results to the reductions seen in this experiment (i.e. 7% and 7.3%). A combination of these strategies could be very effective.

The findings (quantitative on boarding times) and qualitative (e.g. queuing strategies) can be used to explore the likely effectiveness of new ideas and solutions to dwell time problems in a range of contexts. There is still some work to do to solve some of the problems in the model and simulation (i.e. interactions between agents and the environment), as well as opportunities to extend the work to develop a better understanding of other travel situations (e.g. travelling in groups).

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A DECISION SUPPORT SYSTEM FOR THE PRIORITIZATION OF PROJECTS AND INVESTMENTS TO MAXIMIZE IMPACT ON REGIONAL DEVELOPMENT

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ABSTRACT

Funding specific projects and actions may be used to boost a region's economic growth, but maximizing impact requires making wise, well-informed investment allocation decisions. Multiple-criteria analysis provides a means for comprehensively considering and carefully weighing the financial, environmental, political, regulatory, and practical aspects involved in such complex decisions. Designing methodologies that take these variables into account, as well as software tools to effectively manage and support data associated with the various alternatives under consideration can greatly help with this process. This paper presents a methodology for the prioritization of projects aimed at regional development and the decision support tool developed for its implementation. This methodology was used for the elaboration of the Investment Master Plan (IMP) for the PRODEPRO project in Brazil.

Keywords: regional development, decision support system, multiple-criteria decision analysis.

1. INTRODUCTION

Multiple criteria decision analysis (MCDA) is an advanced field of operations research and management science, devoted to the development of decision support tools methodologies to address complex decision problems involving multiple criteria goals or objectives of conflicting nature (Financial Times 2015). Numerous multi-criteria decision making methods (MCDM) have been developed to help with decision problems by evaluating a set of alternatives given a set of criteria. Examples of MCDM include the Analytical Hierarchy Process (Saaty 1980), the Multi-Attribute Utility Theory (Keeney and Raiffa 1993), outranking techniques (Roy 1996), fuzzy techniques (Fuller and Carlsson 1996) and weighting techniques (Keeney 1999).

The application of these techniques within the context of regional development and funding programs is well known and they are found to be very useful for policy decision making (Huang et al. 2011). Abundant literature can be found reporting either the ex-post assessment of the impact of regional development funds (Křupka et al. 2011) or aiming at informing fiscal equalisation of development funds (Hajkowicz 2007). Additionally, multi-criteria analysis is employed both for the comparison of alternatives and for monitoring of implemented actions (Garfi et al. 2011).

In this paper, we focus on the description of a methodology designed for the prioritization of projects aimed at regional development, as well as the decision support system developed to implement that methodology.

In the following section more information on the use-case is presented. Section 3 describes the methodology and general approach whereas in Section 4, the decision support system is precisely explained. In Section 5, the results obtained within the PRODEPRO use-case are outlined. This paper concludes with a summary of the corresponding conclusions.

2. PRODEPRO PROJECT IN BRAZIL

Brazil is the largest country in the Latin American region and the world's fifth largest country, both by geographical area and population. The Brazilian economy is the world's seventh largest by nominal GDP and the seventh largest by purchasing power parity (CIA 2014). In spite of being one of the world's fastest growing major economies in the last few years, further efforts are required in order to reduce the socio-economical inequalities between Brazilian regions. At present, Brazil is developing specific strategies for the economic and social enhancement of the five macro-regions of which it is composed, i.e., Northern, Northeast, Central-West, Southeast and Southern.

The Northeast Region (NE) is the country’s poorest and least developed region where 58% of the total population and 67% of the rural population lives on less than $2/day (IFAD 2014). The NE is the third largest of the five geopolitical regions of Brazil and is composed of nine states: Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe and Bahia. With an area of more than 1.5 million km^2 –more than twice the area of Spain– it represents 18% of Brazilian territory; it has a population of 53.6 million people –28% of the total population of the country– and a contribution of 13.4% of Brazil's GDP (IBGE 2011).

In pursuing a specific NE regional development strategy, the Banco do Nordeste de Brasil (Brazilian Northeast Bank, BNB) and the Inter-American Development Bank (IDB) agreed in 2012 the provision of financial and technical resources for structuring the

Northeast Region Productive Development Programme (PRODEPRO). The main strategic goal of PRODEPRO is increasing the capacity of the NE Region to promote sustainable and competitive growth of its manufacturing sector contributing to economic and social development of the region, creating jobs, and reducing inequalities (IDB 2013).

For the effective launching of PRODEPRO, an Investment Master Plan (IMP) was developed. The IMP allowed the identification and the prioritized proposal of the infrastructures, projects and actions required to achieve the aforementioned strategic objectives. The IMP entailed the following series of goals, among others:

1. Characterising production sectors within the NE Region and detecting their technical, financial, infrastructural, legal, environmental, and institutional needs.
2. Estimating growing and economic contribution of production flows for a time span of ten years.
3. Identifying and prioritizing investment opportunities in infrastructures for the region's production units, including their logistic inter-dependencies.
4. Identifying and improving the capacity of the integrated production flows axis by means of new infrastructures elements for the national and international trade.
5. Developing an Executive Plan describing the investment proposals supporting the development of production flows within the NE region and its hinterland aimed at achieving maximum physical and economic integration between States and Regions.

The IMP was carried out by a joint venture made up by two Spanish engineering SMEs (Proyfe S.L. and Teirlog Ingeniería S.L.) and one local Brazilian partner (ASTEP Engenharia Ltda.).

3. METHODOLOGICAL APPROACH

An MCDM was specially developed for the prioritization of a series of investments in the NE of Brazil but it can be generalized and applied to other cases.

The proposed methodology is partially based on the fundamental principles of the analytical hierarchy process (AHP) - i.e. decomposition of the structure of the problem, comparison of judgments, and hierarchical composition of priorities- and its main goal was to aid decision making by providing the client with a solution for effective evaluation of the projects and investments under consideration within the IMP.

The AHP enables decision makers to structure decisions hierarchically: the strategic goal(s) at the top, evaluation criteria and subcriteria in the middle, and alternative choices at the bottom (as shown in Figure 1). Decision-makers and/or the analysts can define as many subcriteria as deemed necessary. However, a large number of subcriteria might drag out the evaluation process. Provided that some parameters will be more relevant than others for achieving the strategic goals, the final analysis will only consider a set of relevant criteria which will in turn be weighed in relation to its importance. Therefore, those alternatives that perform well on the most relevant criteria will likely get higher scores.

Figure 1. Hierarchical Decision Structure

The methodology proposed in this paper is developed along two main phases and consists of the following steps:

Phase I

1. *Define the problem and the strategic goals*. This step is critical because all prioritization efforts have to be guided by the goals stated here.
2. *Determine judgement criteria*. In order to break down the decision problem, the strategic goals must be translated into relevant aspects (e.g. environmental criterion) which may be used to measure the level of performance of each alternative.
3. *Determine judgement parameters*. Criteria are defined as general assessment dimensions which represent and evaluate the goodness of projects regarding the objectives set. However, each criterion needs to be broken down into a set of relevant sub-criteria (also called parameters) that should have a much more specific meaning.
4. *Determine parameter indicators and scales*. For each parameter, a specific variable (or set of variables, in the case of so-called "compounds parameters") must be identified. Alternatives will be evaluated against each

parameter according to their “indicator” (value of the variable) and a pre-defined “scale”.

Phase II

5. *Determine each parameter and criteria relative weight*. The weights assigned to the various criteria and subcriteria show the relative importance of each one in the multi-criteria under consideration.
6. *Evaluation of the alternatives*. This is the core of the solution process. Input data associated with each alternative and parameter is required for their corresponding assessment.
7. *Determine global scores and rank the alternatives*. Once the scores of each alternative for each parameter have been obtained, parameter weights are taken into account to calculate each project’s global score.
8. *Generation of reports*. Executive Plans are generated based on the ranking of alternatives, budget constraints, and practical or political considerations.

Five main criteria (step 2) were considered for the PRODEPRO project, namely, (i) Social and Territorial Impact, (ii) Production Chain Performance, (iii) Transport and Logistic Improvements, (iv) Environmental Impact, and (v) Project Economic Characteristics.

Amongst the sixteen parameters considered for the PRODEPRO project are the following: Number of states affected, Number of microregions affected, Indigenous territories affected; Number of production chains, companies, and employees benefited; Reduction in logistic costs and times; Contamination and consumption of resources; Time to deployment, and Alignment with state policies and priorities.

The AHP was used to determine the weight assigned to both the criteria and the parameters (step 5). However, the high number of alternatives made it impossible to evaluate them using pairwise comparisons (step 6). Instead, each alternative is given a score for each parameter. In order to do so, the methodology integrates geographic information systems (GIS) and transportation modelling to obtain a set of Key Performance Indicators (KPIs) which are employed throughout the evaluation process. In this methodology, all partial scores are integer values ranging from 1 to 5.

The global score (step 7) is the dot product of the vector of partial scores and the array that contains the weights of the parameters. A linear transformation is used to convert global scores to a 0-100 scale.

Results must be explained to and discussed with the client to select a list of alternatives (step 8) that will exploit synergies and maximize impact. This list has to take into account both budgetary constraints and practical considerations.

In addition, sensitivity analysis shall be conducted to measure the robustness and consistency of the results, in terms of variations in the ranking of the projects assessed under changes in the weights assigned to the criteria.

Finally, it should be noted that discerning and selecting the alternatives is another problem that should be solved (at least partially) in a previous stage.

4. IMPLEMENTATION

A tool named COLMEIA (*colmeia* is the Portuguese word for hive) was developed in Microsoft Excel to handle large amounts of information and perform all the intermediate calculations necessary to carry out the MCDM developed for the PDI PRODEPRO.

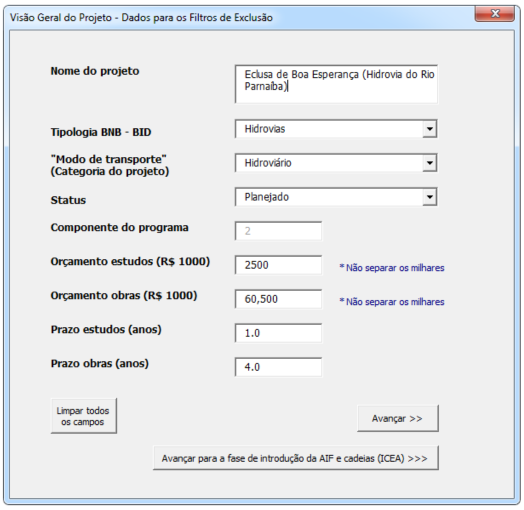
The tool is able to perform the following key tasks:

- Simultaneous analysis and comparison of up to 1000 projects. This includes: storing all data associated with these projects (data from TransCAD transport analysis, generic project profile information such as type, infrastructure budget and location, environmental data from GIS tools, econometric models, etc.), calculating the 1000 individual scores of 1000 projects for each parameter, applying exclude filters to discard projects that should not be eligible for funding, and combining each vector to calculate the overall individual score of each projects.
- Automatic application of the AHP pairwise comparison to calculate the weights of up to 5 criteria (groups of parameters).
- Automatic application of the AHP to calculate the weights of up to 30 parameters (divided into five groups of six parameters). In addition, one or more parameters can be enabled or disabled at any time, if the end-user of the tool so wishes (global scores are recalculated consistently).
- Sort projects by score and priority level to generate action plans based on the total budget available for funding.

The tool allows reviewing and analysing at any time the reasons why some projects have achieved higher ratings than other projects, making all results "traceable". In addition, it is possible to modify at any time the values considered to apply exclude filters, to calculate the importance of parameters and / or criteria against each other (AHP input data), etc.

Along with an effective implementation of the multi-criteria analysis, an extra effort to improve the efficiency of the code was carried out to avoid computation speed issues. On the other hand, a number of applications were implemented in COLMEIA to increase the tool’s usability and automate certain processes. These applications were developed using Visual Basic and created ad hoc to be used by the officers of the BNB and IDB, with a Portuguese user interface. The most important applications implemented are the following:

- Hyperlinks to relevant cells and spreadsheets.
- A wizard to modify key configuration values used in COLMEIA, such as eligibility thresholds (exclude filters) and available budget.
- A wizard for the introduction of new parameters.
- A wizard for the introduction, modification and/or removal of projects (see Figure 2).
- A routine to generate Executive Plans based on the ranking obtained and the budget constraints.



Visão Geral do Projeto - Dados para os Filtros de Exclusão

Nome do projeto: Eclusa de Boa Esperança (Hidrovia do Rio Parnaiba)

Tipologia BNB - BID: Hidrovias

"Modo de transporte" (Categoria do projeto): Hidroviário

Status: Planejado

Componente do programa: 2

Orçamento estudos (R$ 1000): 2500 * Não separar os milhares

Orçamento obras (R$ 1000): 60,500 * Não separar os milhares

Prazo estudos (anos): 1.0

Prazo obras (anos): 4.0

Figure 2. Screenshot of one of the windows implemented for the introduction of new projects.

To complete the description of the tool, the alternatives considered, the input data used, and the output data obtained in the context of the PRODEPRO project are now presented.

4.1. Alternatives under consideration

In order to meet the general objectives of a regional development program, it is necessary to define and propose projects and actions that may be very different in nature but must contribute to satisfy those goals.

The origin of the projects considered in the PDI PRODEPRO was diverse, spanning transportation plans developed by different organizations at national or regional level and requests from different public administrations from the Northeast Region of Brazil.

As transportation infrastructures are crucial for regional development, a significant portion of these projects consisted of new (or expansion of) logistic and transportation infrastructures which will channel the present and forecasted production flows in order to improve the productivity and competitiveness of the NE companies. These projects are also expected to enhance the physical integration between the nine states within the region and with the rest of the country; expanding the regional trade; and fostering exports and attracting foreign investment. Additionally, other type of investments included new transportation, energy, and telecommunications projects.

4.2. Input data

A simulation model implemented in TransCAD was developed to first analyse the present capacity of the network in order to cope with the increase in production-consumption flows expected for the next 10-year period. Second, the impact of the forecasted infrastructures in the modal split accounting for the percentage of freight absorbed by the targeted modes - rail, river and maritime feeder transport- was assessed. The simulation model had a fundamental role for determining, for each project under consideration, parameters such as the reduction in logistic costs and times, the number of production chains, and the number of states and microregions benefited.

The model methodology is based on an adaptation of the four steps model (Ortúzar and Willumsen 2011) and the simulation model itself is based on a previous TransCAD model developed within the Brazilian National Plan for Logistics and Transport.

The model network was obtained from that study and updated with the latest links as well as the investment projects studied in PRODEPRO.

Figure 3 shows the full model network which contains road links (represented in black), rail links (red), sea (blue), and waterways (light blue). Each mesoregion border is depicted in light green and state borders with thick green lines.

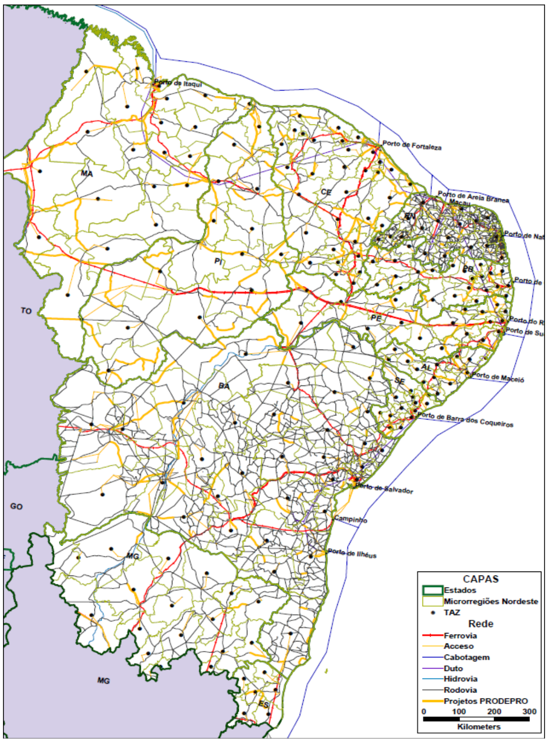


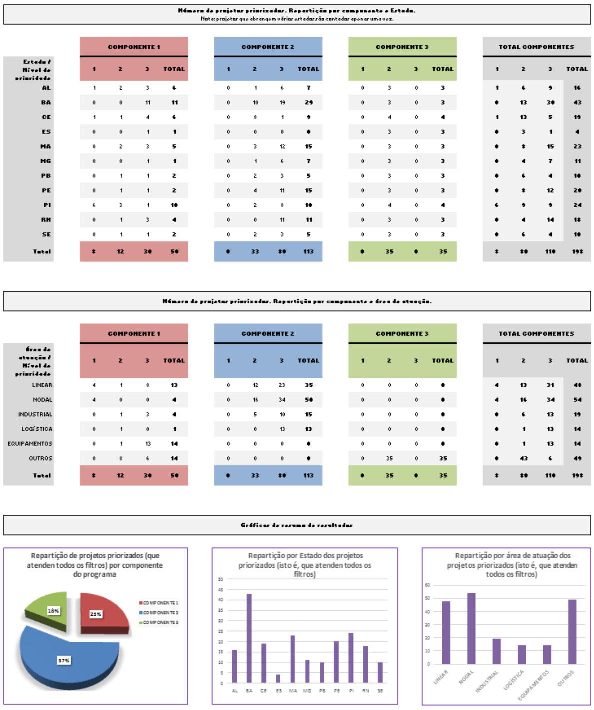
Figure 3. Model network. Investment projects to be analysed are remarked in yellow.

A thorough description of this transport model can be found in (Crespo et al. 2014).

4.3. Output data

The most relevant output data provided by COLMEIA is the ranking of alternatives, which includes their global and partial scores. This ranking is the foundation of the Executive Plan that contains the set of projects finally selected for funding. As explained in Section 3, results must be analysed and discussed with the client.

In addition, COLMEIA generates a number of matrices and graphics (see Figure 4) to report key information such as budget distribution between states, most benefited chains, types of alternatives frequently chosen, and number of eligible projects by state and type, among others.



Número de projetos priorizados. Repartição por componente e Estado.
Nota: projetos que abrangem vários estados são contados apenas uma vez.

	COMPONENTE 1				COMPONENTE 2				COMPONENTE 3				TOTAL COMPONENTES			
Estado / Nível de prioridade	1	2	3	TOTAL	1	2	3	TOTAL	1	2	3	TOTAL	1	2	3	TOTAL
AL	1	2	3	6	0	1	6	7	0	3	0	3	1	6	9	16
BA	0	0	11	11	0	10	19	29	0	3	0	3	0	13	30	43
CE	1	1	4	6	0	8	1	9	0	4	0	4	1	13	5	19
ES	0	0	1	1	0	0	0	0	0	3	0	3	0	3	1	4
MA	0	2	3	5	0	3	12	15	0	3	0	3	0	8	15	23
MG	0	0	1	1	0	1	6	7	0	3	0	3	0	4	7	11
PB	0	1	1	2	0	2	3	5	0	3	0	3	0	6	4	10
PE	0	1	1	2	0	4	11	15	0	3	0	3	0	8	12	20
PI	6	3	1	10	0	2	8	10	0	4	0	4	6	9	9	24
RN	0	1	3	4	0	0	11	11	0	3	0	3	0	4	14	18
SE	0	1	1	2	0	2	3	5	0	3	0	3	0	6	4	10
Total	8	12	30	50	0	33	80	113	0	35	0	35	8	80	110	198

Número de projetos priorizados. Repartição por componente e área de atuação.

	COMPONENTE 1				COMPONENTE 2				COMPONENTE 3				TOTAL COMPONENTES			
Área de atuação / Nível de prioridade	1	2	3	TOTAL	1	2	3	TOTAL	1	2	3	TOTAL	1	2	3	TOTAL
LINEAR	4	1	8	13	0	12	23	35	0	0	0	0	4	13	31	48
NODAL	4	0	0	4	0	16	34	50	0	0	0	0	4	16	34	54
INDUSTRIAL	0	1	3	4	0	5	10	15	0	0	0	0	0	6	13	19
LOGÍSTICA	0	1	0	1	0	0	13	13	0	0	0	0	0	1	13	14
EQUIPAMENTOS	0	1	13	14	0	0	0	0	0	0	0	0	0	1	13	14
OUTROS	0	8	6	14	0	0	0	0	0	35	0	35	0	43	6	49
Total	8	12	30	50	0	33	80	113	0	35	0	35	8	80	110	198

Gráficos de resumo de resultados

Figure 4. Example of reports generated by COLMEIA.

In the following section a summary of the results and conclusions drawn from the study carried out for the PDI PRODEPRO project can be found.

5. USE-CASE RESULTS

As stated by the client (BNB 2014), PRODEPRO's Investment Master Plan (PDI) is not only the program's major planning mechanism but also identifies the most important production sectors in the 11 states covered by PRODEPRO (in the Northeast, Minas Gerais and Espirito Santo), the related bottlenecks and priority investments for each sector and each state.

Within this study, an initial set of 948 projects were considered. By means of an exhaustive filtering and pre-analysis process –which took into account, for each project, its estimate total cost, its current status, and political preferences, among many others- the initial set of projects was reduced to a list of approximately 350, from which 75% were analysed in a comprehensive manner with the criteria and parameters discussed in previous chapters. The remaining projects were analysed under the same methodological framework but using a simplified set of parameters since they were feasibility studies and capacity building projects, and thus still far from certain implementation.

The analysis of the results ultimately led to the proposal of a prioritized set of investments constituting the infrastructure pillar of the PRODEPRO programme.

6. CONCLUSIONS

The methodology and the decision support system used for the elaboration of the Investment Master Plan (IMP) for the PRODEPRO development project in Brazil have been presented.

Whereas the AHP is used to determine the weight assigned to both the criteria and the parameters, the high number of alternatives made it impossible to evaluate them using pairwise comparisons. Instead, each alternative is given a score for each parameter. In order to do so, the methodology integrates geographic information systems (GIS) and transportation modelling to obtain a set of Key Performance Indicators (KPIs) which are employed throughout the evaluation process.

An easy to use, adaptable, and flexible tool has been specifically designed to implement this methodology, as well as to manage and provide decision-makers access to all relevant economic information. By generating new evidence in support of a decision, this tool allows end-users to make more informed decisions, and improves transparency since it provides documentation for future reference and review (traceability).

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AN INTEGRATED DECISION SUPPORT SYSTEM TO SOLVE MULTI-CRITERIA ORIENTEERING PROBLEM

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ABSTRACT

In this work we proposed an integrated support system combining a meta-heuristic algorithm and a multi-criteria decision analysis method to solve an orienteering problem applied to car-pooling system. For this purpose a Genetic Algorithm (GA), an Analytical Hierarchy Process (AHP) are implemented. The research is based on the awareness that decision makers (DMs) often face situations in which different conflicting viewpoints (goals or criteria) are to be considered. Current car-pooling web platforms are focused on the exchange of information among potential users and drivers. The aim of this work is to include in web platform a decision procedure to support driver to organize the tour considering more criteria. The driver has to decide which tour does and which users to take into the trip Preliminary test are given to validate the functionality and usefulness of created integrated decision support system.

Keywords: Orienteering Problem, Car Sharing, Multi-criteria decision support system.

1. INTRODUCTION

In these years a lot of sharing systems in mobility’s field are born due to several opportunity linked to advances in technology and to European people’s lifestyle. The systems known as car sharing, transportation on-demand, car-pooling and others, are some of the mobility solutions proposed to reduce the number of vehicles circulating and increase their occupancy. The major reasons for which these systems have developed itself during the last years are ascribable to: (i) travel cost, (ii) financial means (iii) traffic and environmental questions. Their development is due also to great progress of information and communication technologies like Geographical Information System (GIS) and Global Positioning System (GPS) that have allowed the realization of new and enhanced Intelligent Transport Systems (ITS). All policies and strategies minimizing traffic and travel demand are based on three major elements: cost-sharing, road-sharing, time-sharing. This is true in special way for car-pooling, where users share a car for a long or short trip using usually a web platform to take information and agreement about the travel. Frequently the driver of a car-pooling system, is not interested to realize a profit but only to share the travel costs, in some other cases he is a owner of several cars and for him, the travel sharing is a profit-making business. In literature there are several works that studied and described the car-sharing systems, less for car-pooling systems. Moreover, the great part of these last works take into consideration the user point of view, focusing the attention on communication protocols, rather than to optimize the whole sharing process. Furthermore, nearly all scientific works and web platforms dealing with car-pooling, take into account only the matching between supply and demand. The authors in this work propose a decision support system (DSS), able to introduce elements of optimizations and multi criteria decision making into one-way car-pooling process. The tool is developed from driver’s point of view and the aim is to optimize the car filling and consequently the car’s tour with respect to several criteria as travel cost, travel comfort and respecting the timing. The proposed DSS is structured into two decisional levels. Suppose to have n users distributed on m cities that have to share a travel or a part of travel and they are ready to pay a price for this trip. The first decisional level takes into account the matrix of distance from each city and the price offered by the users. Applying a genetic algorithm able to solve a capacitated orienteering problem we obtain as output the best tour that maximizes the Total Revenue and respects the constrains relative to car’s capacity and time schedule. The designed algorithm returns as output not only the best solution, but also a set of good solutions characterized by a different sequence of visited nodes and by different revenues, travel costs and time schedule. These solutions constituted the input for the multi criteria analysis realized with methods known in literature as Analytical Hierarchy Process (AHP) (Saaty, 1980). The output of the multi-criteria decision-making analysis is an ordered set of solutions that takes into account the criteria weights given by the driver of car-pooling system. The tool presented in this paper can be integrated in several web platforms that manage car-pooling system as: “www.blablacar.com”, “www.autostradecarpooling.it”, "www.carpooling.co.uk", "www.redefinder.com", "www.ride4cents.org", www.eurokm.com and others. This market is a business of several millions of dollars, and it is based on information and communication technologies. After all the service offered is a single travel with a traditional car, the innovative aspect is linked to the way to reserve this service and on the composition of total price of the service. For this reason the great investment in this market have to go on the software innovation direction. The proposed tool could be an additional intelligence to insert into the current web-platforms of car-pooling. The rest of paper is so organized: in the first paragraph a review of literature is given, in the second one the mathematical model and its resolution with genetic algorithm is faced in details. Following, a paragraph on the multi-criteria analysis tools like AHP model and its integration with optimization model is discussed. The last two sections are relative to presentation of results obtained in a real application and comments and conclusions about the presented scientific work. Future researches are proposed, in order to incentive the researchers to suggest innovative solution for this market characterized by a fast growth.

2. LITERATURE REVIEW

Transport is the sector with the fastest growth of greenhouse gases emissions, both in developed countries that developing. Developing countries, rely heavily on energy consumption for its daily mobility. The aim of the different plans to reduce the greenhouse gas emissions and, hence, the adverse climate change impacts, can usually be achieved with different transport policies. In this context, as stated by Yan et al. (2014), carpooling is one method that can be easily instituted and can help resolve a variety of problems that continue to plague urban areas, ranging from energy demands and traffic congestion to environmental pollution.

There aren't many scientific works that face the optimization of car-pooling or car-sharing process from the driver's point of view. Uesugi et al (2007) propose an optimization model to solve the problem to distribute cars among stations in a car-sharing system.

This problem is faced as an Assignment Problem and the system's manager point of view is assumed. Some experimental results of a simulation are given but it is not clear which type of simulation technique is applied.

Maniezzo et al. (2003) take into consideration a problem of partitioning to solve the Long-Term Car Pooling Problem (LCPP), different from Daily Car pooling Problem (DCPP) because the trip is long more than one day. The authors in their paper propose a mathematical formulation and a meta-heuristic resolution approach to solve this problem: to partition the set of users into subset such that each member of the pool in turns will pick up the remaining members in order to drive together to and from the workplace. The LCPP is studied supposing the users as component of an enterprise's staff and solved with an ANTS (Approximated Non-deterministic Tree Search alghoritm). The objective function minimizes the cost of employees' transfer from enterprise's point of view.

In Baldacci *et al.* (2004) the same problem is re-proposed using a different approach to solving the mathematical problem, the Lagrangian Column Generation.

In Calvo *et al*. (2003) DCPP is approached as a Vehicle Routing Problem with pickup and deliveries time windows (VRPPDTW). In this case it is supposed a central decision-maker that collect all information about the needs and solve the model to optimize the assignment of users and routes to the cars. The proposed model is NP-hard so a heuristic based on local search algorithm is implemented in C++ languages to find a solution for this problem.

Most carpooling organizations currently use a trial-and-error process, in accordance with the projected vehicle travel times, for the carpooling, which is neither effective nor efficient. In other words, stochastic disturbances arising from variations in vehicle travel times in current operations are neglected. In order to choose the optimal policy action to reduce the adverse climate change impacts due to the transport sector, Berrittella et al., 2007 applied the analytic hierarchy process. The AHP has become a significant methodology due to its capability for facilitating multi-criteria decisions (Ramanathan, 2001). Nosal and Solecka (2014) proposed AHP model to evaluate an integrated system of urban public transport.

3. THE MATEMATICAL MODEL AND ITS RESOLUTION APPROACH

In this research the problem to fill a car for car-pooling system is faced as a Capacitated Orienteering Problem. In a Capacitated Orienteering Problem there is a set of nodes each one with an assigned score. In the case of car-pooling the authors suppose that the nodes are the cities of users and the score is the price that users is ready to pay for travel from a city to another one. The distance among the nodes is known in terms of miles and in terms of time. The price of users is function of distance between the city of departure to city of arrive. A solution of this kind of problem is represented by single tour or path that satisfy the following request:

- The tour has to start and to end in predefined cities.
- The tour has to respect the maximum time to arrive to the destination.
- The tour has to visit more cities and to collect more users in order to maximize the travel's revenue.
- The car has a limited capacity of 4 persons (1 is the driver)
- The time of departure is known.

The mathematical model can be so formulated. $S_i \geq 0$ is the score associated to node *i*, c_{ij} is the distance associated to path between node *i* and node *j*. The first expression is called Objective Function and represents the Total revenue obtained summarizing all prices paid by users. The first constraint (2) ensures that the city of departure and the city of arrival are included into the tour. The constraint (3) guarantees that each city is visited at most one. The constraint (4) ensures the limited time budget (T_{max}). The constraint (5) guarantees the respect of limited capacity budget (C_{max}). Constraints (6) and (7) are necessary to prevent sub-tours. The binary variable x_{ij} is equal to 1 if the node *i* and the node j are visited then the users of city *i* and *j* take part to travel of car pooling.

$$\text{Max} \sum_{i=2}^{n-1}\sum_{j=2}^{n} S_i\, x_{ij} \qquad (1)$$

Subject to

$$\sum_{j=2}^{n} x_{1j} = \sum_{i=1}^{n-1} x_{in} = 1 \qquad (2)$$

$$\sum_{i=1}^{n-1} x_{ik} = \sum_{j=2}^{n} x_{kj} \leq 1 \quad \forall\, k=2,\ldots,n-1 \qquad (3)$$

$$\sum_{i=1}^{n-1}\sum_{j=2}^{n} c_{ij} x_{ij} \leq T_{max} \qquad (4)$$

$$\sum_{i=1}^{n-1}\sum_{j=2}^{n} x_{ij} \leq C_{max} \qquad (5)$$

$$2 \leq u_i \leq n \qquad \forall\, i=2,\ldots,n \qquad (6)$$

$$u_i - u_j + 1 \leq (n-1)(1-x_{ij}) \qquad \forall\, i, j=1,\ldots,n \qquad (7)$$

$$x_{ij} \in \{0,1\} \qquad \forall\, i, j=1,\ldots,n \qquad (8)$$

The Orienteering problems are classified as NP-hard problems, then, in literature several heuristic and meta-heuristic algorithms are developed to solve these kinds of problems (De Falco et al, 2015). For this reason don't exist exact algorithm to find optimal solution of this problem but only heuristic or meta-heuristic approach able to find rather good solutions. The genetic algorithm is one of these. This meta-heuristic was developed by Holland (1975) and then studied by Goldberg (1989) and it is based on evolution's concept as method to explore the solutions' set. As described in Askin et all (2013) the algorithm starts with a creation of a population of individuals corresponding to a set of solution. Each individual is a solution represented by a chromosome of integer number – combination of nodes to visit – a value of objective function – representative of solution's goodness – a fitness function – indicator of probability to create offspring. In this work each chromosome is encoded as a vector of integer number representing the nodes or the cities of the problem. In this case, the problem's solution is not represented by whole chromosome, but only of a part of this. The chromosome's part or as we call it, the tour, is composed by a sub-set of nodes that can be visited by tourist respecting the limitation time and the limitation capacity imposed. Usually the chromosome's code has a linear structure, the authors proposes a closed loop structure, thanks to it, it's possible to explore a greater number of solutions in a shorter computational time. The set of chromosomes is always structured as population, which size is a algorithm's parameter. The passage from old to new population is the core of the algorithm, following it is explained way. The fitness function value associated to each individual is greater when the individual represent a good solution for the problem. Thanks to this value the new generation will be generated with a more high probability by a set of good parents. Thanks to the use of this value the second generation of individuals will be in average better then the first since generated by the set of best parents of the first population. This mechanism guarantees the convergence of the algorithm but to explore the solutions' area in a better way some elements of variability have to be inserted. These elements are known as genetic operators and the most applied in operation research field are: crossover and mutation operators. The first one generated the offspring as combination of two parts of two chromosome's parents. In our work we implement the single crossover (one cut) and the PMX Crossover (two cuts). The mutation is an operator that changes some genes of chromosome inserting variability into new generation with respect to precedent one. The authors implemented several types of mutation operators as 2-opt and swap procedures that can be applied to population with different probability. Also the elitism mechanism it is implemented in order to create a container of best solutions founded during the several iterations. The algorithm stops when the parameter of iteration's number is reached.

4. MULTI CRITERIA ANALYSIS TOOL

4.1. Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) breaks down a decision-making problem into several levels in such a way that they form a hierarchy with unidirectional hierarchical relationships between levels (De Felice and Petrillo, 2014). The AHP for decision making uses objective mathematics to process the inescapably subjective and personal preferences of an individual or a group in making a decision. With the AHP, one constructs hierarchies or feedback networks, then makes judgments or performs measurements on pairs of elements with respect to a controlling element to derive ratio scales that are then synthesized throughout the structure to select the best alternative (De Felice, 2012). The top level of the hierarchy is the main goal of the decision problem. The lower levels are the tangible and/or intangible criteria and sub-criteria that contribute to the goal. The bottom level is formed by the alternatives to evaluate in terms of the criteria. The modeling process can be divided into different phases for the ease of understanding which are described as follows:

- PHASE 1: Pairwise comparison and relative weight estimation. Pairwise comparisons of the elements in each level are conducted with respect to their relative importance towards their control criterion. Saaty suggested a scale of 1-9 when comparing two components. For example, number 9 represents extreme importance over another element. And number 8 represents it is between *''very strong important''* and *''extreme importance''* over another element. The result of the comparison is the so-called dominance coefficient aij that represents the relative importance of the component on row (i) over the component on column (j), i.e., $a_{ij}=w_i/w_j$. The pairwise comparisons can be represented in the form of a matrix. The score of 1 represents equal importance of two components and 9 represents extreme importance of the component i over the component j.

- PHASE 2: Priority vector. After all pairwise comparison is completed, the priority weight vector (w) is computed as the unique solution of $Aw = \lambda_{max}w$, where λ_{max} is the largest eigenvalue of matrix A.
- PHASE 3: Consistency index estimation. Saaty (1990) proposed utilizing consistency index (CI) to verify the consistency of the comparison matrix. The consistency index (CI) of the derived weights could then be calculated by: $CI = (\lambda_{max}-n)/ n-1$. In general, if CI is less than 0.10, satisfaction of judgments may be derived.

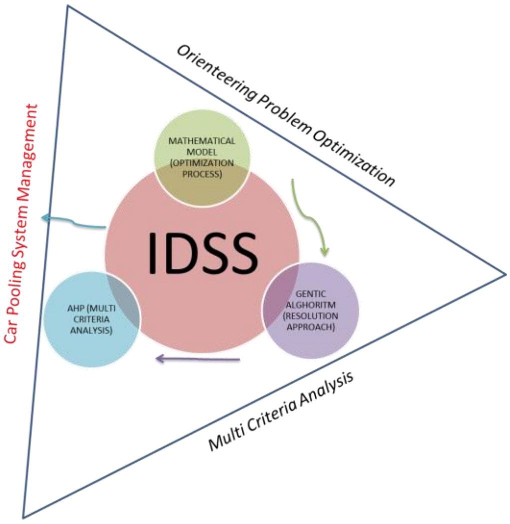


Figure 1: Integrated Decision Support System (IDSS)

For this application the AHP takes as input the results of optimization process and evaluates these under several criteria better explained in the next paragraph. The Figure 1 represents the most significant phase of the proposed integrated DSS. As first activity the mathematical model is supposed to model the capacitated orienteering problem, as second phase we solve the formulation implemented a meta-heuristic known as Genetic Algorithm (GA). Then, we applied a multi-criteria analysis (AHP model) to algorithm's results with the aim to order the founded solutions respect to the following objectives: timing, revenue and comfort of travel.

5. EXPERIMENTAL RESULTS

Experimental results are so achieved. From a web platform of car sharing we select a day and do a query of all users' requests for the same destination. Then, we build a matrix of distance among the several cities with a request and the start and destination point. This experiment is been done on Italian highway network.

Supposing to be Naples (node 0) the origin and Milan the destination (node 14) of car-pooling's travel. We collect 13 requests from the following cities' toll booths: *Caserta, Latina, Rome, Civitavecchia, Viterbo, Grosseto, Orvieto, Florence, Bologna, Genova, Reggio Emilia, Turin, Parma.*

Solving a Capacitated Orienteering Problem with the Genetic Algorithm described in paragraph 3, we obtained a set on n better solutions, so structured:

- List of cities to visit or rather the tour of trip;
- Total revenue coming from users taking part of tour.
- Travel time from origin to destination;
- Travel distance from origin to destination;
- Number of passengers that taking part of the tour.

The Figure 2 represents the algorithm's solution supposing to have a maximum time for the travel equal to 550 minutes, and 4 seats for passengers at most. The algorithm is set to obtain 6 six different solutions.

T max	Distance	Cost	Revenue	Tour					Passengers
550	535	149	212	0	1	7	8	14	3
550	539	150	191	0	1	7	11	14	3
550	550	153	200	0	1	7	9	14	3
550	550	152	201	0	1	3	13	14	3
550	538	150	187	0	3	7	8	14	3
550	549	153	205	0	1	3	11	14	3

Figure 2: GA's solutions with T_{max} = 550 minutes and capacity equal to 4

The same experiment has been repeat for three different Tmax equal to 550, 600 and 650 minutes. Like it is possible to observe from next Figure with more time available the car can keep 4 passengers and fulfilling the car. Moreover, in the last instances with 650 minutes to end the travel, the driver can increase the total revenue linked to transfer.

T max	Distance	Cost	Revenue	Tour						Passengers
600	582	155	270	0	1	3	7	11	14	4
600	593	921	279	0	1	3	7	9	14	4
600	588	158	262	0	1	5	7	11	14	4
600	584	156	283	0	1	5	7	8	14	4
600	598	153	318	0	1	3	4	6	14	4
600	582	154	266	0	1	3	7	13	14	4

Figure 3: GA's solutions with T_{max} = 600 minutes and capacity equal to 4

T max	Distance	Cost	Revenue	Tour						Passengers
650	944	172	319	0	1	3	7	5	14	4
650	905	165	314	0	1	3	5	6	14	4
650	880	160	319	0	1	3	5	7	14	4
650	875	169	310	0	1	5	4	6	14	4
650	874	159	329	0	1	3	4	5	14	4
650	828	161	327	0	1	2	4	6	14	4

Figure 4: GA's solutions with T_{max} = 650 minutes and capacity equal to 4

The outputs of optimization process as before described, are given as inputs of AHP model built as in Figure 5. In the present paper AHP Absolute model is applied (De Felice and Petrillo, 2013). AHP Absolute model is based on paired comparisons among the elements of a set with respect to a common attribute. This process is essential for comparing intangible attributes for which there are no agreed upon measures. Absolute method is typically used in a decision situation that involves selecting one (or more) decision alternatives from several 'candidate' decision alternatives on the basis of multiple decision criteria of a competing or conflicting nature.

Experts team developed pairwise comparison matrices to determine the weights of criteria. Figure 6 shows an example of pairwise comparison. Consistency index has been estimated (CI 0.051). As it is possible to note the most important criteria is "Profit" with a score of 49%, followed by "Time" with a score of 31% and finally is the criteria "Comfort" with a score of 19%.

In AHP Absolute model criteria are further subdivided into a level for intensities. Experts team defined each alternative by assigning the intensity rating that applies to them under each criterion. The scores of these intensities are each weighted by the priority of its criterion and summed to derive a total ratio scale score for the alternative. Each criterion has ratings listed under it. Figure 7 shows the final ranking of the AHP Model.

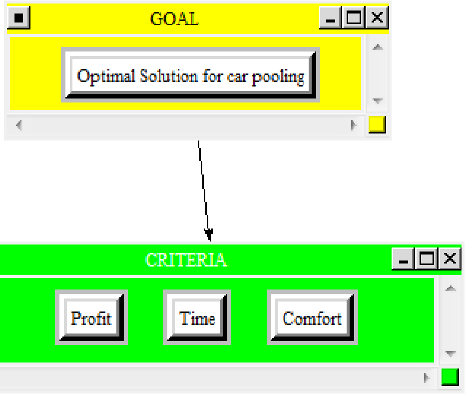
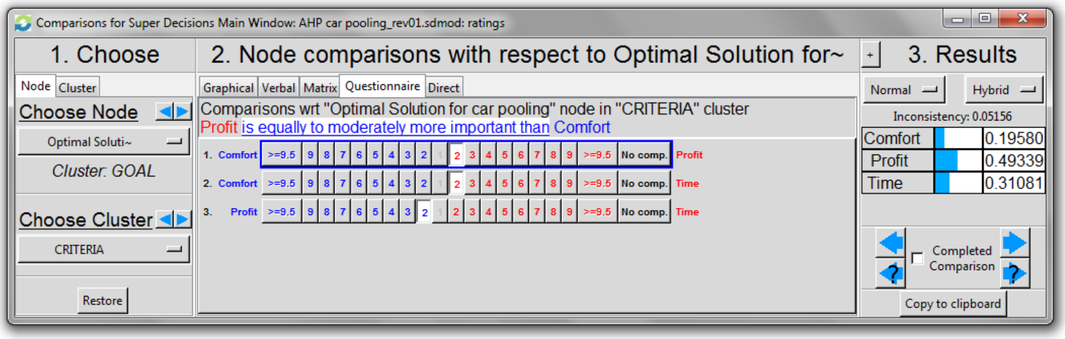


Figure 5: AHP Absolute Model


Comparisons for Super Decisions Main Window: AHP car pooling_rev01.sdmod: ratings

1. Choose

2. Node comparisons with respect to Optimal Solution for~

3. Results

Comparisons wrt "Optimal Solution for car pooling" node in "CRITERIA" cluster

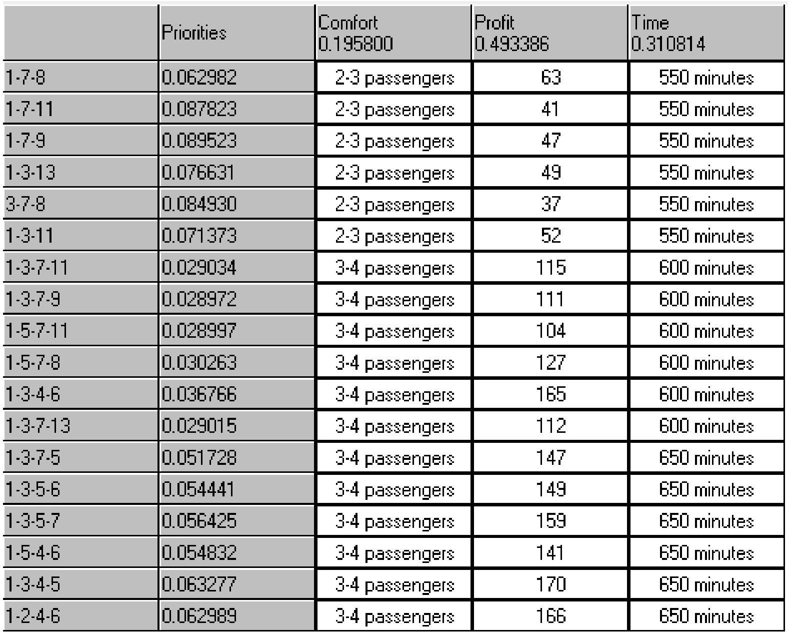
Profit is equally to moderately more important than Comfort

1. Comfort >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Profit
2. Comfort >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Time
3. Profit >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Time

Inconsistency: 0.05156

Comfort	0.19580
Profit	0.49339
Time	0.31081

Figure 6: Pairwise comparison for criteria cluster



	Priorities	Comfort 0.195800	Profit 0.493386	Time 0.310814
1-7-8	0.062982	2-3 passengers	63	550 minutes
1-7-11	0.087823	2-3 passengers	41	550 minutes
1-7-9	0.089523	2-3 passengers	47	550 minutes
1-3-13	0.076631	2-3 passengers	49	550 minutes
3-7-8	0.084930	2-3 passengers	37	550 minutes
1-3-11	0.071373	2-3 passengers	52	550 minutes
1-3-7-11	0.029034	3-4 passengers	115	600 minutes
1-3-7-9	0.028972	3-4 passengers	111	600 minutes
1-5-7-11	0.028997	3-4 passengers	104	600 minutes
1-5-7-8	0.030263	3-4 passengers	127	600 minutes
1-3-4-6	0.036766	3-4 passengers	165	600 minutes
1-3-7-13	0.029015	3-4 passengers	112	600 minutes
1-3-7-5	0.051728	3-4 passengers	147	650 minutes
1-3-5-6	0.054441	3-4 passengers	149	650 minutes
1-3-5-7	0.056425	3-4 passengers	159	650 minutes
1-5-4-6	0.054832	3-4 passengers	141	650 minutes
1-3-4-5	0.063277	3-4 passengers	170	650 minutes
1-2-4-6	0.062989	3-4 passengers	166	650 minutes

Figure 7: Pairwise comparison for criteria cluster

As it is possible to note from Figure 3 the preferable solution is 1-7-9 with a priority of 89%, followed by 1-7-11 with a score of 87%.

6. CONCLUSION AND FUTURE WORKS

In this work the authors present an Integrated Decision Support System (IDSS) that integrate a meta-heuristic and multi-criteria analysis in order to create an intelligent tool for car-pooling system. Actually in fact, all web platform that manage car-pooling system are finalized only to create a communication protocols to match supply and demand. With the proposed tool will be possible to insert inside the traditional system an additional “intelligence” able to found the best combination of travel for the driver point of view. If the users are ready to pay different prices then the driver has to choose the solution that maximize the revenue, minimize the cost of travel, guarantee the comfort and respect the timing. These entire requests can’t be satisfied with a simple optimization or with a simple communication protocols, an integrated intelligent system is necessary and its what the authors have implemented in this work. Future research can focus their attention to rich the proposed tool of other methods, others meta-heuristic (i.e. Ants Algorithm) and others method for multi criteria analysis (i.e. ELECTRE). The aim of these future researches will be offer a complete system flexible and fast for each situation. Will be also interesting introduce directly into the IDSS some elements of communication and negotiation, since in this work we take into consideration only one driver point of view. Another interesting act could be to use the weight of multi criteria analysis in order to realize a multi-objective function of the orienteering problem. These could be the starting points for future researches.

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IMPROVEMENT OF THE WAREHOUSE OPERATION IN THE FURNITURE COMPANY ON THE BASIS OF THE SIMULATION STUDY

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ABSTRACT

The paper highlights the problem of computer simulation usage aimed at the warehouse operation improvement in the furniture company. Attention is paid mainly to the processes of receipt of parts in the warehouse. The simulation study ties together the project of the controlled warehouse implemented by the company. The goal of the simulation study is to verify whether workers are able to complete the intake of all parts within standard working hours. Subsequently, experiments with the use of the proposed model help to formulate recommendations which are to increase the productivity of processes and put down the time needed for the intake process into the warehouse. The Witness simulation environment is used for modelling and the subsequent simulation process. The simulation experiments are evaluated according to the total time needed for the intake of all parts, productivity of workers and the amount of overtime work. Finally, the proposed simulation experiments and evaluation of achieved results are described in detail.

Keywords: warehouse, warehouse operation optimization, modelling, simulation, computer simulation, Witness

1. INTRODUCTION

The right decision-making approach is unavoidable in each complex manufacturing system. Manufacturing companies are currently facing very strong pressure in terms of cost, quality, flexibility, customisation and a product delivery time to the defined market. Production and warehouse systems of these companies have to be flexible and able to react to changing production capacity requirements (Modrak and Pandian 2012). One of the ways to achieve efficiency is through the use of automated manufacturing, implementation available combinations of either manufacturing or replacement strategies (Chramcov, Bucki and Suchánek 2015) or improvement of the warehouse operation.

Warehouse operations efficiency is the key to the success of any company that processes inventories. When efficiency lags, products may not arrive at customer destinations on time, orders can get lost, and low inventory levels can result in stock-outs.

Operational optimization seeks to improve efficiency and effectiveness of a warehouse process. Despite the implementation of new philosophies in e-commerce, supply chain integration, quick response, just-in-time delivery and efficient consumer response that aim at shortening the supply chain by connecting the manufacturer with the end customers and hence gears towards eliminating the existence of a warehouse, many organization are yet able to implement these philosophies successfully (Tompkins and Smith 1998). Warehouses are still a common and central feature in most supply chains due to the partial implementation of lean and agile philosophies. Organizations need to find ways to effectively manage and perform operations inside a warehouse with much efficiency and in turn reduce the storage time and costs involved in the storage. These targets cannot be achieved by blindly adapting and deploying new trends and technologies. There is a need to optimize the technology, operation and manpower in order to get good results and high efficiency (Kare et al. 2009). An overview related to warehouse optimization problems is presented in (Karasek 2013). The author shows the current state of the art in optimization in three groups of interest in logistic warehouses and distribution centres.

Gill (Gill 2006) observes that warehouse management and inventory control are the areas within the supply chain with the greatest potential savings when it comes to optimization of the supply chain. Therefore, by properly managing inventory of an organization and warehouse operations by means of the best practices, management will provide the largest impact on a company's bottom line than virtually any other functional area. Recent investigations also reveal that about 33 per cent of logistic costs can be attributed to the costs arising in inventory management and therefore, a proper investigation of savings that might be achieved within this part of supply chain is necessary and is, in many cases, profitable (Raidl and Pferschy 2010). Warehouse operation optimization generally focuses on how well the warehouse utilizes the existing storage capacity, measuring the impact of our choices of

material handling equipment, labour, methods, procedures, and support systems. An extensive review on warehouse operation planning problems is presented in (Gu, Goetschalckx and McGinnis 2007). This paper provides a detailed discussion on warehouse operation-planning methods together with warehouse design, computational systems, and case studies. A recent survey on the overall warehouse design and operation problems is emphasized in (Rowenhorst et al. 2000). Moreover, in the work (Baker and Canessa 2009), the current literature on the overall methodology of warehouse design is explored, together with the tools and techniques used for specific areas of analysis. The output is a general framework of steps, with specific tools and techniques that can be used for each step. This is intended to be of value to practitioners and to assist further research into the development of a more comprehensive methodology for warehouse design.
This article focuses on a proposal to streamline warehouse operations of the furniture company. It results in the simulation study of the system. Several experiments were designed and subsequently simulated within this study case. The goal of the simulation study was to find a solution to the problem of completing the process of receiving and storing all varieties of pallets (coming within a day) throughout a standard work shift. Therefore, there was a need to suggest measures that would increase the productivity of processes and, at the same time, reduce the time needed for storing pallets which are to arrive on that certain day. Modeling and simulation were implemented in the simulation environment Witness. Validation and verification of the model was performed on the basis of comparison with real operational data and, in particular, on the basis of consultation with the warehouse staff.

2. DESCRIPTION OF THE SYSTEM

Individual processes and incoming stock pallets in the warehouse are schematically illustrated in Fig. 1. This diagram represents the basic elements and relationships of the discussed system and is the basis for the future computer model.

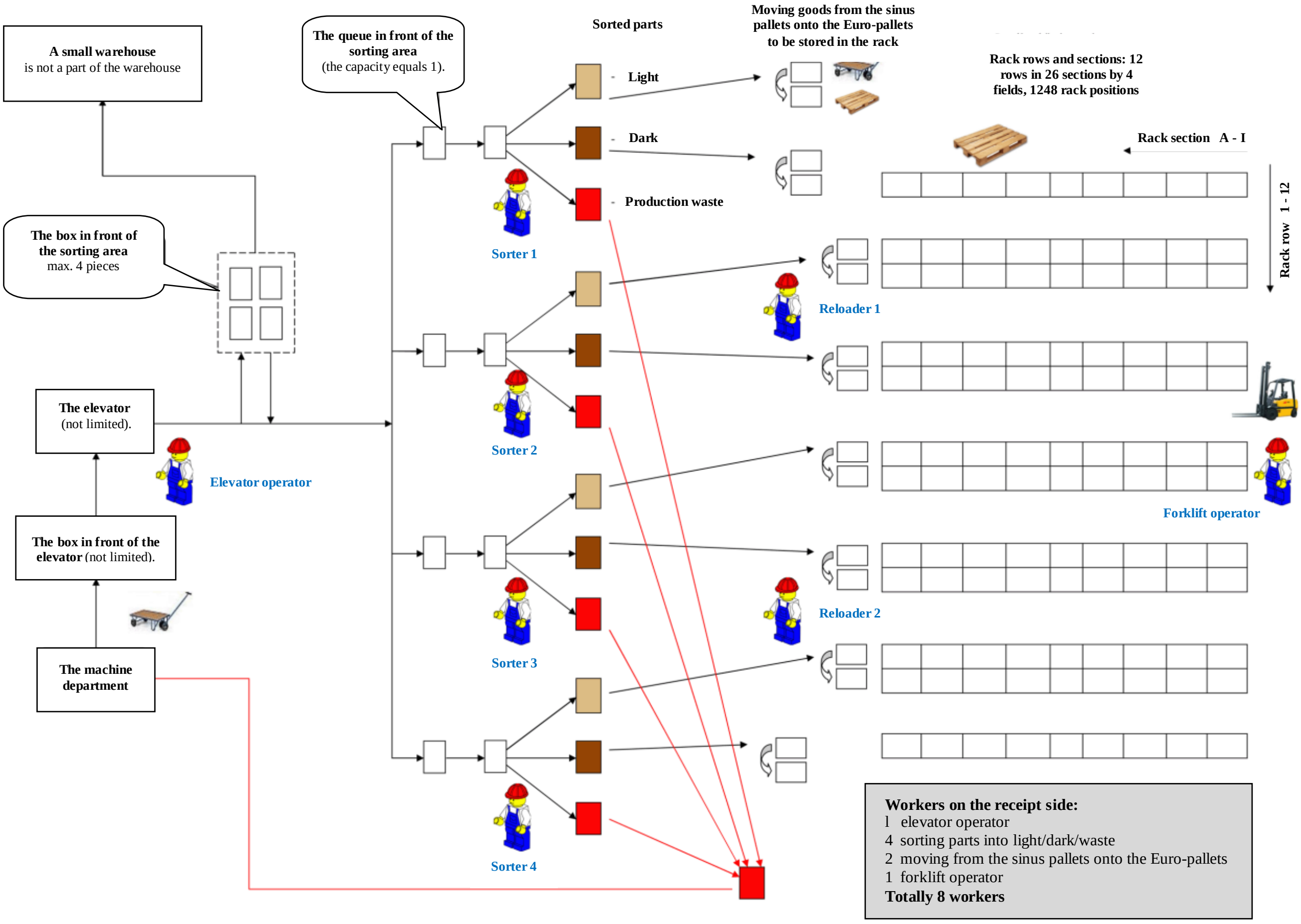

Fig. 1: The conceptual model

As it can be seen from the diagram in Fig. 1, eight workers are employed to secure functioning of the warehouse while receiving and storing. One worker handles operation of the elevator, four workers ensure the process of sorting the individual components to be stored, two workers put components on the rack pallets and one worker operates the forklift. The goal of the elevator service is to supply the workstation which sorts pallets with pallets intended only for sorting. One working cycle consists of several sub-steps. More detailed specification is outlined in Table 1. Some of the incoming pallets are designed for a small stock. This kind of warehouse is not considered in the simulation study. The pallets are put aside by the elevator operator after transporting them to the specified point and the operator of the small warehouse cares of them.

There are four sorting workplaces. Each of them is served by one worker only. Its main goal is to sort parts into light and dark pieces. The duty of the cycle sorting process depends on the specific type and quantity of pieces on a sorting pallet. After completing the sorting process, sorted pallets are moved to the sorting workplace.

Table 1: Description of the working activities of the warehouse employees.

Workplace	**Work activities**	**Operation time**
elevator service	elevator ride to the ground floor for loading pallets	40 s
	walk for a pallet	17 s
	transporting the pallet into the elevator (if there are more pallets in front of the elevator, this step is repeated until the elevator is filled with four pallets)	17 s
	elevator ride to the storing space	40 s
	removing the pallet from the elevator	17 s
	recording the arrival of each pallet by means of the electronic reader	12 s
	transporting pallets to the sorting workstation	19 s
	return to the elevator area	12 s
sorting	sorting process	according to the type and number of parts
	moving a pallet	24 s
reloading	reloading process	according to the type and number of parts
forklifts	finding where the required pallet is currently by means of a reading device	6 s
	ride for the rack pallet	36 s
	picking up the pallet from a rack position	25 s
	transporting the pallet to the sorting workplace	40 s
	stock performance of the new number of parts on a pallet by means of the reading device	20 s
	transporting a pallet to the rack	40 s
	putting a pallet to the rack position	30 s
	return to the sorting workplace for the new task	36 s

There are four sorting workplaces. Each of them is served by one worker only. Its main task is to sort parts for light and dark pieces. The duty cycle sorting process depends on the specific type and quantity of pieces on a sorting pallet. After completing the sorting process, sorted pallets are moved to the sorting workplace.

Until now, the so-called sinus pallets have been used to manipulate with the parts which are not suitable to be stored on the rack. The workhouse space includes 8 workplaces used for reloading operations. They are served by two employees moving between them. The time of placing parts on the Euro-rack pallet is given by a certain type and amount of pieces reloaded on the pallet.

The operator of the forklift delivers a rack pallet of the required type to the sorting place. After carrying out sorting operations, the operator secures restocking Euro-pallets to the appropriate rack. It is important to emphasize that there is only one worker in the warehouse. Table 1 presents individual tasks for this worker including duration. The total time of unloading a rack pallet equals 107s and putting it back into the rack position takes 126s. As seen from the above, it was necessary to collect a large amount of data to form a valid model. The data is analysed and evaluated subsequently.

There are nearly 1,150 kinds of parts stored in a large warehouse. They were divided according to their similarities into 46 type groups for the purposes of the simulation study. Each type group is characterized by four basic characteristics e.g. the ratio of dark and light pieces, sorting time, time of storing operations, belonging to the small or large warehouse.

Times of sorting and storing or manipulation operations as well as times of recording by the reading device were set on the basis of the measurement of direct observation in the workplace. The number of measurements varies according to the length of the working cycle.

Arrival times of the individual pallets in the system are obtained from the output information system of the company.

The warehouse operates in one shift of 8 hours. The shift starts at 6.00 am and ends at 2.00 pm. The lunch break lasts from 10.45 to 11.15 am.

3. MODEL OF THE CURRENT STATE

The model of the current state of the warehouse was created on the basis of a detailed analysis of the system. The simulation environment *Witness* was used to create the model and carry out the subsequent simulation process.

Six experiments were carried out with the created model. Each experiment was based on various input data. These data correspond to 6 specific working days. These days were marked as average by warehouse employees without the occurrence of abnormal conditions and failures. The results of these experiments were compared with the facts and were also consulted with the staff of the warehouse.

One day was chosen on the basis of comparison of the resulting times required to store the last pallet on an individual day. This day was treated as the reference one while carrying out simulation experiments. The day characterized by the highest difficulty time was chosen. The combination of the number of pieces of each type placed on pallets as well as their sorting and reloading times are given.

A target function (evaluation criteria) of simulation experiments were set on the basis of consultation with warehouse workers.

Individual simulation experiments are evaluated by:

- the total time needed for storing all pallets (storing the last pallet);
- workload of individual workers;
- amount of overtime work;
- the number of workers needed for one shift.

3.1. Simulation results of the model of the current state

Simulation results of the current state are shown in Table 2 in the form of exact beginning and finishing times of working activities of individual workers during one day. Moreover, there are real work times and downtimes of individual workers. Workload of a worker is a ratio of the real working time to the total time which the worker spends at the workplace within one working day (i.e. till finishing the last working activity).

Table 2: Simulation results of the current state of the warehouse

Employee	**Beginning of the shift**	**End of the shift**	**Real beginning of work**	**Real end of work**	**Waiting time (downtime)**	**Worktime**	**Workload**	**Overtime**
Elevator operator	6:00:00	14:00:00	6:05:00	14:50:10	5:03:07	3:47:03	42.83%	0:50:10
Sorter 1	6:00:00	14:00:00	6:07:10	15:42:50	3:04:50	6:38:00	68.29%	1:42:50
Sorter 2	6:00:00	14:00:00	6:09:40	15:36:10	4:32:44	5:03:26	52.66%	1:36:10
Sorter 3	6:00:00	14:00:00	6:12:10	15:31:20	4:52:11	4:39:09	48.86%	1:31:20
Sorter 4	6:00:00	14:00:00	6:23:20	16:22:10	5:10:45	5:11:25	50.05%	2:22:10
Reloader 1	6:00:00	14:00:00	6:15:10	16:46:30	5:43:48	5:02:42	46.82%	2:46:30
Reloader 2	6:00:00	14:00:00	6:37:00	16:39:00	7:20:04	3:18:56	31.13%	2:39:00
Forklift operator	6:00:00	14:00:00	6:12:30	16:48:00	0:56:23	9:51:37	91.30%	2:48:00
Total	---	---	---	---	**36:43:53**	**43:32:17**	---	**16:16:10**
Average	---	---	---	---	**4:35:29**	**5:26:32**	**53.99%**	**2:02:01**

From the results it is evident that it was impossible to store the last pallet in the due time shift i.e. till 2 pm. The last pallet was stored more than two hours after the end of the shift. Knowing this fact, a need to employ workers overtime arises. This overtime equals more than 16 hours which gives more than 2 hours per worker on average. The total working time of employees equals 43.5 hours approximately and the waiting time during the work period for all workers equals approximately 36.7 hours. The downtime represents 45.8% of the time spent by workers at the workplace.

From the point of view of individual workers, it is obvious that servicing the forklift is the bottleneck of the system. Utilization of this worker equals more than 90 percent.

4. SIMULATION EXPERIMENTS

On the basis of the simulation results of the model representing the current state of the warehouse it became necessary to propose appropriate solutions to improve warehouse operations. The goal was to sort out and store all pallets in the shortest possible time while reducing and finally eliminating overtime work. Moreover, it was necessary to specify an appropriate number of staff at each work position of the warehouse.

The time-scaling of simulation experiments was carried out from two points of view. First of all, there was a need to increase the flow of the system i.e. to eliminate bottlenecks in the process of receiving and storing in the way which can enable us to minimize the total time of storing all pallets. Secondly, there was a need to minimize the waiting time of individual workers i.e. maximize their workload.

The first experiment tries to remove the bottleneck of the system. According to the simulation of the current state (see Table 2) a forklift operator seems to be the bottleneck. For this reason, the option including adding the second forklift operator was added in order to improve the flow of the system.

Results of this simulation experiment are clearly shown in Table 3. By means of adding another operator of the forklift the average workload of the discussed workers went down to 52%. The bottleneck was moved to the sorting area where workers are characterized by their 62% average workload. A possibility of increasing the number of sorting places cannot be taken into account due to the dimensions as well as physical layout of the warehouse.

Table 3: Simulation results including adding one more operator of the forklift

Employee	**Beginning of the shift**	**End of the shift**	**Real beginning of work**	**Real end of work**	**Waiting time (downtime)**	**Worktime**	**Workload**	**Overtime**
Elevator operator	6:00:00	14:00:00	6:05:00	13:57:40	4:15:21	3:42:19	46.54%	0:00:00
Sorter 1	6:00:00	14:00:00	6:07:10	15:17:50	2:13:27	7:04:23	76.08%	1:17:50
Sorter 2	6:00:00	14:00:00	6:09:40	14:19:40	2:56:11	5:23:29	64.74%	0:19:40
Sorter 3	6:00:00	14:00:00	6:12:10	14:37:20	3:24:00	5:13:20	60.57%	0:37:20
Sorter 4	6:00:00	14:00:00	6:23:20	14:17:20	4:26:13	3:51:07	46.47%	0:17:20
Reloader 1	6:00:00	14:00:00	6:14:30	15:24:40	4:53:19	4:31:21	48.05%	1:24:40
Reloader 2	6:00:00	14:00:00	6:15:00	15:24:10	5:33:44	3:50:26	40.84%	1:24:10
Forklift operator 1	6:00:00	14:00:00	6:12:30	15:26:30	3:57:22	5:29:08	58.10%	1:26:30
Forklift operator 2	6:00:00	14:00:00	6:13:10	15:26:50	5:02:54	4:23:56	46.56%	1:26:50
Total	**---**	**---**	**---**	**---**	**12:42:30**	**19:29:30**	**---**	**8:14:20**
Average	**---**	**---**	**---**	**---**	**4:04:43**	**4:49:57**	**54.22%**	**0:54:56**

Increasing forklift service by one operator leads to accelerating storing all pallets nearly by 1.5 hours. The total utilization of all workers remained very similar to the current state. The amount of overtime fell by 8 hours. Therefore, it is worth considering to what extent the reduction of storing time of all pallets is the key issue for the company. Moreover, it is important to find out whether it is worth investing in another forklift and a trained employee.

A more detailed analysis of the workload of individual workers revealed that workers are busier in the afternoon hours than before the midday. This is due to a higher number of incoming pallets to be stored in the afternoon hours. For this reason, several experiments were designed and carried out. They solve the problem of moving the working shift of individual workers. Table 4 presents the results of the simulation where the beginning of the working shift of one reloading worker was moved to 11.15 am. This time corresponds to the time of return from the lunch break.

Table 4: Results of the simulation experiments including moving the working shift of the reloading worker

Employee	**Beginning of the shift**	**End of the shift**	**Real beginning of work**	**Real end of work**	**Waiting time (downtime)**	**Worktime**	**Workload**	**Overtime**
Elevator operator	6:00:00	14:00:00	6:05:00	14:45:50	5:00:16	3:45:34	42.90%	0:45:50
Sorter 1	6:00:00	14:00:00	6:07:10	15:34:50	2:56:52	6:37:58	69.23%	1:34:50
Sorter 2	6:00:00	14:00:00	6:09:40	15:43:40	4:58:27	4:45:13	48.87%	1:43:40
Sorter 3	6:00:00	14:00:00	6:12:10	16:11:40	5:08:48	5:02:52	49.52%	2:11:40
Sorter 4	6:00:00	14:00:00	6:23:20	15:28:10	4:22:01	5:06:09	53.89%	1:28:10
Reloader 1	6:00:00	14:00:00	6:14:30	16:44:50	5:07:05	5:37:45	52.38%	2:44:50
Reloader 2	11:15:00	15:15:00	11:15:00	16:47:20	2:48:28	2:43:52	49.31%	1:32:20
Forklift operator	6:00:00	14:00:00	6:12:30	16:49:30	1:03:16	9:46:14	90.26%	2:49:30
Total	**---**	**---**	**---**	**---**	**7:25:12**	**19:25:38**	**---**	**14:50:50**
Average	**---**	**---**	**---**	**---**	**3:55:39**	**5:25:42**	**57.04%**	**1:51:21**

Results of the experiment indicate that the work time of the reloading worker was shortened by 4 hours (moving the beginning of the shift to 11.15 am and the ending of the shift to 15.15 pm) however; this measure did not have a major impact on prolonging the period of storing all pallets. This period was extended only by 90 seconds. Thus fewer resources were required to store all pallets (fewer man-hours). At the same time there was an increase in the average workload of staff of the whole process of receiving and storing by 3% and the amount of overtime fell by 1.5 hours.

Based on the results of previous experiments, several new experiments were designed and carried out. These experiments remove the bottleneck of the forklift operator and at the same time purposefully move the working shift of individual workers.

Table 5 presents results of one of the best experiments which comprises the aforementioned conditions.

The bottleneck (the forklift operator) was supported by another operator beginning with 11.15 am. This worker is employed part-time in the process (half shift). This measure covers the bottleneck of the storing process which is caused by the increased intake of pallets in the second half of the work shift. The beginning of the working shift of all warehouse employees was moved unlike the current state (see Table 5). Additionally, the length of one reloading worker’s shift was shortened to its half.

Table 5: The results of the simulation experiment concerning adding one more operator of the forklift and moving the working shift of individual worker

Employee	**Beginning of the shift**	**End of the shift**	**Real beginning of work**	**Real end of work**	**Waiting time (downtime)**	**Worktime**	**Workload**	**Overtime**
Elevator operator	6:30:00	14:30:00	6:30:00	14:08:10	4:00:28	3:37:42	47.52%	0:00:00
Sorter 1	6:30:00	14:30:00	6:32:20	14:13:10	2:01:18	5:41:52	73.81%	0:00:00
Sorter 2	6:30:00	14:30:00	6:36:00	15:14:30	2:42:45	6:01:45	68.97%	0:44:30
Sorter 3	7:00:00	15:00:00	7:00:00	14:30:10	2:47:15	4:42:55	62.85%	0:00:00
Sorter 4	7:00:00	15:00:00	7:00:00	14:29:00	2:24:46	5:04:14	67.76%	0:00:00
Reloader 1	6:30:00	14:30:00	6:39:30	15:25:00	3:05:59	5:49:01	65.24%	0:55:00
Reloader 2	11:15:00	15:15:00	11:15:00	15:17:00	1:29:23	2:32:37	63.06%	0:02:00
Forklift operator 1	6:30:00	14:30:00	6:37:30	15:24:30	1:39:11	7:15:19	81.44%	0:54:30
Forklift operator 2	11:15:00	15:15:00	11:15:00	15:27:00	1:38:59	2:33:01	60.72%	0:12:00
Total	---	---	---	---	**21:50:05**	**19:18:25**	---	**2:48:00**
Average	---	---	---	---	**2:25:34**	**4:48:43**	**65.71%**	**0:18:40**

Introduced measures shortened the time of storing all pallets by 17% i.e. 8 hours 57 minutes. This means loading the last pallet during 15 hours 27 minutes. Moreover, average utilization of the warehouse employees was also increased in comparison with the reference day by 11.7 %. At the same time the amount of overtime work was reduced by 83%. A forklift operator was added to the process of storing pallets employed for half of the work shift. Additionally, the shift of the worker responsible for reloading pallets was shortened to a half. In this case, the number of man-hours remained unchanged.

4.1. Evaluation of experiments and recommendations

The goal of the simulation study was to find the effective number of the warehouse workers, increase the productivity of the process of receiving and storing pallets however, the most important is the need to decrease the time needed to store all the pallets. While looking for a satisfactory solution the whole range of simulation experiments was carried out. Some of them are described in the paper above. Their results show that making processes in the warehouse more effective consists in moving individual workers‘ shift and supporting the working position of the forklift operator in the period between 11.15 am and the end of the shift. This assumption is proven by the results of the last experiment. The comparison of the results of chosen experiments including results of the simulation of the reference day is given in Table 6. From the above comparison it can be stated that under the terms of the last experiment all pallets can be stored in less than 9 hours which means reducing a storing time compared to the reference day representing the current state by nearly two hours. In this case, there is a need to add one extra worker to operate the forklift in the process of receiving and storing pallets. Therefore, the effective number of employees in the warehouse equals 9 but one person for the reloading position and one forklift operator are required for this process for only 4 hours a day. The number of man-hours per shift is therefore unchanged in comparison with the current state. Due to this fact, there was also an increase in the average utilization of warehouse employees and especially for steady usage of these workers It was impossible to remove the overtime work. However, reducing the amount of overtime work by 83% can be considered a very good result. Thanks to a more detailed analysis of individual overtime jobs it is further possible to reduce the amount of overtime work namely by means of a better distribution of the workforce at the end of the work shift. It depends on a suitable approach to solving this kind of problem and especially team behaviour of workers (mutual assistance) at the end of the work shift.

Table 6: Comparison of simulation experiments

Target function	**Reference day**	**Experiment 1**	**Experiment 2**	**Experiment 3**
Time for storing the last pallet	10:48:00	9:26:50	10:49:30	8:57:00
Real time of storing the last pallet	16:48:00	15:26:50	16:49:30	15:27:00
Average utilization of warehouse employees	53.99%	54.22%	57.04%	65.71%
Amount of overtime	16:16:10	8:14:20	14:50:50	2:48:00
Average overtime of warehouse employees	2:02:01	0:54:56	1:51:21	0:18:40
Number of workers needed for one shift	8	9	8	9
Number of man-hours	8	9	7.5	8

5. CONCLUSIONS

The simulation study of the furniture company warehouse continues the warehouse management project. After starting the warehouse operation, the company was facing the problem of effective staff utilization within one working shift and a long sorting and storing time of all parts made by the preceding manufacturing process. The simulation study shows the possibilities of more effective staff utilization with newly organized processes so that the workers are able to complete storing of all components within the standard working time with the minimal number of overtime hours. The proposed simple measures clearly lead to a significant reduction in the time needed for storing all parts, reduction in overtime and balancing the workload of individual workers.

The paper presents the possibilities afforded by using computer simulation for the design and identification of reserves in warehouse systems. Using concrete examples, it is demonstrated that the use of the Witness simulation environment - not only for the initial creation and design but also in suggestions designed to increase the affectivity of existing warehouses is valid and effective.

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THE SIMULATION EXPLORATION EXPERIENCE EDUCATION OPPORTUNITY IN HIGHER EDUCATION

Preparing College Students to Thrive in Chaos

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ABSTRACT

An issue in higher education today is that while the demand for distributed simulation expertise keeps growing, not enough experts are teaching the subject in our colleges and universities. This matters because a well-prepared workforce is essential if we are to apply distributed simulation—as we must—to the hazardous, difficult, risky, even life or death complexities of the 21st Century. The Simulation Exploration Experience (SEE) with government, industry and academia support, enables international inter-university student-teams to learn simulation by doing it, study HLA and its standards, work collaboratively with other dispersed and diverse student teams, gain needed skills, learn about employer expectations, discover possibilities and gain confidence. The SEE model suggests potential for Modeling & Simulation (M&S) collegiate research and education in distributed systems, perception, communication, the tensions between rules and disruptive innovation, collaborative teamwork, the economics of simulation, and the purpose of M&S higher education itself.

Keywords: Collegiate level simulation education, virtual collaboration, virtual tutoring, simulation employability

1. INTRODUCTION

As a technical and educational initiative, the Simulation Exploration Experience (SEE) offers college and university students a rare opportunity to become more employable by becoming more skillful in the field of simulation. Since 2011, a partnership of government, simulation industry, professional associations and academia has championed, challenged and created collaborative college-level modeling and simulation education. Each year, with faculty support, ten or more highly dispersed inter-university teams design, develop, test and execute a student-driven simulated lunar mission. With faculty advisors, SEE student teams participate through university classes, independent study, research assignments, and capstone courses, even, inter-departmental and other team projects. SEE is enriched by participating faculty, industry mentoring, technical forums, audio-visual meetings, special tutorials, and one-on-one support from National Aeronautics & Space Administration (NASA) and industry experts.

Led by NASA, SEE joins students, faculty, and simulation professionals in building knowledge, skills, career confidence, and capability through real-time application of distributed simulation. In the past five years, SEE has engaged 18 university departments in 16 universities in North America and Europe in this distributed simulation experience. In addition, students from Israel pursued research in scenario development and High Level Architecture (HLA) visualization, as an alternative to design of specific space vehicles or moon equipment. Interest has also developed in Southeast Asia with teams in South Korea and Japan. Only the 2011 earthquake, tsunami, and nuclear disaster caused the team from Japan to withdraw. Within the U.S., through the American Indian Higher Education Consortium (AIHEC), 5 tribal colleges continue to support SEE infrastructure, research, 3D-modeling, branding, team recognition programs and demonstrations. SEE has and continues to contribute to post-graduate education and preparation for permanent employment.

This paper addresses SEE as a significant contribution to international higher education in modeling and simulation and as an on-going exploration of how best to educate ourselves and students, as an admittedly "error-prone specie", to survive and succeed in a precarious natural universe in which we have embedded potential for technological disaster. This scenario is what Harvard educator Christophe Dede says calls for education to teach students "to learn to thrive in chaos."

2. THRIVING IN CHAOS

SEE began with a simple idea. Interest college students in modeling and simulation as a profession, have them learn simulation interoperability and standards by "doing" them, prepare them and, in the process, help them discover possibilities.

Figure 1: Chaos at the Heart of Orion (NASA, 2008)

A small group of industry and government simulation experts, first discussing the concept at a 2009 Simulation Interoperability Workshop (SIW), recognized the need for graduates prepared to work in the field. They were aware that college graduates, looking for post-graduation work, had seldom learned to actually do distributed simulation, which is increasingly at the heart of the complex systems that define the twenty-first century.

The Simulation Interoperability Standards Organization (SISO) supports teams with free standards, industry members (The AEgis Technologies Group, ForwardSim, Pitch AG, and VT-MAK) have offered free software licenses, and NASA proffers content, supporting systems and project management. All provide mentors, present tutorials, and support project planning. SISO sponsored the first event in Boston, in 2011, at the Spring Simulation Multi-conference, followed by the Spring2012 SIW, both co-sponsored with the Society for Modeling and Simulation International (SCS).

In summer 2011 LIOPHANT Simulations (www.liophant.org) began leading reprises and demonstrations in Europe. In 2014 (Genoa University) and in 2015 (Pitch) presented SEE demonstrations and presentations at SISO Day at ITEC (International Technology Education Conference). The Kennedy Space Center (KSC) Center for Life Cycle Design leads outreach for SEE and, each year, demonstrates data capture from the event at the "NASA Place" booth at I/ITSEC, the Interservice/Industry Training Simulation and Education Conference. SCS hosted SEE in 2014 and 2015.

3. THE SEE ENTERPRISE

SEE is an anomaly in today's environment; it is independent, using in-kind, "insane dedication", donations, and much appreciated *management* support, SEE has thrived and survived in the absence of dedicated project/program funding. It is supported and led by NASA in execution of its responsibilities under U.S. Office of Management and Budget Circular A-119 (OMB, 1998) to support the use, as well as the development, of voluntary consensus standards. Within SEE, as in space exploration, NASA uses High Level Architecture (HLA) Evolved software and accompanying standards that include HLA. SISO is the IEEE sponsor of M&S standards, recognized under OMB A-119 international organizations.

An industry/government and academic Executive team builds and maintains an electronic scaffold supporting the faculty, students, and industry supporters. NASA and industry volunteers provide a structure for communication, resources, and systems. The SEE Technical team provides faculty advisors and student teams with the tools and advice to do the job. Faculty present the theory and practice of modeling and simulation interoperability and visualization, with a focus on distributed simulation. Industry and government HLA experts support development, testing, and execution of the work performed by the student teams under the direction of faculty advisors.

Figure 2: Screenshot taken from NASA Visualization Engine, used for Simulation Visualization

By 2013, after hundreds of hours of research, the program leaders affirmed, along with Simon Taylor, Ph.D., leader of the Modelling & Simulation Group (MSG) in the Department of Computer Science, Brunel University, London, that there "were too few experts teaching distributed simulation." (Taylor 2014). The SEE mission, to increase employability of college students for work in the field of modeling and simulation, became, "To Champion, Challenge and Create Collegiate-level modeling and simulation education". The emphasis broadened beyond technology to address project management. The first event in Boston, call "SmackDown", included student teams from the U.S., France, and Italy. Additionally, a team from Israel used the experience to study HLA visualization and scenario development. (Originally named 'SmackDown', the official name was changed to the Simulation Exploration Experience (SEE) in 2014 in order to focus on the experience as a student collaboration in which success depended on teamwork rather than on a competition with only a single winner.) Of note, over the past 18 months, some faculty have independently assigned 20-25% of the students' grades to participation in SEE.

4. COMMUNICATION AND PERCEPTION

4.1 Communication

As SEE has matured as a higher education experience, the Executive team looked increasingly at issues of perception and communication among these diverse and dispersed teams. Our student teams, from differing cultures, nationalities, and languages, require continual, consistent attention to communication among all the participants.

Even short distances between people lead to degradation of communication. SEE, conducted in English, addresses a major challenge in the integration of diverse plans. Students submit a 50-word (or less) summary of what they plan to do and with whom the team will interact. These synopses are unfailingly clear and concise. The students participate actively in audio-visual conferences and test sessions. Nonetheless, vigilance is necessary because it is easy to overlook different perceptions that exist among them or, to assume that what is transmitted is what is understood.

In the beginning, the teams depended on email and telephone to communicate. In 2013, Milton Chen, Chief Executive Officer of VSEE.com, joined as a partner, providing free audio-visual internationally. Communication and interactivity improved greatly by his generosity. Tag-up meetings via VSEE.com, for issue resolution, status reporting, and testing, give all members of the teams opportunity for steady communication.

The SEE website, www.exploresim.com, has grown since 2011. Led now by faculty and alumnae from the Institute for American Indian Art, it reflects how SEE increasingly represents integration of Art into the traditional STEM (Science, Technology, Engineering and Math) fields to join the emerging education model STEAM (Science, Technology Engineering, Arts, and Mathematics). This involves recognition of the connections and contributions of the arts (liberal, fine, applied and performing) with STEM in 21st Century education.

The website includes the SEE Starter Kit, (a digital toolkit developed by the University of Calabria working with the NASA Johnson Space Center (JSC)), tutorials on HLA (Björn Möller, Pitch), recorded presentations from Dr. Mikel Petty, faculty advisor from University of Alabama, Huntsville, and links to free resources, including software. E-mail still proves effective for communication across time zones, but SEE relies increasingly on its online Technical Forum, using VSEE.com, that offers and facilitates archival support, tracking data, and both peer-to-peer and mentoring support.

Efforts to clarify project planning and communicate team roles and responsibilities led to the publishing in 2015 of LIFT-OFF, a guide for Faculty Advisors and Student Teams (Elfrey 2015). A pdf document, it contains information on authoritative support for SEE activities. Guide sections list Faculty Advisors, Industry Team members, and members of the NASA/industry Technical Team and the Executive Team. LIFT-OFF also contains authoritative information on resources (both funded and in-kind), and includes free access to NASA's Distributed Observer Network (DON), a simulation visualization engine. A section on Student Teams lists Requirements and Roles, and a Plans-in-Action section describes the scenario process, schedule, and lunar mission event conducted each Spring.

Even with this infrastructure in place, the task of communication is never complete. Plans for 2016 address improving the process, with intent to strengthen and verify two-way communication. Experience has proven that when teams are so highly dispersed, it is easy for information to be lost. The SEE 2016 teams, drawing on lessons learned from SEE experience and other virtual teams, will adhere to an adaption of Star Dargin's (Dargin 2015) Corporate Education Group's list of Best Practices for Managing Virtual Teams in a form appropriate to the SEE enterprise:

1. "Develop and use a communications management plan and team operating agreements.
2. Slow down to speed up. Take the time upfront to understand all the environments and cultures you are working in.
3. Select appropriate technologies for team interactions.
4. Create a virtual personality and presence by exploring your strengths, weaknesses, and natural tendencies.
5. Be a great host/hostess. Create places where the team looks forward to and can meet for unplanned interactions.
6. Run effective virtual team meetings. … create, foster, and reinforce engagement and interactions frequently."

4.2 Perception

Because post-graduation can seem uncertain and ambiguous to college students, the SEE Executive team takes responsibility to bring some clarity and certainty to post-college planning and action. Often, students do not know where to begin, or how, or the value of what they have learned and done (for example, strengths as a learner, roles in student governance, summer and other work, extracurricular activity as well as learning HLA and highly distributed teamwork). They may not see how these attributes connect with employment. Students rarely have insight into employer expectations or what opportunities exist or who can help. Ambiguity is compounded because most open jobs are never posted. Despite all the technology available, there is nowhere an efficient or effective employment system.

SEE teams participate in a planning model that requires further definition and communication. SEE does provide students opportunity to explore their own preferred skills, learn about options (perhaps never considered) and talk with people doing work of interest. Within SEE teams, students determine who wants to do what tasks. This can involve s a process of increasing conscious awareness not only of skills but also of their preferred skills. SEE opens our teams not only to the possibilities presented by the mission, but also opportunity to see the possibilities that the simulation profession offers. Simulation is truly trans-disciplinary – inclusive of physicists, engineers, computer scientists, modelers, graphic artists, project managers, mathematicians, psychologists, writers, and systems analysts, as well as specialists and domain experts in innumerable fields. Applications range from aerospace to zoology, time- and resource-saving, and, especially, hazard reduction, injury prevention and life-saving occupations.

SEE enables students to start or build a professional network, increase information resources, and build credibility and visibility. SEE currently enables students to expand their self-knowledge, options, and resources. What is needed, perhaps, is to provide a focus on strengths, specific targets, and truly helpful support that can lead to effective action and enhanced "life after college."

Changing perception is a hallmark of simulation. Simulation, done well, results in an "Aha!" reaction as people perceive what was previously abstract, confusing, ambiguous or unknown. The last century has brought proof, as a basis for cognitive science, that perception of reality is internal, mental, not absolute or external, and is shaped by our experience, history, language, culture, health, biases, and, even, prejudices, as well as knowledge how much of what we are aware of happens outside our awareness (Bennett 2015).

A demonstration, long popular in introductory psychology and familiar in training exercises, shows us that some "illusions", such as the distorted room and chair demonstrations (Ames 2015), in Figure 3 below, can be so strong that our brains, even with conscious effort, cannot change or control them. We see 3 chairs in the top row. But the demonstration shows us, in the bottom row, that they are merely disjointed lines and not anything like chairs. But when we look again and again, knowing they are not chairs, we see 3 chairs. No matter the effort we make, we see those 3 chairs.

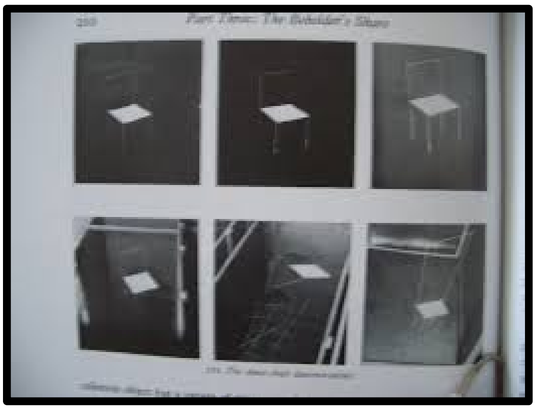

Figure 3. Distorted chair illustration

Another example, "A New Ambiguous Figure" of either an old or a young woman (below – it is both!) (Boring 1930; Fisher 1968) reminds that perception, especially within a pluralistic multi-cultural team, means that we can never assume that we perceive the same event in exactly the same way.

5. VIRTUAL COLLABORATION

SEE exemplifies virtual collaboration. It serves as laboratory and model for space exploration by global corporate, inter-Agency and Inter-governmental similar enterprises. Originally, when called SmackDown, the program was, often, described as "co-opetition", maintaining the usual college competition concept as a precursor to corporate competition. SEE teams do maintain a sense of competitive pride, of wanting what they do to be the very best. But the overriding sense is of teams cooperating to develop and present a simulation of lunar mission events.

Indeed, the highlight of every event is when the teams conduct testing for the simulated mission. Suddenly, they help one another and join in to troubleshoot, collaborate. What has become increasingly evident is that complex simulation projects, like space operations, are a team sport requiring trust, openness, interaction and a balance of risk and responsibility. This teamwork may seem almost impossible to achieve, but it happens every time. Anyone working on space exploration knows that if you do not collaborate in space, you shall, most likely, die. It is a situation of everybody wins when nobody loses. One team working on SEE infrastructure stated, "Only when you utilize each unique piece of the puzzle can you realize the whole picture." (Tompkins 2012).

Figure 4. A New Ambiguous Figure

In 2014, KSC developed the new Technical Forum for posting status, questions and concerns. Students credited it with providing them with valuable timely information and enabling them to get answers from one another thus making collaboration that much more effective.

SEE tools support collaboration with distant partners, enabling them to both see and talk with one another. In 2014, two SEE inter-continental participants who had only worked remotely and never physically met, were, by chance, both at the AEgis Technologies Group booth at I/ITSEC, when one recognized the other from prior VSEE online meetings. Such a happening, a factor in strengthening collaboration, would, otherwise, have been impossible.

NASA provides faculty advisors with access to the KSC Distributed Observer Network, built on a Unity game engine, that NASA uses to display (using 3-D models) the virtual lunar mission elements and activities that the teams create using HLA and other distributed simulation standards. Having DON to work with enables the teams to see and correct mistakes early in the process, test ideas and work more confidently with one another. SEE also serves as a test bed for DON.3, which NASA will be releasing in late 2015.

6. BALANCING RULES AND DISRUPTIVE TECHNOLOGY

It is easy when working with visualization of simulation to become enthralled with the technology. Simulation's amazing promise can lead us to thinking that only what is new is valuable. Yet we do not always need cutting edge tools. A simple sketch, rather than a million dollar presentation, often provides exactly what people want and need to know. The question that SEE tries to perpetuate and address is, "What is the appropriate technology for what we are trying to do?" Sometimes it is the latest technology. Sometimes it is not.

A mature technology is so simple that, as Buckminster Fuller remarked, it seems like magic. Today simulation is amazing, but not yet magic. Switching on an electric light is an example of magic. So, too, is reading and writing, technologies which, when new in Attica Greece, were resisted by some who saw it reducing human ability to memorize, think and display intelligence. Neil Postman (Postman 1985, 1993) reminded his students and audiences that a technology is not without ideological bias, and that it is not always evident at the beginning, who will win and who will lose. With the best of intentions, a technology may have consequences that were not only unintended but harmful. These lessons are common and, even, expertise is not enough. It is important that SEE participants keep this in mind.

However, true expertise is a goal for participating. SEE respects the rules that underlie success in simulation. Not only are students expected to obey the laws of physics, but also to follow directions, and respect both requirements and deadlines.

Recent research states that it takes 10,000 hours to become an expert (Gladwell 2008). SEE endeavors to support that path, with advisors to encourage, probe, question and offer feedback. Knowing that it takes more than practice "to get to Carnegie Hall", SEE mentors are motivated, perhaps, by the story that Aristotle told, that practice gives us our best and our worst flute players.

6.1 The "Two Sigma Problem" and Virtual Tutoring

B.S. Bloom's early studies (Bloom 1984) pointed to the value of tutoring, and startled educators, reshaping the traditional bell curve with no tutored students failing. In particular, he saw results pointing to the great value of peer and self-tutoring, a factor evident in SEE. Student teams, solving problems they have raised and, even, created, find themselves explaining the situation to themselves before, even, raising it in the SEE Technical Forum.

With SEE, the cadre of tutors starts with the students tutoring themselves individually, then one-another.

Students who discuss challenging problems, as Bloom noted, tend to converge on solutions through the process. Originally thought of as "Peer Instruction" (Mazur 1997), more recent research (Crouch 2001; Lazr 2008) suggests that it is the group give-and-take that opens people to better answers.

With SEE, such collaborative support may be down the hall or across an ocean. Also, with SEE, expert tutors - industry and government - are available, as requested, to supplement the classroom. SEE provides tutorials on HLA, standards, NASA systems, and more. Through various professional associations, the SEE Executive Team seeks to expand that cadre. SEE as a virtual internship or apprenticeship might be examined to augment and reinforce learning, establish useful behavior for employment and reflection on the individual and societal purpose of education. The SEE team aspires to more conscious support of learning and simulation; industry already brings students in contact with professionals who are excited by simulation, intrigued by its challenges, and eager to inspire others. Programs intended to improve the process of tutoring suggest the efficacy of talking through problems, especially with mentors. Although citing that tutored students all succeeded, Bloom called it a "problem" because tutoring is expensive and there are too few of them. SEE provides an effective and economical tutoring alternative.

7. SEE AND STATE-OF-THE-POSSIBLE

The discussion to this point has focused on the components and activities that make up the SEE Enterprise. In each of the sections described above are elements of the organization, structure, and infrastructure comprising SEE. Not one of the sections by itself addresses or describes a process, procedure, activity, or method that is new or unique to engaging in simulation and modeling activity. Yet the SEE enterprise is arguably unique. It began as an experiment to explore the feasibility of putting together a set of program activities designed to "champion, challenge, and create" more effective ways to give students of modeling and simulation real experience of what it means to be a simulationist – loosely described as one who practices simulation using the M&S tools, processes, methods, and practices available from academia and industry. Driving the experiment was the belief of early SEE proponents that M&S education, in particular education about distributed simulation, was broadly lacking in providing students with opportunity to learn, by actual hands-on work, what is really required in execution of actual M&S-based projects.

What has evolved since first envisioned in 2009 is a comprehensive endeavor that combines many elements – described in the sections above – that together comprise a state-of-the–art process for transfer of learning from academia to the domains of industry and government, in which M&S use grows continually for addressing and solving evermore complex problems in many, many disciplines. It is the fusing of technology, art, and ideas, coordinated through a customized communications and collaboration framework, and applied to a specific problem space amenable to solution using simulation, that is arguably the state-of-the-art in learning practical use of distributed simulation and modeling.

Typical workplace experience for students involves either summer internships, or participation in a specific project that the student can contribute to; in either situation, the student is most likely to exercise those skills learned in academic classes. Only by happy accident is a student exposed to new and different aspects of M&S. SEE, in contrast, expands that experience, by *intentionally* focusing on design conceptualization and work via collaborative effort to literally enable separately conceived and developed models and simulations to operate together, efficiently and effectively, in the same virtual world. SEE focus is on lunar simulations and modeling of space operations in deep space beyond. But the principles of design, development, test, integration, and operation must all be employed to yield a working simulated lunar mission as designed by the student-faculty teams, working with NASA and industry partners.

This enforced integration of academic endeavor, problem-solving, and practical application to address problems of the kinds faced by industry and government is the unique value provided by SEE. In five years experience, SEE leadership has not found any comparable program.

8. METHODS

One of the main purposes of this paper is to illustrate the benefits enabling an methodology for learning distributed simulation, technical collaboration, and teamwork as an integrated endeavor, and also to make the argument that education in simulation at its best includes learning of systems design, concept exploration and visualization, systems interfacing and integration, and use of the tools that enable testing and interconnection of simulations and models geographically distributed.

The SEE methodology employed is interwoven throughout the sections above. In this section, a more concise description of methodology is provided. The last section addresses benefits and outcomes expected to accrue to SEE participants.

8.1 METHODOLOGY

The methodology employed for each year's project is straightforward. The sequence is presented here in bullet format. The culmination of the project is a ninety minute live online demonstration of the developed models and simulations, with some teams at the selected venue, and others participating remotely via Internet. All is coordinated through a NASA SEE server and VPN, conducted in accordance with a scripted storyline. This is called the Main Event ('ME'). In the bulleted list below, the nominal timeline for development and execution of the ME is show in brackets in this format: (ME – x), with 'x' the number of months prior to the ME.

Preparation.

- SEE Executive and Technical Committees contact previous year's participants to assess/obtain commitment for current year effort. In parallel, outreach is conducted to inform and invite new teams to participate. (ME-11)
- SEE Website, on-line resource, and model repository contents are reviewed and updated by industry and NASA volunteers. (ME-10 to -2)
- A core faculty advisor team is identified (2 to 4 faculty); this group identifies and forms a "SEE Student Team Coordinating Working Group (STCWG)". (ME-10)
- Initial team tag-up meetings are conducted using VSEE.com, to organize the new year's project work. (ME-9)

Event Development

- University teams investigate and decide on what simulation activities they will perform for the SEE event. Faculty advisors create event concept of operations, working with the STCWG, for consideration by Executive and Technical teams. (ME-9 to -4)
- NASA and industry partners contacted, software licensing and use of DON3 engine arranged for participating teams. (ME-8 to -4)
- Executive committee outreach conducted to attract event sponsorship; committee also initiates discussion with various organizations to determine venue and dates for SEE event. ME-8 through -4)
- Executive committee develops update of the SEE LIFT-OFF Guide; Technical Committee updates on-line resources (Federated Object Models (FOMs), Federation Agreements, etc.). [Note: LIFT-OFF Guide provides event timeline, lists team requirements (submission of deliverables, etc.), and provides a comprehensive listing of resources available to every team, which includes a schedule of offered online tutorials on topics relevant to team project work.] (ME-6; update, ME-4)
- Faculty advisors assign teams to subgroups for coordination of model, simulation, and scenario development. (as teams form, ME-7 to -4)
- Developed scenario elements are integrated by combined Executive and Technical Committee effort into a workable scenario script and story line. (ME-6 to -4)
- Individual teams develop and test (standalone) developed models/simulations. Advice and mentoring is available via NASA and industry volunteers. NASA also makes available specific testing services; an example is an automated service to review and assess FOM issues. (ME-7 to -4).
- On-line tutorials made available to teams (ME-6 to ME-2)

Testing and Execution

- Technical committee initiates bi-weekly and weekly online tag-up meetings to address integration and interface questions and technical issues (ME-3 through main event minus 2 weeks)
- Weekly online tag-up meetings conducted for network integration and testing of all teams' models, and to test operate within the NASA Environment Federate. Technical feedback and advice provided as needed to individual teams. (ME-3 continuing until 2 weeks prior ME).
- Executive Producer collects team event activity descriptions (a required team deliverable), and refines ME storyline and sequence of simulation activity demonstrations be shown as elements of ME. (ME-4 to ME-2)
- ME storyline and simulation/model changes frozen, to support final integration testing. (ME-2. Some modification allowed to support testing and integration across network and to align to ME storyline).
- ME posters, flyers, brochures, and posters developed for distribution. (ME-5 to -3)
- Detailed ME schedule developed to guide events at selected venue. (ME-4 to -2).
- Final integration testing and rehearsal of ME timeline and storyline. Weekly online sessions. (ME-1; complete 2 weeks prior ME)

Main Event Execution

- NASA hardware infrastructure packaged for shipment to venue. (ME-two weeks).
- Teams (those participating locally at venue) travel to site, set up and conduct verification testing and rehearsal on site. Remote teams participate via Internet and VSEE.com.
- At venue site, NASA staff and teams conduct final set up, integration testing, and rehearsals.
- Support staff distribute flyers, demonstration materials, and brochures to interested audience
- Main Event conducted (typically day 2 or 3 of conference schedule)

- Team debrief follows event, with assigned staff determining participant awards
- Awards Ceremony conducted.

9. ECONOMICS, EDUCATION AND EMPLOYABILITY

"The U.S. Bureau of Labor Statistics (BLS) estimates that job opportunities for software developers are expected to rise by 22% between 2012 and 2022. Career paths for simulation and game developers include chief technology officer, systems consultant, or information systems manager. Developers may also be promoted to project managers or systems analysts." (Study.com 2015). It is this sort of reporting that generated the initial interest in developing the SEE enterprise. NASA and industry experience in recruiting new talent to its programs generated the original idea of "Smackdown", now SEE. Graduates entering the "simulation" market come equipped with a variety of traditional academic degrees. Yet "the (simulation) profession draws on expertise in a number of areas and does not fit neatly into any single category." (De Aennle, 2009). What has been missing from most educational programs is a mechanism for providing students practical experience in the execution of real projects entailing use of distributed modeling and simulations tools, techniques, processes, and teamwork. SEE evolved to provide such experience; it offers students one aspect of that critical bridge between academic learning and working successfully on real-world projects: working in a team environment, taking a project from idea formation through design, development, testing and execution. This SEE process can be, in a real sense, considered the equivalent to a summer internship; in many ways, participating in an SEE event really is a concentrated internship, a hot-bed experience, under the combined guidance of NASA and industry experts working with the student team and faculty advisors.

10. EXPECTED OUTCOMES

For the major investment parents and students make in a college education, employment is an obvious desired outcome. But there is more. Our schools also educate students to be responsible citizens, prepared to serve the society.

Specifically, in terms of collegiate-level simulation, the educational purpose of SEE includes not only individual employability but growing understanding of the potential for simulation as a field for research, an industry with untapped value and a curious player in our understanding and mastery of perception and communication.

Simulation supports dynamic interactive problem solving. It offers insights into challenging conundrums, and helps people see things that have been difficult, complex, and sometimes impossible to grasp. Simulation employs models - illusions of reality - to get closer to the truth of the matter and to better understand what was not previously understood. Like acting, it opens minds to possibilities: how a bacterial illness progresses, how an accident or a crime really took place, how to improve a product or process or, even, how best to explore space. Simulation begins with, to quote Shakespeare, "airy nothing", but can evolve to enable large dispersed teams working over decades to discover options and negative probabilities, strengths as well as weaknesses, and true support within available resources. With simulation and modeling help, large teams can establish great, complex multi-decadal enterprises never imagined or conceived before. Some think of simulation as merely software, but this dimension of understanding, reusing, and repurposing ideas and finding what is important says that simulation plays a special role in both betterment and beginnings. It starts, continues, and completes many a yet-to-be defined issue. Such narratives include Utopias, transformative tools, pioneering, industrialization, equality of opportunity, individual worth and technology's place in it all.

Narratives change, as some fallacy becomes obvious and society accepts new truths and narratives. Until that happens, the story resonates in one form or another. Buckminster Fuller, in Spaceship Earth, joined those, like native Americans, First Nation, who remind us that we are stewards of the resources that sustain our lives. The famous Big Blue Marble picture of Earth, snapped by an astronaut returning from the Moon to Earth, remains a reminder of its fragile beauty, and has often received credit for reviving the Environmental interest sparked by Rachel Carson.

SEE does not prescribe a narrative. In studying and performing simulation, however, students consider options and possibilities that may emerge from beneath the scenario and technology they are immersed in. In this simulation exploration *experience*, students narrate and work at a confluence of science, digital technology, dedicated mentors, teachers and a great story. They are—perhaps almost unaware—that they are imagining a truly awesome, history-changing, future when humans, finally, for the first-time, move off the planet.

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practical simulation experience that it has come to be. Mr. Waite served as SEE Industry Chair from its inception unless his sudden and untimely passing in July 2015.

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THE ASSURANCE OF QUALITY AND RECOGNITION OF RESEARCHER’S SKILSS IN EUROPE TOWARDS SMART ENERGY REGIONS PARADIGM

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ABSTRACT

Abstract— the needs for highly qualified researchers, the necessity to gain PhD faster and in more efficient way and the lack of own, i.e. university’s resources, fosters Riga Technical University to enhance acquisition of Open European Initiatives in the beginning stage of researcher’s carrier. The quality assurance procedure was modeled with the aim to assure mature recognition of researcher’s qualification in EU. The proper planning of acquisition of European initiatives, mainly Erasmus and COST programs for development the individual research of early stage researchers, may have a critical contribution towards strengthening of industry driven research activities and competences of young researchers’ generation. The case study of successful contribution into COST project targets achievement made by early stage researchers is described in this work.

Keywords: education, early stage researchers, quality assurance modelling, scientific project management, individual traineeship, COST actions, ERASMUS.

1. INTRODUCTION

Entering in the new education stage as a PhD rises an opportunity for students to open their minds for bringing new ideas practical solutions for new open areas in the frontier of the technology development line. The extreme difference from master studies organization and teaching approach brings difficulties for PhD students for self-organization and bringing sufficient result in limited time. The training planning via individualization of training structure as well as appropriate trainee PhD’s in the transferable skills fostering to gain PhD faster and in more efficient way. The proper planning of acquisition of European initiatives mainly Erasmus and COST program for development the individual research of early stage researchers may have a critical contribution towards finalization the specific part of research in more efficient way.

The first sufficient contribution of early stage researchers (ERSs) as finalized standalone research in specific novel topic is very important towards the carrier development and establishing new research directions and groups. The authors believe that sharing the experience and specific case studies among different stages of the research lowers entrance resistance barriers and increases efficiency of individuals within the group.

This work promotes the results of COST 1104 “Smart Energy Regions” project.

The number of examples collecting from individual experience of PhDs on different stage is given. The feedback of individuals in order to improve a common training structure in the PhD gives a common list of real steps to be done in order to structure common education process in the proper way.

The target of the research is to demonstrate, how to structure the education process of PhD students in the proper way managing a training process in own scarce resources conditions, but by acquisition all possible external resources, mostly of Open European Initiatives. The paper is structured as follows. Authors describe the specific of doctoral studies in Riga Technical University in Section II. The individual training plan case study of one of PhD students is depicted in Section III. Section IV reveals a single computerized Kuldiga region utilities management and control system case study, implemented by PhD students with their leader – RTU professor. The main contribution of the research, general results and possible directions for the future work are discussed in the Conclusion of the paper.

2. THE SPECIFIC OF DOCTORAL STUDIES IN RIGA TECHNICAL UNIVERSITY

The Riga Technical University is developing on the way from good regional technical education structure towards the third level university, active in both research and education dimensions. The budget structure transformation in the past ten years shows that the income from research activities in RTU grows from nearly ten present up to nearly forty presents of the budget, and a trend of this growth is remaining stable therefore, it requires well trained researchers in very limited time.

There are about 500 doctoral students in RTU (Ribickis, Kunicina, and Galkina 2010). The number of students in all programs is shown at Fig. 1. The doctoral students of RTU are employed for the basic work as scientific assistants according to qualification.

The main scientific cooperation is ongoing cooperation with Latvian industrial partners. Nowadays, when Latvian economics appears recovering after the crisis, the financial state of Latvian companies allows them invest more in research and development. Therefore, a cooperation with academics becomes more productive.

One of the opportunities for PhD student – ESR to apply their knowledge and to strengthen collaboration between the industry and RTU, is to take part in the small projects. RTU usually supports annually approximately 30 projects with the budget no more than 12000 euro per one project. RTU finances by 30%, but an industrial partner - the other 70%. A competition among postdocs for participation in such projects is very high, for example, in 2014 the number of applications, submitted for financing, exceeded 5 per one accepted for financing project.

The usual state stipendium of a doctoral student is 114 euro per month, the direct state crediting of PhD students is 85 euro. Is not need to reimburse this credit, if a student defended successfully PhD thesis in 5 years after starting of PhD studies.

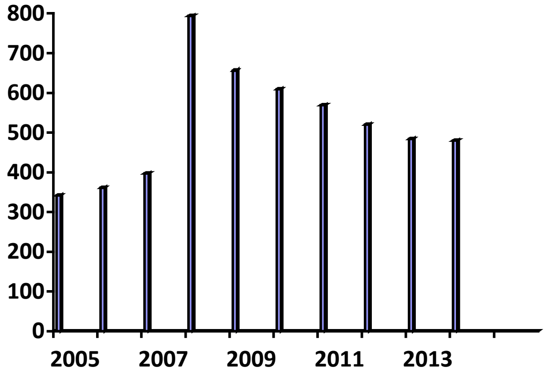

Fig.1. The dynamics of Doctoral students in RTU (2005-2014 years)

In 2014 RTU 480 full time PhD students. The RTU strategic priority is to archive 30% incomes of budget from scientific projects.

The annual competition for the young scientists Award was introduced in 2006 with the aim to enhance scientific research in RTU, to involve young scientists in research activities and to evaluate the results of the scientific research work of RTU young scientists.

The main priority in the research staff training in RTU is development of doctoral studies in high-technology research-intensive fields. Financial tools, which RTU applied during the last years, allowed to upgrade and modernize scientific equipment for experiments and PhD student training.

There are several other opportunities to support postdocs, for example, participation in the Cooperation of science and technology (COST) projects, but it is very much dependent on the initiatives of postdoc.

2.1. The quality assurance

The quality assurance of new generation of researchers is a new direction of the training education approach. The international experience of motilities, secondments as well as industrial projects rises a need to train new generation of PhDs and masters as internationally focused researchers to be able to establish carrier in industrial and in research centers in Europe. The aim of establishing of voluntary quality assurance procedure is to assure education' system relevance and effectiveness, the relevance of indicators selected, suitability of system to needs, quality of evaluation and monitoring reports, and relevance of report findings. Taking into account the lack of quantitative criteria used in curricular development/ improvement activities the process of quality evaluation is mostly based on qualities' assessment approach. Unlike routine evaluation and accreditation procedures in the universities, our project does not plan to arrange evaluation committee for new developed curricular quality evaluation. The quality assurance procedure consists of 6 main parts of PhD students.

1. Research objectives and tasks

Researchers explain the problem issues and motivation, why they decided to develop a particular topic. They shortly describe the targets and tasks to be implement, they shortly explain results and achievement, as well as its impact.

2. Study content and organization

The student's opinion regarding those points is evaluated by regular annual monitoring reporting system in RTU Extranet ORTUS.

3. Studies and evaluation of knowledge

The student's opinion regarding those points is evaluated by regular annual monitoring reporting system in RTU Extranet ORTUS.

4. Study provision, resources and management

The Doctoral Study department with cooperation with doctoral school makes a specific annual monitoring reporting.

5. Quality Assurance

The Doctoral Study department with cooperation with doctoral school makes a specific annual monitoring reporting.

6. Sustainability

The evaluation of carrier impact and future plans done by Doctoral Study department with cooperation with doctoral school provides specific annual *monitoring reports, and also includes individual fellowship programs and grants efficiency evaluation.*

The results of 2014/2015 year evaluation shows that competence of young generation of researchers involved in quality assurance procedure is much higher than average level of Riga Technical university, mainly due to the availability of very intensive industrial and international scientific research opportunities.

2.2. PhD Students Training Support by EU Financed Projects

The support of "*European Social Fund project Support for the implementation of doctoral studies at Riga Technical University*" is available for very limited number of PhDs, and it is 1138 euro per month. The limited resource for individual supervision of trainers requires to arrange individual trainings in the well-structured way. The cooperation with industrial partners helps to ensure proper quality of the research results of the early stage researchers.

As the majority of Latvian universities and research centers RTU faces difficulties to finance scientific research due to the lack of finance, allocated by Latvian government. On Fig. 2, the structure of scientific research financing in RTU in 2014 is shown. It becomes obvious that new PhD have to have the abilities to acquire financing sources via variety of EU and other international organizations scientific research programs and projects.

- State budget financing: 29%
- RTU internal sources: 0.6%
- Contract works for the industry: 8%
- EU and other international sources financing: 62%
- Other sources: 0.1%

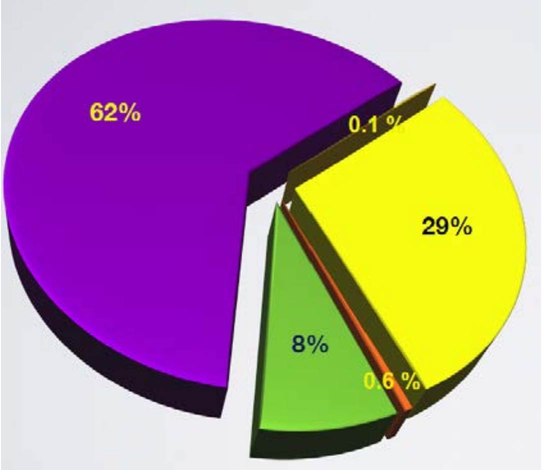

Fig. 2. The structure of scientific research financing in RTU in 2014

The introduction of a course "*Scientific project management*" (RTU 2014) has to help young PhD researchers to obtain necessary skill. Introduction of such course appeared successful, due to well-structured study material, comprehensive course hand book and competent teaching staff. However, the implementation of this training course is not enough for "financial successful", because necessary knowledge is only one of three necessary components to develop and manage a new projects. The motivation of project initiators and ongoing support are essential for initiation of new projects.

The other important competence is the ability to sell final product on real market and the next one is the ability of a young scientist to work in risk conditions. In the real life the ability to develop and sell final product on real market is mainly competence of a scientific adviser, i.e. a head of a structural unit of a scientific institution. In particular, in a frame of European Social Fund financed project „*Development of doctor program and its quality in Riga Technical University*" two important free choice study subjects „Intellectual Property Protection" and „Planning of experiments" were introduced. These study subjects help students to formalize and finish their research results and also to make results of their research ready to the market.

The technical support of doctoral students was ensured due to the participating in the project "*Improvement of doctor studies effectiveness with the use of distance education*" ensured PhD students a lot of new technical possibilities. Due to new equipment: computers, notebooks, cameras, microphones, it is possible to connect by ten users into one net, that is useful for the doctor student's individual tutorials and communication in scientific work as well.

The subjects that are interested for doctoral students are elaborated and published on RTU website, using new equipment, which was bought in last four years. Such website environment is used for training purposes and for communication among doctoral students and contacts with cooperation partners in other countries.

2.3. PhD Students Involvement in Scientific Research Projects

Doctoral student's involvement in scientific research projects, as a part of practical training, gives them valuable knowledge and practical skill, how to make qualitative project proposal, how to apply for international founding projects and how to cooperate inside international research teams.

The most real possibility for a student is to take part in COST, EUREKA (EUROSTARS), seventh framework programs or other projects. The usage of some structural funds programs, which are managed in Latvia, is also actual. The information about program's aims, structure, application procedure, samples of successful and not successful applications, all this is the way, how to motivate doctoral student to make his (or her) first project application. Students realize, that they really could take a part in such projects, even that they do not have previous knowledge about this scientific program and financing possibilities, before they take part in this training course.

EUREKA program's project development now is very actual, because this is ongoing European Regional Fund program in a frame "Business and innovations" 2.1.1.2.activity "Support for the international co-operation of the projects in science and technologies" (EUREKA, HORIZON 2020 program, etc.). Furthermore, this financial resource allows to reimburse project proposal preparation expenses and it is a chance for new researchers to get financial support for its future work in RTU as researchers. Unfortunately only few new calls in EUREKA program were issued last years, because of shortage of financial resources in Latvian budget. For example, cooperation in EUREKA project Hybrid Modular Home Media Equipment was not so efficient, because a project team had to postpone the project activities, waiting till the next year for financing. Obviously, all this troubles negatively influenced the project realization.

In Latvia, where research capability of small country is limited, a cooperation with other international partners is critical to increase efficiency and financial incomes from research activities. Partners search sometimes is not so simple, and the existing relationships of scientific advisers are not enough for preparation of successful proposal for international project. The possibilities to find partners in conferences or from scientific societies are not so efficient, as direct cooperation during research in common projects. Therefore, nowadays the Erasmus exchange program, *European Cooperation in Science and Technology (COST)* actions or any other direct cooperation programs are critical.

The RTU annually awarded young scientist, for example, Dr. Kaspars Kalnins, which has a particular experience in Seventh Framework projects, during scientific project management course hold practical seminars that help students to prepare HORIZON 2020 framework project proposal in efficient way.

3. INDIVIDUAL TRAINING PLAN CASE STUDY

The individual traineeship planning is the obligatory activity coordinated by RTU Doctoral Study department. It gives a certain degree of independency to PhD student and his supervisor. The individual traineeship plan consists of study subjects, scientific work stages, other works (including summer schools, traineeships), and publications.

Each PhD student possess different skills. Let's consider case of PhD student, which defended his PhD in July, 2014 in electrical engineering. Before applying for PhD studies he had extremely good background in the telecommunications. In addition, he came from an industry with very good knowledge of technology area, having contacts in the sector, expertise in the project management as in national as well as in the international research projects. The main motivation was to enlarge his potential working area, to shift in the academic research group as well as to gain a new level of knowledge and expertise in the area of electrical engineering. His area of research is related to design of ICT systems for control of geographically distributed critical infrastructure objects in the dedicated geographical region.

The missing skills in electrical engineering to be developed during PhD training time were the preparation of scientific articles, the ability to scientifically justify innovation, the ability to define targets and millstones for scientific research activities, as well as Matlab modelling and simulation.

The annual individual plan of PhD training was settled up for him. He has been involved in research activities of the systems control branch of Institute of Industrial Electronics and Electrical Engineering (IEEI). The first two years of training where dedicated to the development of prototype, as well to specific training in electrical engineering. He utilized the possibility to use Short Term Scientific Mission, first of all in Lulea University of Technology (Sweden), and then in University Tor Vergata Rome (Italy) in order to develop a specific model to research interdependencies of Critical infrastructures in cooperation with prof. E. Casalicchio. The results of this research are published (Zabasta, Casaliccio, and Kunicina 2014; Zabasta, Casaliccio, and Kunicina 2013). In the last decade of his PhD he joined the COST TU 1104 (Smartener, 2014) Latvian team. This opens the opportunity to gain experience in the area of wider application of his technological prototype in the other types of critical infrastructure in terms of smart energy regions.

His prototype is applicable for green house concept promoting in terms of definition in the Energy efficiency directive (Directive, 2012). This concept was also discussed during COST TU 1104 meetings, and it gave a possibility to formulate new ideas for future research and develop a carrier after PhD study as qualified researcher and a project manager in the area of smart metering, infrastructure control, and electrical engineering in the control team of IEEI.

The results of overall empirical self-evaluation contribution of different training aspects towards successful PhD is depicted in the Fig. 3. It is possible to make a conclusion that the main factors of successful PhD becoming are regular training and close collaboration between a student and adviser.

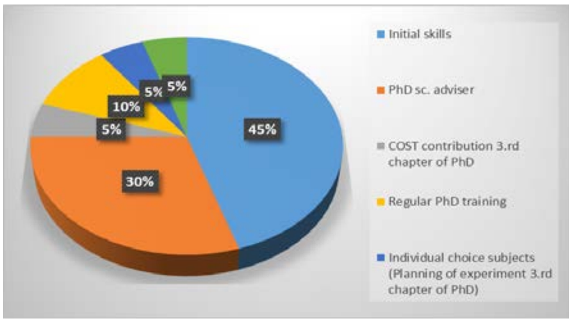

Fig.3. Overall empirical self-evaluation contribution of different training aspects towards successful PhD

4. JOINT DOCTORAL SCHOOLS

Annual Doctoral School sessions (Doctoral School, 2013), held in the spring semester, have become a good tradition in Riga Technical University. The School brings together all doctoral students of the faculty Energy and Power Engineering as well as visitors from other technical universities to discuss jointly the progress and results of research and to find new ideas for future work. It is also a great opportunity to hear lectures from internationally recognized experts in the field of electronics and power engineering. The School sessions have place in RTU Sports and recreation center “Ronisi”.

To participate in this event, each PhD student or a group of students submits an essay and prepares a presentation of their doctoral thesis, the relevance and preliminary research results. In 2014 the, besides Latvian and Estonian students, the students from two Azerbaijan universities, from Kosovo and from Ukraine also participated in the School thanks to bilateral cooperation and Erasmus agreements signed between RTU and its partners.

In parallel the annual Doctoral School sessions also are held in Pärnu, Estonia, usually in January in cooperation with Tallinn University of Technology. For example, Fig. 5 shows the students at symposium “Topical problems in the field of electrical and power engineering” and “Doctoral School of Energy and Geotechnology II” held in January 2014.

The Symposium is an activity specially intended for PhD students to present their research projects and to get in touch with many international PhD students and highly experienced professors and researchers from partner universities and enterprises.

Here are only some topics for discussion at Symposium in Parnu, in January 2015: Renewable Energy Sources and Resources, Micro grids, Energy Saving and Power Management Systems, Power Electronic Converters for Energy Generation, Transmission and Distribution, Electrical Drives and Robotics, Electromagnetic Compatibility, and Electrical Engineering and Lighting.

In order to promote multidisciplinary collaboration between PhD students from different engineering areas, the following special sessions will be organized during the Symposium:

- Mechatronics;
- Mechanical and thermal engineering;
- Education, cooperation and financing in higher education;
- PhD Studies in European Universities: Possibilities and Opportunities;

Fig. 4. The Estonian 15th International Symposium

In addition to the regular sessions organizers invite tutorials on various topics related to the general theme of the Symposium. A tutorial should present the state of the art technologies from the leading European universities. Fig. 4 shows PhD students of RTU Electrical and Power Engineering faculty, who participate in the demonstration session of Doctoral School.

5. A SINGLE COMPUTERIZED KULDIGA REGION UTILITIES MANAGEMENT AND CONTROL SYSTEM CASE STUDY

5.1. Administrative reform in Latvia

In a frame of the COST 1104 “Smart Energy Regions” Latvian research team consisting of two PhD students an in years 2012-13 elaborated a research in order to discover problems faced by Latvian regions in the field of energy management in region public utilities.

In 2009 Latvia implemented an administrative reform aimed to move from a *two-level* local public governmental (1st level - 26 regions and 6 cities comprised, and the 2nd level - approximately 400 parish councils) structure to *a one local level* - 110 new regions and 9 cities. Before the administrative reform, public district heating (DH) and water supply management had been operating in each parish, town or city substantively, but due to the reform, the water infrastructure and DH ownership and maintenance has been shifted from the parish level to region municipal one. Therefore, the new established regions have faced an important problem, on how to organize DH and water supply services throughout the region area.

Before the reform, each parish administration operated public infrastructure all alone, (in rare cases getting contributions and resources from the region budget). The majority of parishes did not have sufficient competence and enough of resources to maintain adequate infrastructure that partly was built with the support of EU Funds. Therefore, the majority of region governments recognized necessity to create a single system for providing utility services across its territory.

A study carried out by the team covering three regions in the Kurzeme district: Kuldiga, Aizpute and Ventspils, revealed common problems. Each parish independently performed public water and DH services, maintained accounting and obtained payments from customers; therefore, the regions administration did not have correct information concerning the overall situation on its territory. Since each parish maintained its own customer billing and property accounting system, the region administration was not able to provide a common policy related to clients and debtors, due to a lack of timely information. A significant part of the municipal property was not equipped with water and heat meters at the entrance to the building, thus water consumption in many cases was determined by local consumption standards, for example, per person and sometimes by the number of animals owned by property owner. Different water tariffs were applied, which were not determined based on actual costs. Because of privatization formerly public DH, water supply and sewerage infrastructure in many parishes was ended up in private hands and the new owners charged.

5.2. Objectives and Methods

This case study was based on a research on public utilities and public services provided after Kuldiga region has been created during administrative territorial reform in Latvia in 2009. The case study investigated three municipality's owned utilities: Kuldiga Heat, Kuldiga Water and Kuldiga Public Facilities.

The objective of the research was to make a study in Kuldga region, related to district heating, water supply and public facilities services:

- Identify the regional public water management, DH and public facilities companies' technical support, human resources, financial resources and maintenance organization.
- To provide recommendations how to optimize the public utilities organization and management by offering the necessary action plan for single computerized water and DH networks management and control framework.

The next target of the research was to offer a computerized model for optimizing water supply and DH management in the regions under consideration:

- To develop a description of the technical solution;
- To prepare a description of the technical equipment and technical documentation;
- To prepare an indicative cost estimate and recommendation about implementation steps.

Outcomes of the study are related to the following fields: Social, Economic, Environmental, and Technical. This research outcomes to be used for further regional utility companies and public facilities development and modernization. Furthermore, the outcomes provide perception for the industry about technological solutions required by municipalities and public utilities.

Methods have been used: stakeholders interviews (the heads and the specialists of utility companies, Regional Council key persons), statistics investigations, innovative projects experience research related to ICT technology accommodation for local needs. Representatives of utility companies, Regional Council and parishes representatives and Ventspils High Technology Park researchers also participated in this research.

5.3. Outcomes of Research

- The research revealed that the public services, provided by community's utilities, are decentralized, fragmented and inefficient.
- A single computerized utilities management and control system model for Kuldiga region has been developed.
- Introduction of single computerized utilities management and control system in Kuldiga region would improve social, economic, environmental and technical situation of the region.

Development of the single utilities management and control system was supported by all involved utilities and region council members. However, local administration faced significant barriers, such as the lack of financial resources, fears related to increasing of tariffs, the lack of technical competencies and necessity to adjust legislation (Zabasta, Kunicina, Korjakins, Ziravecka, and Patlins, 2014).

6. SUPPORT OF POSTDOC AND RESEARCHERS MOBILITIES

The support of postdocs provided by COST actions is very useful for Latvian PhD students, postdocs and researchers. The several scientific supports was done, for example Short Term Scientific Mission in University of Madrid, Lulea University of Technology (Sweden) and then in University Tor Vergata Rome (Italy), and University of Applied Sciences of Berlin (Germany) and etc.

The Erasmus and Erasmus plus support could be used for very limited number of motilities. For example, Dr.sc.ing. Professor Nadezhda Kunicina from Riga Technical University (Latvia) visited University of Applied Sciences "Hochschule für Technik und Wirtschaft Berlin" nine days in October 2014, and delivered lectures on the topics "Specific of project management in Baltic countries and "How to write scientific paper". The lectures topics comprise overview of literature, introduction in Energy saving technologies and its application in Latvia according to the program "Construction and Real Estate Management". The visit has been implemented in accordance with the Erasmus+ Inter-Institutional Agreement between University of Applied Sciences and Riga Technical University.

7. CONCLUSIONS

Doctor studies and individual researchers training play an important role in the training of scientific staff for sustainable development of Latvian economics.

It becomes obvious that new PhD have to have the abilities to acquire financing sources via variety of EU and other international organizations scientific research programs and projects.

Thanks to acquisition by early stage researcher's competences necessary for scientific project management, several projects were implemented in order to improve infrastructure and capacity of the training process in RTU.

The individual traineeship gives a certain degree of independency for PhD student and his supervisor and encourages a student to achieve the end result in more effective way. It is possible to make a conclusion that the main factors of successful PhD becoming are regular training and close collaboration between a student and adviser.

The international PhD School, specially intended for PhD students, encourages them to present their research projects and to get in touch with many international PhD students and highly experienced professors and researchers from partner universities and enterprises

PhD student's participation in the EUREKA, COST, ERASMUS networks and in particular in the COST 1104 "Smart Energy Regions" demonstrated ability to provide a research in order to discover problems faced by Latvian regions in the field of energy management in region public utilities. From the other side, participation in COST actions gives PhD students an invaluable experience and enlarge their contact net.

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VOLUNTARY EDUCATION STANDARDIZATION IN STUDY ENERGY EFFICIENCY DIRECTION PROGRAMS IN EUROPEAN UNION AND NEIGHBORHOOD REGIONS

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ABSTRACT

The experience in development of compatible study programs in electrical engineering obtained by Tempus Energy project partners, in particular Riga Technical University and University of Pristina in Kosovska Mitrovica is described. The curricula developed in a frame of Tempus project is a good step forward of mutual recognition of study programs between EU countries and EU partner's countries universities. It creates a good background for Erasmus+ activity implementation – students and teaching staff mobility between EU and non-EU partner countries. The new set of study programs, module based teaching approach for undergraduate's and masters student, shared teaching library, modelling and simulation approach for the teaching process, made in the frame of Tempus Energy project are depicted. The problem issues, solutions and examples in the development and modernization of compatible study programs in EU partner's countries universities are discussed.

Keywords: education, modelling and simulation, voluntary standardization, electrical engineering, compatible study programs, TEMPUS program.

1. INTRODUCTION

The Bologna process defined the common goal: to create a European space for higher education in order to enhance the employability and mobility of citizens and to increase the international competitiveness of European higher education.

In 2010 ministers responsible for education proclaimed that European Area of Higher Education (EHEA) is constructed but the process of harmonization in EHEA continues. Tree steps were done in the early stage of the Bologna Process to solve the problem of mutual recognition of higher education diplomas, namely: adoption of a system of comparable degrees; introduction of the three major levels of higher education (bachelor, master, and PhD); introduction of the European Credit Transfer and Accumulation System (ECTS). At least in 2005 at the Bergen Ministerial Conference "A Framework for Qualifications of the European Higher Education Area" was agreed (Ferreira and Filipe 2009).

Two basic degrees, Bachelor and Master, have been adopted by every participating in Bologna process country; sometimes in parallel to existing degrees during a transition period, sometimes replacing them completely. EU countries and EU partner's countries universities are currently in the implementation phase, and an increasing number of graduates have now been awarded these new degrees.

However, a problem of incompatibility between EU countries and EU partner's countries higher education systems cause the problems for students, which desire to get courses in EU universities. For example:

- Courses taken by student in EU countries cannot be taken into account as credit points;
- Shift in time between courses;
- Different teaching time of students and master students;
- Different teaching topics for the students with the similar specialities.

2. EU EXPERIENCE SHARING VIA TEMPUS PROJECT "ENERGY"

Since 2012 Riga Technical University (RTU) the Institute of Industrial Electronics and Electrical Engineering (IEEI) as coordinator leads TEMPUS IV project "Development of Training Network for Improving Education in Energy Efficiency" (ENERGY). The project is focused on the development and modernization of a set of compatible study programs (including lecture courses, laboratory classes and appropriated didactic materials) in 4 declared directions: enhancement of energy efficiency, energy saving energy effective materials and use of renewable sources.

In this project 14 universities from nine countries will work together in order to share the best practice in academic work (see Table 1). The project will be finished in the October 2015.

Academic staff of the of EU universities is involved into coordination of the modernization and developing of unified curricula and study programs making them compatible with EU standards. Furthermore the academic staff of EU partner's universities is involved into training process in EU Members Countries (mobility), modernization and developing of compatible and unified curricula, as well as in the training of bachelor and master students (Zabasta, Kunicina and Zhiravecka 2013).

Table 1: Participants of the project Energy

Short name	The name of the university	Country
RTU	Riga Technical University	Latvia
TUT	Tallinn University of Technology	Estonia
VU	Vilnius University	Lithuania
LUT	Lublin University of Technology	Poland
KTU	Koszalin University of Technology	Poland
KU Leuven	KU Leuven Oostende	Belgium
UDJG	"Dunarea de Jos" University of Galati	Romania
KHAZAR	Khazar University	Azerbaijan
QU	Qafqaz University	Azerbaijan
NAA	National Aviation Academy	Azerbaijan
BSU	Belarusian State University	Belarus
BNTU	Belarusian National Technical University	Belarus
BSATU	Belarussian State Agrarian Technical University	Belarus
UPKM	University of Pristina in Kosovska Mitrovica	Kosovo

E – Learning platform (as e-library) has been created as a common methodological base for study subject's curricula storage and sharing tool. This platform has to integrate all courses in teaching languages into one technological platform that will allow managing them as shared recourses in daily work with teachers and students.

Furthermore, the project activities also include new course materials testing during 1 year, preparation of accreditation process on compatible curricula and networking among higher education institutions between Member States and Partner Countries.

Starting the project the leading partner' team committed with consortium team's member motivators and benefits for participants:

- Involvement into Bologna process, recognition of a curricula.
- New equipment for laboratories.
- Opportunity to travel and create own network of researchers.
- Additional salaries for teachers, interpreters and professionals.

From the very beginning Management team got an awareness about the hurdles and problem issues and first of all very different English language skill among the members of the management team. Fortunately, the majority of fellows have the second language knowledge – Russian, therefore, the Russian was used as an auxiliary tool. Personal ambitions may become a serious encumbrance for the sub teams, working on training course books, therefore compromises were achieved, sometimes thanks to sacrificing the quality. Due to the bureaucracy of the government institutions of Belarus three partners started project activities with 15 month delay, moreover, a specific public procurement legislation put additional hurdles to Belorussian partners. However, the Management team has been mitigated risks, rescheduled tasks, and found the way how to arrange students training before supplying laboratory equipment.

The first task for the partners was to find the way how to arrange elaboration of compatible with EU standards common courses. As a result of discussions an approach, which satisfy all partners was accepted. The idea, which unites all participants, despite of different background, different education system etc. is to develop ten "master" courses in English. At the next step EU partners' universities develop own courses, which comply with national legislation, university's standards and to be translated to the teaching languages. So each university may to adjust such master course to comply to existing or a new study program keeping in mind compatible with EU standards.

However, here is a risk that courses and programs adjustment to the national legislation of education systems may lead to large divergence and in realty the gap between EU and EU partners' education systems will not be bridged sufficiently.

Therefore, the assumption was made in the beginning of the project that it is possible to develop "master" modules-courses, which will be utilised by EU partners as core courses for development compatible with EU education system programs that will bring EU partners closer. The assumption was verified during the project and the results have been evaluated at the end of the project.

2.1. New training courses development:

Ten creative teams comprising academic and teaching staff representatives from all partners were nominated to develop "master" modules-courses. Management team coordinated activities of the creative teams and accepted the deliverables of their job. In order to keep in a focus creative teams activities the common workshops by course topics are held during the project. At the time of elaboration of this paper eleven workshops have been held, usually in parallel with Management team meetings. A Table 2 depicts the courses and partners in charge of these tasks.

Table 2: New “master” courses and responsible

	Course	Responsible	Course materials is in e-library
1	Distribution of power energy	KU Leuven	+
2	Effective lightening	RTU	+
3	Energy effective materials	LUT	+
4	Energy saving technologies	RTU	+
5	Power electronics	RTU	+
6	Gas- and Hydrodynamics	RTU	+
7	Heat pumps	UDJG	+
8	Hydrogen energy	RTU	+
9	Solar energy and photovoltaics	VU	+
10	Wind energy	KU Leuven	+

However, to develop a new course in the team, comprising 19 PhD representing eight partners from 7 countries (see example of the team developing master course Energy saving technologies at Fig. 1) is not an easy task. The team leader has to show leadership, competences in the subject, patience and diplomacy.

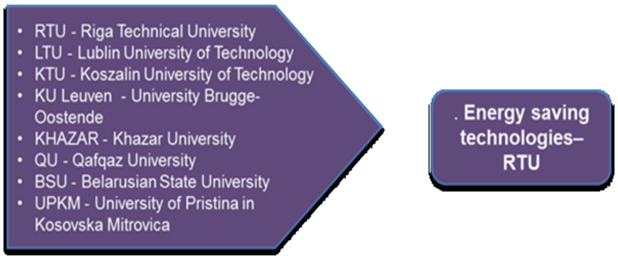

Figure 1: Example of the team developing master course Energy saving technologies

On the base of master courses in English, EU partner’s universities elaborated their courses adjusted to particular university needs. According to the project targets partners now create also laboratory works, lectures materials, presentations, tests (quiz). Teaching – learning materials should be translated into teaching languages: Serbian and Russian. Unlike Belarus and Serbian universities, Azerbaijan universities provide training in English. At the time of elaboration of this paper the Energy project was in the progress, therefore EU partner universities still continued elaboration of the new training courses. The Table 3 gives a perception, how EU partner universities transformed and utilised master course materials into 30 new adjusted courses. Due to the lack of the space only 10 course of 4 partners are shown in the Table 3.

Table 3: Example of the transformation from the “master” courses into partner’s universities courses

University	Course for testing	Course materials in e-Library	Translation into national language
BNTU	Mechanics of Fluids and Gases	Not	Not
	Non-conventional and renewable energy sources	Yes	Not
	Secondary Power Resources	Yes	Not
	Fuel and its usage	Not	
NAA	Luminophors	Not	
	Algorithm of Thermo-gas Dynamic End Heat Transfer Modelling for Turbine Blades	Not	
	Physical Properties and Application of Photosensitive Semiconductor Converters	Not	
Qafqaz University	Renewable Energy (Windy Energy)	Not	
	Fluid Mechanics (Gas and Hydrodynamics)	Not	
Khazar University	Renewable Energy	Not	

2.2. New courses testing:

All of 30 new courses have been tested during two semesters. A special form of the testing report has been created taking into account RTU, EU partner’s universities and other universities experience (Kirkpatrick 2009, Haslam 2010). Polling, questionnaires, interviews were applied as for evaluation of testing results. The feedback is obtain from the main teaching- training process stakeholders: students, student organisations and academic and teaching staff. For evaluation of students and student organisation feedback a quantitative method is used, but for academic and teaching staff – quantitative approach due to the small number or recipients and willingness to get much broad comments and suggestions about tested courses. The questionnaires for students have been available in English, Serbian and Russian, furthermore universities may adjust questionnaires taking into account own experience and diverging culture of project partners. An example of a questionnaire for the students is provided in the Table 3.

Table 3: A part of a questionnaire used for students polling

Nr	**Questions**	**Evaluation (1-5)**
1	The introduction makes the students familiar with the subject content and way of the final control	
2	The course was well-structured and the themes were explained in a comprehensible manner	

3	During the course its theory is highly confirmed with practical tasks, activities or laboratory works	
4	This course and the other subjects mutually supplement each other	
5	Visual material is understandable and illustrate the material well enough	
6	The assignments and activities initiated self-sufficiency in decision making	
7	The tasks and activities promoted practical application of theory and creative thinking	
8	Recommended literature sources were accessible and helped in acquiring the course materials	
9	Lecture materials and course books are mutually complementary	

New courses testing in real teaching – learning process induced one unexpected effect: EU partner's universities appeared willingness to arrange additional short term courses and workshops in order to tune and to improve the content of the courses in particular areas, in which EU universities do have competences. For example, at the KU Leuven two days' workshop on Wind energy and Effective lightening and Energy saving technologies, which was announced before testing, the number of applicants increased in twice, when courses testing was ended. Additional workshops, student trainings, and mutual visits between EU universities and EU partner's universities and also between EU partner's universities have been arranged.

2.3. Modelling and simulation approach for the teaching process

In the last few years RTU developed a program "Computer control of electrical technologies" for master degree and for doctoral degree students. This experience has been taken into account for new courses developed under RTU leadership: Energy Saving Technologies, Effective Lighting, Power Electronics, Gas and Hydrodynamics and Hydrogen Energy. In the next subchapters three examples of modelling and simulation approach for the teaching process are presented.

Example of Model-Driven Approach for Testing of Embedded Systems

One of the research topics in the focus of RTU is related to computer control of all shapes and sizes embedded systems. Embedded systems have more non-functional properties, more complex software structure and development process compared to simple systems. In the past few years, there have been a number of cases where errors in the software and hardware of embedded systems led to human casualties and massive losses. Existing methods for testing embedded systems are incomplete and do not ensure automation of the testing process or correspondence to current trends in software development. These methods are based mostly on general testing standards and do not support testing of non-functional features of embedded systems (Grigorjevs, Ņikiforova 2009).

To make development of embedded systems reliable, new methodologies, programming and specification languages have been introduced by Applied Computer Science Department. Standardized principles of model-driven architecture (MDA), the available development environments and tools stimulate automation of the entire software development cycle have been used. One of the tools used by MDA is a Unified Modelling Language (UML), which provides a testing profile to support the testing process. However, even though the testing profile was standardized in 2005, there are still no generally accepted methods for automating the testing process and generating test cases based on the system model.

As a result of the research, a method was developed for testing the non-functional properties of embedded systems, as well as the set of tools developed to ensure transformation of UML models and generation of test cases. The suggested method is based on the fundamentals of model-driven software development and general principles of model transformation. To test the application of the method, it was approbated by verification of time constraints for a real-time payment card system, for which these properties are critical for performing standard activities (Grigorjevs, Ņikiforova 2009).

Risk-based methodology for evaluation of critical infrastructures interdependencies

Critical infrastructure's (CI) (electricity, heat, water, information and communication technology networks) security, stability and reliability are closely related to the interaction phenomenon. Due to the increasing amount of data transferred, increases dependence on telecommunications and internet services, the data integrity and security is becoming a very important aspect for the utility services providers and energy suppliers. In such circumstances, the need is increasing for methods and tools that enable infrastructure managers to evaluate and predict their critical infrastructure operations as the failures, emergency or service degradation occur in other related infrastructures.

The presented method is based on a systematic approach for computing metrics and performance indices of interdependent critical infrastructures based on their information content, expert views and risk analysis capabilities. A risk-based methodology is based on generic risks and assurance levels using security properties: availability, confidentiality and integrity. Unified Modelling Language (UML) is proposed in order to define a model for research of critical infrastructures interdependences (Zabasta, Nikiforova, and Kunicina 2012).

The goal of the presented approach is to address the challenge of monitoring of the state of critical infrastructures and their interdependent services. Our hypothesis is, that it is possible to reduce the complexity of a service through abstraction to a common (risk related) set of parameters. This enables to compare critical infrastructures designed to serve a very different purpose (energy, telecommunication, water supply, transport and etc.) and composed of very different infrastructure components. It enables also to monitor important system parameters like availability, confidentiality and integrity. The abstraction to a small set of common parameters will encourage service providers to share them with interdependent providers.

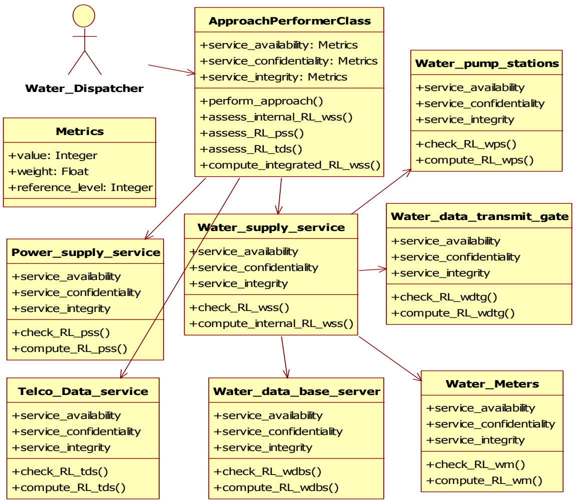

Figure 2: Interdependencies Class diagram

Fig. 2 shows nine classes, where five of them represent water supply service and its components, one class represents power supply service, one class represents data transmission service and one class (Approach Performer Class) starts and controls services risk level assessment process. Operations reflect the activities executed by each class. The parameters of attributes and operations in each class have been omitted in the interest of figure clarity. One particular class, namely "Metrics", have been created in order to describe parameters of classes' attributes and classes' operations. The class has attributes "value", "weight" and "reference level" that are referred to service parameters (availability, confidentiality and integrity). Creation of particular class makes sense since unified normalized parameters are applied to divergent CI.

The ontology proposed in Fig. 2 was created in order to study CI interdependencies of the particular city, but can be readily adapted to other cases, taking into account the specifics of each city.

The main advantage is that the model is easily extensible for including additional parameters and is ubiquitous for heterogeneous CI. Another benefit of the CI security model for businesses is the ability to compare different types of infrastructure using common risk related parameters.

The approach enabling critical information sharing among service providers allocated in neighborhood looks quite attractive, because it helps to CI owners to make more qualified decisions and to plan risk mitigation actions. However, the question is how to encourage service providers to elaborate, refine and issue critical information to other CI owner.

MATLAB® Simulink® State Flow simulation model for evaluation of critical infrastructures interdependencies

Using a simulation model, is experimentally tested a method that allows to explore the water supply network nodes the average down time dependence on the battery life time and the battery replacement time cross-correlations, within the parameters set, when outages in power infrastructure arise and taking into account also the impact of telecommunication nodes. The model studies the real case of Latvian city Ventspils. The proposed approach for the analysis of critical infrastructures interdependencies can be useful for practical adoption of methods, models and metrics for CI operators and stakeholders (Zabašta, Casaliccio, Kuņicina, Ribickis 2014).

The contribution of this research is:

- To describe how the simulation approach allows to model in deeper details critical infrastructures coupling and their behavior.
- To develop a MATLAB® Simulink® State Flow simulation model of a modern water supply system (composed of water supply nodes, telecommunication nodes and power system nodes).
- To simulate the impact of effect of power nodes outages on telecommunication and water supply nodes and to assess the impact of failure propagation, using metrics developed in previous researches.
- To describe dependences between infrastructures by polynomial and to minimize impact on water node down time.

A simulation model experimentally tested a method that allows to explore the water supply network nodes the average down time dependence on a battery life time and a battery replacement time cross- correlations, within the parameters set, when outages in power infrastructure arise and taking into account also the impact of telecommunication nodes. The model studies the real case of Latvian city Ventspils. The proposed simulation scenario describes water distribution network nodes interaction with electricity and telecommunications network nodes.

An assumption is made:

- A model allows to explore the water supply network nodes the average down time dependence on the battery life time and the battery replacement time cross- correlations, when outages in a power infrastructure arise and taking into account also the impact of telecommunication nodes.
- It is possible to examine the interaction with a polynomial, and minimize the water supply network nodes the average down time within bound parameters.

$$R_{i,j,k} = f(t, m_j^1, m_j^2, \ldots. m_j^p, m_k^1; m_k^2 \ldots. m_k^p; m_i^1, m_i^2 \ldots m_i^r) \rightarrow \min$$

$$m_j^l \in M_j; m_k^n \in M_k; m_i^r \in M_i$$, where

$R_{i;j}$ - function *f*(.) time *t*. A specific set of metrics: M_j (power supply network), M_k (telecommunication network) and M_i, (water supply network), used to measure infrastructures *j, k and i* performance level.

This study uses MatLab® Simulink® StateFlow modelling and simulation tool as a popular engineering and scientific modelling tool.

Simulation data have been processed by EDAOpt experimental results processing tool developed by researchers of RTU.

The analysis of the WDN nodes average downtime ratio dependence on backup battery lifetime (BLT) and backup battery replacement time (BRT) cross-correlation parameters specified parameters is made. EDAOpt computed the polynomial coefficients of the quadratic approximation with one attempt exclusion.

$R = 2.3532 – 0.3894*X_1+0.00812*X_2+ 0.0289*X_1*X_1+ 0.0035*X_1*X_2$

The following local approximation is carried out with the aim of identifying possible local minims. Looking at Fig. 3, one can see at least two local minimums within modelling parameters set. Fig. 3 depicts three-dimensional images that demonstrate the correlation between the water WDN nodes BLT, BRT and WDN nodes downtime.

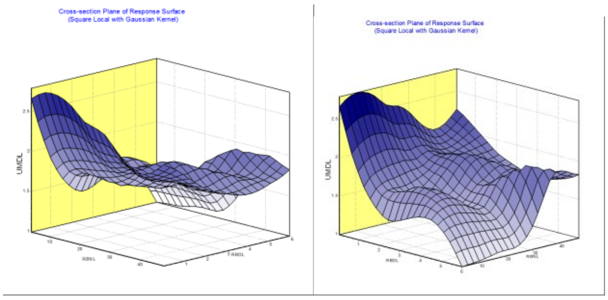

Figure 3: Quadratic approximation with one attempt exclusion following local approximation

Using *MatLaB® Simulink® Stateflow* simulation model is designed and experimentally tested a method, which, unlike the existed methods, allows to explore the water supply network nodes the average down time dependence on the battery life time and the battery replacement time cross - correlations, within the parameters set, when outages in power infrastructure arise. The impact of outages in telecommunication nodes also is taking into account. It has been proven that:

- Water nodes down time shows by a quadratic polynomial described the dependence of the backup battery life time lifetime (BLT) and backup battery replacement time (BRT) cross - correlation in parameters set;
- Although approximations graphs shows that in the explored parameter range polynomial function approaches to a minimum when BLT tends to peak, however, local minimums of the function are revealed, which are associated with a telecommunications network nodes resilience to external power supply interruptions;
- Explored that backup power sources for water supply network nodes is an effective solution, taking into account the reasonable costs, however, it is not sufficient to ensure consistent and reliable data collection, because the physical dependency ratio is 0.77 , but the time scale of physical dependency ratio is 0.67;
- The solutions that ensure consistent and reliable data collection from the water supply network objects can be: backup power source lifetime increasing or / and additional (redundant) network node installation that in this way increase the sensor network robustness.

3. EVALUATION AND INTERPRETATION

The feedback from the students shows very positive results. The student's satisfaction by the courses was evaluated in 5 points scale: from "1" as "Strongly disagree" by "5" as "Strongly agree". According to the Fig. 4 more than 68% of the surveyed students put the highest mark to the new courses, moreover the worse mark was not put by the surveyed students. The student organisation testing showed also very similar results.

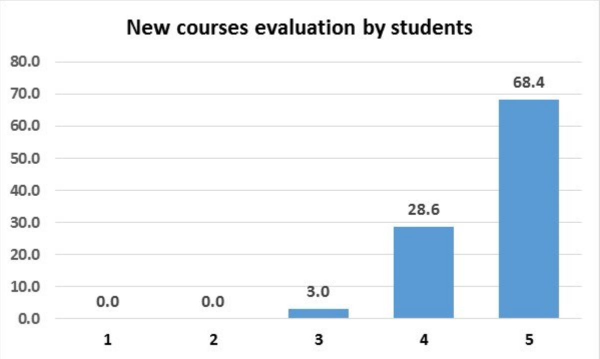

Figure 4: Students satisfaction by new courses evaluated in percent

The feedback from the teaching staff at the time of elaboration of this paper was in the progress, however the available suggestions pointed out the need to focus on laboratory works improvement. Such suggestions should be considered as sound, because the supply of labs equipment for new courses is overlapped in several partner's universities. However presented results cannot be recognised as final one, because two EU partner's universities of seven ones did not finish jet processing of the testing results.

We should recognise the testing results very carefully, because rather short time of monitoring of the new courses. The reason is that at the first stage of evaluation the audience could be too optimistic about new courses developed together with academic staff of EU universities. From the other side too high expectations about new courses could make the audience too pessimistic.

3.1. Conclusion related the assumption

Coming back to the assumption made in the beginning of the project that it is possible to develop “master” modules-courses, which could be utilised by EU partners as core courses for development compatible with EU education system programs that will bring EU partners closer we came to important conclusions.

First of all EU partner’s universities pursued the target to develop new comparable courses and to implement its legalisation process as much as possible. It is possible now to say with certainty that EU partner’s universities will fulfil new courses development by the end of the project (the minimum one, but the maximum 13 courses by one university), however legalisation, e.g. accreditation results, differ very much among the partners. Conditionally EU partner’s universities could be divided in three groups depending on the maturity of accreditation results (see Fig. 5).

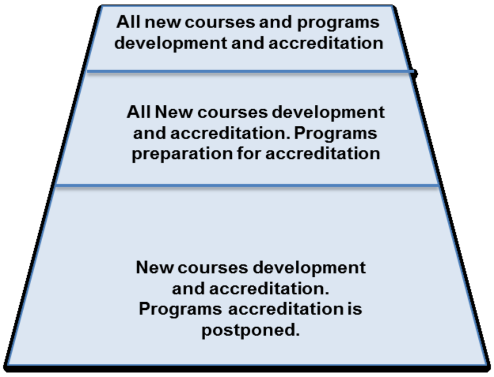

Figure 5: Conditionally EU partner’s universities classification depending on the maturity of accreditation results

Only one EU partner’s university was able to fulfil accreditation of the training program, named “Electrical and Computing Engineering” in the ministry of Education”, so to achieve the highest level, but it happened mostly by the high autonomy status of the university. Three partner’s universities provided internal courses accreditation in their universities and now made preparation for courses accreditation as a part of master students training programs. The legislation of their country and the status as private university provided an opportunity to achieve the second level according to our classification. The other tree partner’s universities provided internal courses accreditation in their universities, however the further accreditation process is not clear, due to large gap in EU and national legislation related in high education issues.

3.2. Discussions and conclusions

Being aware that the project is still in a progress, thus some of the tasks are not completed yet, however the research authors may come to preliminary conclusions.

1. First of all a real progress is achieved related the main project target – to develop unified curricula and study programs making them compatible with EU standards
2. A permanent project Management team (about 15-20 persons) notably improved its English language skill. The progress could be noted at each Management team meeting.
3. Better mutual understanding and better different cultures awareness was achieved. Different academics terminology, sometime the same designations were used with total different realisation, at the start of the project led to wrong conclusions. The responsiveness, a culture of decision making of the partners, the quality of reporting is improving gradually. The regular Management meetings and quality assurance measures helped to achieve a progress.
4. Different readiness of universities and different legislation of partner’s education systems impacts ability EU partner’s universities to follow Bologna process. Only one project is not enough to develop study programs compatible with EU standards. The target can be achieved step by step following by notable adjustments in legislation. Mostly it is an issue of Ministry of Education of Belarus.
5. At this project stage one cannot unequivocally say that whether partner’s universities resolved the problem of students training programs compatibility. Firstly, only one partner’s university of seven participants provided full study program accreditation. Secondly, master student programs envisage two years learning process, therefore new courses testing and elaboration into training programs plus accreditation will require additional efforts beyond this project.

4. THE CASE OF THE UNIVERSITY OF PRISTINA IN KOSOVSKA MITROVICA (UPKM)

Faculty of Technical Sciences (FTS) as the largest educational institution within the University of Pristina in Kosovska Mitrovica (UPKM) was established in 2001 by integration of former Faculty of Electrical Engineering, Faculty of Mechanical Engineering, Faculty of Civil Engineering and Architecture and Faculty of Mining and Technology. Currently FTS operates as a Polytechnic institution with 19 study programmes in three levels of education: undergraduate, master and doctoral studies. More than 160 teachers and assistants provide proper education for more than 1200 students.

With such diversity of study programmes covering broad variety of engineering fields, FTS is struggling to adopt and implement modern curricula based on the needs of local and international labour markets.

In order to implement its vision and goals, FTS invested lot of efforts in preparation of accreditation materials for all study programmes, taking into account experiences of other fellow institutions.

Participation in international projects proved itself as the best way for incorporation of good practices and experiences of foreign universities. Student and staff mobility, workshops and trainings enabled gaining of new knowledge indispensable for creation of new curricula with the aim to make it compatible with EU educational practices.

In this regard, one of the most popular programmes has been Tempus programme of the European Commission. It proved itself as a very useful tool for harmonization of educational practices of EU and partner countries.

With this idea as a guide mark, FTS participated in several EU-financed programmes, one of which was an actual Tempus project "Energy" under coordination of Riga Technical University.

Rather large consortium of EU and partner countries higher educational institutions, this project under the leadership of RTU invested significant human and financial resources in order to harmonize energy efficiency-related study courses in partner countries as much as it is possible with EU ones. This goal should be achieved through sharing of the knowledge and experiences among partners, compilation of course books, provision of laboratory equipment and preparation of laboratory materials. It shown itself as a tricky and complicated task due to the size of the consortium and variety of different national educational legislation and practices.

Project goals set by FTS included the following:

- Development of new modernized curriculum in the area of energy efficiency
- Accreditation of newly introduced courses developed in the course of the project
- Compilation of several course books with the participation of project partners
- Purchase of laboratory equipment
- Installation of equipment and development of laboratory instructions
- Participation of staff and students in workshops, teacher and student trainings
- Testing of results

The main challenges in the case of UPKM included specific political situation in the North of Kosovo, differences between national and EU legislations in the area of public procurement and the level of language skills of students and staff. It influenced the purchase of the project equipment and translation of course books into Serbian language.

FTS introduced and accredited the following new courses:

- Distributed generation
- Grid integration of renewable energy sources
- Energy in general

FTS participated in compilation of the following course books:

- Distribution of power energy
- Wind energy
- Power electronics

FTS staff and students actively participated in events organized within the project framework.

Despites all of problems and obstacles, results of the project are more than satisfactory. The rate of enrolment and testing implemented among staff and student showed significant level of satisfaction with new courses and materials developed within the project framework.

Flexible approach in relation with the development of course books and selection of equipment, enabled participants to adopt what is the most suitable for them and to tailor programmes and courses according to their needs, taking into account different educational and legislative environments, in order to implement project goals in the best possible way.

Bilateral agreements with project partners will enable the future cooperation and joint participation in different projects.

Remaining tasks include completion of laboratory equipment and development of laboratory materials, as well as translation of course books into Serbian language.

The present situation in the labour market as well as future developments will ensure the high rate of employability of graduate students in this study programme. This will have as a consequence significant level of interest of future students to choose this study programme.

All abovementioned will assure long-term sustainability of results achieved during the project. Priceless experiences gained during the project implementation will enable future improvements.

Future challenges and remaining tasks for next projects include development and accreditation of new study programme, accreditation of new study programme in English language, development and introduction of new courses and textbooks, purchase and installation of new equipment.

Completely new study programme which is under accreditation will include the following courses:

- Renewable Energy Power Plants
- Renewable Energy Project Analysis
- Energy Effective Materials
- Effective Lightening
- Power Plant Heat Exchangers
- Solar Photovoltaic Electricity Systems
- Principles of Power Electronic Converters
- Wind Power Generation
- Grid Integration of Renewable Energy Sources
- Distributed Generation
- Master thesis

5. IMPACT AND SUSTAINABILITY OF THE PROJECT RESULTS

The successful collaboration between EU and EU partner's universities encouraged project participants to observe further steps beyond the project and to utilise lessons learned.

5.1. EU partner's countries – Belorussian universities

Striving to reform Belarussian high education system according to the Bologna process, the Ministry of Education of Belarus set the target to reform curricula from the existing system "5 plus 1" to the system "4 plus 2", which should comply with the Bologna system principles, in the area of physical sciences.

However, decreasing a training period from 5 to 4 years for physics and engineering specialists causes a certain risk providing an impact on the labour market. First of all, it is a challenge for research institution and enterprises due to supply of specialists with a qualification different from that of the previous graduates. Before Ministry of Education planned proportion of 5 and 6 year specialists in physics specialities as 90% and 10% that conformed labour market tendencies. By now, 5-years trained specialist qualification meets industry requirements, but specialists with 6-years training cycle were requested mostly by universities and small part of research institutions. However, in EU countries a proportion between professional bachelors and professional masters significantly differs, for example in Baltic countries it is about 70% and 30% (depending on the industry), therefore, the labour market in EU countries is focusing on professional masters graduates in much higher degree than in Belarus, which maintains former Soviet education system.

That is why Belorussian partners came to conclusion to initiate a new project in order to reform curricula in sphere of applied physics. The project will focus on a curricula modernisation in the field of functional nanomaterials production and nanotechnology, including photonics.

Furthermore, a new project aims to deepen and strengthen the curricula reform. Unlike the previous project it should address new training programs for practice-oriented master-level students complying with Bologna system principles and labour market requirements. Based on the acquired experience, the new project would broaden the number of beneficiary-universities, involving industry, professional associations and Ministries representatives working in the sphere of Education of Belarus.

5.2. EU countries – positive experience from cooperation and new ideas

Situation analysis related the status RTU among other |Latvian and neighboring universities revealed the weaknesses and the strength of the university:

- Unfavorable demographic factors cause low competition for bachelor's studies programs.
- RTU is an insufficient number of students graduate, the number of graduates diminishes each year.
- There are a large number of dropouts in the 1-2nd year study.
- RTU devotes too little efforts to develop new study programs (the most recent study program "Intelligent Robotic Systems" accredited in 2013).
- Without additional measures the situation deteriorates: the market segment of RTU is shrinking.
- Fortunately, RTU has competent staff, who are able to develop new programs and directions and to attract new students and to promote RTU's image and to compete with the other Baltic universities.

One of the decisions made before the end of the project is to develop 4 new courses for foreign students in 2015-16, namely: Energy saving technologies, Hydrogen energy, Power electronics, and Effective lighting. Based on the course materials created in cooperation with the project partners RTU elaborated 5 course books in English, which will be used as learning material for planned courses. This is a result of the efforts of the majority of the project partners including all EU partners' universities.

The other decision derived from project results is to develop two new academic programs: a program "Adaptronics" for professional bachelor and master students and a program "Electrical Engineering and Transport Information Systems" also for professional bachelor and master students.

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DISCOVERING SOCIAL NETWORKS USING A MOBILE PHONE GAME

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ABSTRACT

This paper is part of a larger project, which applies a social medicine approach to complex Aboriginal health issues in Northern Australia. A major component of this project is the construction and use of multiplex social networks, both with Aboriginal communities and associated health care worker networks. In an attempt to overcome difficulties with language diversity and poor survey response, a mobile computer game is under development for determination of the social networks. This paper discusses simulations of the game developed to optimize the server-side processing required to elucidate the network.

Keywords: social network analysis, simulation, norm change, gamification, cell phones, health, Australia, Northern Territory, Aboriginal, health

1. INTRODUCTION

There is increasing interest in the use of social network analysis (SNA) to understand patterns of interactions that may provide for more efficient health delivery systems. This is particularly so when practices and communication of prevention can be used by the community in conjunction with medical advice and treatments (Kothari, Hamel, MacDonald, Meyer, Cohen, & Bonnenfant, 2014; Shakya, Christakis, & Fowler, 2014). As these papers show, the use of SNA is also useful in the design and delivery and health programs in developing countries, where existing medical infrastructure and public health practices may be lacking. A similar issue can also exist in developed economies like Australia, where populations have different levels of access to medical services and may lack sufficient social networks of health prevention and information. An example discussed in this paper is Aboriginal health in Northern Australia.

There are several aspects of Aboriginal health, where poor outcomes may necessarily are be related to the lack of medical technology, drugs or treatment protocols. They may arise instead through issues of *social medicine*, where communication shortcomings frustrate prevention and treatment goals (see for example Preston-Thomas, Fagan, Nakata, & Anderson, 2013). In this project we focus on social networks, specifically *network resilience,* merging the latest theories in social network analysis and computer simulation with qualitative research and a leadership-development training program.

Network resilience is the capacity of a network to recover from threats and shocks. However, in the health domain, network resilience may have effects that can be positive and/or negative:

- **It is beneficial** when it helps a community to support its members, such as in providing food and assistance to the sick, or emotional support to those who have suffered loss or mental health difficulties.
- **It may be harmful** if it impairs the reduction of social contact needed to control a dangerous infection (for example, the Ebola epidemic in Africa in 2014) or the drug resistant forms of tuberculosis (Andre, Ijaz, Tillinghast, Krebs, Diem, Metchock, Crisp, & McElroy, 2007).
- **It may also be harmful** if in that it may obstruct leadership and community empowerment to break adverse social practices/norms (Carsten, Uhl-Bien, West, Patera, & McGregor, 2010).

Young & Burke (2009) show that social norms may emerge which result in some people receiving adverse medical treatment:

> *...a 75 year old heart patient is more likely to receive an invasive treatment either coronary angioplasty or bypass surgery in Tallahassee, a city with a relatively high pro- portion of younger cardiac patients (62 and under), than in Fort Lauderdale, a city with a comparatively older patient population. Since surgery becomes riskier with age, 75 year olds in Tallahassee are likely to have worse outcomes than 75 year olds in Fort Lauderdale, even with no differences in the average competence of physicians or other quality factors across the locations.*

Thus social norms, which can be deleterious, are difficult to break, and ways of bringing about a *tipping point* to another more productive norm are eagerly sought (Young & Burke, 2009) . For the spread of epidemics, such as H1N1 Spanish Flu, computer simulation has now reached the level of modelling every person in a community, 280 million agents in the case of the Los Alamos *Epicast* model for the USA (Germann, Kadau, Longini, & Macken, 2006). We aim to construct similar models to those aimed at epidemic threats, such as Extensive Drug Resistant TB, for which the methodologies are both well established. Gardy, Johnston, Sui, Cook, Shah, Brodkin, Rempel, Moore, Zhao, & Holt (2011) concluded that had Social Network Analysis (SNA) been conducted in association with historical data screening, TB outbreaks could have been prevented.

The project aims to investigate the important relationship (for an example see Fuller, Hermeston, Passey, Fallon, & Muyambi, 2012) between understanding the complexity of the networks within communities and Aboriginal Community Health (ACH) Centers and their associated care workers (ACHWs) and to elucidate thus understanding that highlight the flow of not pathogens, but ideas, information and influence, along social networks. It targets widespread health problems, such as hepatitis B (increases liver cancer risk), scabies (also increases liver cancer risk), renal failure and cardio-rheumatology. In all these cases the drugs and treatments are well established and cheap, subsidized to make them easily accessible. (Preston-Thomas et al., 2013) for example, highlight the need for "culturally appropriate patient education resources" for chronic hepatitis B. Figure 1 shows the overall project framework.

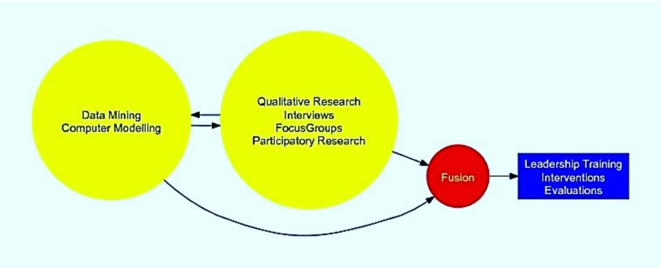

Figure 1: Project Structure

An essential requirement of the project is to ascertain the networks links between community members, ACHWs (Associated Health Care Workers) and the cross links between the two groups. A new mobile phone game is under development for building these networks, and this paper describes a simulation model for how it does so.

2. PROJECT BACKGROUND

For infection diseases, such as pandemic flu, and currently Ebola, simulation plays a major role in predicting spread of the disease and testing intervention strategies, in the *Epicast* model (Germann et al., 2006) with an computer agent for every person in the United States. The network of connections among individuals, through schools, shops, public transport are explicitly represented to get as accurate estimate as possible of the infection trajectory.

2.1. Social network analysis for health

In chronic diseases networks are equally important, but they are *social networks*, where the infective agents are not the pathogens, but information and influence. From the early days of network thinking, when Watts (1999) introduced *small world networks* to explain the six degrees of separation phenomenon, through the rapid growth in understanding scale free networks, introduced by (Barabási & Frangos, 2014) to the exponential random graphs (Pattison & Robins, 2002) which underlie many social phenomena, the structure of networks has emerged as a key driver of social dynamics.

Social networks focus on the relational and interactional ties between units (Wasserman, 1994). Christakis & Fowler (2009) cite numerous examples of network effects in medicine, such as the influence of friends of friends of friends (three degrees of separation) on obesity. Centrality is the key concept from graph theory needed in SNA. From the node level point of view can be measured in terms of degree (the number of ties to and from an actor). Structurally, centrality is measured in terms of closeness (the extent to which an actor is close to all others in the network) and betweenness (the extent to which an actor lies in the shortest path to all others in the network). So, it is implied that *degree centrality* shows the strength of actors' communication activity while *betweenness centrality* indicates an actor's control of communication (power and influence) and *closeness centrality* shows actors the minimum time and efficiency for communicating with other actors in the network (or communication efficiency, see Chung & Hossain, 2010). Granovetter (1973) introduced the idea of the strength of weak ties, as the first influential study on the importance of relations of actors in social networks, arguing that individuals obtain new and novel information from weak ties rather than from strong ties within the individual's group structure. If *i* has a strong tie with *j* and *k*, then *j* and *k* themselves are likely to become friends (the *homophilly* principle). Thus, strong ties will tend to cluster into cliques. The bridge *ij* in Figure 2 is a weak tie that brings novel information to each group.

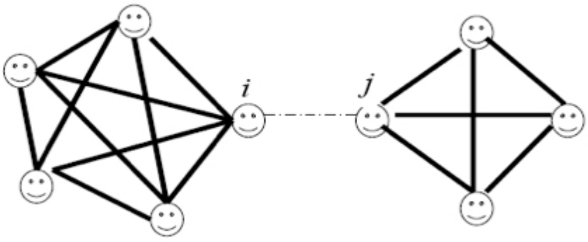

Figure 2: Weak vs.Strong Ties

As an individual's personal network grows over time, the extent of information coming from closely knit clusters ends to become redundant (Chung & Hossain, 2010). Actors are in a better position to benefit from interactions with others, who are not well connected themselves or are not well organized. Based on this idea Burt (2009) introduced the idea of structural holes. Holes in the network refers to the absence of ties that would otherwise connect unconnected clusters together. For instance, as it is shown in Figure 3, the network on the left contains many structural holes while the one on the right contains few. In other words, the lack of connections among unconnected nodes in a network form the holes in the structure. Individuals who bridge these holes attain an advantageous position that yields information and control benefits (Chung & Hossain, 2010).

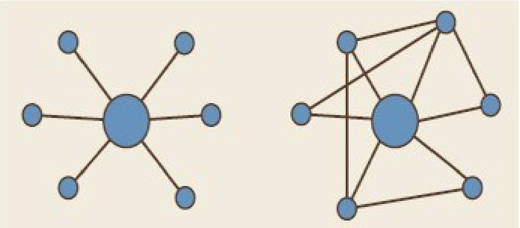

Figure 3: Two ego networks with different structures

Network effects on an individual's ability to perform better have been documented in studies on community health, communications, sociology and social psychology (Coleman, 1988; Guetzkow & Simon, 1955; Leavitt, 1951) and actors with a dense social network perform better (Oh, Chung, & Labianca, 2004; Reagans & McEvily, 2003). Furthermore, actors who are rich in structural holes (connections to social clusters or groups who are themselves not well connected) are better situated in their social network to obtain, control and broker information (Burt, 2009). In the field of medical innovation, Social Network Analysis (SNA) proved useful for understanding the diffusion of innovation among physicians (Coleman, Katz, & Menzel, 1957). It also proved fruitful for understanding the social processes which intervened during the initial trials of the drug gammanym, from the time when it was adopted by a few local innovators to the time when it was ultimately used by the entire medical community.

2.2. Australian Aboriginal health issues

Several major health problems within Aboriginal communities are essentially Non-Communicable Diseases (NCDs), such as renal failure and liver cancer. The primary causal factors include pathogens for which there are straightforward treatments and vaccines. The solutions lie therefore not in conventional but in social medicine, which involves lifestyle choices and effective communication and influence. Thus understanding social networks is essential to addressing questions in social medicine.

In network epidemiology studies traditional SNA has been widely used to understand mental health (Perrucci & Targ, 1982), social network and health status (Seeman, Seeman, & Sayles, 1985) and the spread of HIV disease (Morris, 1993). Little is known about how the social immunity and resilience which is embedded in social networks of Aboriginal Communities.

Recent developments in network theory surround *multiplex networks* (Bianconi & Dorogovtsev, 2014). In such a network, there is one set of nodes (usually people, but could include animals or other agents), but with multiple layers, each layer connected by a different mechanism. So, for example, a community may have school, work and sport networks, each connecting its members in different ways. Such multiplex networks have quite different properties compared to single layer networks, and are often more difficult to break apart.

There are five levels of the multiplex network, each targeted by a separate mission of the game:

- The kinship network of family ties
- The peer network of friends of similar age and occupation, such as teenage groups;
- The cultural / community ties, spreading out hierarchically from the community elders.
- The information links, which defines the trust network for data about health risks and treatments.

There are two coupled social networks involved: the networks of the Aboriginal Health Care Workers; and the networks of the individuals within the communities themselves. The nature of this coupling and the associated dynamics are significant in improving existing, and identifying new, interventions. Better health outcomes require changing social norms. We propose the use of leadership training will help bring about change, with effects continuing beyond the lifetime of the project (Evans & Sinclair, 2015).

Building computational models of social systems often hits the major difficulty of taking qualitative data from interviews, focus groups and other tools, and creating quantitative, algorithmic decision procedures to put into the computer model. Yet this data flow is critical to building better agent-based models of socio-economic systems. Numerous findings, such as Preston-Thomas et al. (2013) highlight the significance of communication and information dissemination in Aboriginal Health. Understanding the way influence travels along social networks within Aboriginal communities is essential to formulating the most effective leadership training protocols. The overarching project integrates agent-based computer modelling and social network analysis, underpinned by extensive qualitative research applied to Aboriginal health. It also features the incorporation of the research findings into leadership training as its capstone health intervention.

3. SIMULATION TO MODEL NORM CHANGE

This project features a new hybrid approach to overcoming immunity to change (Keagan & Lahey, 2009). It will use computer simulation, infused by the network data, to determine the drivers and key network properties of social norms. It will then simulate various interventions to create tipping points (Young & Burke, 2009) in these norms. Such interventions could range from turning an influential individual, to adding financial incentives to alternative behaviors. The computer models require a decision process for the agents and a network model for the communication between them. The latter is inferred from the qualitative and historical studies. The decisions use the Quantal response model (McKelvey & Palfrey, 1998), common in choice modelling. Such models require a utility, ui, corresponding to each possible action and temperature parameter, T = 1 , which governs how much noise there is in the choice. At high temperatures, the choice is random. At low temperatures, only the choice with maximal utility is chosen. A simple implementation, where Pi is the probability of making choice i, from a set of M choices is:

$$P_i = \frac{exp^{(\beta u_i)}}{\sum {}^k_i \ exp^{(\beta u_k)}} \tag{1}$$

Such models need both verification and validation (Midgley, Marks, & Kunchamwar, 2007). Verification is the process of establishing that the software will perform as required. It will be accomplished using: independent code reading by team members; testing system level conservation quantities; checking for expected trends; and sensitivity analysis. Graphs and networks are visualized with standard software such as *Pajek* and *Matlab*. To detect tipping points, however, we will get some parameter values where the model is very sensitive. To check that these are genuine tipping points (as opposed to numerical instabilities or in- felicities), we use a battery of established techniques (Scheffer, Carpenter, Lenton, Bascompte, Brock, Dakos, Van De Koppel, Van De Leemput, Levin, & Van Nes, 2012): increased variatiance; long correlation lengths; flickering; and maxima in mutual information and transfer entropy (Barnett, Lizier, Harré, Seth, & Bossomaier, 2013; Bossomaier, Barnett, & Harre, 2013; Harré & Bossomaier, 2009).

The Community Health Simulation Model (CHSM) embeds the social network and the choice mechanism in an Agent Based Model (ABM) with one agent per person for at least two communities, the associated Aboriginal Health Care Workers and other stakeholders. To determine its validity it will simulate a range of health outcomes as presently observed and parametrization and network structure fine-tuned accordingly. The validated model will then be run for various scenarios suggested by current health priorities and the data from the social network analysis. It will determine which links need to be strengthened or broken in order to achieve better health outcomes.

4. THE GAME

This game is single player, but uses a web site and server-side processing to elucidate the SNAs. There are three levels. Each level corresponds to one of the components of the multiplex network.

There are prizes at each level. At the first level, everybody wins a small prize, say around $50, typical of the cost for an experimental subject. The second level involves a smaller number of larger prizes and the third a single new smartphone.

The game starts with a random network on the server. Each player gets a challenge, to link two faces, say A to C, via other faces presented as an option, say, a,b,c,d. The player, Leesha, say, has to choose a person which will give the shortest path to C. Suppose Leesha chooses b. The server now increases the strength of link b, and generates a new set, x,y,z, C. Leesha chooses again and again, until she chooses C.
At the beginning, Leesha gets a score just for completing the task, so it's easy to begin with The server meanwhile has added strengthened her links. Future guesses from other players get higher scores and the link strength goes up slightly super linear with number of hits. Thus the network gets more and more realistic as the game progresses.

A strategy already used in games is employed to increase engagement. Everybody is trying to maximize his/her score and can see a league table. But everybody effectively has to cooperate to open the next level. This would occur when the network is stable (details to be worked out about how to measure this.) At this point all links which never received reinforcement are deleted. To help with this collective goal, the growing network could be visualized in the game.

An important aspect to this: all the people in the game do not need to play. In fact, one could restrict players to a target age group, so that we get the network as perceived by that group. Not sure about whether this is a good thing. The game is only weakly language dependent, requiring just a hundred words or so of text at the start of the game. This is especially important for remote Aboriginal communities where English may sometimes be a second, third of fourth language.

5. SIMULATION MODEL

First we consider the need for the simulation model and then go on to provide the details.

5.1. Need for the simulation model

Running tests with human players is very time consuming, both before during and after the experimental run. Yet there are numerous game parameters and algorithmic details to optimize:

- Players can enter a link with various levels of certainty, say, definite, strongly believe, and unsure. Each decision needs to assign a lower candidate weight to the link. The weights of these links determine the ratio of false positive (high weight to unsure) and true negative (low weight to unsure).
- The number of games needs to be set for the human trials, or at least some maximum value needs to be imposed. But the network will asymptote to the correct set of links, so the convergence needs to be examined to determine the most effective stopping point.
- AT the outset it is not known what the fine structure of the networks will be. They may be assortative, homophilic and so, and each network will present different learning challenges. Thus the server needs to predict and adapt to these structures to optimize the presentation of faces for refining the links. These issues can all be addressed by simulation.

6. DETAILS OF THE GAME AND SIMULATION

The simulation model first generates a network, either random or small world, for the community. For each player, it then generates a reduced network and adds noise. So each player has a network which connects everybody in the community (all nodes of the graph), but with varying strength according to how well they know somebody.

At each time step each player works out the shortest path between the target faces, given their own network knowledge. This path is inversely weighted by their certainty of each link. So, the shortest path may be longer than the number of actually steps needed to get from one node to the other, because this reduced number of links has greater uncertainty. In more detail, each player has a set of links comprising:

- Their direct links, which have value 1, since they are certain;
- Their next neighbor links, in other words, the links of their friends; these are less certain and have a value q_{nnn} , which is set to 5;
- Their remote links, which are random, but biased towards the correct network, which have a weight q_{rem} , currently set to 20.

The larger values of the next neighbor and remote links means that shortest paths will avoid these links if possible. The game is then iterated for a number of rounds, with each player playing once in round. Each time a link is used by a player, the learned network is updated on the server. But the link strength is updated by the reciprocal of the link value. Thus a remote link (player uncertain about it) contributes less to the growing network.

The game simulation is built in Matlab R2012b, using the $matlab_b\, gl$ toolbox available from Matlab Central on the Mathworks website (www.mathworks.com.au/matlabcentral/).

7. RESULTS

The community size was set at 200, as above. The number of players, 50, was varied along with the number of nodes. Figure 4 shows the results for a random graph. The green line shows the number of links correctly identified on the server. The red (solid) line shows false positives, which increase slowly as the games progress. The blue line (major dashed) shows the true negatives, which decrease as the game progresses.

To play a game, defined here as one face set, could probably be completed in around 10 seconds. If we say that an average of 5 are completed per minute, the total time would be 200 minutes, which is quite feasible for a play anywhere anytime mobile phone game.

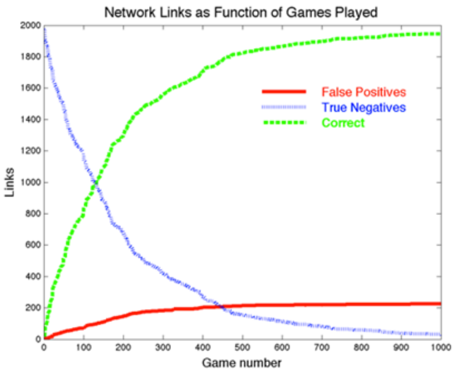

Figure 4: Simulation results showing true positives (descending curves) and false positives (rising curves) for a random graph.

Figure 5 shows the same plots for a small-world (Watts, 1999) network. The number of direct neighbors was 20 and the probability of rewiring 0.1. This gives approximately the same number of links as the random graph case. The two networks are quite similar, although the small world is slightly easier to learn. This is fortunate, since it is more representative of likely community structures. It is also fortunate that the differences are not too great, since it suggests the game will be robust to the actual community structure.

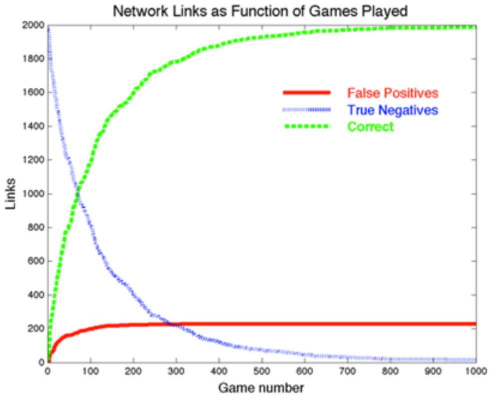

Figure 5: Simulation results showing true positives (descending curves) and false positives (rising curves) for a small world network.

8. CONCLUSIONS AND FURTHER WORK

The simulation model described here demonstrates that it should be possible to get good network estimates within an acceptable timeframe. The next stage of the project is to test the effectiveness within actual cohorts of players. Pre-testing of the game will be carried out on two student cohorts, form quite different social structures: a regional university in NSW; and the University of Hong Kong. The student cohorts will contain 200 students matched to similarly sized Aboriginal communities. For these cohorts the networks determined by the game will be validated by surveys, focus groups and interviews.

Furthermore we believe the use of a mobile game methodology outline in this paper has much to offer the field of SNA. SNA relies on extensive interviews, where respondent ability to describe a network may vary, along with other members of that network (Bader & Schuster, 2015; Gummerus, Liljander, Weman, & Pihlström, 2012; Xu, 2011). The use of secondary information to describe social networks, may also be limited in that to what extent respondents' value or actively use a network encapsulated by events or online linkages may be difficult to determine without directly questioning them. In short, the use of the game methodology as outlined in this paper may be an important addition to a social network analysis, which relates directly back to the demonstration of a social network as a communication channel of importance to respondents.

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A GENETIC ALGORITHM TO DESIGN TOURISTIC ROUTES IN A BIKE SHARING SYSTEM

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ABSTRACT

The aim of this paper is to study a Bike Sharing Touring (BST) applying a mathematical model known in operation research as Orienteering Problem (OP). Several European Cities are developing BST in order to reduce the exhaust emissions and to improve the sustainability in urban areas. The authors offer a Decision Support Tool useful for the tourist and the service's manager to organize the tourists' paths on the basis of tourists' desires, subject to usable time, place of interest position and docking station location. The model analyzed presents two innovative aspects compared to a classic OP. The first one is that the start and the arrival point of routes aren't necessary coinciding and pre-conditioned. The last one is that the knowledge of tourist tours allows to book the visit to a point of interest and doing so to optimize efficiency of the whole system and not only of the single tourist tour.

Keywords: Orienteering Problem, Bike Sharing Tourist, Decision Support System

1. INTRODUCTION

Bike sharing schemes are short term urban bicycle rental schemes that allow to pick up bicycles at any self-serve bicycles station and return them to any other bicycles station. This structure makes bicycle - sharing ideal for point-to-point trips. The bike sharing process involves several units and parties like bikes, docking stations, station services and users. The characteristics of these systems are often in continue evolution and differ country to country. The European's interest in this kind of mobility, with particular focus on big cities, has increased in the last year. For this reason recently many funds and several scientific research are focused on improving the bike sharing service for the users and for the head of management.

In our research we aim to improve bike sharing service, thanks to a Mobile Tourist Guide (MTG) of new generation, able to support the cyclist or tourist to decide which point of interest to visit and in which sequence. This decisional process is known in literature as Tourist Trip Design Problem (TTDP) and very often is defined as an extension of another problem called Orienteering Problem (OP).

In the OP, several location have an associated score and have to be visited only once to obtain a total trip score. The objective is to obtain a score as high as possible without violating a given time restriction.

A Tourist Trip Design Problem (TTDP) consists into finding the best tour or more tours taking into account a set of N locations to visit with the respective scores. The score is considered as a representation of the user preferences with respect to that particular point to visit. Moreover, this problem is made more complex by the limitation imposed by users in terms of time. Generally the tourist knows in advance the time that can use in a tourist tour. Others elements of complexity to solve this kind of problem are: opening time of Point of Interests (PoIs), weather conditions, uncertainty about the scheduled visit times caused by queues or service blackout, preferences expressed by the users on the route used to reach the PoI.

In order to face some of these complexities, researchers have proposed several approaches. In paragraph 2 a literature review is presented. In the following two paragraphs the Orienteering Problem is detailed and our solution approach based on Genetic Algorithm is proposed. In the last two paragraphs, experimental results and conclusion are given.

2. LITERATURE REVIEW

This work develops an algorithm that permits the creation of touristic routes, in which each location have associated a score and the tour have to be completed in a specific time T_{max}. The described route-planning problem can be considered as an application of the OP.

In the OP, several locations with an associated score have to be visited only once in order to obtain a total trip score. The objective is to obtain a total trip score as high as possible without violating a time restriction.

There has been works on exact methods that have yielded solutions to smaller sized problems. Due to the computational limitations of the exact algorithms, the heuristic procedures were explored.

The first heuristics were proposed by Tsiligirides (1984) and are known as the S-algorithm and the D-algorithm. The S-algorithm uses the Monte Carlo method to construct routes using probabilities correlated to the ratio between node score and node distance from the current node. The D-algorithm is built based upon the vehicle scheduling method proposed by Wren and Holiday (1972). This approach operates by dividing the search area into sectors that are determined by two concentric circles and an arc of known length. Sectors are varied by changing the two radii of the circles and by rotating the arcs. A route is built when all nodes in a particular sector have been visited, or it is impossible to visit any other node of the same circle without violating the T_{max} constraint.

Golden, Levy and Vohra (1987) propose an iterative heuristic for the OP which consists of three steps: route construction using a greedy method, route improvement using a 2-opt swap, and center-of-gravity which guides the next search step. Golden, Storchi and Levy (1986) present an approach that is divided in three steps: initial route selection that is performed by using the center of the gravity procedure, then the node insertion and node deletion procedure.

Golden, Wang and Liu (1988) combine Tsiligirides's S-algorithm concept, the center of gravity, and learning capabilities into another approach to solve the OP to provide probabilities for node selection. Keller (1989) uses his algorithm for the multi-objective vending problem to solve the OP. A path construction phase uses a measure identical to that of the S-algorithm. This is followed by a three steps improvement phase that uses node insertion and identification of node clusters. Wang, et al. (1995) propose an artificial neural network approach to solve the OP. A Hopfield-like neural network is formulated and a fourth order convex energy function is devised.

Ramesh and Brown (1991) propose a four-phase heuristic for the generalized orienteering problem, i.e., the cost function is not limited to a Euclidean function. The four phases consist of nodeinsertion; cost improvement, node deletion and maximal insertions. The route is improved by a 2-opt procedure followed by a 3-opt procedure in the second phase. In the third phase, one node is removed from the current route and one node is then inserted in an attempt to decrease the length of the route. Finally, as many unassigned nodes as possible are inserted onto the current route in order to increase the total score.

Chao, et al. (1996) introduce a two-step heuristic to solve the OP. In the first step, initialization, by using the starting and ending nodes as the two foci of an ellipse and the max T constraint as the length of the major axis, several routes are generated and the one with the highest score is the initial solution. The initial route is then improved by a 2-node exchange in the cheapest-cost way, and then improved by a 1-node improvement that tries to increase the total score.

Golden and Silberholz (2009), propose two parameters iterative algorithms approach to solve the generalized orienteering problem. There are three phases: initialization in which the path is constructed and optimized by a 2-opt procedure, path tightening that is a local-search method that adds nodes to a solution when its length is less than the length limit, increasing that solution's score as much as possible and iterative modification in which the current solution is modified.

The Orienteering Problem (OP) is used to model single day itineraries. On the other hand, additional constraints for the itinerary, such as maximum budget to spend, or maximum number of POIs of certain type to be visited could be considered. Garcia et al. (2009) extend ILS (Iterated Local Search) to solve the Multi Constraint TOPTW, which allows to modeling the constraints related the maximum allowed budget to spent and maximum allowed POIs of certain type or category to visit. Souffriau et al. (2011) introduced a web–based tourist decision support system. The system uses the Arc Orienteering Problem (AOP), which is a single tour arc routing problem with profits. In AOP the arcs are associated with profits and travel costs and the goal is to find a route from a starting node to an end node with maximum profit and total travel cost not higher than a given value. Souffriau et al. use the AOP to solve the problem of planning cycle trips in the province of East Flanders. Their solution approach is based on a Greedy Randomized Adaptive Search Procedure (GRASP). This web–based system is extended with an SMS service that provides cyclists "in the field" with routes on demand.

The City Trip Planner introduced by Vansteerwegen et al. (2011) is a web-based tourist expert system that proposes custom-made city trips, tailored to the user's interests and context. The system is implemented as a web site. This system uses a meta-heuristic iterative Greedy Randomized Adaptive Search method. For each interaction, a list of possible visits is generated from an initial solution, which contains only the start and end of each tour. Those visits that have a heuristic value below a certain threshold are eliminated. A random visit from the remaining list is selected and applied to the current solution. The algorithm maximizes the tourist's trip satisfaction, by selecting the most interesting visits while respecting all constraints.

Černá et al. (2014) introduced a new problem in Combinatorial Optimization, namely the Most Attractive Cycle Tourist Path Problem (MACTPP), modeling the design of an origin-destination path with maximum attractiveness, subject to budget and duration constraints. The objective is to maximize the reward accumulated by traversing the arcs and the nodes of the path. These can be traversed several times, each time with a different satisfaction. Černá proposed an ILP model, which was solved by commercial software, with a dynamic generation of violated constraints.

Although the OP is studied from several researchers only during the recent years some authors proposed a genetic approach. With respect to heuristic or meta-heuristic approach, the Genetic Algorithm is generally able to explore a greater solutions' number. Good results are given by this approach in several field, the major critic to this method is relative to computational time. Tasgetiren and Smith (2000) propose a Genetic Algorithm (GA) to solve the orienteering problem. A permutation representation is used and a penalty function is employed to help search the infeasible region. Four test sets are used. Tasgetiren's results are competitive, though the computational time is relatively high. Romero et al. (2012) propose a bi-level optimization model for the optimal location of bike-sharing stations, using a genetic algorithm, where the goal is to maximize the number of travelers that use the system. Its lower level is a modal split and assignment model, capable of reflection the interactions between car and bicycle mode. Time-reducing strategies applied to the genetic algorithm methods are valid, because the program returns similar solutions, with great computing time-savings. Finally De Falco et al. (2015) develop an evolutionary algorithm to generate personalized multiple-day itineraries with time windows using a linear chromosome encoding. Most recently other different metaheuristics are proposed to solve the OP as Ant Colony Optimization. Liang et al. (2006) develop and compare an ant colony optimization approach and a tabu search algorithm. Then Schilde et al. (2009) developed a multi-objective solution approach, which is a variant of the OP. Their approach outperforms the five-step heuristic of Chao et al. (1996), which deals with single objective OP instances. They developed a Pareto ant colony optimization algorithm and a multi-objective variable neighborhood search algorithm, both hybridized with path relinking. With respect to actual state of art in this paper we propose a Genetic Algorithm with a particular chromosome encoding that introduce the concept of "closed loop" for the chromosome's structure. This new configuration explores in more ample way the solution space obtaining good results in a short computational time.

3. PROBLEM DESCRIPTION

In this work, as mentioned in the introductory paragraph, the authors face the Tourist Trip Design Problem (TTDP) as an Orienteering Problem (OP). In the OP, a set of N location corresponding with nodes *i* is given, each with a score S_i. The starting point and the end point are fixed. The time t_{ij} needed to travel from vertex *i* to *j* is known for all vertices. The problem became more complex because not all the vertices can be visited since a given threshold Tmax limits the available time. The goal of the OP is to determine a path, limited by T_{max} that visits some of the vertices, in order to maximise the total collected score. The scores are assumed to be entirely additive and each vertex can be visited at most once.

The orienteering problem can be formulated as follows: $S_i \geq 0$ is the score associated to node *i*, c_{ij} is the cost associated to path between node *i* and node *j*. Usually n nodes are considered in the Euclidean plane. Since the distance and travel time between nodes are determined by the geographical measure, distance is used as the representative of path's cost. Generally, the mathematical model of the OP is formulated as follows:

$$Max \sum_{i=2}^{n-1} \sum_{j=2}^{n} S_i \, x_{ij} \qquad (1)$$

Subject to

$$\sum_{j=2}^{n} x_{1j} = \sum_{i=1}^{n-1} x_{in} = 1 \qquad (2)$$

$$\sum_{i=1}^{n-1} x_{ik} = \sum_{j=2}^{n} x_{kj} \leq 1 \quad \forall\ k=2,\ldots,n-1 \qquad (3)$$

$$\sum_{i=1}^{n-1} \sum_{j=2}^{n} c_{ij} x_{ij} \leq T_{max} \qquad (4)$$

$$2 \leq u_i \leq n \qquad \forall\ i=2,\ldots,n \qquad (5)$$

$$u_i - u_j + 1 \leq (n-1)(1-x_{ij}) \qquad \forall\ i, j=1,\ldots,n \qquad (6)$$

$$x_{ij} \in \{0,1\} \qquad \forall\ i, j=1,\ldots,n \qquad (7)$$

Where (1) represents the problem's Objective Function to maximize as total collected score *S*. Constraint (2) guarantee that the path starts in vertex 1 and ends in vertex *N*. Constraint (3) ensures the connectivity of the path and guarantee that every vertex is visited at most once. Constraint (4) ensures the limited time budget *T*. Constraints (5) and (6) are necessary to prevent sub-tours. Constraints (7) requires that the variables are binary. The decisional variable x_{ij} is equal to 1 if the node j to i are connected, 0 else. This formulation guarantee as result a tour able to:

- Visit as many PoI*s* as possible as sub-number of nodes;
- Visit PoIs at most once;
- Visit PoI*s* that maximize the Total Score (Objective Function)
- Visit PoI*s* connected among them
- Visit PoI*s* respecting the limitation time.

4. SOLUTION APPROACH

The concept of Genetic Algorithm (GA) was developed by Holland (1975) and then described by Goldberg (1989). GA are stochastic research techniques based on the mechanism of natural selection proposed by Darwin's theory: the strongest species has the greater opportunity to pass their genes to future generations via reproduction. Sometimes particular crossover procreates an original individual that start a new generation of individuals better than the old one. In the GA this randomness is opportunely reproduced to explore in a larger way the solution research area.

As reassumed in Askin et al. (2013), GA starts initializing a First Population composed by a pre-determinate number of individuals. Each individual is characterized by several elements such a chromosome and a fitness value. The individual's chromosome is composed by several gene that can assume binary or integer value, the combination of these genes usually represents the problem's solution thanks to a correspondence between the gene's value and the problem's variables value. The individual's fitness value corresponds to solution goodness, and it's basic to determinate the individual's probability to survive at evolution process, so that bad individuals or bad problem's solutions are destined to not have a long life into population. The difference between the old and the new population in the evolutionary process is guaranteed by the presence of two important and always applied operations called Mutation and Crossover. After several generations, the best solution converges, and it hopefully represents the optimum or suboptimum solution to the problem at hand. GA are successfully applied to different contexts in order to solve a very large number of problems, for this purpose various and original genetic operators are developed, that revisit the original concept of mutation and crossover. Despite that, there are not yet many works in literature that have applied GA for solving Orienteering Problem especially in the last years. Tasgetiren and Smith (2000) is one of the lasts significant works in this field.

4.1. Encoding and Decoding

Encoding. In this work the authors propose the following encode of chromosome. Each chromosome is encoded as a vector of integer number representing the PoIs of our problem or the nodes, as we will call them from now on. In our case, the problem's solution is not represented by whole chromosome, but only of a part of it. The chromosome's part or as we call it, the tour, is composed by a sub-set of nodes that can be visited by tourist respecting the limitation time imposed. As showed in the Figure 1 we suppose that in each chromosome is contained one o more admissible tour for our Orienteering Problem.

In more details, our chromosome is composed of all nodes that the tourist wants to visit, without the start node and the end node. This choice depend on the following consideration:

- the start and end nodes are defined by the problem and they have to be inserted into each tour;
- the start and the end nodes don't have an associated score so that the goodness of solution is independent from them.
- The start and the end nodes are added to solution in a second step in order to calculate the effective length of tour in terms of time.

This coding of chromosome with respect to problem's solution, represented by a single tour, allows to have only admissible solutions, better or worst on the basis of Total score reached by visiting more nodes or better nodes.

Decoding

The original contribution of this paper consists into use a closed loop structure for the Chromosome. In this way it is possible to change the starting point of tour and to explore a great number of solutions for each chromosome. In Figure 1 a usually linear structure of chromosome is given. In the Figure 2 the same chromosome is represented in a closed loop structure. The numbers inside of the chromosome represent the PoIs or nodes to visit on the basis or visiting order. For example in the Figure 1 the first tour is given by nodes *"2","1","6","5","4"*. Wanting to find only 1 tour we identify the objective function value of chromosome as the objective function value of the best tour found inside the chromosome. Thanks to this assumption the research of tour inside the chromosome takes on a great importance. For this reason we introduce a closed structure.

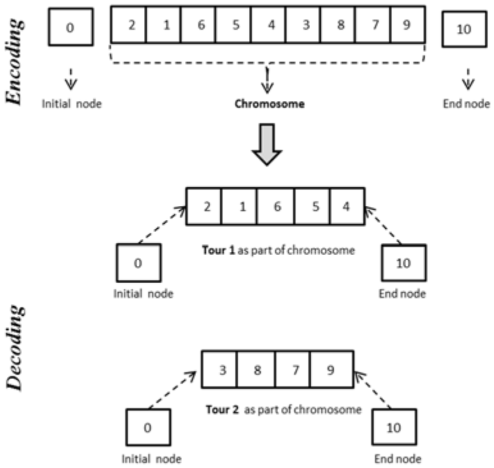


Figure 1: Linear Chromosome Structure code

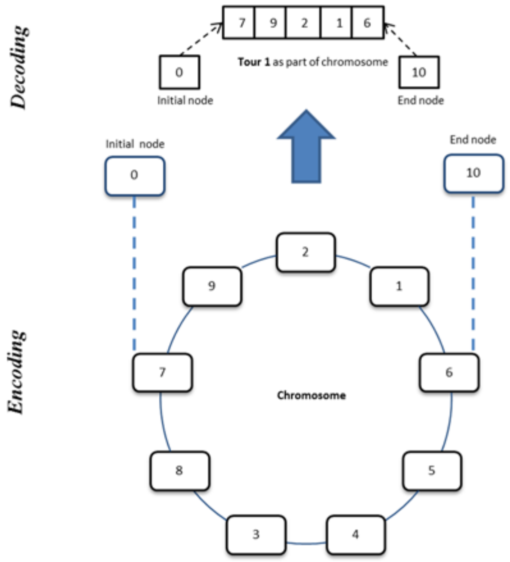


Figure 2: Closed loop Structure of Chromosome code

Thanks to this structure also the tour containing nodes at the initial and the end of chromosome can be considered in one same tour. In this way the solutions founded and evaluated for each chromosome are many and it is necessary a little number of interactions to found a good solution.

4.2. GA structure and Genetic operator

The general structure of the genetic algorithm, we have accomplished in this work is described below. In this application the individual is an object containing these information: chromosome, fitness function, objective function's value, the first and the last tour's node. Thanks to this structure, for each individual we can evaluate several tours and to obtain good problem's solution also with small population's sizes.

Genetic Algorithm

```
Parameters Setting
Population size $PS$
Number of nodes (Chromosome's length) $n$
Best Solutions Containers (BSC) size $B$
Frequency rate of genetic operators
Frequency rate of parents' selection from BSC
Number of interactions $i$ (as terminal condition)
Maximum time $T_{max}$ for visiting nodes
Set Pop (0) empty
Set BSC (0) empty

Initialization
- Generate a feasible solution randomly as individual
- Save it into the population Pop (i)
- Compare it with individual inside the BSC
        If a worst solution is inside the BSC then
        Update the BSC inserting the generated
        Individual and canceling the worst solution
- Loop until the population's size $PS$ is reached
- Calculate Fitness Function for each individuals of Pop and BSC
While the number of iteration is not equal to predefined value of iterations do
Set iteration i = 0
Selection
Roulette function for selecting two individual as first and second parent sometimes from Pop and sometimes from BSC, on basis of Frequency rate of parents' selection from BSC
Crossover
- Apply PMX operator with frequency rate defined in parameters setting to obtain two new individuals as offspring
- Apply Single Crossover operator with frequency
    rate defined in parameters setting to obtain two
    new individuals as offspring
- Chromosome decode as n tours
- Evaluate Fitness Function
- Evaluate the BSC's updating

Mutation
- Apply Smart swap operator with frequency rate defined in parameters setting to obtain two offspring as mutation of individuals generated at Crossover level
- Chromosome decode as n tours
- Evaluate Fitness Function
- Evaluate the BSC's updating

Build
- Build new Population Pop (i+1) as collection of individuals generated with Crossover and Mutations Operation
    If there are 3 iterations with the same best
    Individual, insert into Pop 20% of random
    Individual
Next i
End
Return the best solution
Return the best individual containing the best tour as solution of Orienteering Problem
```

The GA, typically uses two kind of genetic operators, Mutation and Crossover, in order to increase the probability to explore a greater area of solution with respect to others heuristic algorithms as Local search, Tabu search and Greedy. On the basis of this kind of problems and above all on the basis of its complexity, these operators can be used in an original way or in an original combination. In particular we have chosen to use 4 kind of operators:

- Single Crossover
- PMX Crossover
- Smart Swap
- 2-opt

Thanks to a probability definition, it is possible to test the effect of each single operator on chromosome. Generally the three operators are structured in way that a chromosome can be subject to all operators.

4.2.1. Single Crossover

Single Crossover operator proceeds in two steps, firstly two parents are selected randomly from population(i) – with I we represent the algorithm's iteration – secondly each pair of individual chosen is combined to obtain two offsprings. The ways to combine the genes of parents' chromosome are many and one can be preferable to another mainly on the basis of chromosome code.

In this work we have chosen two kinds of Crossover: Single and one known as Partially Matched Crossover PMX.In Medes (2013) is well expalined as with the Single Crossover operation, an integer position x along the chromosome is randomly selected. The offspring is created swapping all the genes between x+1 and l as chromosome's length.

4.2.2. Partially-Matched Crossover (PMX Crossover)

PMX Crossover is the second one crossover operator used for our genetic algorithm. Basically, like for Single Crossover we select randomly two parents that will create two offsprings containig part of the parents's chromosome.

In this case, two integer positions x_1 and x_2 along the chromosome are randomly selected. The two integers are used as indexes to select the part of chromosome to transfer from one parent (for example the mother) to child, the rest of child's chromosome will transfer to it from the other parent (for example the father). To avoid genes' redoubling a swapping technique is reproduced. The PMX – crossover operator is explained in the Appendix A Figure 5.

4.2.3. Smart Swap

Smart Swap is a variation of Random Swap Operation (RSO). RSO is a well-known operator of Mutation. The mutation operators have the task to preserve the diversification into solution's area search. In the Random Swap, two genes of father's chromosome are randomly selected and then exchanged to generate the offspring's chromosome. As a difference with respect to the crossover, applying this operator it isn't necessary a couple of individuals but just one.

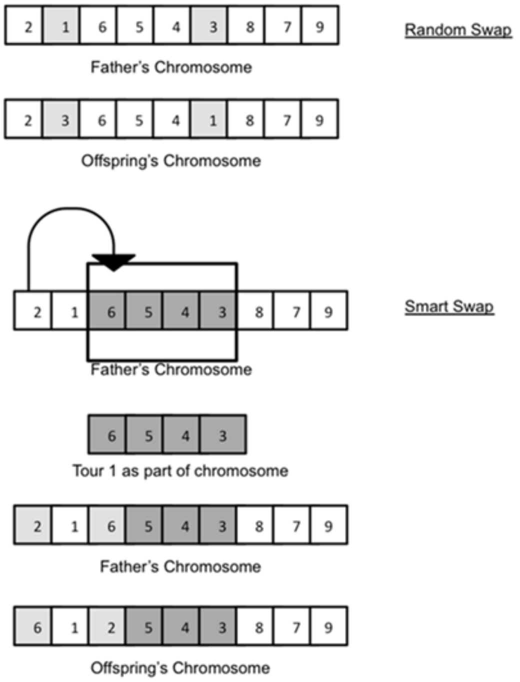


Figure 3: Smart Swap

For the structure of our chromosome code, in our work, it is necessary to apply a Smart Swap, if infact the two genes are selected into the best tour of chromosome, the total score does not change. This means that we don't generate enough variation to individuals' population. To overcome this limit we impose to select one of the two genes outside the best tour of chromosome.

Thanks to this order, we can evaluate more different solutions with different total score. Figure 3 represents the most important difference between the Random Swap and the designed Smart Swap.

4.2.4. 2-opt Mutation

2-opt is a simple local search algorithm first proposed by Croes in 1958 to solve the traveling salesman problem. The main idea behind it, is to take a route that crosses over itself and reorder it so that this does not happen. It compares every possible valid combination of the swapping mechanism and gives good results in several routing problem as Vehicle Routing Problem (VRP) but also Capacited Vehicle Routing Problem (CVRP).

4.2.5. Elitism

A variant of the general process of constructing a new population is to generate a separate container called Best Solution Container (BSC) that contains the bests solutions founded during the last iterations. When a new population is generated, the parents are selected through a probability, a part from old population and the other part from BSC. This strategy is known as *elitist selection* and guarantees that the solution quality obtained by the GA will not decrease from one generation to the next.

5. EXPERIMENTAL RESULTS

To evaluate the performance of the algorithm, we have proceeded firstly testing it with instances known in literature Chao (1996). Subsequently the algorithm has been implemented to a real case in the Naples town and the results are presented below.

5.1. Algorithm's validation

To validate the developed genetic algorithm and solve an orienteering problem for bike sharing tourist, we test it with the instances data Set 2 proposed by Tsiligirides (1984).

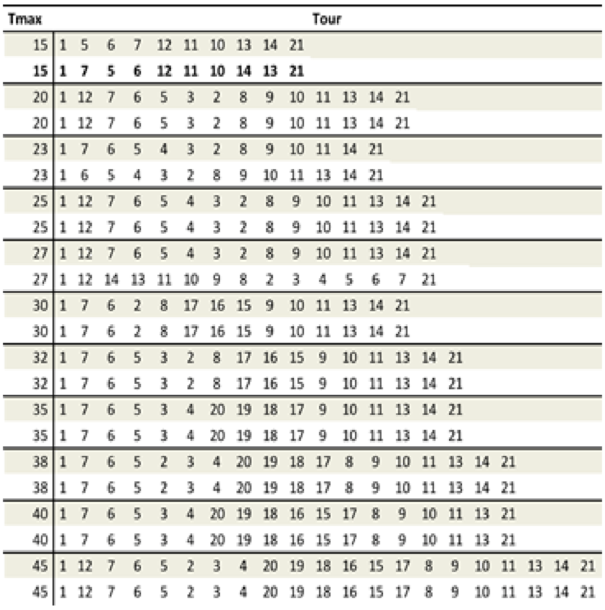
The Appendix A shows our validation results and compares them with the results of others heuristic method used to solve an orienteering problem. Our approach is indexed with GA*, another GA is proposed in Tasgetiren (2000), NN (neural network) is proposed in Wang (1995), C (heuristic) is proposed in Chao (1996) e T (stochastic algorithm) is proposed in Tasgetiren (2000). We obtain for each instance the same value of objective function with respect to the others approaches; we don't obtain always the same sequence of visited PoIs but different sequence with the same value of objective function and in one case we have the same value of objective value but a better value (lower value) in terms of tour length (L_path). This result can be a starting point for a multi-objective optimization useful to take into consideration not only the Score of PoI but also, for example, the arrival time. However, our goal to validate the algorithm has been achieved thanks to this application.

The Table 1 and Figure 4 reassume the test realized with this data set known in literature as Set 2 of Tsiligirides (1984). In the grey row we report the results obtained by Tasgetiren (2000) with a Genetic Algorithms, in the corresponding white row, we present our results for the same data. Thanks to closed structure of chromosome, the algorithm found good solution after a little number of iterations and with a computational time of the order of few seconds.

Table 1: Comparison of results on Tsiligirides's data set 2: objective function value.

Tmax	T	C	NN	GA	GA*	L_path
15	120	120	120	120		14,56
15					**120**	**14,40**
20	190	200	200	200		19,88
20					200	19,88
23	205	210	205	210		22,65
23					210	22,99
25	230	230	230	230		24,13
25					230	24,13
27	230	230	230	230		24,13
27					230	26,98
30	250	265	265	265		29,85
30					265	29,85
32	275	300	300	300		31,63
32					300	31,63
35	315	320	320	320		34,51
35					320	34,51
38	355	360	360	360		37,84
38					360	37,84
40	395	395	395	395		39,78
40					395	39,78
45	430	450	450	450		44,44
45					450	44,44

Figure 4: Comparison of results on Tsiligirides's data set 2: tours



Tmax	Tour
15	1 5 6 7 12 11 10 13 14 21
15	**1 7 5 6 12 11 10 14 13 21**
20	1 12 7 6 5 3 2 8 9 10 11 13 14 21
20	1 12 7 6 5 3 2 8 9 10 11 13 14 21
23	1 7 6 5 4 3 2 8 9 10 11 14 21
23	1 6 5 4 3 2 8 9 10 11 13 14 21
25	1 12 7 6 5 4 3 2 8 9 10 11 13 14 21
25	1 12 7 6 5 4 3 2 8 9 10 11 13 14 21
27	1 12 7 6 5 4 3 2 8 9 10 11 13 14 21
27	1 12 14 13 11 10 9 8 2 3 4 5 6 7 21
30	1 7 6 2 8 17 16 15 9 10 11 13 14 21
30	1 7 6 2 8 17 16 15 9 10 11 13 14 21
32	1 7 6 5 3 2 8 17 16 15 9 10 11 13 14 21
32	1 7 6 5 3 2 8 17 16 15 9 10 11 13 14 21
35	1 7 6 5 3 4 20 19 18 17 9 10 11 13 14 21
35	1 7 6 5 3 4 20 19 18 17 9 10 11 13 14 21
38	1 7 6 5 2 3 4 20 19 18 17 8 9 10 11 13 14 21
38	1 7 6 5 2 3 4 20 19 18 17 8 9 10 11 13 14 21
40	1 7 6 5 3 4 20 19 18 16 15 17 8 9 10 11 13 21
40	1 7 6 5 3 4 20 19 18 16 15 17 8 9 10 11 13 21
45	1 12 7 6 5 2 3 4 20 19 18 16 15 17 8 9 10 11 13 14 21
45	1 12 7 6 5 2 3 4 20 19 18 16 15 17 8 9 10 11 13 14 21

5.2. Real Application

In this paragraph we propose the results obtained for the bike sharing tourist problem in the city of Naples. We consider 30 PoIs, all included into urban areas of the city. We fix the PoIs of departures and of arrival and the maximum time that the tourist has to visit the city, variable from 20 minutes to 100 minutes.

We calculated the distance matrix and set the algorithm parameters (numbers of individuals, population and BSC's size, Frequency rate of genetic operators, frequency rate of genetic operators) on the basis of preliminary tests that have given the best configuration of algorithm.

After a great number of tests realized on instances known in literature and cited by Chao et al., we reached the configuration used for this real application. For example on Set 2 of Tasgetiren, tests reported in Table 1, the best average of objective function founded on 10 tests for the same instance. As Population's size we chose to use a number equal to *2n* with *n* the number of nodes or PoIs. This value has been chosen because is a size that allows the presence of few couple of identical individuals. After several tests and observations, we reached this configuration:

- Population's size: 2 n
- Probability to Crossover: 0.8
- Probability to Single Crossover: 0.8
- Probability to PMX Crossover: 0.2
- Probability to Mutation: 0.4
- Probability to Smart Mutation: 0.6
- Probability to 2-opt: 0.4
- Probability to have a parent for elite: 0.1

Table 2: Real Application results

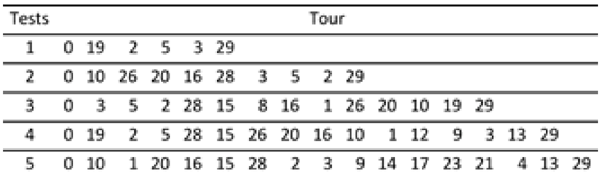
Tests	Iteration's Number	T_{max}	F.O.
1.a	100	20	30
1.b	200	20	30
1.c	500	20	30
1.d	1000	20	30
2.a	100	40	70
2.b	200	40	75
2.c	500	40	75
2.d	1000	40	75
3.a	100	60	95
3.b	200	60	100
3.c	500	60	105
3.d	1000	60	110
4.a	100	80	120
4.b	200	80	130
4.c	500	80	130
4.d	1000	80	130
5.a	100	100	145
5.b	200	100	150
5.c	500	100	160
5.d	1000	100	160

At this point we change for each instance of the problem only the number of iterations to find a better solution for the real application studied. The obtained results are described in Table 3. The first column represents the test's number, the second one the maximum time in which the tourist can visit the city (T_{max}), the third the objective function of founded solution. L_Path represents the time for the tour and the last column contains the iteration's number. In the Figure 5, the tour is represented as sequence of nodes (or PoIs), that the tourist will visit into the available time.

Table 3: Details of tours for real application's instances: objective function value.

Test	Tmax	Ga*	L_Path	Iteration's Number
1.a	20	30	19	100
2.d	40	75	40	200
3.g	60	110	60	1000
4.a	80	130	80	200
5.e	100	160	98	500

Figure 5: Details of tours for real application's instances: tours.



Tests	Tour
1	0 19 2 5 3 29
2	0 10 26 20 16 28 3 5 2 29
3	0 3 5 2 28 15 8 16 1 26 20 10 19 29
4	0 19 2 5 28 15 26 20 16 10 1 12 9 3 13 29
5	0 10 1 20 16 15 28 2 3 9 14 17 23 21 4 13 29

The following figures show, as the goodness of solution is directly proportional to number of iterations but not always. In fact, for small instances with low T_{max}, a great number of interaction don't increase the solution founded with few iterations, for this reason a small calculation time (3-4 seconds) is enough to obtain the best solution of the problem. This is not true for greater instances, for example with T_{max} =80, there is an important difference between the solutions founded with 100 iterations respecting to solutions founded with 1000 iterations. The figures represent all results founded for every T_{max} and every number of iterations considered. For each test we run 10 times the algorithm with the aim to compare the best and the most frequent value of objective function founded. In both cases the curve of results is crescent with respect to the number of iterations.

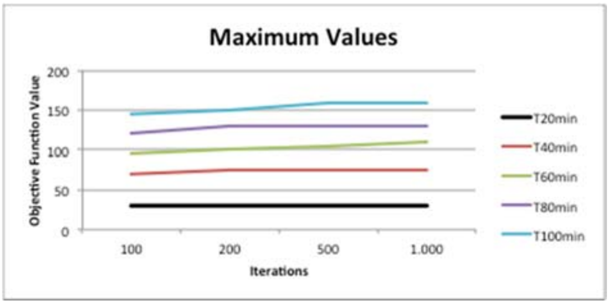


Figure 6: Maximum Value of Objective Function

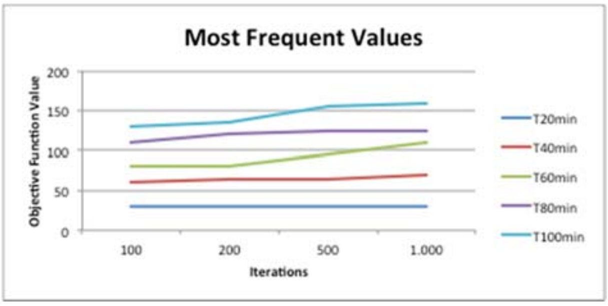


Figure 7: Most Frequent Value of Objective Function

The GA is coded in Visual Basic and implemented on Mac OS X Version 10.6.8. Processor 1.86 GHz Intel Core 2 Duo 2 GB 1067 MHz DDR3. We choose Visual Basic because it is easily translatable in others web oriented programming languages.

6. CONCLUSION

Actually the greater challenge in this research field is to propose systems able to: (*i*) give good solution in the shortest time possible (few seconds); (*ii*) react to dynamic realty of environment; (*iii*) interact with other mobility service in order to plan a greater trip in or out of the city. The systems developed have to be usable on smartphone, tablet, or pc and online or outline. The usefulness of this service system is high both for user as much as for the service manager. Thanks to these solutions it will be possible to know in advance the number of people that will visit a point of interest and then to organize the staff for the reception. On the other side it will be possible to make inaccessible a point of interest before planning the trip so that the tourist can maximize its satisfaction in the pre-determinate time for visiting. Future researches have to consider the possibility of tours' definition taking into account information about the amount of resources like battery or hydrogen of bikes. In this case the problem changes and the maximization of utility is subject to time respect and fuel availability. This kind of problem will be very useful to face another important question of bike sharing system's manager, the position of docking stations with respect to more popular tours.

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APPENDIX A

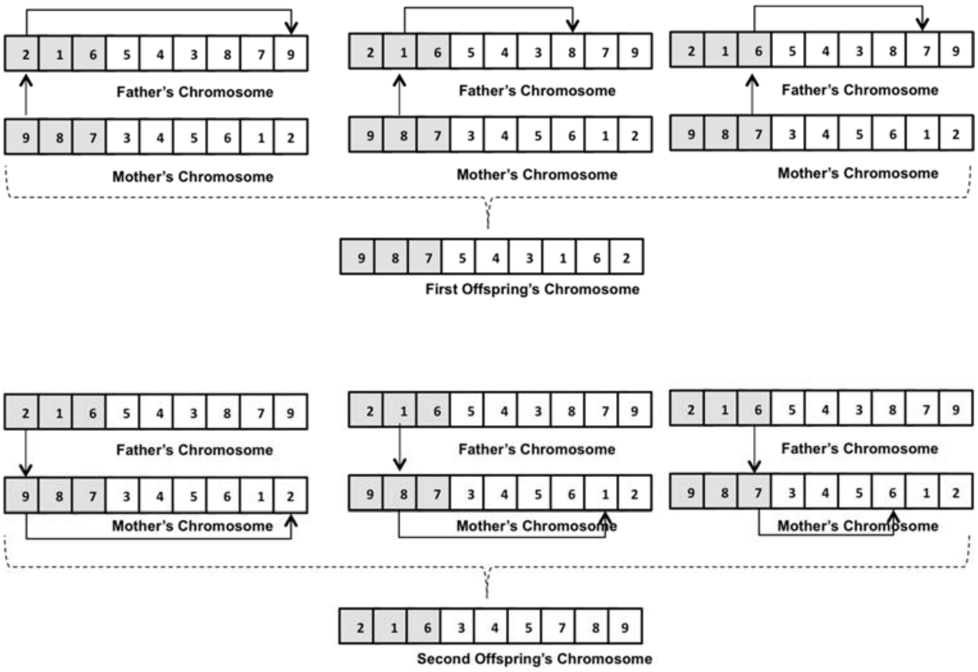

Figure 8: PMX-Crossover Operator

DEVELOPING EFFECTIVE VIRTUAL REALITY TRAINING FOR MILITARY FORCES AND EMERGENCY OPERATORS: FROM TECHNOLOGY TO HUMAN FACTORS

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ABSTRACT

The use of Virtual Reality (VR) for training is increasingly common in the military and in emergency operator fields. One of the main problems with the use of VR for training is the fact that the technology, although advanced, is not enough on its own. Technological aspects like fidelity and sensorial realism are certainly important in developing effective training techniques, but there are others that need to be considered. Focusing on human factors from the earliest stages of designing VR training can increase effectiveness and reduce the possibility of ineffective or even harmful effects of the training. This approach, called "Human-Centered VR Training Design," is characterized by being both multimodal (i.e., oriented to several aspects of user experience) and multilevel (i.e., based on the integrated use of technical and methodological solutions); it has undergone preliminary testing by Selex ES within the project Minerva in collaboration with psychological researchers at the University of Milano-Bicocca.

Keywords: Virtual Reality, Training, Military, Emergency Operators, Human Factors

1. VIRTUAL REALITY FOR THE TRAINING OF MILITARY FORCES AND EMERGENCY OPERATORS

The use of Virtual Reality (VR) for training is increasingly common in the military (Koźlak, Kurzeja, & Nawrat, 2013; Reist et al., 2013; Rizzo et al., 2011; Rizzo et al., 2013; Seidel & Chatelier, 2013; Summers, 2012) and in the emergency operator fields (Brady, Lee, Pearce, Shintaku, & Guerlain, 2015; Farra, Miller, Timm, & Schafer, 2013; Hsu et al., 2013; Pucher et al., 2014). This level of endorsement is linked mainly to the possibility offered by VR to simulate complex, highly stressful scenarios in a safe, customizable and dynamic environment (e.g., flight simulator, simulations of battlefields or emergency scenarios) (Seidel & Chatelier, 2013; Wilkerson, Avstreih, Gruppen, Beier, & Wooliscroft, 2008). In addition, training in a virtual world has been reported to be a good compromise between the traditional alternatives of classroom-based training and real-world training exercises (Hsu et al., 2013; Rizzo et al., 2011).

VR has been adopted by both the military and emergency operators for the training of physical (e.g., the repetition of the steps to follow during an emergency helicopter landing) and mental skills (e.g., managing a health-related emergency situation).

The three main areas of application of VR within these fields can be summarized as follows:

1) Procedural training: focuses on the training of single procedural skills. Some examples are military flight simulation (An, Li, Xu, & Shi, 2011; Zhao, Xu, Ye, & Li, 2011) and emergency medicine simulations (Bartoli et al., 2012; Ferracani, Pezzatini, Seidenari, & Del Bimbo, 2014);
2) Management of complex situation training: relates to contextual or relational skills, including team communication and decision making (Hoch & Kozlowski, 2014; Pucher et al., 2014), battlefield simulations (Rizzo, Parsons et al. 2011) and disaster preparedness training (Freeman et al., 2001; Kizakevich et al., 2007; Wilkerson et al., 2008);
3) Emotion and stress management training: concerns coping with stress. Examples include stress management training for military forces (Cosenzo, Fatkin, & Patton, 2007; Rizzo et al., 2012) and PTSD management training (Rizzo et al., 2015; Rizzo et al., 2012; Cosenzo, Fatkin, & Patton, 2007) and PTSD management training (Rizzo et al., 2015).

2. IS TECHNOLOGY REALLY ENOUGH? THE IMPORTANCE OF HUMAN FACTORS

A few years ago there was a "technology rush", with the aim of developing the most effective VR system for training; in particular, a VR system with the maximum level of sensory realism, or "physical fidelity," which is the objective level of sensory realism that a VR system provides. More specifically, physical fidelity refers to the degree to which the physical simulation looks, sounds and feels like the operational environment in terms of the visual displays, controls, audio and haptic devices, as well as the physics models driving each of these variables (Becker, Warm, Dember, & Hancock, 1995; Rinalducci, 1996).

But how realistic does a VR system need to be in order to fulfill its training goals? On the one hand, it is possible that unrealistic situations may lead to ineffective or even harmful effects of training. For example, the enhancement of haptic fidelity has been shown to be a fundamental element for surgical training when fine motor skills, accuracy and delicate tool control are required (Basdogan et al., 2004). On the other hand, because of the learning abilities and perceptual limitations of the sensory, motor and cognitive systems of users, a perfect VR system is not always necessary (Scerbo & Dawson, 2007). A number of studies have even demonstrated that a high transfer of learning can be achieved with simple simulators when training soft and hard skills (Scerbo & Dawson, 2007).

Physical fidelity and sensorial realism are certainly important elements to be considered during the design and development of a VR training system, but there is more to the story. The concept of fidelity, in fact, is not limited to that of sensorial realism; more generally, it refers to the extent to which the virtual environment emulates the real world (Alexander, Brunyé, Sidman, & Weil, 2005; Lintern, Roscoe, Koonce, & Segal, 1990). The level of fidelity of a VR system includes a large number of subcategories (Stoffregen, Bardy, Smart, & Pagulayan, 2003) related not only to its technological features, but also to the users' subjective characteristics, or "human factors" (Riva & Mantovani, 1999; Wann & Mon-Williams, 1996). Due to the close bond between the user and the system within virtual environments, it may be impossible to segregate human factors from design issues when striving to achieve the potential of VR technology. It is the capabilities and limitations of the user that often times will determine the effectiveness of virtual worlds.

3. DEVELOPING VIRTUAL REALITY TRAINING THROUGH A "HUMAN-CENTERED DESIGN"

Designing usable and effective interactive virtual worlds is a new challenge for system developers and human-factors specialists. An understanding of human-factors issues can thus be used to provide a systematic basis by which to direct future VE research efforts aimed at advancing the technology to better meet the needs of its users. This need is best articulated by Shneiderman, 1992), who stated that "analyses of VR user-interface issues may be too sober a process for those who are enjoying their silicon trips, but it may aid in choosing the appropriate applications and refining the technologies" (p. 224).

Thus, an interdisciplinary approach including users, trainers, designers, psychologists and technology experts can define concrete guidelines that may support strategic choices and training design activities evaluation. Human-factors practitioners such as psychologists and trainers can assist in making significant contributions to the theoretical understanding of human-virtual environment interaction (HVEI). Focusing on the users' characteristics and needs from the earliest stages of the design of a VR can increase its effectiveness.

This can be done by adopting a "Human-Centered VR Training Design" that provides an understanding of issues related to the subjective experience of the user and to the particular aims of the training from the early stages of development. Knowing the different elements involved in the task means that VR scenarios are tailored to the user, adopting the most suitable technology selected according to the needs of fidelity dictated by the specific task. This is possible through an analysis of the specific task to be trained, not only from a procedural point of view but also from a cognitive one (see Figure 1).

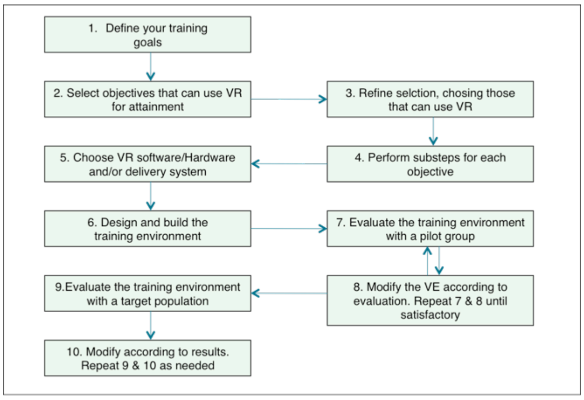

Figure 1: "Human-Centered VR Training Design Model" (adapted from Pantelidis, 1995)

4. A PRELIMINARY INVESTIGATION OF THIS APPROACH AND FUTURE DIRECTIONS

This approach, that could be defined as a "Human-Centered VR Training Design," is characterized by being both multimodal (i.e., oriented to several aspects of user experience) and multilevel (i.e., based on the integrated use of technical and methodological solutions). It has undergone preliminary testing by Selex ES within the project Minerva in collaboration with psychological researchers at the University of Milano-Bicocca. The interdisciplinary approach proposed could contribute to the definition of concrete guidelines that may support future strategic choices and training design activities in the development of VR training for military and emergency operators. Future studies will replicate the preliminary test conducted in order to thoroughly investigate the usefulness of this new integrated approach in the design and development of effective VR training.

This innovative approach has been tested by Selex ES within the project Minerva in collaboration with psychological researchers at the University of Milano-Bicocca and five staff members at the Scuola Interforze di Aerocooperazione di Guidonia. Testing sessions were the first opportunity to give a preliminary demonstration of how academic methods and know-how can be adopted to improve the efficacy of specific VR training scenarios.

Each scenario has been evaluated from a multilevel point of view, and in particular:

1) Subjective user's experience level: interviews, focus groups and the administration of self-report questionnaries (e.g., SUS, STAI-Y1). In particular, the following aspects of the VR experience were evaluated:
   - Sense of presence (i.e., user's subjective sensation of "being there" in the scene depicted) (Riva & Mantovani, 2000);
   - Usability (i.e., the extent to which users can achieve specified goals with effectiveness, efficiency and satisfaction (McMahan, Bowman, Zielinski, & Brady, 2012; Sutcliffe & Kaur, 2000);
   - Cybersickness (i.e., user symptoms similar to the common symptoms experienced when people get motion sickness, like headache, nausea and vomiting) (Kennedy & Fowlkes, 1992; LaViola Jr, 2000);
   - Experienced emotions.
2) Behavioral-observational level: observations and video recording of the non-verbal (e.g.,facial expressions, posture, gestures) and verbal (e.g., evaluation of communication flows) behaviors of the users;
3) Physiological level: assessment of the physiological response in order to give objective indexes of the emotional and cognitive states experienced by individuals during the VR scenarios. In particular, during VR sessions skin conductance response, heart rate and facial muscle activation have been recorded.

Collected data are being analyzed and will be used to develop hypotheses of improvement and redefinition of the tested VR training scenarios. In general, the interdisciplinary approach proposed could contribute to the definition of concrete guidelines that may support future strategic choices and training design activities in the development of VR training for military and emergency operators. Future studies will replicate this preliminary test in order to investigate the usefulness and effectiveness of the proposed approach in the design and development of VR training.

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BETTER STATISTICAL FORECAST ACCURACY DOES NOT ALWAYS LEAD TO BETTER INVENTORY CONTROL EFFICIENCY: THE CASE OF LUMPY DEMAND

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ABSTRACT

Neural network (NN) modeling has been applied to forecasting of lumpy demand (Gutierrez, Solis, and Mukhopadhyay 2008; Mukhopadhyay, Solis, and Gutierrez 2012) and empirically compared with a number of well-referenced methods traditionally applied in studies on lumpy demand forecasting – simple moving average, weighted moving average with optimal weights, simple exponential smoothing, Croston's method, and the Syntetos-Boylan approximation. The overall superiority of NN over the other methods, in terms of forecast accuracy based on a number of scale-free error statistics, was demonstrated. However, demand forecasting performance with respect to standard accuracy measures may not translate into inventory systems efficiency. Applying a (*T*,*S*) inventory system, we consider fill rate (FR) as service criterion. We conduct simulation searches to find order-up-to levels required to meet a target FR of 0.90 or 0.95. We find that significantly higher levels of on-hand inventory are required when using the more statistically accurate NN forecasts.

Keywords: lumpy demand forecasting, forecast accuracy, scale-free error statistics, inventory control, simulation search

1. INTRODUCTION

Demand for an item is said to be *intermittent* when there are intervals during which no demand occurs. Demand is erratic when there are large variations in the sizes of actual demand occurrences. When demand is both intermittent and erratic, it is said to be *lumpy*. Intermittent or lumpy demand has been observed in both manufacturing and service environments – e.g., electrical equipment, jet engine tools and veterinary health products (Willemain, Smart, Schokor, and DeSautels 1994), the automotive industry (Syntetos and Boylan 2001, 2005), maintenance parts for aircraft, both commercial and military (Ghobbar and Friend 2002, 2003; Eaves and Kingsman 2004; Syntetos, Babai, Dallery, and Teunter 2009), electronic components (Gutierrez, Solis, and Mukhopadhyay 2008; Mukhopadhyay, Solis, and Gutierrez 2012), and professional electronics (Solis, Longo, Mukhopadhyay, Nicoletti, and Brasacchio 2014).

Syntetos, Boylan, and Croston (2005) proposed a scheme for categorizing demand into four classes (smooth, erratic, intermittent, and lumpy), as originally presented in the doctoral thesis of Syntetos (2001). The SBC scheme (for Syntetos, Boylan, and Croston) uses cutoff values of 0.49 for CV^2 (the squared coefficient of variation of demand sizes and 1.32 for *ADI* (the average inter-demand interval). SBC suggests $CV^2 < 0.49$ and $ADI > 1.32$ to characterize intermittent (but not very erratic) demand and $CV^2 > 0.49$ and $ADI > 1.32$ to characterize lumpy demand.

Simple exponential smoothing (SES) will adjust the demand forecast upward immediately after a demand occurs and downward if no demand occurs. Croston (1972) noted that, when demand is intermittent, therefore, the SES forecast results in a bias that places the most weight on the most recent demand occurrence. To address this bias in SES, he proposed a method for forecasting intermittent demand involving separate exponential smoothing of the nonzero demand sizes and the inter-demand intervals.

While Croston's method (CR) used a common exponential smoothing constant α, Schultz (1987) proposed separate smoothing constants, α_i and α_s, to be respectively used in updating estimates of inter-demand intervals and nonzero demand sizes. Eaves and Kingsman (2004) present a clear specification of CR involving these two smoothing constants.

A positive bias in CR, arising from an error in Croston's mathematical derivation of expected demand, has been reported by Syntetos and Boylan (2001). A correction factor of $\left(1-\alpha_i/2\right)$, applied to the CR estimator of demand, was suggested by Syntetos and Boylan (2005). This correction of the bias in CR has come to be known in the intermittent demand forecasting literature (Boylan and Syntetos 2007; Gutierrez, Solis, and Mukhopadhyay 2008; Mukhopadhyay, Solis, and Gutierrez 2012) as the Syntetos-Boylan approximation (SBA). We note that, while the correction factor is specified in terms of α_i, Syntetos and Boylan (2005) themselves apply SBA using a common smoothing constant $\alpha = \alpha_i = \alpha_s$. SBA has, in fact, been commonly implemented in this manner.

The above three methods (SES, CR, and SBA) are traditionally cited in the intermittent demand forecasting literature. As well, Syntetos and Boylan (2005) have evaluated a 13-period simple moving average (SMA) in comparison with SES, CR, and SBA.

Gutierrez, Solis, and Mukhopadhyay (2008) and Mukhopadhyay, Solis, and Gutierrez (2012) applied neural network (NN) modeling in forecasting lumpy demand. They used a multilayered perceptron trained by a back-propagation algorithm (Rumelhart, Hinton, and Williams 1988) using three network layers (as suggested by Xiang, Ding, and Lee 2005):

- One input layer for input variables,
- One hidden unit layer, and
- One output layer of one unit.

This NN architecture was applied to an industrial dataset consisting of 24 time series. Gutierrez, Solis, and Mukhopadhyay (2008) compared the forecasting performance of NN to those of the SES, CR, and SBA methods.

In addition to NN modeling, Mukhopadhyay, Solis, and Gutierrez (2012) evaluated one additional 'non-traditional' method for forecasting lumpy demand: a five-period weighted moving average with optimized weights (WMA5) determined by way of a standardized ordinary least squares regression with current period demand as target variable and the five most recent lagged period demands as predictor variables.

Mukhopadhyay, Solis, and Gutierrez (2012) initially used separate smoothing constants α_i and α_s, as proposed by Schultz (1987), in the application of CR and SBA. Apparently in view of the adjustment of the positive bias in CR by the correction factor of SBA, the latter was found by Mukhopadhyay, Solis, and Gutierrez (2012) to be consistently superior to the former for every single α_i and α_s combination tested. Furthermore, they did not observe any substantial improvement in forecast accuracy resulting from the use of separate smoothing constants α_i and α_s. As a result,

In this paper, therefore, we shall focus – as Mukhopadhyay, Solis, and Gutierrez (2012) did – on the comparative performance of the following four forecasting methods:

- SES
- SBA
- WMA5
- NN.

For intermittent demand, the use of low smoothing constant values in the range of 0.05-0.20 has been recommended (Croston 1972; Johnston and Boylan 1996). Syntetos and Boylan (2005) used the four α values of 0.05, 0.10, 0.15, and 0.20 for the SES, CR, and SBA methods. Gutierrez, Solis, and Mukhopadhyay (2008) and Mukhopadhyay, Solis and Gutierrez (2012) used these same four values.

This paper is organized as follows. In Section 2, we describe the industrial dataset, the partitioning of data into training and test samples, and error measures that have been used to assess forecast accuracy. In the next section, we briefly summarize the findings of Gutierrez, Solis, and Mukhopadhyay (2008) and Mukhopadhyay, Solis and Gutierrez (2012) in their empirical investigations of forecasting performance. In Section 4, we discuss results of our inventory control performance simulations. Section 5 is our concluding section.

2. DATASET, DATA PARTITIONING, AND FORECAST ACCURACY MEASURES

2.1. Dataset and Data Partitioning

Gutierrez, Solis, and Mukhopadhyay (2008) and Mukhopadhyay, Solis, and Gutierrez (2012) used actual demand data from an electronic components distributor operating in Monterrey, Mexico. The dataset involves 24 stock keeping units (SKUs), each with 967 daily demand observations. As a forecasting method, WMA5 applies to the dataset in terms of weekly demand over a 5-day work week.

All 24 SKUs exhibit lumpy demand, with values of CV^2 ranging between 9.84 and 45.93, and values of ADI between 2.63 and 3.28 (see Table 1). These CV^2 and ADI values are all clearly consistent with the SBC specification of $CV^2 > 0.49$ and $ADI > 1.32$ for lumpy demand.

Gutierrez, Solis, and Mukhopadhyay (2008) used the first 624 observations of the 967 daily demand observations in each of the 24 time series to 'train' the NN model (the *training* or *calibration* sample). The forecasting methods were then tested on the final 343 observations (the *test* sample). This generated an approximately 65:35 partitioning (65% training data and 35% test data).

In addition to the 65:35 partitioning, Mukhopadhyay, Solis and Gutierrez (2012) also applied an 80:20 split as suggested by Bishop (1995), as well as a 50:50 partitioning.

2.2. Forecast Accuracy Measures

Gutierrez, Solis, and Mukhopadhyay (2008) used the following three scale-free error statistics to compare forecast accuracy:

- mean absolute percentage error (MAPE),
- relative geometric root-mean-square error (RGRMSE), and
- percentage best (PB)

Mukhopadhyay, Solis and Gutierrez (2012) applied median relative absolute error (MdRAE) as a fourth scale-free measure.

Table 1: Basic Dataset Statistics

Series	1	2	3	4	5	6
Mean Demand	251.02	262.08	271.60	274.43	278.01	324.84
Std Dev of Demand	1078.80	985.19	1305.36	1221.31	1191.04	1387.20
z (% of Zero Demand)	69.6	67.2	67.3	65.9	64.3	63.8
CV^2	18.47	14.13	23.10	19.81	18.35	18.24
ADI	3.28	3.05	3.06	2.93	2.80	2.76
Series	7	8	9	10	11	12
Mean Demand	237.09	274.31	253.77	346.04	303.11	321.61
Std Dev of Demand	743.88	1134.55	959.19	1710.19	1229.80	1149.70
z (% of Zero Demand)	67.6	66.7	65.6	66.2	65.0	64.8
CV^2	9.84	17.11	14.29	24.43	16.46	12.78
ADI	3.09	3.00	2.90	2.96	2.86	2.84
Series	13	14	15	16	17	18
Mean Demand	299.15	296.07	288.78	305.81	228.74	352.32
Std Dev of Demand	1425.87	1321.28	1090.65	1257.98	889.07	1480.69
z (% of Zero Demand)	66.4	65.9	64.8	65.0	66.2	63.7
CV^2	22.72	19.92	14.26	16.92	15.11	17.66
ADI	2.98	2.93	2.84	2.86	2.96	2.75
Series	19	20	21	22	23	24
Mean Demand	322.98	355.48	328.70	394.84	314.33	410.00
Std Dev of Demand	1054.75	1609.05	1390.67	2675.95	1438.57	1929.56
z (% of Zero Demand)	61.9	65.3	64.2	67.0	64.3	67.3
CV^2	10.66	20.49	17.90	45.93	20.95	22.15
ADI	2.63	2.88	2.79	3.03	2.80	3.06

3. FORECASTING PERFORMANCE

Using MAPE, RGRMSE, and PB as error measures, Gutierrez, Solis, and Mukhopadhyay (2008) independently validated earlier findings (Syntetos and Boylan 2005) of the superiority of SBA over SES and CR. Moreover, they found that NN modeling, even under a relatively simple network topology, generally performs better than SES, CR, and SBA for the lumpy demand SKUs under investigation.

Mukhopadhyay, Solis, and Gutierrez (2012) added the following to the earlier evaluation:

- WMA5 as a forecasting method,
- MdRAE as a fourth scale-free error statistic, and
- 80:20 and 50:50 data partitions.

They found both ‘non-traditional’ methods (NN and WMA5) for forecasting lumpy demand to outperform the methods that are well referenced in the intermittent demand forecasting literature (SES, CR, and SBA). In particular, NN showed superior performance overall with respect to both MAPE and MdRAE as forecast accuracy measures, under all three data partitions (50:50, 65:35, and 80:20). What was found especially noteworthy was that SES and SBA, which have been traditionally applied to intermittent demand forecasting, did not appear as a ‘best’ method except in six of the 288 error statistic comparisons (24 SKUs × 4 error statistics × 3 partitions) that they reported.

4. INVENTORY CONTROL PERFORMANCE

Demand forecasting and inventory control performance have traditionally been examined independently of each other in the literature (Tiacci and Saetta 2009). Recognizing that demand forecasting performance with respect to standard accuracy measures may not translate into inventory systems efficiency, Solis, Mukhopadhyay and Gutierrez (2010) made an initial attempt to extend beyond the empirical investigation of forecasting performance reported in the earlier studies (Gutierrez, Solis, and Mukhopadhyay 2008; Mukhopadhyay, Solis, and Gutierrez 2012). The results of that first attempt, conducted by ‘simulating on the dataset’ in view of the difficulty in mathematically characterizing lumpy demand, were by-and-large inconclusive.

4.1. Demand Characterization

One of the issues in forecasting intermittent or lumpy demand is the assumption of a distribution of demand occurrence. Syntetos and Boylan (2006, p. 39) cited three criteria proposed by Boylan (1997) for assessing suitability of demand distributions:

- *a priori* grounds for modelling demand,
- flexibility of the distribution to represent different types of demand, and
- empirical evidence.

Syntetos and Boylan argued that compound distributions can represent demand incidence and demand size by separate distributions, and that the negative binomial distribution (NBD) is a compound distribution with variance greater than the mean, with “empirical evidence in its support.” They declared the NBD “to meet all criteria” and accordingly selected NBD to represent intermittent demand over lead time (plus review period) in their stock control simulation model. Other studies (e.g., Boylan, Syntetos, and Karakostas 2008; Syntetos, Babai, Dallery, and Teunter 2009) have similarly conducted empirical investigations of stock control using the NBD to characterize intermittent demand over the lead time (plus review period), citing Syntetos and Boylan’s (2006) declaration that the NBD “satisfies both theoretical and empirical criteria.”

Use of the NBD to characterize demand may apply to intermittent (but not very erratic) demand. However, empirical investigation of lumpy demand datasets has shown that the NBD may not provide an acceptable approximation for many SKUs exhibiting lumpy demand. For instance, Solis, Longo, Mukhopadhyay, Nicoletti, and Brasacchio (2014) instead apply a two-stage approach to characterizing lumpy demand, where Stage 1 involves a uniform (continuous) distribution defined over the interval (0,1) and Stage 2 involves an NBD. While this two-stage alternative has been shown to fairly adequately characterize certain lumpy demand data, it unfortunately fails in the case of the 24 SKUs under consideration with their high degree of lumpiness.

Sani and Kingsman (1997) applied simulation on a dataset consisting of long series of daily demand data over five years for 30 low demand items. In view of the failure to mathematically characterize the 24 SKUs in the current lumpy demand dataset, our simulations of inventory control performance similarly take the form of a single run performed on the test sample (consisting of the final 343 observations for the 65:35 partition or the final 193 observations for the 80:20 partition).

4.2. Inventory Control System

A periodic review inventory control system has been recommended for intermittent demand (Sani and Kingsman 1997). An order-up-to (T,S) system, where T and S respectively denote the review period and the base stock (or 'order-up-to' level), has been used in recent intermittent demand forecasting studies that investigate both forecast accuracy and inventory control performance (Eaves and Kingsman 2004; Syntetos and Boylan 2006; Syntetos, Babai, Dallery, and Teunter 2009).

Eaves and Kingsman (2004) simulated a (T,S) system on actual demand data, aggregated quarterly, for 18,750 SKUs randomly selected out of some 685,000 spare parts for aircraft of the Royal Air Force of the UK. Forecast-based order-up-to levels S were determined as the product of the forecast demand per unit of time and the 'protection interval', T+L (where L is the reorder lead time). Implied average stockholdings were calculated using a backward-looking simulation assuming a common fill rate (or percentage of demand to be satisfied from on-hand inventory) of 100%. Among the five forecasting methods they evaluated (SES, CR, and SBA included), SBA yielded the lowest average stockholdings.

In the current study, we assume a (T,S) system with full backordering. For this preliminary report, inventory is reviewed on a weekly basis (T = 5) and the reorder lead time is three days (L = 3). The literature suggests a safety stock component to compensate for uncertainty in demand during the protection interval. For each SKU, we calculate s_{tr}, the standard deviation of daily demand over the training sample. We apply a 'safety factor' k to yield a safety stock level of $k \cdot s_{tr}$. The replenishment quantity q_t at the time of review is then given by

$$q_t = (T+L)\cdot F_t + k\cdot s_{tr} - I_t + B_t \,. \tag{1}$$

where F_t is the forecast calculated at the time of review t, and I_t and B_t are, respectively, the on-hand inventory and backlog.

Two of the most commonly used service level criteria for inventory systems (Silver, Pyke, and Peterson 1998) are:

- Probability of not stocking out in a given period, and
- Fill rate (FR)

FR is noted to have considerably more appeal for practitioners. We consider target FRs of 0.90 and 0.95 (or 90% and 95%), as in Syntetos and Boylan (2006). Using spreadsheet modeling, we conduct simulation searches to find, for each of the four forecasting methods under evaluation (SES, SBA, WMA5, and NN), the safety factor k needed to meet the target FR.

4.3. Simulation Results

We first report on simulation results arising under a 65:35 data partition with a target FR of 95%. In Figure 1, we graphically compare the average on-hand inventory levels arising from use of the four forecasting methods. While Mukhopadhyay, Solis, and Gutierrez (2012) found both NN and WMA5 to outperform SES and SBA (as reported in Section 3), average on-hand inventory levels appear to be higher overall for WMA5 and NN.

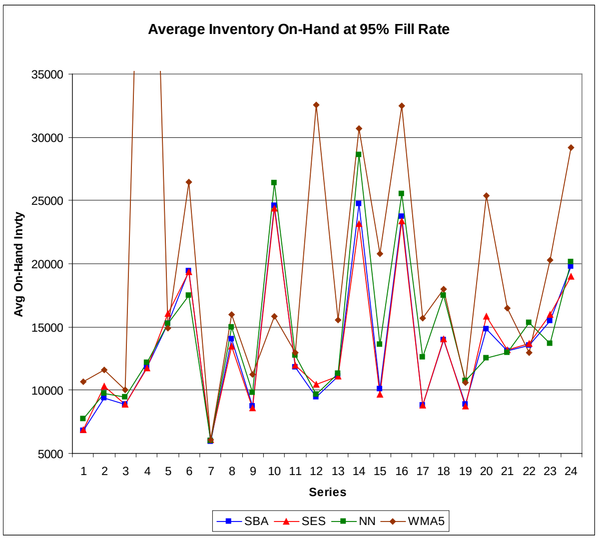

Figure 1: Average Inventory On-Hand with a 95% Fill Rate Under 65:35 Data Partitioning

SES yields the minimum average inventory on-hand for 11 of the 24 SKUs, SBA for six, NN for four, and WMA5 for three. We index the average inventory on-hand using SBA as base (SBA = 100), and those indices are summarized in Table 2. Using a t-test of the hypothesis that mean index = 100, the right-hand tailed test is highly significant for both NN/SBA (p-value = 0.0040) and WMA5/SBA (p-value = 0.0075) but not significant for SES/SBA (p-value = 0.2311).

The average backlogs resulting from a 95% target FR, arising under a 65:35 data partition, are similarly indexed using SBA as base. Resulting indices are summarized in Table 3. Using a t-test of the hypothesis that mean index = 100, the test is not significant for SES/SBA, NN/SBA, and WMA5/SBA.

We likewise summarize the simulation results arising under an 80:20 data partition with a target FR of 90%. The average on-hand inventory levels are graphically presented in Figure 2. In this case, NN yields the minimum average inventory on-hand for 10 of the 24 SKUs, SES for seven, SBA for four, and WMA5 for three.

Similarly, if average inventory on-hand is indexed using SBA as base, the overall average indices are 101.0 for SES/SBA, 106.7 for NN/SBA, and 141.1 for WMA5/SBA. The right-hand tailed t-test of the hypothesis that mean index = 100 is highly significant for WMA5/SBA (p-value = 0.0025), significant for

NN/SBA (p-value = 0.0409), and not significant for SES/SBA (p-value = 0.2095).

Table 2: Indices of Average Inventory On-Hand with a 95% Fill Rate Under 65:35 Data Partitioning, Using SBA as Base

	Index		
Series	**SES / SBA**	**NN / SBA**	**WMA5 / SBA**
1	100.3	113.0	155.9
2	109.6	104.0	123.4
3	99.6	106.3	112.9
4	99.6	103.4	605.5
5	105.0	99.9	97.7
6	99.8	90.3	136.4
7	102.3	101.4	102.1
8	95.7	106.4	113.6
9	98.3	112.3	128.7
10	99.2	107.4	64.5
11	101.4	107.9	109.9
12	110.4	102.3	343.8
13	99.6	101.6	139.9
14	93.5	115.6	124.0
15	96.0	135.4	206.6
16	98.3	107.7	137.0
17	99.6	143.1	177.8
18	100.5	125.2	128.8
19	98.1	120.7	119.1
20	106.8	84.6	171.5
21	100.6	98.8	126.0
22	101.3	113.4	95.9
23	103.4	88.6	131.4
24	96.1	101.8	147.3
Average	100.6	108.0	158.3

Table 3: Indices of Average Backlog with a 95% Fill Rate Under 65:35 Data Partitioning, Using SBA as Base

	Index		
Series	**SES / SBA**	**NN / SBA**	**WMA5 / SBA**
1	103.9	126.8	144.3
2	100.5	88.0	94.6
3	102.3	89.1	127.7
4	99.9	103.4	99.9
5	104.0	106.9	114.4
6	100.0	100.0	100.0
7	101.4	114.9	65.9
8	100.0	100.2	91.9
9	104.5	69.7	75.1
10	103.8	91.1	120.3
11	104.8	86.6	119.9
12	103.3	71.2	109.2
13	109.4	103.4	105.8
14	100.1	102.4	108.7
15	108.1	64.9	118.0
16	102.2	98.0	136.1
17	93.0	110.5	95.9
18	99.2	92.7	104.6
19	105.0	77.9	64.9
20	100.0	99.3	100.3
21	100.9	107.0	84.9
22	97.8	104.3	70.8
23	86.2	110.5	64.3
24	99.8	99.8	104.1
Average	101.2	96.6	100.9

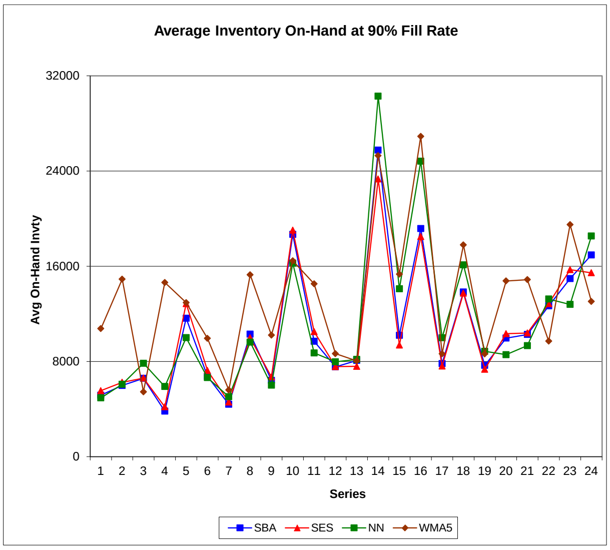

Figure 2: Average Inventory On-Hand with a 90% Fill Rate Under 80:20 Data Partitioning

Average backlogs and corresponding indices for a 90% target FR arising under an 80:20 data partition show overall average indices of 100.9 for SES/SBA, 96.8 for NN/SBA, and 102.7 for WMA5/SBA. Using a t-test of the hypothesis that mean index = 100, the test is not significant for SES/SBA, NN/SBA, and WMA5/SBA.

5. CONCLUSIONS AND FURTHER WORK

Owing to the difficulty in mathematically characterizing lumpy demand distributions, particularly with the degree of lumpiness found in the industrial dataset currently under consideration, we applied simulation on the dataset in the current work. This was possible due to the length of the time series (967 periods), albeit not quite as rigorous as in simulation studies involving mathematically specified demand distributions.

Gutierrez, Solis, and Mukhopadhyay (2008) found that NN modeling, even under a relatively simple network topology, generally performs better than SES, CR, and SBA for the 24 lumpy demand SKUs under investigation (as reported in Section 3). Mukhopadhyay, Solis, and Gutierrez (2012) reported the 'non-traditional' NN and WMA5 methods to outperform SES and SBA (as also reported in Section 3).

We conducted simulation searches associated with target fill rates of 90% and 95%. With average on-hand inventory using SBA as base, the indices for WMA5/SBA and even for NN/SBA are significantly above 100, indicating that average on-hand inventory levels are higher overall for WMA5 and NN.

In the current study, we find support for earlier assertions that demand forecasting performance with respect to standard accuracy measures may not translate into inventory systems efficiency. In particular, an NN model was found to outperform the SES and SBA methods in performance with respect to a number of scale-free traditional accuracy measures, but appears to be inferior when it comes to inventory control performance.

We appear to have generated evidence to support the assertion that, at least for items exhibiting a fairly high degree of demand lumpiness, statistical forecast accuracy does not necessarily lead to better inventory control efficiency.

Further work remains in terms of simulation searches that have yet to be conducted.

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MODELING HUMAN BEHAVIORS IN MARINE ENVIRONMENT FOR ANTI-PIRACY OPERATIONS

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ABSTRACT

The paper addresses the need to create realistic simulation environments to test operational procedures and technological solutions for maritime interdiction with special attention to Piracy; the authors developed human behavior models to represent the maritime traffic and their rational and emotional reactions to the patrolling vessels and to their actions; this simulation applies intelligent agents and stochastic discrete event simulation for addressing this context and it was experimented also within an interoperable framework to be federated with real systems (e.g. C2, planners) and with other models (e.g. weather forecasts, training equipment).

Keywords: *Human Behavior Modeling, Intelligent Agents, Maritime Interdiction, Discrete Event Simulation*

1. INTRODUCTION

In complex scenarios involving presence of humans it is always pretty hard to develop simulations able to consider the influence of the people behavior; even in maritime sector the presence of general cargo, pleasure craft and small medium size boats is often very high affecting the whole scenario; this aspect becomes even more critical when it becomes necessary to address asymmetric threats that are hard to be discriminated within the traffic and that use it as a coverage operating as not cooperative targets and adopting special behaviors.

This becomes evident if we think to the problem to identify fishing vessels that are carrying out smuggling or illegal immigration actions over a scenario among others operating regularly; in this sector the use of technological solution, mature command and control and operational procedures is crucial, but to evaluate their efficiency and resilience respect false alarms it is pretty hard due to needs of time and costs for experiencing them at sea and the limitation of fixed scenarios. Indeed it is evident the necessity to use stochastic simulation to address these aspects respect other methodologies [3] even in order to identify emerging situation [44]. Therefore in case of trace driven scenario, regulated by historical data, the limited or absent interaction with the interdiction actions requires to be able to reproduce rational and emotional reaction and behavioral model should be introduced; it is evident that a smuggler is not escaping as soon as he perceive the presence of a patrol ship if they consider reliable their coverage, while a fishing vessel probably will try to stand away from Navy ship to don't waste time in inspections. So it is not enough to collect historical data on traffic, and it becomes necessary to create dynamic behavior models for the traffic itself. This paper addresses this issues with special attention to the context of piracy even if the proposed techniques could be easily applied to other contexts in Maritime Interdiction or in other sectors,

2. THE APPLICATIVE CONTEXT

Modern Piracy is a reality that, even if mitigated in some area along the most recent years, is still present and dangerous over many different world regions and requires very big efforts for being properly addressed; indeed sometime the solutions could result not sustainable in terms of costs making this as trade off game between Nations and Pirates. This phenomena was arising back along last 25 years: since 1990s capturing ships, holding them and their crews for ransom and stealing what is on them, has been carried out by armed groups acting mostly in the territorial sea. By the international definition these groups are called piracy which consists of "any illegal acts of violence or detention, committed for private ends by the crew or the passengers of a private ship or aircraft and directed on the high seas against another ship or aircraft, or against persons or property on board such ship or aircraft" [42]. Piracy is a phenomenon grown in the absence of a government able to enforce the law, and this is a common situation in the Indian Ocean. In

Somalia, for example, during recent years pirate activity absorbed a growing number of people and became ever intense, up to a maximum of 160 attacks in 2011 [28].

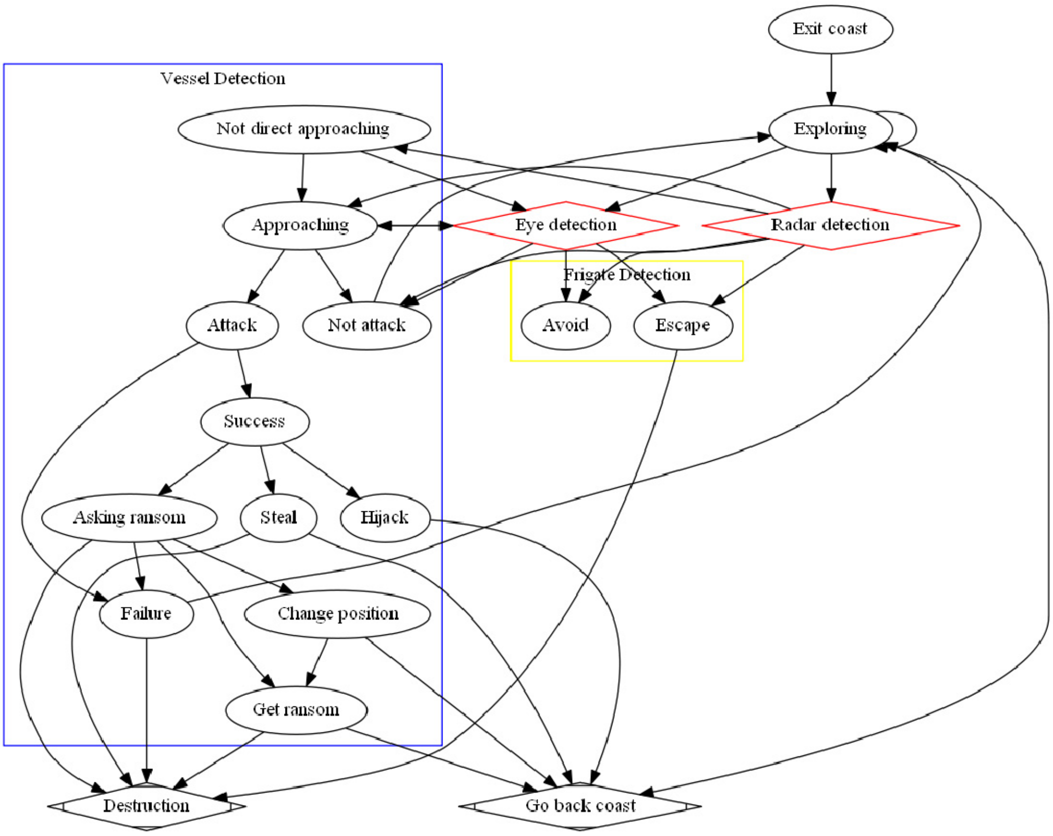

Figure 1: Example of Model of the Pirate Behavior

Taking advantage of the continuous lack of an effective government and of political and armed fights going on in Somalia, pirates became a serious menace in the area between the Horn of Africa and the Arabian peninsula [41]. Although from 2011 the Somali attacks have decreased, piracy remains a threat for maritime traffic as already anticipated. In fact in the first six months of 2015, the IMB (International Maritime Bureau) reported 134 pirates boarded on ships worldwide, which have increased in comparison with the 116 of the corresponding period in 2014. To have an idea of the danger let's highlight that in 2015 pirates boarded 106 vessels to steal crew belongings, money and other ship's property, attempted 15 attacks and hijacked 13 vessels. Therefore only 15 out of 134 boarding failed. Only in South-East Asia there was in a average one attack every two weeks, and about 38% of the 13 hijacks were carried out in this area [29]. These facts reveal that international attention must still consider piracy as a threat for international maritime routes.

Furthermore, piracy has a cost for international finance. In 2008 the overall costs of piracy in the Pacific and Indian Oceans alone were estimated up to US$16 billion [25]. In 2014, although there is no estimation, the cost remains high considering that 245 attacks were reported, only 48 cases less than 2008 [28]. The human costs are remarkable, not only for the loss of lives but also for the trauma inflicted upon hostages and their families. So it remains an aspect to not underestimate, both for human and financial costs. To combat this incessant threat, government and researchers have developed various measures to put piracy under control and to mitigate the risks it implicates.

The IMB has instituted some guidelines to enforce defense on cargos and ships and has identified some maneuvers to escape dangerous situations

3. M&S AND PIRACY

In addition, researchers are studying different strategies to prepare naval fleets to defend sailing routes from pirates [15]. It is common to use a simulator that could experiment and train maritime operators, with different solutions to diverse scenarios [7,16,27,37, 43, 45, 46]; by the way the interoperable simulation technologies here proposed have been successfully used also in commercial application devoted to improve training, safety and security [12, 47]. Although simulation has long been used for naval warfare purposes, there is little work on modeling civilian maritime traffic, one of these is the Matrics project [22]. This project models the behavior of transport ships near the Canadian shore; in this case the used model is based on fluid mechanics and it doesn't represent vessel interactions and other complex structures in maritime traffic.

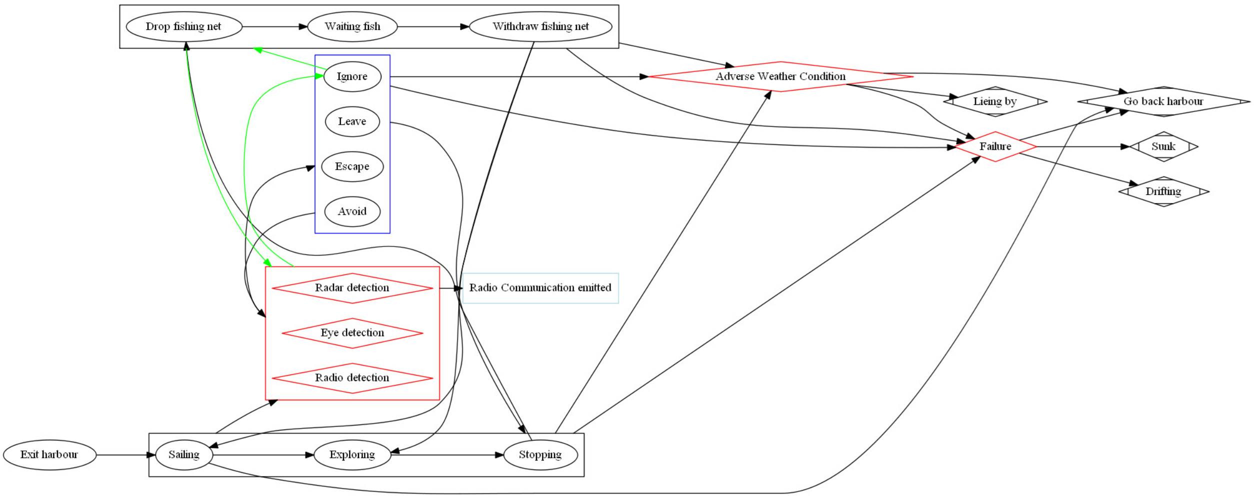

Figure 2: Fishing Boat Behavioral Model

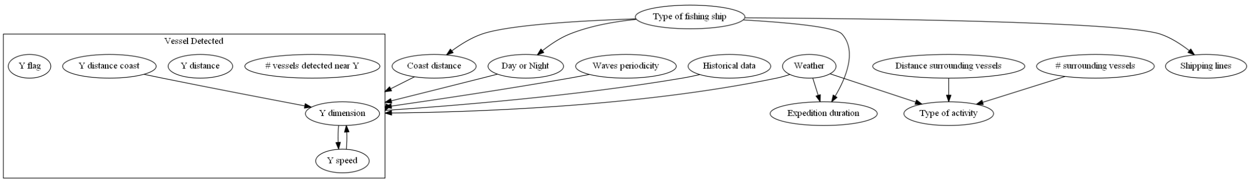

Figure 3: Interactions among Variables and Boundary Conditions

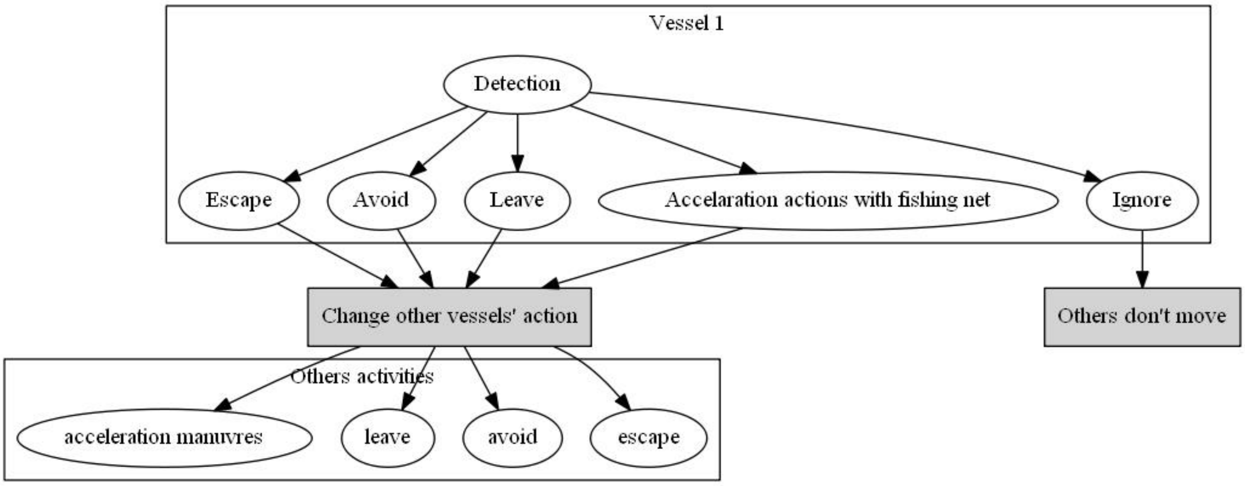

Figure 4: Example of Model Evolution based on Presences of other Ships

By applying agent-based techniques, Jakob and colleagues developed a simulation to detect and, in case of necessity, suppress piracy. They use Google Earth-based front end to visualize the outputs [30, 31]. They follow the example of numerous agent-based simulations available for other traffic and transportation domains, such as air and road traffic [34,35]. The use of planning could be based on multiple approaches and methodologies and its combination with simulation provide further capabilities to address complex phenomena affected by stochastic factors [11, 23, 25, 32].

Indeed discrete event stochastic simulation was extensively used by the authors for addressing piracy in research projects and initiatives [7, 13]; PANOPEA was created to study these phenomena respect the agility of NATO Net-Centric Command and Control Maturity Model (N2C2M2). [6]

This model was applied to Aden gulf scenarios reproducing several thousands of surface boats, all cargo traffic and different coalition of military vessels by using Intelligent Agents (IA) embedding complex Human Behavior Models (HBM) [8]; indeed these IA are a tailored marine NCF (Not Conventional Framework) developed by Simulation Team by using IA-CGF models (Intelligent Agent Computer Generated Forces) for reproducing human behavior in different contexts [4,5,9, 14].

In addition, several other simplified models were from PANOPEA (Piracy Asymmetric Naval Operation Patterns modeling for Education & Analysis) for being applied for other purposes in piracy simulation as collaboration between Simulation Team and other partners [18]; these models usually don't simulate the details of all the traffic including the small medium size boats; for instance MALICIA (Model of Advanced pLanner for Interoperable Computer Interactive Simulation) was created as support for tactical decisions and integration a resource and operational planning optimizer and a scenario analysis tool as well as a special set of algorithms to be used as decision support system [17]; another simplified model derived from the proposed case was JAMS2 (Joint Advanced Marine Security Simulator) customized for being used within EKOE (Environment Knowledge and Operational Effectiveness) to test an innovative evolutionary system devoted to define patrolling strategies over a fixed set of assets [21].

Starting from the idea that navy forces could be trained with a simulator, it is necessary to better model both maritime traffic and pirate activity.

The authors carried out researches for using MS2G (Modeling, interoperable Simulation and Serious Games) for training in different contexts including piracy and to evaluate complex scenarios [16, 20]. In this paper it is presented the study of the possible movement of fishing and cargo ships with pirate ones at sea. We developed some conceptual models to understand how they move and how they interact with each other. To model this interaction we hypothesized that some biological model, such as a prey-predator model at sea, in combination with game-theory could represent well this kind of relations. Pirates are described as predators and ships as potential prey. So ships are represented in an agent-based or individual-based model (IBM), with each agent carrying information about its position, its type of vessel and other information, as in a biological model every agent wears its physiological state and its species.

So first of all we identified all possible behaviours of all the actors and we put them in relation with each other in a conceptual model (for example Fig. 1). Secondly, we analysed the relations existing among different vessels corresponding to autonomous agents in a multi-agent system. Vessels in the system are capable of moving freely within the spatial boundaries of surface waters while interacting with the maritime environment and other vessels (either directly-via communication or indirectly-via environment).

This study was used to implement behavioral models within simulators piracy as dynamic solution to address these complex problem; indeed the authors developed different simulators dealing with this phenomenon derived from PANOPEA for different applications, including MALICIA and JAMS2 [17,21]; in this paper it is proposed the use of HBM to carry out the experimentations on Simulation Team Piracy simulator for evaluating the effectiveness and efficiency of anti-piracy operations. Indeed these simulators are derived from PANOPEA and are stochastic, discrete event, interoperable agent driven simulators based on IA-CGF. In general the IA-CGF are able to interoperate through use of HLA Standard (High level Architecture) and are available to be federated with other systems and models; therefore some of these simulators don't enabled such functions and adopt asynchronous web services for exchanging scenario Data Base [33].

4. THE PROPOSED CONCEPTUAL MODEL

In this work it is presented a set of models to be embedded in the agents devoted to direct the simulation that could be applied to pirate simulators derived from PANOPEA; indeed the general framework proposed Is based on discrete event stochastic simulation, under this paradigm intelligent agents (IA) are used to control the vessels and to reach to their perceptions and their own scenario awareness.

The marine IA-CGF control the vessels and reproduce the dynamic nature of the maritime traffic in real world as well as the behaviors of small medium size boats such as fishermen and pirates under coverage.

The solution generated by this agent driven simulation is applying a predator-prey model in water where ships considered as fishes are "hunted" by predators that are pirates. An agent based model was used to create the different species' behavior. The mechanism that will choose the right behavior for the predator could be evolved by using Genetic Algorithms in order to optimize the related parameters (e.g. threshold distance for the attack, tolerance invading safe corridors, acceptable weather condition and parameters defining the size of the attack team and their coordination level).

In this model the pirates as a predator sail around randomly and if they see a prey-vessel in their vision radius they try to catch the closest one by sailing at maximum speed towards it. In contrary as a prey do, if vessel spots a predator it will immediately goes away with its maximum speed; obviously each vessel is characterized by its own parameters defining speed, maneuverability, sea keeping, sensor range, resolution, mimetic capabilities, etc. This kind of relation is pretty close to the simplest predator-prey model; moreover in a biological system, as a result of the presence of predator "A" through an area, the prey may change its behavior in ways that make themselves more difficult to be captured by predators. This may involve changes in the group's behavior, such as greater alertness or reduction of activities that increases risk of predation for example, advertising and feeding [24]. In our case for example fishermen could change the duration of the fish expedition or the period where nets are in the water. Here it's presented all type of behavior that all the agents of the simulation could perform.

It is pretty important to include in these models the the use of human behavior modifiers considering influence of stress, fatigue, aggressiveness and fear on agent decision making; this was experienced extensively by Simulation Team in multiple context and scenarios [8].

The following types of vessels are presented in the simulation:

- merchant ships or cargo identified as large ocean-going vessels carrying cargo over long distances on international maritime routes, primary targets of pirate attacks;

- pirate ships are vessels of different types and sizes operating close to transport lines, where they are looking to attack, board and hijack cargo ships; pirate ships usually are large "motherships" acting as floating bases from which skiffs[1] are launched to attack;
- fishing ships are vessels used to fish; they could be a possible target for pirates.
- navy frigates are military vessels operating in piracy-affected areas and capable of armed action to neutralize pirates.

In this paper the model for the military vessels is not analyzed in details, assuming that the patrol is controlled by the genetic planning optimizer; indeed the others object behavior could be further developed based on the specific scenario [10].

Indeed the predators are used to do much more than just move as response to the behavior of their prey, so, in the same way, the pirates perform diverse behavior and not only searching and boarding vessels along they operates; in similar way the IA are adopting behaviors to support their mimetic among fishing boats as cloaking procedures. Nevertheless there are many alternatives that could be evaluated and simulation allows to evaluate and investigate their impact on cargo vulnerability as well effectiveness of possible counter measures from the military vessels. Hereafter it is proposed examples of behavior models.

Pirate Model

Historically, in biology, studies have been focused on prey behavior that treats predators as unresponsive subjects rather than participants in a behavioral interaction. This oversight has not only led to an incomplete view of behavioral interactions between predators and preys, but has also obscured an entire class of such interactions that occurs at large spatial scales. Here a detailed analysis is presented about pirates behavior considered as a predator.

Usually pirates move from the coast with a "mothership", that could be a merchant ship or a fishing vessel. That ship enables pirates to operate over a much larger area and it is less affected by the weather. It carries arms, fuel, support material and attached skiffs which are used for attacking ships. In general there are two skiffs that are small high speed (up to 25 knots) open boats that facilitated the ship approach. To simplify the model, the mothership and the skiffs are both considered as a unique structure, that goes out of the coast "exit coast" and explores the sea until a vessel is intercepted. After this, pirates start the approach (that could be direct or indirect to misdirect the ship) and they chose to attack or not attack, depending on the kind of ship, weather conditions, or type of defense. The attack is conducted with the skiffs alongside the ship being attacked to enable one or more armed pirates to climb onboard. Pirates frequently use long lightweight ladders and ropes to climb up the side of the ship. Once onboard pirates will generally make their way to the bridge to try to take control of the vessel usually using small fire arms. Once on the bridge, pirates could start some different attacks:

- "steal" is when pirates go up to the ship to steal what they transport or the money in the strongbox;
- a "hijack" is when pirates have boarded and taken control of a vessel against the crew's will;
- "asking ransom" is when pirates ask ransom making the crew or only the master hostage or the entire vessel, in this case they usually move the vessel in a controlled area.

In the model only the macro movements of the pirates on skiffs or the ship attacked were represented.

Figure 1 proposes the synthesis of their movement model; indeed in the proposed representation of the model, the statuses are presented as dark circles (transition status) or diamonds (absorbing status) while the arrows are the alternative possible transitions; the red diamonds are events that could influence behaviors; the large blue square encapsulates all behaviors related to a ship detection are, while the yellow one includes those in relation with the military vessels.

Indeed after the attacking the ship, the pirates could fail in capturing it: this could be due to the intervention of navy vessels and neutralization of pirates; therefore the attack failure could happen also for other reasons such as cargo self-defense procedures or weather conditions; in these case the pirates could turn back on their stand-by operative modes and continue the sea exploration for potential preys. In this model the situation awareness of the pirates based on direct or indirect information on the military vessel operations and positions could lead to escape actions in explicit or concealed way based on the boundary conditions (e.g. weather, info available, other vessels into the area) related to the current dynamic situation (e.g. current distance, visibility, distance to the coast, etc.).

Fishing Model

In similar way to pirate behavioral model, also the fishing boat model describes the statuses and reactions to evolving situation: the boats sail out of the harbor to fish; in case of interception of some potential coast guard ship or military vessels, by radar, radio or eye detection, the boat-agent could choose to avoid interception, escape (sail full sea speed or high speed to prevent interception), leave (sail out softly at low speed) or ignore. It will depend on condition at contour, such as ship identification, flag, direction of the ship etc. These behaviors are pretty similar to that one of the pirates; so it is evident that this increase the military vessel difficulty for identifying pirates and avoiding false alarms. Indeed the fishing boats are almost impossible to be discriminate from pirates in terms of physical and kinematic features (e.g. speed,

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[1] A skiff is a small, flat-bottomed open boat with a pointed bow and a flat stern. It was originally developed as an inexpensive option for coastal fishing. Skiffs used by pirates are powered by outboard motors.

size, shape, model and type), but the not cooperating behaviors of fishermen trying to avoiding waste of time with inspections combined with the mimetic behavior of the pirates contribute to make even more difficulty the anti piracy missions. In figure 2 the model is proposed representing possible conditions as dark circles (transition statuses) and diamonds (absorbing statuses); indeed also in this case the red diamonds corresponds to events influencing the behaviors, while the big blue square addresses all behaviors dealing with vessel detection. The green arrows proposed by the figure correspond to mean that this way is almost unique possible (very high probability), corresponding to the fact that if vessel detects a navy ship when its nets are in the water it could only wait until all the nets are back on the ship to activate leaving procedures or similar behaviors. In case that the fishing ship is dropping, withdrawing nets, or waiting for the fish, it has a obligate choice to ignore any sighting because it is considered that the loss of the nets has too elevated cost. In this case the ship could only accelerate the maneuvers but since the process is not concluded, it has to wait. In addition here we represent the case of adverse weather conditions where ships could sink or drift or go back to the harbor.

Cargo Model

Cargo behaviors are aiming to reduce two opposite target functions addressing traveling time/cost and risk while moving in the dangerous area; due to these reasons the cargo are using their scenario awareness to avoid pirates and to adopt procedures to prevent boarding risks; in case they suspect presence of pirates they could request support to the military vessels considering reaction time and probability of request acceptance based on dynamic situation. A boat is evaluated as pirate based on its behavior and characteristics considering positions, distance, course, presence of other boats, boat identification and flag, etc. In fact one of the most effective ways to defeat a pirate attack is using speed to try to outrun the attackers and make it difficult to board. There have been no reported attacks when ships have been proceeding at over 18 knots. It is possible however that pirate' tactics and techniques may evolve to enable them to board faster moving ships by using multiple attacks, even if it hasn't happened yet [25].

Boundary Conditions

In this section, variables that are independent from the behavioral models, but influencing them, are described as well as their interconnection.

Indeed some very important boundary conditions are weather conditions, day time, coast distance and historical data. In fact the first two determinate if ships could stay and operate at sea; these factors are continuous; in addition the simulation allows to consider that the visibility conditions due to sun, moon light, fog, rain along day and night. The distance from the coast is another particular relevant variable because piracy attacks usually don't happen very far from the coast: it will be too dangerous for the mothership and risky also in case of success.

Historical data could be useful to determine the "High Risk Area" defined as the area where pirates' activities and/or attacks have taken place. Usually attacks have taken place at the farthest of the High Risk Area [41].

These variables affected the pirates' behaviors; indeed the level of pirates' activity varies greatly due to weather conditions and activity by military forces. Pirates' business generally is reduced in areas affected by the South West monsoon, and it is increased in the period following the monsoon.

As a prey behavior, pirate movements could change in relation of how many vessels are in proximity as well as based on the cargo density. So another variable is related to the characteristics of surroundings vessels such as distance, dimension, activity, flag etc.

In Figure 3 the interaction among variables and boundary conditions is proposed for a specific example where weather conditions influence the expedition duration etc..

Social Behavior

Although behavior is often examined within a dual relation, behavioral interactions are also influenced by the broader social context such as the presence of other vessels as partially anticipated. In fact interactions with neighbors vessels and boats could be an useful source of information about the surrounding environment influencing the behavioral decisions. This phenomena is well known also in the biological systems where it is demonstrated that individuals adjust their behavior when neighbors are present. More specifically the presence of neighbors influences defense against predators both in fish and sea birds [26, 36, 40].

In parallel with biological systems, we expect also that individuals alter their behavior based on evaluation of surrounding groups, in order to improve their potential in terms of "fitness" that, in this case, is represented by avoiding pirates attacks. In natural ecosystems, this is particularly effective for territorial species that have long-term relationships with neighboring groups [26]. Indeed similarities could be find with fishing boats that could be also considered stable since they always stay mostly in the same areas to practice their fishing activities; due to these reasons pirates and fish boats are expected to know the behavioral models of the entities on the area making more simple for them to avoid interception by military ships by hiding among other small medium size boats as well by knowing usual behavior of coast guards.

For most of the time, each vessel pursues its individual goals, but there are also situations where multiple vessels interact dynamically. Such interactions are characterized by different nature; for instance there are non-cooperative interaction such as that one when a pirate attack a cargo or when boats moves away to avoiding inspections and wasting time with coast guards and warships; there are also collaborative interaction such as when navy assets are collaborating within one or different coalition to achieve pirate interceptions or when merchant vessels' calls for help from navy vessels. Indeed the collaboration to defend each other results as an effective way to fifth piracy. The models proposed by the authors are characterized by these aspects, so in case of presence of others vessels the behavior change; in facts in a High Risk Area, ships have a major benefit to stay in contact (in close proximity or by radio) with others to improve their possibilities to avoid pirates.

5. BEHAVIORAL MODEL EFFECTS ON SIMULATION

The effect of behavioral models is measured by the simulator in terms of overall performance respect multiple variables

$$CIT(t) = \frac{nTId(x)}{n}$$

$$CIT_{AVG}(t) = \frac{\int_t^{t+dt} nTId(x)dx}{n\cdot(\mathrm{dt})}$$

$$CIT_{min} = \min\left(\frac{nTId(t)}{n}\right) \forall t \in (t_0, t_{end} - \mathrm{dt})$$

$$CIT_{max} = \max\left(\frac{nTId(t)}{n}\right) \forall t \in (t_0, t_{end} - \mathrm{dt})$$

$$CIT_{STD}(t) = \sqrt{\frac{\int_t^{t+dt}\left\{\frac{nTId(x)}{n} - \left[\frac{\int_t^{t+dt} nTId(y)dy}{n\cdot(\mathrm{dt})}\right]\right\}^2 dx}{\mathrm{dt}}}$$

CIT(t)	Instantaneous Scenario Awareness measured in terms of percentage of correct identifications over total number of targets
$CIT_{AVG}(t)$	Average percentage of correctly identified target over a time frame
CIT_{min}	Minimum percentage of correctly identified target
CIT_{max}	Maximum percentage of correctly identified target
$CIT_{STD}(t)$	Standard Deviation on the percentage of correctly identified target over a time frame
nTId(t)	number of targets correctly identified at t time
t_{end}	Simulation Ending Time (e.g. 7 weeks)
t_0	Time to start data collection the Scenario Awareness
n	number of targets
dt	amplitude of the time window used to estimate average scenario awareness, in this case it was used a 3 days setting

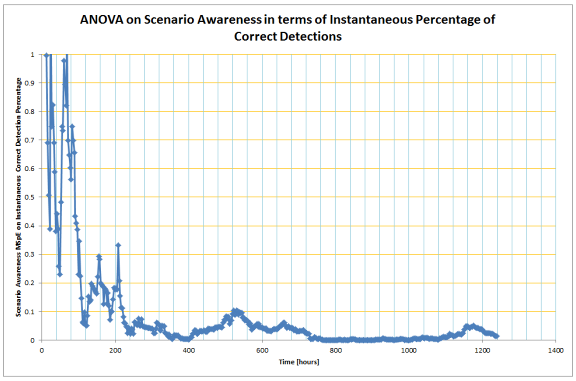

Figure 5: ANOVA on Instantaneous CIT

Obviously these target functions are just an example among many others evaluated by the simulator (e.g. reactiveness, reliability, coverage, resilience etc.); in particular these ones provides an evaluation of the dynamic situation of the scenario awareness.

In order to evaluate the models it was fundamental to adopt VV&A (Verification, Validation and Accreditation) as set of critical steps along the whole model development process [2]; indeed in behavioural models it is very difficult to collect data related to real case studies and it is necessary to conduct experimental analysis and dynamic validation [1]; indeed in the paper are shortly described the main dynamic VV&A used during experimentation; in this case ANOVA (Analysis of Variance) was used through evaluation along time of the variance of the experimental error [39].

$$MSpE\_CIT_{AVG}(t) = \frac{\sum_{i=1}^{r_0}\left[CIT_{AVG}(t) - \frac{\sum_{j=1}^{r_0} CIT_{AVG}(t)}{r_0}\right]^2}{r_0 - 1}$$

$$MSpE\_CIT_{STD}(t) = \frac{\sum_{i=1}^{r_0}\left[CIT_{STD}(t) - \frac{\sum_{j=1}^{r_0} CIT_{STD}(t)}{r_0}\right]^2}{r_0 - 1}$$

r_0	number of replications to be used for evaluating influence of stochastic factors

In figure 5, 6 and 7 the ANOVA is applied by analyzing the temporal evolution of the Mean Square pure Error (MSpE); the stabilization of confirms the validity of the simulator and allow to estimate the confidence band respect the influence of stochastic variables; the stabilization period in this case is around 30 simulated days.

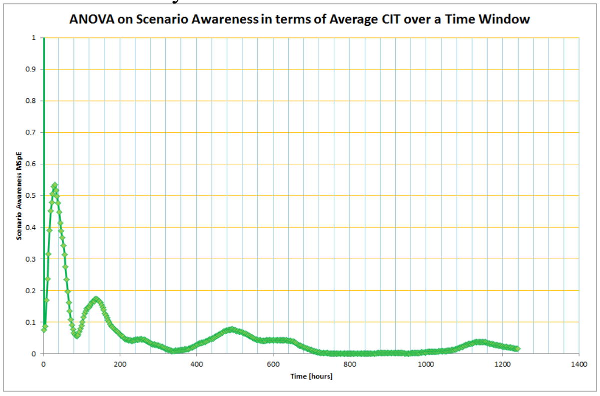

Figure 6: MSpE on average CIT

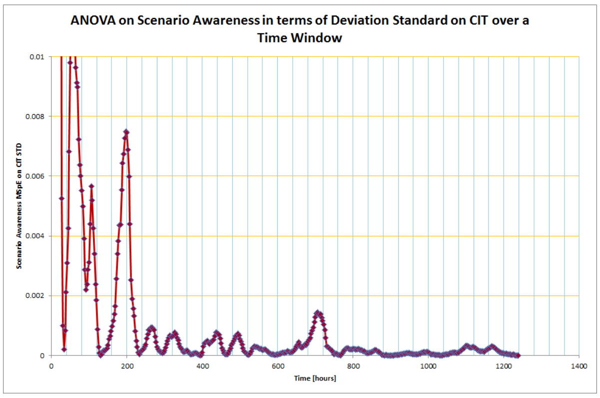

Figure 7: MSpE on CIT Standard Deviation

The implementation of the model in Java using Simulation Team libraries allows to complete a simulation within few seconds for such period confirming the potential for using such approach for extensive experimental analysis.

6. CONCLUSIONS

The current models represent and interesting approach in modeling complex behaviors by considering mutual reaction among rational and emotional entities in dynamic environments; the use of biological examples as inspiration to define the models of the pirates was effective in creating a more realistic evaluation of countermeasures and their effectiveness considering the mimetic strategies applied by the pirates and the non cooperative behavior of small medium size fishing boats. The different models developed could be used to populate different scenarios and to support testing new technological solutions and/or operational procedures for piracy as well for other maritime contexts; in addition this study confirmed the validity of the IA-CGF and their capabilities further extending them with these new HBM. The authors are planning to use further develop these models to address thread networks and other complex contexts through extensive use of the behavioral models within MS2G paradigm.

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