THE 15TH INTERNATIONAL CONFERENCE ON MODELING AND APPLIED SIMULATION

SEPTEMBER 26-28 2016
CYPRUS

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THE 15TH INTERNATIONAL CONFERENCE ON MODELING AND APPLIED SIMULATION, MAS 2016

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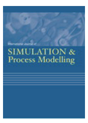

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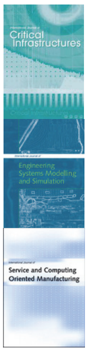

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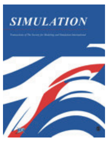

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WELCOME TO MAS 2016!

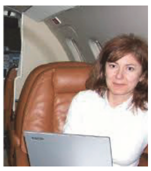
On behalf of the International Program Committee it is our pleasure to present to you the proceedings of the 15th International Conference on Modeling and Applied Simulation – MAS 2016. MAS 2016 is a renewed opportunity for its participants to share, discuss, advance on theories and experiences in this field, bringing together researchers, scientists and practitioners, coming from the "M&S world".

Along the last years, the MAS conference moved around Europe (Vienna, Athens, Bordeaux, Rome, etc.) as part of the International Multidisciplinary Modeling & Simulation Multiconference (I3M). Therefore, attending this conference is an unique opportunity not only for discovering new simulation methodologies, theories and applications but also for experiencing a multidisciplinary framework in which simulation is applied to different sectors, from Industry to Logistics, from Defense to Automation and Control, from Healthcare to Food Operations and processing.

This year, the MAS proceedings include high quality scientific papers that will be also submitted for indexing in the SCOPUS database. An overview of the papers reveals that Modeling & Simulation based approaches are used for decision support in complex real-world systems, for forecast and inventory management (mostly in industrial plants and supply chains), for logistics and retail and for multidisciplinary applications in Industrial Engineering and Aviation. The simulation paradigms used range from discrete event to distributed and parallel simulation, from agent based modeling to hybrid simulation and simulation based optimization. The MAS 2016 conference also hosts joint sessions with the other I3M conferences including a special focus on Human and Social Modeling Behavior.

In closing, we would like to thank, and all members of the International Program Committee, our sponsors, all the authors (for submitting their works) and the invaluable works made by reviewers. We are all contributing to make MAS a truly great conference that grows year by year.

Welcome to Larnaca and to Cyprus where, in addition to a fruitful conference, we hope you will enjoy the history, the cultural background and the great hospitality.



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A special thank goes to Prof. Loucas S. Louca from University of Cyprus as Local Organizer and to all the organizations, institutions and societies that have supported and technically sponsored the event.

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INNOVATION PROCESS IMPROVEMENT – A BEST PRACTICE APPROACH

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ABSTRACT
Many process improvements attempt to predict and measure but lack a systematic and scientific process of verification and validation. This paper proposes an innovative idea to improve the packaging claiming area in Dubai airport using a best practice approach which integrates discrete event simulation modelling and several lean tools such as value stream mapping (VSM), Kanban system and Pareto analysis. This will allow a thorough examination of the proposed improvements and also permit quick verification and validation without any financial implication. The obtained results proved the feasibility of the proposed innovative idea in this paper and the concerned performance measure are improved massively. In addition, the introduction of the Kanban Cards and operating in a pull system environment make the arrival terminal at Dubai airport as a state of the art terminal.

Keywords: lean tools, innovation, process improvement, best practice

1. BACKGROUND

The Dubai government's diversification is from a trade-based oil country to an extended empire of import and export sectors and other services. The diversification has made Dubai a world centre and a number one destination for work, business, investment and leisure, resulting in a property boom from 2004 to 2014. In November 2015, Dubai won the Expo 2020 over many competitors. The theme of Dubai's World Expo is 'Connecting Minds, Creating the Future' and its focus is on three areas: sustainability, mobility and opportunity, which are the key drivers of global development (Dubai Airport, 2015). All of these activities have attracted millions of people to visit and live in Dubai; the statistics from Dubai Airport indicate that the 2010 total passenger inflow of 47.26 million increased to 78.01 million passengers in 2015 (Dubai Airport, 2016).

The above development process has occurred on a huge scale and accordingly has caused a dramatic rise in the quality and efficiency requirements in airport operations, which has required the rapid enhancement of security measures. This puts pressure on passenger service levels and retail income as a consequence of longer waiting times at departure check-in and as well as arrival security check points.

2. INTRODUCTION

Continuous change is characteristic of the majority of processes; therefore modelling a large, complex process can be an intimidating task. Discrete event modelling is the process of describing the behaviour of a complex system as a series of well-defined and ordered events, and works well in virtually any process where there is variability, constrained or limited resources, or complex system interactions (Rockwell Automation, 2016). Modelling is the process of describing the physical system in mathematical terms (Doeblin, 1998); the response refers to the solution of the model that identifies the behaviour of the physical system. Simulation is a method to imitate a real life situation in the form of a model that may be based on a mathematical formula. This model is subjected to different inputs and disturbances, if any, to monitor and record the output. Value stream mapping helps an organisation identify the non-value adding elements in a targeted process. This technique is similar to process mapping, which is frequently used for planning in organisations. In some cases, value stream mapping can be used in the first stage to identify areas in which to target kaizen events for process improvement. Rother and Shook (1999) provided a suitable approach and a practical guide tool for lean implementation. VSM has become the preferable methodology for lean practitioners. In addition to lean tools, several performance metrics have been developed to evaluate improvements in lean implementation, such as overall leanness evaluation. The term leanness describes the process of lean principles (Wan and Chen, 2008); in other words, leanness defines whether or not the company is lean. Many authors and lean practitioners argue that attention must be focused on how to make the company lean rather than on whether the company is lean or not (Wan and Chen, 2008).

3. THE METHODOLOGY: BEST PRACTICE APPROACH

The study objective is to improve the airport process by implementing an integrated system that combines lean tools and simulation modelling. There are eight steps in the proposed methodology to achieve the objectives of the present study.

a. Define the performance indicators for the airport as targets for improvement.
b. Design the process flow for passengers.
c. Carry out survey and data collection.
d. Verify and analyse the present state by value stream mapping and identify the non-added value.
e. Demonstrate the present state using simulation modelling.
f. Identify the gaps and define the problem.
g. Verify and analyse the proposed solution in its future state by value stream mapping.
h. Demonstrate the future state by modelling and simulation.

It has been found that there will be five main performance indicators namely: total queue time; throughput (passenger out); completion time; total number in the queue; and utilisation, corresponding to speed, quality, dependability, flexibility and cost respectively as shown in figure 1. The speed can be seen from the total time that each passenger takes between arriving and being reunited with his luggage and leaving the airport. The quality is determined by the number of passengers processed during the total processing time. Dependability can be determined from the completion time —whether it is short or long—in addition to other factors indicating reliable process flow and equipment. Flexibility can clearly be seen from the total number in queue of all passengers; this can be a sign of bottlenecks during peak times. It will normally contradict utilisation. High utilisation means low flexibility and vice versa. Finally, the cost is related to the full utilisation of the process: it is also related to most of the other factors in the simulation models developed in this paper.

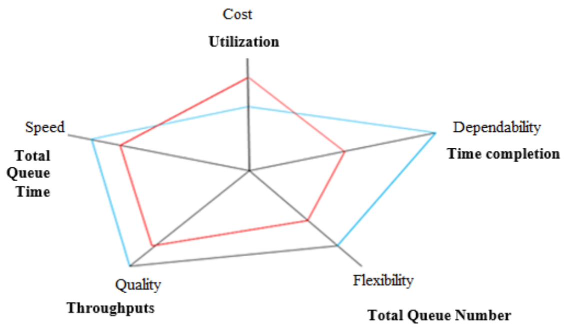

Figure 1: Five performance indicators (Slack et al., 2007)

Several lean tools introduced in the next section indicated several gaps in the area of validation and process improvement. The methodology used in this case study presents an integrated based approach that combines simulation and modelling with lean tools.

In addition, the methods are carefully selected based on their advantages and disadvantages for validation, as well as on the plan to complete this research. Value stream mapping involves gathering information from customers or from the airport as primary data. These collected primary data would be in terms of passenger flow, capacity of the airport and the process time taken.

4. ANALYSIS OF THE PRSENT STATE

In its present state, the complete passenger flow in the terminal building, from check-in to boarding and from de-boarding to luggage claim, as seen in Figure 2, has been analysed by value stream mapping before being modelled in a simulation arena. Two models have been distinguished based on the origin and destination of the passengers.

Once the passenger has completed his de-boarding from the aircraft, he will need sometimes to walk based on Dubai airport or any large international airport for around 10 to 15 minutes until he crosses the passport point and the security checks. Following that, the passenger needs to wait in the luggage claim area for around 20 minutes and up to one hour. The process time is calculated from the time the passenger enters the airport until he is out of the airport.

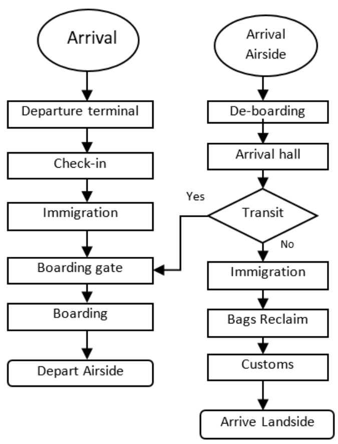

Figure 2: Process of passenger handling

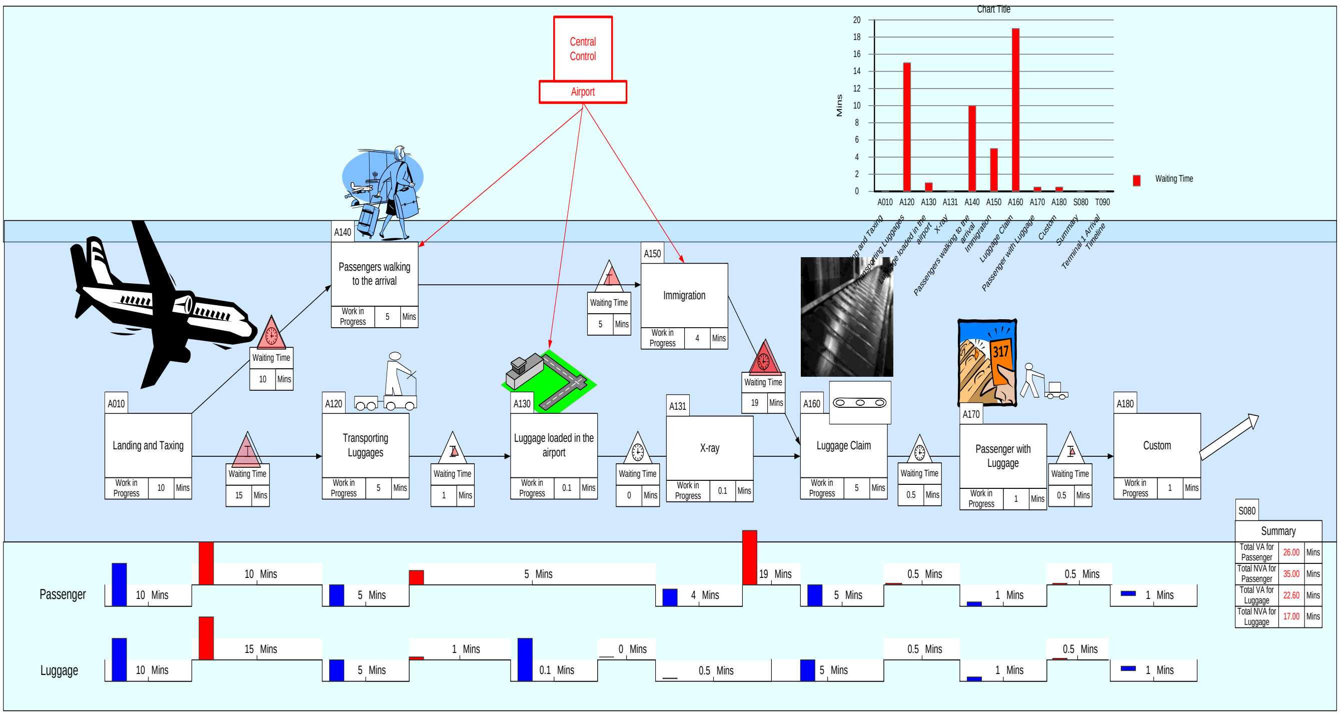

Figure 3: VSM for present state on arrival

In Figure 3, the model for the present state of arrival focuses on luggage claim, passenger handling, immigration process time and the time taken by passengers to complete the process.

In Figure 4, the e-VSM software can generate more than one piece of data in the same bar; this will indicate the ratio between the waiting time and the work in progress. From this figure, the work in progress is shown to be quite good and optimised. Therefore, the direction for focus will be on the waiting and queuing times.

Figure 4 also shows that the longest waiting time is in luggage claim, followed by transporting of luggage and then waiting in the immigration queue. To analyse this further, a Pareto analysis was applied and is displayed in Figure 5. From the Pareto analysis, it is seen that around 80 per cent of the non-value added and the maximum waste time is found in luggage claim and the transport of the luggage. The need for a better solution has now become obvious.

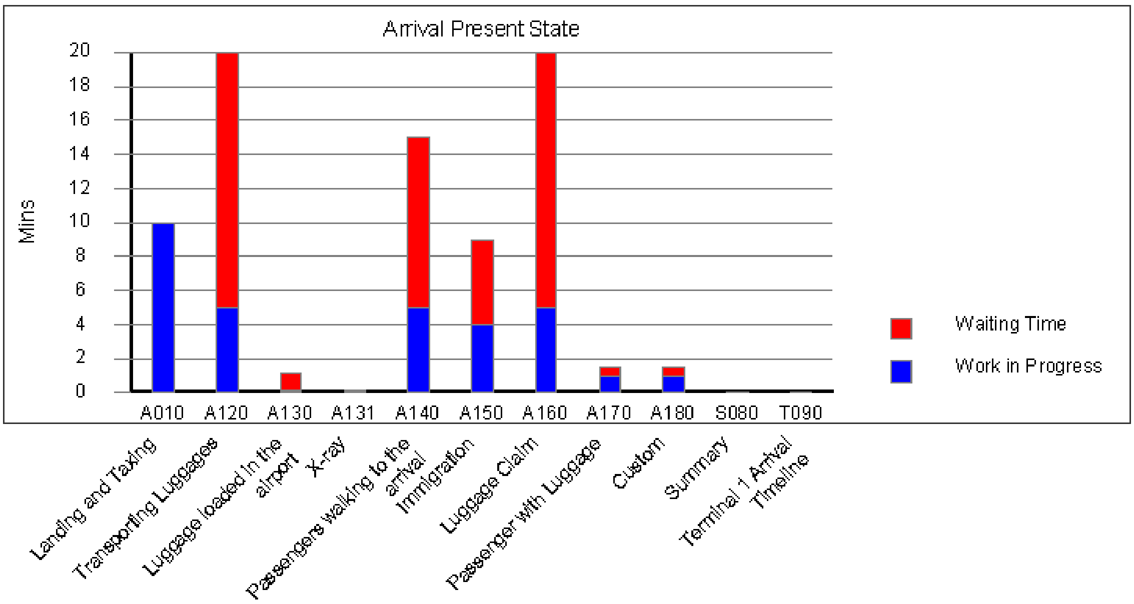

Figure 4: Arrival present state chart

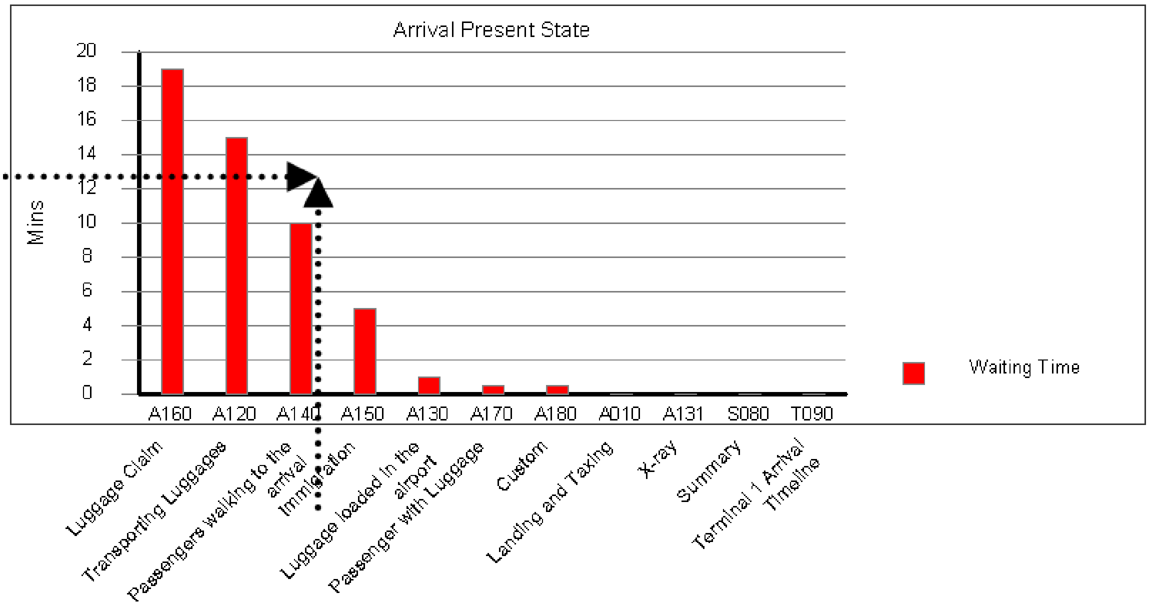

Figure 5: Pareto analysis

5. DEMONSTRATION OF THE PRESENT STATE

Figure 6 demonstrates the arrival present state simulation model, each passenger is reunited with his luggage in the luggage claim area after completing the immigration process. Finally, at the end, a customs point checks the passengers on their way out. The value stream mapping visualises two types of flow: the flow of the luggage and the flow of the passengers.

The VSM identifies the non-value added and the waiting or wasted time, and opens the space for improvement and corrections (Freire and Alarcón, 2002). The simulation will validate and determine the physical dynamic behaviour of the process modelled and will help in making decisions.

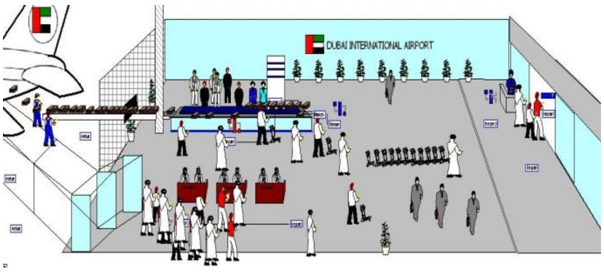

Figure 6: Present state on arrival

6. ANALYSIS OF THE PROPOSED SOLUTION

The VSM shown in Figure 7 analysis the proposed innovative idea and the opportunities of the airport to adopt the concept of the shortest distance between two lines as one straight line.

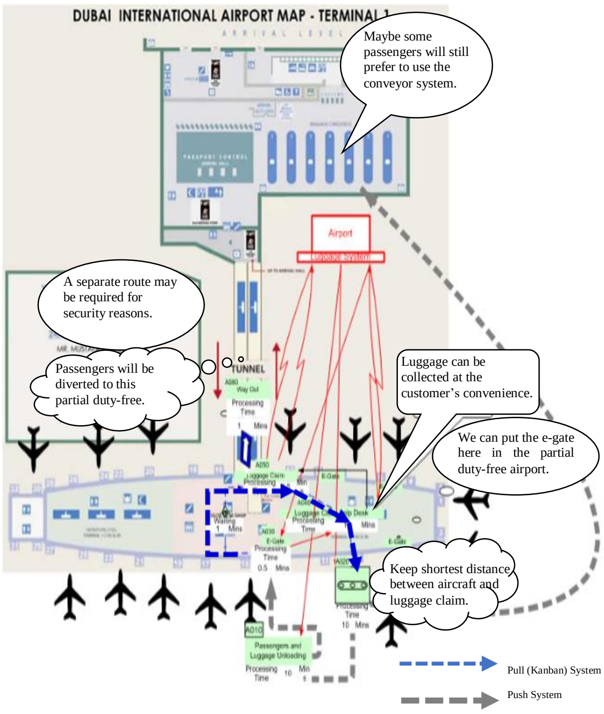

Figure 7: Overview of VSM for future state in arrivals terminal

The process starts from the aircraft tagged with A010, as all process blocks in the stream mapping need to be tagged. The process blocks in the VSM are: aircraft (A010); conveyor belt (A020); e-gate (A030); luggage claim help desk (A040); luggage claim (A050); and way out (A060). The flows of the passengers and luggage are indicated as a push method: once the passenger reaches the airport and after crossing the e-gate, he can be diverted to the duty-free area where his luggage will be waiting for him in the luggage storage. The passenger will need to use state-of-the-art technology—based on kanban methodology, a pull method (Ohno, 1988)—to request a claim for luggage so that the system will notify the robot arms to unload the luggage from the storage unit to the checkout counter. The blue dot lines correspond to the kanban (pull) system and the thick grey arrows indicate the push method. After performing the request at the luggage claim counter, a signal will be sent to the storage area for arranging and, at the same time, information will be displayed on a large screen for those passengers who have requested their luggage giving the counter checkout number in sequence.

In Figure 8 shows the present timeline for arrival; it takes a minimum of one hour to leave the airport. This may be extended to more than two hours during peak times and accumulated delays.

However, it is expected that the timeline for arrival in future state will be shorten massively and the minimum time required for the passenger to complete his process and reach the exit is 35 minutes. However, after some adjustments, this was corrected to 41 minutes by simulation.

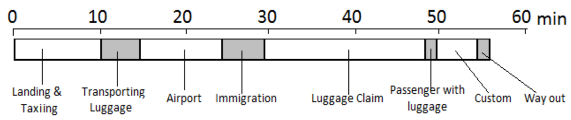

Figure 8: Time line for arrival present state

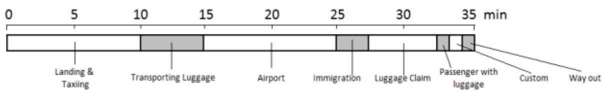

Figure 9: Time line for arrival future state

7. DEMONSTRATION OF THE PROPOSED SOLUTION

The proposal suggests full automation of the handling system similar to Amsterdam airport (Hullegie, 2006) but with storage units for baggage. The concept here is for the luggage to wait for the passenger and not for the passenger to wait for the luggage, so fully automated state-of-the-art technology will be used as the best and most innovative systems, including replacing the conveyor belt with a storage unit that will be loaded and unloaded through robot arms (as seen in Figure 10).

In Figure 11, the proposed simulation model uses a match block to match the passengers and their luggage, with careful disposal of one of the outputs to eliminate the second entity being displayed, always required when dealing with a match block. There are two robots for loading the storage unit, each piece of luggage takes approximately 15 seconds to be loaded by the robot. This value is taken from a similar application where the storage unit is not foreseen. Due to the limited space at airports, this innovation is much needed. In addition to a reduction in operational costs, increased capacity and the adoption of more security regulations will meet customer satisfaction.


Figure 10: Luggage handling by robot at Amsterdam airport (Hullegie, 2006)

The passengers reach the airport within ten minutes. After e-gate facilities and passport counters, they are diverted to the duty-free area. Once the passengers arrive there, a counter for calling the luggage can be used, and as soon as the name of the piece of luggage and each passenger's identification number is displayed on the wide screens, they will be required to check out at the counter, with an indication of which counter number they need to approach.

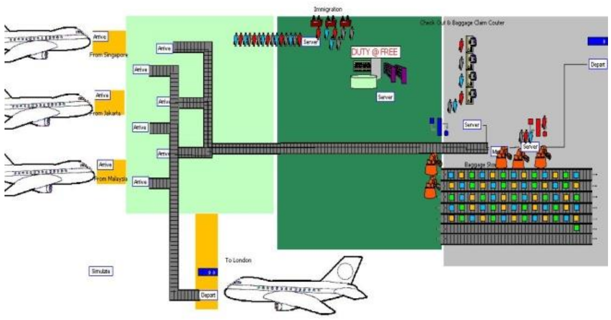
Figure 11: Overview of the proposed replacement of the conveyor luggage with counter and robots

The output of the two simulation models shows the flow of the passengers and luggage; waiting times and other performance indicators; the tally time; the utilisation; the queue time; and the queue number. This information was sent to the output file by Arena Simulation Software. The output file shows the dynamics of the luggage and passenger handling. From the overview chart, the bottlenecks and their causes can be determined. In addition, it estimates the boundaries between which the performances of the luggage and passenger flows are considered to vary.

Figure 12 shows the utilisation in several processes. The utilisation in immigration is around 53 per cent and in customs 17 per cent. However, the remaining utilisation is very poor; this is because all passengers are depending on the process that delivers the luggage to the conveyor belt.

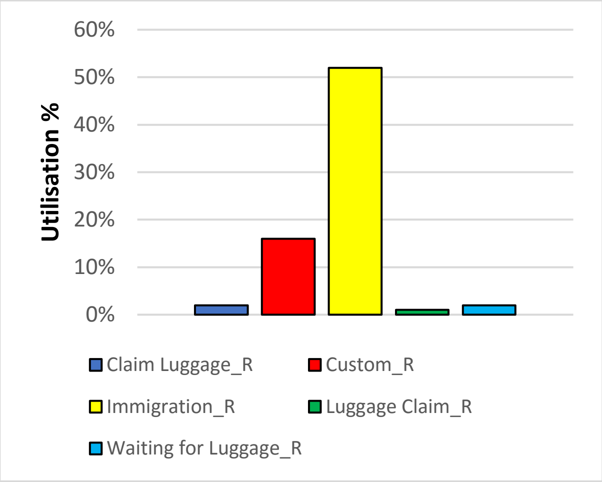

Figure 12: Arrival present state: utilisation schedule

In Figure 13, the total number seized is always 72; this is because the total number of passengers for this model was 72 passengers and 72 pieces of luggage. Total number seized in luggage claim process simulation was 144 because this is a combined process of passengers and luggage. However, the luggage claim resources shown in figure 13 recorded as 115 which indicate long queue for luggage claim.

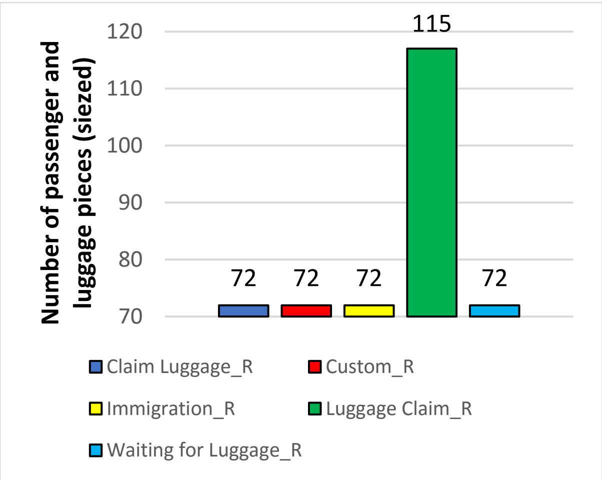

Figure 13: Arrival present state: total number seized

In Figure 14, the future state utilisation increases significantly in all aspects of the process—for example, the luggage claim control centre is 20 per cent, where the present state was less than one per cent. The robot used for loading and unloading the luggage is between 33 per cent and 44 per cent, as the number of robots is reduced, increasing the time of loading, but the overall utilisation increases. It is also noted that immigration in the present state is similar to the future state; however, the overall utilisation in immigration increases slightly from 53 per cent to 57 per cent. This can be regarded as the free path of the passengers in the downstream of the process.

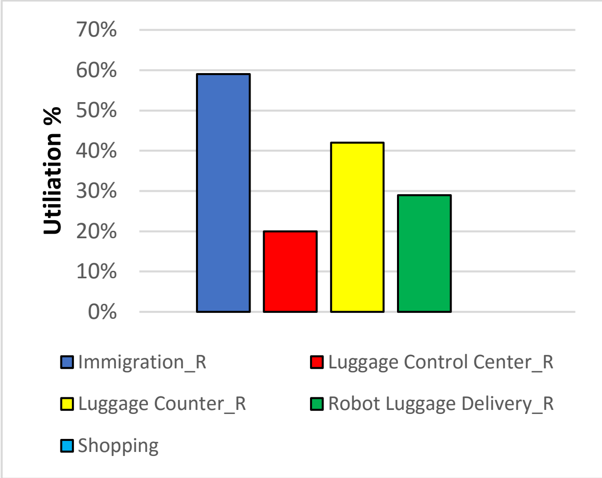

Figure 14: Arrival future state: utilisation schedule

The free path created was the duty-free area, where no queue was required. The passengers can wait in that area until they receive notification from the wide screen noting their ticket details for luggage collection.

In Figure 15, the total number seized was 72 and it was constant for all the processes; this indicates a smooth flow from the start of one process to the end.

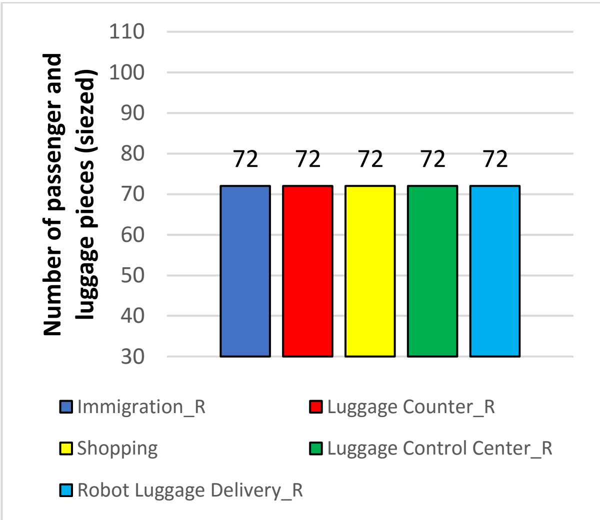

Figure 15: Arrival future state: total number seized

In Table 1, the total time for the 71 arrival passengers at the present state completed in 63 minutes (one passenger is rejected by security): the first passenger to exit the airport was recorded at 32 minutes. The throughput was 71 or 72 in 65 minutes. In the future state, the throughput was 72 in 41 minutes; the first passenger to exit the airport was recorded at 18.5 minutes. The queue time for the present state was 34.5 minutes as a maximum, and 17.25 minute as an average for the immigration process. The future state showed an improvement, as the queue time was reduced to 26.5 minutes maximum and 3.2 minutes average. The maximum queue number was recorded as 54 and 62 for the present and future states respectively. This is due to the fact that in the future state the waiting time and the arrangement of waiting seats or shopping was foreseen.

Table 1: Passenger Exit Airport and Immigration Queue Time

Simulation for Arrival	**Present State**	**Future State**
Total Passenger	72	72
Number of Passenger exit airport	71	72
Time of First passenger exit airport	21 min	18.5 min
Time of all passenger exit airport	63 min	41 min
Immigration Max queue time	34.5 min	26.5 min
Immigration average queue time	17.25 min	3.2 min

The results in the arrivals at the present state and future state can be compared by the percentage of utilisation in various process. In present state, the percentage of utilisation of the immigration counter is 53 percent whereas in future state is 57 percent. In the present state, the utilisation of luggage claim is less than one percent and custom is 17 percent. In the future state, the percentage of luggage claim counter is 20 percent and the luggage checkout counter is 43 percent. The performance greatly enhanced because three robots are applied in the luggage claim system and two more in the loading area.

The reduced capital requirement shows no change in the present state. However, in the future state, the speeding up of the luggage handling process by the automation of the luggage system, and the increase in utilisation overall, combined the two processes of luggage claim and security into one process. This reduces the cost and the space and increases the space for duty-free shopping.

In summary, the case study proved that, with the help of the proposed best practice approach, any idea can be examined and tested. The results obtained from the models were satisfactory considering the minimum data provided for this project.

8. CONCULUSIONS & RECOMMENDATIONS

The following ideas were generated and examined in this paper.

1) Replacing the conveyor belt in the luggage claim area at the arrival hall in an airport. This can be done by moving part of it or most of it away from the visibility of the customer upstream in order to have better control. This is called the material decoupling point in supply chain management (Olhager, 2012), and extends the information decoupling point downstream to the customers/passengers to deliver accurate information about their luggage arrivals. This will lead to customer satisfaction and will shorten the time and the distance between the passengers and the aircraft.

2) Using check-in counters as checkout counters, by applying the reverse flow path of luggage—what can be sent to the aircraft can be received in the same way. This needs a storage buffer for the luggage and can be designed to store the luggage temporarily. Once the passenger arrives in the arrival hall, he or she will approach a calling point for luggage—a push button that will send a signal to the computer, calling for the luggage to be unloaded from the storage shelves. The storage unit will be equipped with robot arms that will be able to upload and download the luggage to the shelves and identify the luggage location through a sophisticated intelligent system such as **r**adio frequency identification (RFID). The storage unit will be able to read and identify the luggage and will be triggered by the kanban system. The kanban system is based on a pull command from the passenger: once the luggage is called, the kanban card will be created and sent to the computer system for the luggage unit to unload the called luggage.

3) Once the passenger arrives at the airport, the flow path can be redesigned in order for the passenger to wait for the luggage while visiting the duty-free shopping areas. A liquid-crystal display in the form of LCD screens can be located in many areas displaying information about the flight and the luggage arrival status and general information guidelines.

4) In order to avoid delays at take-off because of passengers not showing up in the boarding area, there should be zones for uploading luggage according to the availability of the passengers to avoid unloading the luggage of a passenger who did not show up in the boarding hall. Adopting a ‘last in, first out’ policy should not reward the late attendance of passengers.

5) Incremental change is always the safest approach in adopting a process improvement. The introduction of the checkout counters can be implemented parallel to the conveyor belt arrangement to ensure a smooth change and to allow for any corrections needed during the implementation process.

6) Bringing the airport to the city means that passenger will not need to perform the check-in or drop-in luggage process once he has decided to travel. Airport branch counters for specific airlines, for example, can handle partial loads that stress the entire system in the airport. This is already implemented: for example, check-in can be done through the internet, and drop-in luggage in the present practice of some of airlines is one or two days before departure. The passenger can go to any branch and drop his luggage after security checks. However, in the

authors' opinion, the system has not yet been proved. The airport can also be brought to the city by extended and express transport between the airport and the city, as at Heathrow Airport, where express trains can transport the passengers from central London to the airport terminal in ten minutes. Another way of extending the airport to the city is to bring life to the airport by extending buildings to be used for general exhibitions, as implemented in Dubai Airport, where most of the biggest exhibitions are conducted on the airport premises. Expanding the areas shared by the public and the passengers at the check-in counters—circulation areas in BAA's terminology (Edwards, 1998)—can be useful and the same system can be carefully implemented in the arrival process. However, for security reasons, it may not be practical to allow a mixture of arriving passengers and the general public before the customs point.

7) Door-to-door delivery service. Many passengers—especially those who are returning to their homes—would like to avail themselves of this kind of service. This would shorten their arrival process time and reduce the load in the airport arrival section. A door-to-door service is available in some countries like the United States, which ensures the delivery of luggage on a next-day basis, or within 48 hours.

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A SIMULATION MODEL TO EVALUATE THE LAUNDRY ORDER SCHEDULING AND EFFECT OF DISRUPTIVE EVENTS IN INDUSTRIAL LAUNDRIES

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ABSTRACT

Flexibility with respect to response to the customer requests as well as an optimized resource consumption and associated cost savings hold a potential to increase the competitiveness of laundries. Consequently, it is essential for them to operate quick, reliable and cost effective. Simulation analyses are a suitable method to illustrate laundries processes, to evaluate different laundry order scheduling strategies, to identify the effects of errors in the operations and to improve the sequences within commercial industrial laundries. In this paper we describe two developed discrete-event simulation models for characterizing logistical processes in laundries. The results showed an increased lead time by using a random arrangement of the laundry order. The FCFS (First Come First Serve) as well as the EDD rule (Earliest Due Date) are qualified to schedule and optimize the order. Furthermore, a simulation study has shown that urgent jobs have a most influence on the lead time of the textiles.

Keywords: laundry, microscopic simulation model, laundry order scheduling, disruptive events

1. INTRODUCTION AND MOTIVATION

Industrial laundries are production systems in which manual and automatic processes are combined. Due to an increasing competition and a strong customer orientation, the requirements for laundries have increased in recent years. Achieving these requirements, like low prices, fulfilment of individual customer wishes or the customer satisfaction by quick, flexible and on time cleaning as well as delivering, is essential to ensure an economic success. In contrast to manufacturing companies, laundry product are not produced by existing resources but pass through a wash cycle within an industrial laundry. Based on the increased variety in customer and product structures, the laundries are confronted with complex and stochastic processes and handled with a varied number of articles. In order to fulfill the customer orders on time, the sequence order has to be carefully planned. Thus, information about the type and number of articles in the incoming goods are of major relevance. However, there is a limited predictability and transparency of orders and processes in the laundry logistics.

Due to this lack of information regarding the composition and amount of orders, the scheduling of the laundry order is based on uncertain data and is determined by the use of personnel's empirical knowledge.

Scheduling of jobs in industrial applications has been extensively researched and thereby a variety of schedule concepts are described in previous works (Vinod and Sridharan 2010, Ramasesh 1990, Blackstone et al. 1982, Maccarthy and Liu 1993, Graham et al. 1979). However, these solutions mainly target applications in general manufacturing sectors or for example the automotive industry and therefore, are not aligned with the predominant targets and restrictions in industrial laundries. Cheng et al. (2015) described an algorithm of laundry lining procedure scheduling based on RFID.

Despite the automation of processes in washing, drying, mangling, folding and stacking, the interfaces between the processes are still little automated and are usually carried out manually. These interfaces between the automated processes can cause highly variable handling times. Even short disruptions or a complete failure of machines often occur due to overloading, unpredictable defects or mishandling. Since the laundry is a service provider, there are often additional special orders of customers, which are then introduced as express orders in the processes. These urgent orders cause delays and are difficult to predict. On the current status, a suitable and extensive maintenance as well as a fault management is still missing. Consequently, there is an absence of consideration of random errors and their effects on the processes in the work of laundries. However, the mathematical optimization of scheduling does not represent this dynamic and stochastic behavior with the effects of disruptive events. Therefore, the previously determined optimum wash sequence must be tested and assessed by a material flow simulation on robustness against disorders.

In order to evaluate the scheduling of laundry sequences and the influence of stochastically occurring errors, simulation analyses need to be determined. The implementation of such simulation studies were shown to be a suitable method to characterize conventional production systems (Kuhn 1998, Dangelmaier et al. 2013, Verein Deutscher Ingenieure 2000). However, the applications for the industrial sector of laundries are currently insufficient described.

2. CONCEPT OF THE MODELS

A commercial industrial laundry facility consists of several regions and laundry circulation flows. The customer provides the input for the laundry in form of dirty items. Within the laundry, the items are sorted and the order of handling steps in a particular sequence is defined. Fig. 1 shows an exemplary overview of the process structure and possible process routes the item pass through in an industrial laundry. Each step in the process contains numerous case processing or machining steps. For instance the drying area consists of different drying machines, shafts or transport/unloading elevators. A detailed structure and values of processing times of each operation step have been adopted from a reference laundry.

The order and selection of the processing steps and their individual processing time varies for each article, taking into consideration the type of laundry, textile type (e.g. mangling or terry cloth), the consumer (hotel or hospital), type of economy (own or leasing textiles) and type of customer (normal or urgent customer) (Brandau et al. 2015).

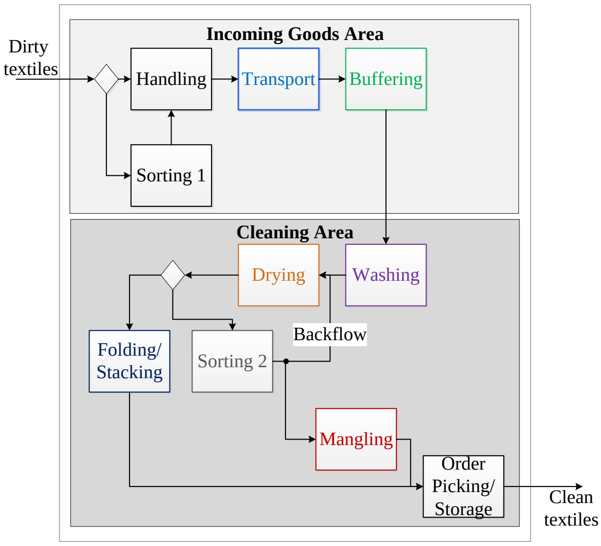

Figure 1: Scheme of the Process Steps and Material Flow in Laundries

By using the RFID technology as well as an automatic reading/identification system in the incoming goods department, the necessary transparency is given. This offers the possibility of optimal planning, management and monitoring of processes and the entire system. Moreover, the RFID technology offers the ability to respond to potential process errors and the maintaining of competitiveness.

2.1. Wash Sequence Scheduling

Currently, the schedule is prescribed due to the route plan and customer order. The washing orders are assigned in the ratio of terry to mangling cloth of 1:3. By providing detailed information about the incoming goods, further sequencing strategies can be implemented.

The scheduling is based using input data as a delivery list given with customer orders. Contrary to the real system, the detailed structure of all delivered orders is known at the beginning of the planning period. The determination of the order strategies was carried out in two steps (see Tab. 1). In the first one, the customer orders are sorted in accordance with predetermined practical priority rules (RND: randomly distributed, FCFS: First Come First Serve and EDD: Earliest Delivery Date). The sorting is carried out separately in each tour due to the different delivery times of the goods.

Table 1: Strategies of Scheduling the Laundry Order

<table>
<tr><td colspan="8">Step 1</td></tr>
<tr><td colspan="3">RND</td><td colspan="2">FCFS</td><td colspan="3">EDD</td></tr>
<tr><td colspan="8">Step 2</td></tr>
<tr><td rowspan="2">RND</td><td rowspan="2">T</td><td rowspan="2">C</td><td rowspan="2">T</td><td rowspan="2">C</td><td rowspan="2">T</td><td colspan="2">C</td></tr>
<tr><td>1:3</td><td>2:4</td></tr>
</table>

The second phase involves sorting the washing jobs within the customer orders. The subjective experience and knowledge of the laundry employees cannot be displayed. Therefore, the arrangement of orders is selected using fixed predetermined priority rules, which are inspired by the behavior of the staff:

- The washing jobs are randomly arranged (RND),
- The arrangement is time-oriented in order of decreasing processing time (T),
- The arrangement based on the change of the washing jobs with the different textile type (with a ratio 1:1 of mangling and terry cloth) (C).

The strategy of changing washing jobs in step 2 (with EDD rule in step 1) was extended with different ratios to characterize the model under more realistic conditions. The conditions 1:3 and 2:4 describe the ratio of mangling to terry cloth. The priority rules are based on the assumption that customer orders are processed successively according to the sequence of the first step.

2.2. Effect of Disruptive Events

The categorization and analysis of disruptive events are based on the model structure of an industrial laundry (see Fig. 1). To determine the effect of disruptive events, all possible occurring errors in industrial laundries were recorded for each handling process within each area (sorting area, transport area, buffer area, washing area, drying area, folding/stacking and storage area) in the model structure under the following aspects: element, reason, effect, duration and frequency.

The failure element is defined as the laundry item. The reasons, effects as well as the duration and frequency of various errors like stopping, falling or snagging of articles or quality defects through cleaning/handling processes were categorized. Reasons could be

sensor/technical defects, capacitive problems, foreign objects in the system, insufficient filling or the input of unplanned jobs. The effect of a disruptive events are demonstrated by the damage of laundry items, repeated process runs, short blockages, long standstills of processes up to direct sequence influences. Errors resulted in an increased lead time and quality defects.
The selection and illustration were implemented by an adapted Failure Mode and Effects Analysis (FMEA) method and clustering with a bubble chart. The rating with the FMEA method is based on a multiplicative calculating of a Risk Priority Number (RPZ) (Illés et al. 2007). The classification was performed with the parameters effect, duration and frequency. Thus, the degree of severity of a disruptive event can be classified. It could be observed that disturbances, which occur during the automated applications or flow production, are very serious.
Equally critical is the input of urgent orders. The error evaluation based on the three rated parameters is shown in Fig. 2. The duration is illustrated in the x-axis and the frequency in the y-axis. The diameter of the bubble demonstrates the failure effect. The figure shows that the majority of errors can be classified in the Quadrant III. They are highly frequented and of limited duration. In particular, disturbances of the areas transport, buffer, mangling and the folding/stacking region fall into this quadrant.
The disrupted events were included in the model as integrated distributions and scenarios. They were applied based on the categorization and their influence on the laundry order:

- quadrant 1:
  - high effect: scenario
  - medial effect: no consideration
  - less effect: no consideration
- quadrant 2:
  - high effect: scenario (errors of the washing machine)
  - medial effect: scenario/ individual
  - less effect: individual
- quadrant 3:
  - high effect: distribution/scenario (errors of folding/stacking region)
  - medial effect: distribution
  - less effect: distribution
- quadrant 4:
  - high effect: scenario (loss of laundry items)
  - medial effect: distribution
  - less effect: individual

Consequently, most of the failures of the areas transport, buffering, mangling and folding/stacking were applied using distributions, whereas scenarios serve to apply errors in the washing and drying area.

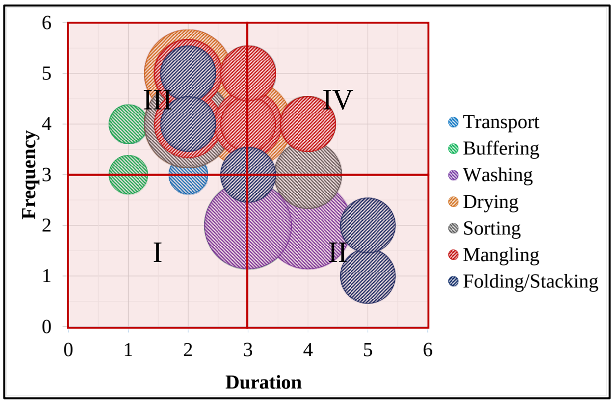

Figure 2: Degree of Severity of Disruptive Events

3. SIMULATION MODELS

To evaluate the selected strategies for planning the washing sequence and determine the effect of errors, the production process of a laundry was replicated with two simulation models. Therefore, the flow of material or laundry item is considered from arrival to the delivery.
During the simulation, individual laundry items are temporarily batched for washing and subsequently unbatched. Process times of manual as well as automatic handling steps are modelled as stochastic distributions. The random numbers limits were selected based on expert interviews.
The simulation model is thus intended to reproduce the stream of individual items of laundry. In this paper, the discrete-event simulation approach with a high level of detail was chosen to implement the simulation studies of logistics processes in industrial laundries (Schenk et al. 2006). The washing job, including a various amount, composition and type of articles as well as delivery date, serve as an input parameter for the simulation models (see Fig. 3). Values of a reference laundry served as input data. Therefore, an exemplary tour list was adopted with customer orders as input data. This list is based on the delivery in real systems, represents a partial section of the daily incoming amount of laundry and contains twelve sales orders, which are delivered at four points in time.

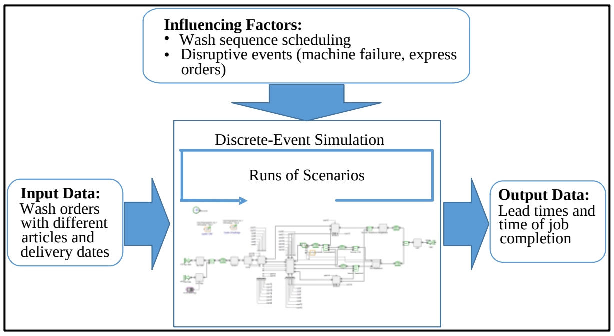

Figure 3: Input and Output Data as well as Influencing Factors of the Simulation Models (Brandau et al. 2015).

However, in order to represent the customer structure in the containers as well as the content of the containers, the filling of the container was determined by additional programming. For this purpose, a random filling with a wide products range on the basis of the type of economy and textile type was selected. Through the knowledge of the weights of individual items and the permissible load of 100 kg per container, the number of products per container is randomly set between 1 and 100. By using an algorithm with a random number and the resulting weight of the articles, the container is loaded up to a cumulative value of 100 kg.

The output of the simulation include the lead time and time of job completion, which is an indicator for the delivery reliability. The fundamental factors to influence the simulation model are the laundry order scheduling and disruptive events like machine failure or urgent orders (see Fig. 3).

3.1. Wash Sequence Scheduling

The following Fig. 4 shows the implemented simulation model using the software *Tecnomatix PlantSimulation* (Siemens). The verification was carried out by observing and controlling the several processing steps of laundry handling out in the simulation model (trace file analysis). Previous rough calculations supported additionally the model verification. Because of an insufficient data basis from the real laundry, the partial results of the simulation were validated by expert discussions. These were conducted by inspection and recording of process times and sequence descriptions in direct cooperation with the laundries.

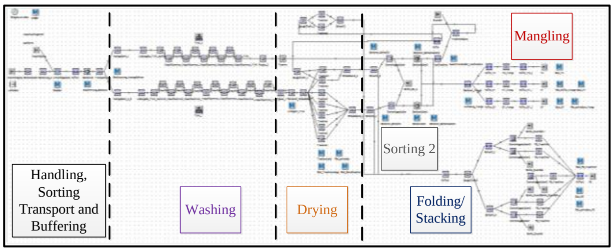

Figure 4: Simulation Model for Evaluation of the Wash Sequence Scheduling

To evaluate the washing order sequence, a base scenario, which includes a list of supply of articles, customers and delivery dates, were generated. This scenario does not contain any disruptive events. The selected strategies of scheduling were implemented and evaluated taking regard of the objectives of a short lead time and a high delivery reliability (Schuh 2006). Ten runs per strategy (step 1 and 2) were chosen for implementation. In total, 80 runs with 24 hours have been carried out.

3.2. Effect of Disruptive Events

The discrete-event simulation model was implemented using *ExtendSim* (Imagine That Inc.) (see Fig. 5). Optimized wash sequences with short lead times using suitable schedule rules, which are the result of the first model, was used as input values for simulation. The validation and verification were performed, similar to the simulation model of the wash sequence scheduling, by using a trace file analysis and expert controls.

In addition to the failure-free base scenario, the errors were included in the simulation with distribution functions or scenarios as described in section 2.

A disruptive event was realized using a shutdown of the activity. If a shutdown occurs, the actual process or activity stays down, the items were kept and the process will be resumed after the failure time.

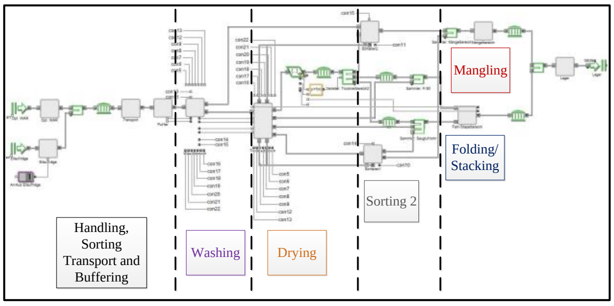

Figure 5: Simulation Model for Calculation of the Effect of Disruptive Events

A disruptive scenario includes the distributed errors as well as some selected failures. The implementation was realized through the following dramaturgy steps:

1. Base scenario (failure-free)
2. Interference scenario 1 (distributed errors)
3. Interference scenario 2 (distributed errors and urgent orders)
4. Interference scenario 3 (distributed errors, urgent orders and failures of the main process route)
5. Interference scenario 4 (distributed errors, urgent orders and failures of the side process route)
6. Interference scenario 5 or worst case scenario (all errors and urgent orders)

The simulation model was tested using ten simulation runs per scenario and evaluated in terms of the effect of the disruptive events on the lead time and delivery performance.

4. RESULTS AND DISCUSSION

4.1. Wash Sequence Scheduling

Nine scheduling strategies were tested and evaluated in the simulation. Tab. 2 shows the list of calculated values using various strategies, sorted according to their rating. The total process time is defined as the working time all twelve sales orders need from the initial time of the first article to the completion time of the last. The lead time of a customer order is determined by the entry of the first textile and the exit of the last out of the system. Here, the average value of the lead times of all orders and the corresponding standard deviation were calculated. Moreover, the amounts (AMT) of the delayed orders as well as the amounts of the delayed washing processes were listed.

Table 2: Lead Times and Delivery Performance in Dependency of the Scheduling Strategies

Strategy		Total Process of all Orders [h]	Mean Lead Time [h]	AMT of delayed Custo-mer Orders	AMT of delayed washing Pro-cesses
Step 1	Step 2				
EDD	C (1:3)	10.67	2.94 ±1.2	0	0
EDD	C (2:4)	10.7	2.97 ±1.2	0	0
EDD	C	10.65	2.92 ±1.2	0	0
FCFS	C	10.65	2.94 ±1.2	0	0
EDD	T	10.78	3.03 ±1.2	0	0
FCFS	T	10.8	3.04 ±1.2	0	0
RND	C	10.65	3.00 ±1.2	1	2
RND	RND	10.65	3.14 ±1.2	1	3
RND	T	11.17	3.28 ±1.3	1	6

These results show that the strategy of the random arrangement of customer orders leads to delayed finished washing jobs and is therefore unsuitable.
The constant standard deviation of 1.2 hours of the lead time can be explained with the distributed values of the various process times, the difference between the average lead time in dependence of the several textiles, e.g. mangling or terry cloth, and the type of consumer. By using the FCFS as well as the EDD strategy delays were avoided.
Moreover, the arrangement of the washing jobs by the largest processing time resulted in a higher lead time. Due to a changing arrangement of washing jobs with different textile type, the total lead time can be reduced. Both strategies are applicable for achieving the objectives.
Despite minimal longer total processing times compared to the strategies of an changing arrangement, the best results can be obtained from the strategies EDD/C (ratio 2:4) and EDD/C (ratio 1:3). By applying these strategies, delays can be avoided and maximum delivery reliability can be achieved due to an optimal machine capacity utilization of the dryer system reduced waiting periods. The minimal longer processing as well as lead time may be due to the consideration of a partial detail of a daily delivery list. The washing jobs cannot be continuously included in the system with an optimum relation. Waiting times due to exhausted resources of the dryer system are not completely avoidable. The EDD/C (1:3) strategy provides the best results in the considered example by using the simulation experiments.
The results of the simulation runs indicate that the scheduling strategies EDD/C (ratio 1:3), EDD/C (ratio 2:4), EDD/C and FCFS/C are suitable to plan the wash sequence. These were used in the study of the effect of disruptive events.

By consideration of the process times of each machine, the mangle of the small textiles was identified as a bottleneck with an occupancy rate of approximately 93%, based on the total simulation time. The high occupancy occurs due to long waiting times and blockage effects. This extension of lead times does not result in a delayed job completion in the considered order and duration of simulation. Nevertheless, these results illustrate the need of further research.

4.2. Effect of Disruptive Events

Fig. 6 shows the results of the simulation runs. As expected, the worst case scenario (scenario 6) shows the highest lead time. Moreover, the occurrence of urgent orders (scenario 3) has the most effect of the lead time and result in an increase of this value. The high standard deviation can be observed due to the reasons explained in section 4.1 and additional by using distributions to implement the Time Between Failure (TBF) and Time To Repair (TTR). Here, the triangular and exponential distributions were used, respectively. Interestingly, the strategies EDD/C and FCFS/C show a higher lead time compared to the other strategies for all scenarios. Failures of the main (scenario 4) as well as the side process route (scenario 5) generate a similar effect and lead time. In general, an increase of the lead time can be observed with an increased scenario.

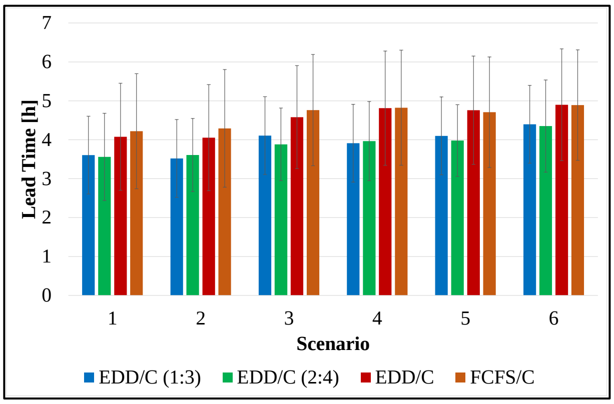

Figure 6: Lead Times in Dependency of the Occurrence of Disruptive Events and Scheduling Strategies

Tab. 3 illustrates the related total process times and the amount of the delayed customer orders. It is shown that scenario 1 as well as scenario 2 causes no delayed customer orders by using the four scheduling strategies. Furthermore, the total process time increases rapidly in scenario 3 and the occurrence of urgent orders. This confirms the trend from Fig. 6. One delayed order occurs by using scenario 3 and 5, respectively. However, no trend or relation can be observed. As expected, the worst case scenario generates the longest total process time and, in addition, two orders cannot be finished at the given time. These results show that the suggested scheduling strategies are suitable to plan the wash sequence and only in the case of errors in each area, which is an unlikely event, not all due dates can be fulfilled.

Table 3: Delivery Performance in Dependency of Disruptive Events and Scheduling Strategies

Scenario	Strategy		Total Process of all Orders [h]	AMT of delayed Customer Orders
	Step 1	Step 2		
1	EDD	C (1:3)	10.55	0
	EDD	C (2:4)	10.5	0
	EDD	C	10.61	0
	FCFS	C	10.64	0
2	EDD	C (1:3)	10.54	0
	EDD	C (2:4)	10.54	0
	EDD	C	10.65	0
	FCFS	C	10.65	0
3	EDD	C (1:3)	10.6	1
	EDD	C (2:4)	10.59	0
	EDD	C	10.69	0
	FCFS	C	10.78	0
4	EDD	C (1:3)	10.59	0
	EDD	C (2:4)	10.7	1
	EDD	C	10.72	0
	FCFS	C	10.82	0
5	EDD	C (1:3)	10.62	0
	EDD	C (2:4)	10.6	0
	EDD	C	10.7	0
	FCFS	C	10.75	0
6	EDD	C (1:3)	10.67	1
	EDD	C (2:4)	10.65	0
	EDD	C	10.73	0
	FCFS	C	10.74	1

In further project work, an evaluation system for the laundry order scheduling in terms of robustness will be developed. Therefore, a suitable weighting of the model parameters (scenario, factors) must be defined and tested. Due to this evaluation system it will be possible to judge the quality and robustness of wash sequences against failures or errors.

5. CONCLUSION

In summary, the suitability of discrete-event simulation model to characterize the processes in industrial laundries was presented. The simulation depending on the laundry order scheduling strategies show an increased lead time by using a random arrangement of the laundry order. The FCFS (First Come First Serve) as well as the rule of EDD (Earliest Delivery Date) are qualified to schedule the order. The simulation study with consideration of disruptive events show a significant effect of urgent jobs on the lead time.

ACKNOWLEDGMENTS

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MULTI-OBJECTIVE EVOLUTIONARY ALGORITHMS OF CORRELATED STORAGE ASSIGNMENT STRATEGY

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ABSTRACT
The traditional research on storage assignment strategies mostly concerns the single-objective optimisation problem (SOP) of travel distance in order-picking systems, in spite of diverse criteria. Considering the correlation between stock-keeping units, this paper presents multi-objective evolutionary algorithms of correlated storage assignment strategy for the multi-objective optimisation problems (MOP). Two types of objectives are considered. One is time consumption, consisting of travel time (converted from travel distance) and pick time, implying the MOP into SOP. The other is a parallel convergence of time consumption and energy expenditure. The multi-objective insertion and exchange algorithms are developed, and further improved through a skip method. After that, a model for a single-block warehouse with four routing strategies is built in Matlab to evaluate these algorithms. The experiment shows that the correlated storage assignment strategy can improve multiple objectives, by comparing with the full-turnover strategy.

Keywords: order-picking, correlated storage assignment strategy, multi-objective evolutionary algorithm

1. INTRODUCTION
Order-picking is a highly time-consuming and labour-intensive activity in warehouse management. Starting at the depot with a picking order of stock-keeping units (SKUs), quantity, and pick positions, the order-picker travels in a warehouse, collects SKUs in the racks and takes them back to the depot. This activity accounts for as much as about 55% of warehousing costs (Koster, Le-Duc, and Roodbergen 2007), so the storage location assignment plays a very important role in the warehouse operations.
Given a low-level, one-block, picker-to-parts order-picking system with SKUs, two problems are considered: how to assign the SKUs to the storage locations and how to determine the travel route of the order-picker. Both of them directly affect the efficiency of warehouse operation. Nevertheless, Frazelle (1989b) proved the storage location assignment problem to be non-deterministic polynomial-time hard (NP-hard), and the shortest route was frequently studied as the travelling salesman (TSP) problem in graph theory. In fact, the travel route is just one special case of it (Jünger, Reinelt, and Rinaldi 1995). The Hamiltonian cycle problem was proved to be NP-complete (Karp 1972), implying the TSP problem was typically NP-hard (Glover and Kochenberger 2006). As a result, diverse storage assignment strategies and routing strategies are developed heuristically to obtain practical solutions to the warehouse management problem.
For the storage location assignment problem (SLAP), Koster, Le-Duc, and Roodbergen (2007) stated that five types of storage assignment policies were usually used: random storage, closest open-location storage, dedicated storage, full-turnover storage, and class-based storage. However, Van Den Berg (1999) pointed out that randomised and dedicated storage policies are actually extreme cases of the class-based storage policy, because all the SKUs can be seen as one class by the randomised storage, whilst each SKU is seen as one class by the dedicated storage. The picking frequency and the cube-per-order index (COI, Heskett 1963) are often applied by the full-turnover strategy. In addition to picking frequency, the COI also takes the volume of SKUs into consideration.
Moreover, the correlation between SKUs in the picking orders was further studied to develop correlated storage assignment strategies (CSAS). Frazelle and Sharp (1989a) formulated this problem into a correlated assignment strategy, and conveyed that this strategy can achieve the same goal, instead of hiring more workers and improving the additional hardware. After that, Frazelle (1989b) developed the CFZS (cluster first, zone second) procedure. The non-complementarity measure between two SKUs was used to formulate the correlated storage assignment strategy as a p-median problem (Rosenwein 1994).
Amirhosseini and Sharp (1996) stated that six measures could be used to describe the correlation. Bernnat and Isermann (1998) developed the “easy sequencing heuristics” by means of an analysis of the correlation between SKUs in matrix, using a threshold to limit the correlation between SKUs in itemsets. Liu (1999) combined the clustering of SKUs and the sequence of picking lists and developed a zero-one integer programming model.
Mantel, Schuur, and Heragu (2007) developed order-orientated slotting for S-shape and vertical lift modules,

presenting an interaction-frequency-based quadratic assignment heuristic, but it is also an NP-hard combinational optimisation problem, and very difficult to find the exact solutions (Sahni and Gonzalez 1976). The cluster-based rule and the cluster-based and turn rule were developed for the establishment of the priority list (Bindi, Manzini, Pareschi, and Regattieri 2009). Based on a mathematical model and two direct heuristics, two hybrid genetic algorithms with different crossover mechanisms were presented (Xiao and Zheng 2012).

Chiang, Lin, and Chen (2014) presented the modified class-based heuristic and the association seed-based heuristic based on the weighted support count, testing them with the S-shape strategy. With the precondition that each column/bay contained only a single SKU, a two-phase solution heuristic was presented, consisting of a minimum delay algorithm and a layout generation (Wutthisirisart, Noble, and Chang 2015). Zhang (2016) presented a methodology to develop the algorithms of the correlated storage assignment strategies, and developed sum-seed clustering and static-seed clustering to mine itemsets, four ways of sorting itemsets and single SKUs, and the insertion algorithm.

In the travelling salesman problem, a salesman travels from his home city, visits all the other cities on the list only once, and finally returns to his home city. To finish this work as soon as possible, the shortest route has to be found. Although Little, Murty, Sweeney, and Karel (1963) developed the branch-and-bound method to reduce the search time for the optimum route, the calculation time grows exponentially. The calculation is still extremely time-consuming when there are too many cities. In order-picking, the depot and all the picking positions in one picking order can be seen as “cities” in the travelling salesman problem.

Due to the difficulty of the search for optimum routes, numerous routing strategies are heuristically developed to provide both economical and practical solutions. Roodbergen (2001) presented five heuristic routings of order-pickers: S-shape, return, midpoint, largest gap, and combined, and the order-picking could be either single-sided or double-sided. Hompel, Sadowsky, and Beck (2011) discussed the S-shape strategy with/without skip and single-sided/double-sided return strategy further. Sadowsky (2007) developed formulas for calculating travel distance under single-sided and double-sided return strategies, midpoint strategy, as well as S-shape strategies with and without skip, based on a certain picking probability distribution of SKUs. In fact, the picking probability distribution of SKUs is very complex and dynamic, but little research was done on the travel distance calculation of actual picking orders under diverse routing strategies.

Since travel distance has a great effect on the productivity of order-picking, the reduction in travel distance was often set as an optimisation goal of order-picking systems. However, past research has been limited to single-objective optimisation problems, and more criteria should be considered in the optimisation of order-picking systems.

Multi-objective optimisation is a common problem in diverse fields of science and engineering. It deals with a simultaneous optimisation of multiple criteria, which may be in conflict with each other. A usual way was to weigh the priority of the criteria, so that MOP could be converted into a single-objective problem (Sooksaksun 2012). However, the weights were subjectively pre-defined, and the objective values range was perhaps limited, which meant that the decision-maker could only get a little information about potential trade-offs through this simple solution (Nguyen and Kachitvichyanukul 2010).

In the past decades, MOP has been studied a lot in enormous fields and a vast array of algorithms has been developed. The multi-objective evolutionary algorithms (MOEA) were considered as a feasible solution to MOP, because a set of representative Pareto optimum solutions could be found in a single run (Ding and Wang 2013).

However, MOP and MOEA have seldom been applied in warehouse management research. Molnar and Lipovszki (2002) presented a genetic algorithm with Pareto elitist-based selection to optimise the routing and scheduling of order-pickers in a warehouse, considering time constrain, labour and earliness/tardiness penalty costs. Önüt, Tuzkaya, and Doğaç (2008) developed a particle swarm optimisation algorithm to search for the optimum layout, as regards the classified products by turnover rates. Sooksaksun (2012) proposed a Pareto-based multi-objective optimisation approach to minimise the travel distance and maximise the usable storage space, using the number of aisles, the length of the aisles, and the partial length of each pick aisle as variables. He also studied the Pareto front of the problems by multiple objective particle swarm optimisation.

In this paper, the correlation between SKUs has been considered in order to optimise the storage location assignment problem in respect of multiple objectives, including the travel distance, pick time and energy expenditure of the order-picker. The correlated storage assignment strategy has been further developed with multi-objective evolutionary algorithms to obtain feasible solutions.

The remainder of this study is shown as follows: Section 2 presents a mathematical model; Section 3 concerns algorithms; Section 4 shows a modelling in Matlab; Section 5 develops methods of calculation; Section 6 deals with an experiment, whilst Section 7 concludes the study.

2. MATHEMATICAL MODEL

In this section, a mathematical model is presented for the multi-objective optimisation problem of storage location assignment. Section 2.1 shows the notations. Section 2.2 presents the assumptions, whilst Section 2.3 describes the problem.

2.1. Notations

An xyz coordinate system is established for the warehouse's storage locations, using x for the number of columns, y for the number of rows and z for the number of racks. The storage location in the first row of the first column of the first rack is set as the origin. The following notations are used to formulate the mathematical model.

Table 1: Notation

Variable	Description
$a_{d,l}$	Boolean variable
a_w	Width of pick aisle
$b_{d,l}$	Boolean variable
b_w	Half-width of cross aisle
d	Number of pick aisles (from left to right)
$d_{\max,l}$	Number of the rightmost pick aisle with pick positions of picking order l
$d_{\min,l}$	Number of the leftmost pick aisle with pick positions of picking order l
k_l	Number of travelled pick aisles of picking order l
k_p	Weight of energy expenditure for picking
k_t	Weight of energy expenditure for travelling
$l = 1, 2, \cdots, L$	ID of picking order
l_c	Width of a pick aisle and two racks
l_p	Length of a pick aisle and width of a cross aisle
n_x	Total number of columns
n_y	Total number of rows
n_z	Total number of racks
$p = 1, 2, \cdots, H$	ID of SKU
$q = 1, 2, \cdots, H$	ID of storage location
$t_{d,l}$	Boolean variable
$t_{z,l}$	Boolean variable
u_l	Length of storage location
u_w	Width of storage location
v	Travel speed of order-picker
$x_{a,d}$	x value of the last pick position in pick aisle d of UP
$x_{b,d}$	x value of the last pick position in pick aisle d of LP
$x_{d,l}$	x value of the last pick position in pick aisle d of picking order l under RB
x_s	x value of the last pick position of picking order l under SB
$x_{z,l}$	x value of the last pick position in rack z of picking order l under RS
z_l	Number of the last rack of picking order l
S_l	Travel distance of picking order l
F	Assignment matrix
G	SKU priority list

2.2. Assumptions

An actual order-picking system is extremely complex with numerous changeable conditions, but the prerequisite of an optimisation is the definiteness of every factor and parameter. To develop algorithms of an optimisation, assumptions have to be made to limit order-picking systems into a mathematical model. In this study, the order-picking system is analysed under the following assumptions.

1. The warehouse has one block, with all racks placed in parallel, see Figure 1.
2. The depot locates at the first corner of the first cross aisle and the first pick aisle.
3. Only one order-picker is responsible for the warehouse, and works in the picker-to-parts way.
4. The storage locations have the same length, width and height.
5. The number of SKUs is the same as the warehouse storage capacity.
6. Each SKU has a unique storage location.
7. SKUs of the same column in a rack are stored decreasingly by picking frequency in storage locations which are sequenced increasingly by pick time.
8. The order-picker moves at a constant speed.
9. The time consumption of the order-picker is stable for the same vertical position in the columns, whilst picking up SKUs and putting them in the picking cart.

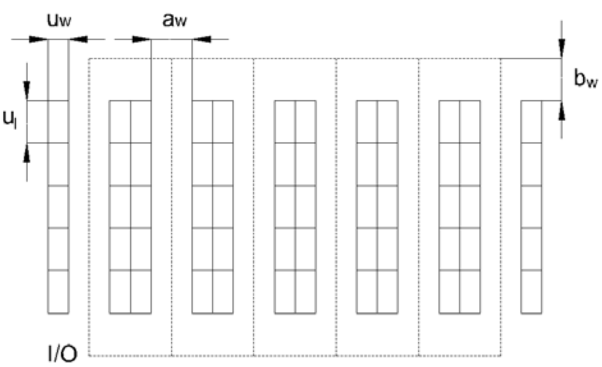

Figure 1: Warehouse Layout

2.3. Problem description

The storage location assignment is a combinational problem of SKUs and storage locations. Given a warehouse with H storage locations and H SKUs, an assignment matrix **F** is used to describe the exact assignment plan. The row numbers and column numbers of **F** match the ID of SKUs and storage locations respectively. If SKU p is stored in the storage location q, let $\mathbf{F}(p,q)$ equal to 1, otherwise 0. The row vector **G** with H elements stands for the SKU priority list. The ID of SKUs for each storage location is saved as the corresponding element of $\mathbf{G}$. The function $f_n(\mathbf{G})$ presents the diverse objective functions of the optimisation. With a certain routing strategy as a precondition, a general mathematical model of this multi-objective problem for the storage location assignment is summarised in the following:

$$\min F(\mathbf{G}) = (\mathrm{f}_1(\mathbf{G}), \cdots, \mathrm{f}_n(\mathbf{G}))$$
$$\text{s. t.} \begin{cases} \sum_{p=1}^{H} \mathbf{F}(p,q) = 1,\ \mathrm{q} = 1,2,\cdots H \\ \sum_{q=1}^{H} \mathbf{F}(p,q) = 1,\ \mathrm{p} = 1,2,\cdots H \\ \sum_{p=1}^{H}\sum_{q=1}^{H} \mathbf{F}(p,q) = H \end{cases} \tag{1}$$

Travel distance is often used as a criterion of the single-objective optimisation. For simplification, the travel speed of the order-picker is usually set as a constant. As a result, the minimisation of travel distance can be converted into the minimisation of travel time, so that travel time and pick time can be added together, and this multi-objective optimisation problem is turned into a single-objective optimisation problem. Set $\mathrm{f}_t(\mathbf{G})$ as the objective function of travel time, and $\mathrm{f}_p(\mathbf{G})$ as the objective function of pick time. The converted single-objective function (CSF) is presented as followed:

$$\min F(\mathbf{G}) = \mathrm{f_t}(\mathbf{G}) + \mathrm{f_p}(\mathbf{G}) \tag{2}$$

In contrast, the unit of energy expenditure is different to that of time consumption. Theoretically, they can be weighted to get the weighted product as the objective. However, this method makes little sense when optimising order-picking systems, as the weights are defined empirically. A heuristic approach is to simultaneously search convergent solutions of time consumption and energy expenditure. Set $\mathrm{f}_{te}(\mathbf{G})$ as the energy expenditure of travelling and $\mathrm{f}_{pe}(\mathbf{G})$ as the energy expenditure of picking. Considering the three criteria together, the multi-objective function (MF) is further developed:

$$\min F(\mathbf{G}) = ((\mathrm{f_t}(\mathbf{G}) + \mathrm{f_p}(\mathbf{G}), \mathrm{f_{te}}(\mathbf{G}) + \mathrm{f_{pe}}(\mathbf{G})) \tag{3}$$

Compared with the single objective optimisation of the storage location assignment problem, which is NP-hard (Frazelle 1989b), this model is more complex, and it is more difficult to find optimum solutions. Practically, an SKU priority list and a storage location list are usually formed and then merged together, to complete the storage location assignment problem. As a result, algorithms have to be developed to obtain the two lists.
On the one hand, algorithms for the storage location list are determined by routing strategies. It is relatively easy to present heuristic methods for it. With the S-shape strategy, the SKUs are usually stored from the depot in the racks of the first pick aisle, and then change the direction in the next pick aisle, just like an S-shape. With the double-sided return strategy, the assignment is always carried on from the bottom to the top in each pick aisle and the sequence of pick aisles is from left to right (Zhang 2016). Different to this is the single-sided return strategy, where the SKUs are assigned to storage locations of each rack from bottom to top and from left to right. The heuristics of the midpoint strategy are more complex: the SKUs are firstly assigned to storage locations in the first pick aisle, then the lower half of the rest of the pick aisles from bottom to top and from left to right and, finally, in the upper half of the rest pick aisles from top to bottom and from left to right.
On the other hand, heuristic algorithms for the SKU priority list are more complex, because they are deeply affected by the structure of picking orders. Thus, feasible algorithms need to be developed for these optimisation problems.

3. MULTI-OBJECTIVE EVOLUTIONARY ALGORITHMS

Based on the objective functions of the mathematical model in Section 2, multi-objective evolutionary algorithms are developed in this Section. These algorithms progressively approach the optimum solution to the storage location assignment problem, scanning all the SKUs.
Different to the common application of genetic algorithms, which exchange the positions of items in the sequence and treat them equally, the priority of storage locations must be taken into consideration when developing algorithms for the storage location assignment problem, because of the various travel distances between the depot and storage locations.
Due to the complex correlation between SKUs in the order structure, if the assignment of multiple SKUs is changed simultaneously, the effect on the objective function will be greater. To approach the optimum solution step-by-step, the insertion algorithm (Zhang 2016), which considers improvement by single positions, can be adapted for these multi-objective optimisation problems of storage location assignment, considering the correlations of SKUs to find convergent solutions. The result of the full-turnover storage is used as the object to be improved, to provide a better initial solution, and the number of correlated SKUs for the scanned SKU is limited to an experimental threshold to avoid unnecessary calculation. The following processes present the multi-objective insertion algorithm (MIA):

1. Use the decreasing sequence of SKUs by picking frequency as the original SKU priority list.
2. Scan the SKU in the first position of the original SKU priority list and find its correlated SKUs to the right of it in the original SKU priority list, calculate their correlation values.
3. Save the correlated SKUs and the correlation

values in the first and second columns of a matrix, and decreasingly sort the rows based on the value in the second column.

4. Try each correlated SKU in this new order: take each of them out and insert them in the SKU priority list after the scanned SKU. If the objective function converges, replace this original SKU priority list with the new one, and scan the next position in the original SKU priority list. Otherwise, continue with the next correlated SKU.
5. If no improvement can be found within the experimental threshold of the number of the correlated SKUs, scan the next position in the SKU priority list as the processes (2-5).

Another option for the approach to the optimum solution is the multi-objective exchange algorithm (MEA). Instead of taking a correlated SKU out and inserting it after the scanned SKU, this method exchanges the storage locations of the SKU after the scanned SKU and the correlated SKUs, in order to seek out a better performance of the objective function. The steps (1-3 and 5) are the same as before, but step 4 is different:

4. Try each correlated SKU in this new order: exchange the storage locations of the SKU after the scanned SKU and the correlated SKU. If the objective function converges, save this new SKU priority list as the original one, and scan the next position in the original SKU priority list. Otherwise, go on with next correlated SKU.

However, these algorithms can be further improved. A skip method is used to improve their efficiency: if the correlated SKU is in the same column of the rack with the scanned SKU, skip it. In this way, the multi-objective insertion algorithm with skip (MIAS) and the multi-objective exchange algorithm with skip (MEAS) are further developed.

4. MODELLING IN MATLAB

To evaluate these multi-objective evolutionary algorithms of a correlated storage assignment strategy, a model is established in Matlab with a practical interface, in which all the parameters of the picking orders, layout and algorithms, as well as the experiment plan, can be defined.

Four modules are included in this model. The first module presents the generation of picking orders, based on five assumptions about the proportion and distribution of SKUs (Zhang 2016); the second module deals with the order analysis to calculate picking and correlation frequencies; the third module includes all the algorithms; the last one is responsible for the calculation of diverse objectives: travel distance, travel time, pick time, and energy. See Figure 2.

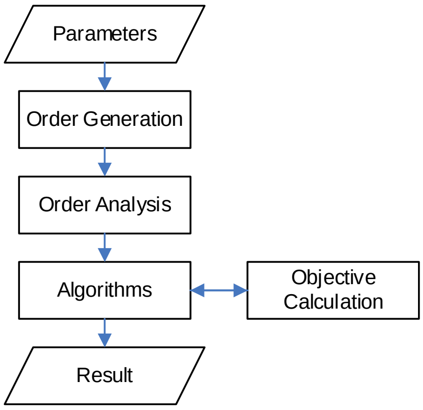

Figure 2: Modules in Matlab

To continue this model, five procedures are undertaken: firstly, set up variables and experiment plans; then, run the pre-calculation to initialise the parameters; next, run the calculation of diverse algorithms; lastly, the result is analysed, saving the outcome in Excel. See Figure 3.

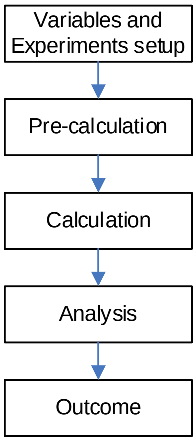

Figure 3: Implementation Procedures

5. METHODS OF CALCULATION

This section presents the formulas for the calculation of the objective functions, including travel distance, time consumption and energy expenditure.

5.1. Travel distance calculation

The travel distance of order-picking is significantly affected by routing strategies. In this study, the S-shape strategy (SB), the single-sided return strategy (RS), the double-sided return strategy (RB) and the midpoint strategy (MB) are considered in the experiment, and the travel distance is calculated per picking order and finally added up. The movement of the order-picker can be classified into two types: movement in pick aisles and cross aisles.

let $l_c = 2u_w + a_w$ and $l_p = 2b_w + u_l n_x$.

5.1.1. Travel distance of SB

The S-shape strategy offers two possibilities in which the number of travelled pick aisles k_l in picking order l is odd or even.

$$S_l = \begin{cases} 2l_c(d_{\max,l}-1)+l_p k_l, \text{ if } k_l \text{ is even;} \\ 2l_c(d_{\max,l}-1)+l_p(k_l-1)+2(b_w+u_1(x_s\text{-}0.5)), \\ \quad \text{otherwise.} \end{cases} \quad (4)$$

5.1.2. Travel distance of RS

In this case, there are two pick paths in a pick aisle, and each of them is for the rack next to it. So, the total width of pick aisle is set as $2a_w$ for the double-sided return strategy.

$$S_l = \begin{cases} 2(2(u_w+a_w)(\lfloor (z_l+1)/2 \rfloor -1)+a_w) \\ \quad +\sum_{z=1}^{z_l} t_{z,l}(b_w+u_1(x_{z,l}-0.5))), \text{ if } z_l \text{ is even;} \\ 4(u_w+a_w)(\lfloor (z_l+1)/2 \rfloor -1) \\ \quad +\sum_{z=1}^{z_l} t_{z,l}(b_w+u_1(x_{z,l}-0.5))), \text{ otherwise.} \end{cases} \quad (5)$$

$$t_{z,l} = \begin{cases} 1, \text{ rack } z \text{ has pick positions of order } l; \\ 0, \text{ otherwise.} \end{cases}$$

5.1.3. Travel distance of RB (Zhang 2016)

$$S_l = 2(l_c(d_{\max,l}-1)+\sum_{d=1}^{d_{\max,l}} t_{d,l}(b_w+u_1(x_{d,l}-0.5)))$$

$$t_{d,l} = \begin{cases} 1, \text{ pick aisle } d \text{ has pick positions of order } l; \\ 0, \text{ otherwise.} \end{cases} \quad (6)$$

5.1.4. Travel distance of MB

The midpoint strategy is a variant of the double-sided return strategy. It divides the whole warehouse into the upper part (UP) and the lower part (LP). If no more than one pick aisle in the upper part has pick positions, the division of the warehouse is no longer sensible, and the double-sided return strategy is more probable for this situation. Otherwise, the order-picker goes through the first pick aisle with pick positions, then picks up the rest of SKUs firstly in the upper part, and then in the lower part.

$$S_l = \begin{cases} 2(l_c(d_{\max,l}-1)+l_p+\sum_{d=d_{\min,l}+1}^{d_{\max,l}-1} a_{d,l}(b_w+u_1(x_{a,d} \\ \quad -0.5)+b_{d,l}(b_w+u_1(n_x-x_{b,d}+0.5))), \\ \quad \text{if } d_{\max,l}-d_{\min,l}>1; \\ 2(l_c(d_{\max,l}-1)+l_p), \text{ otherwise.} \end{cases}$$

$$a_{d,l} = \begin{cases} 1, \text{ pick aisle } d \text{ in LP has pick positions} \\ \quad \text{of order } l; \\ 0, \text{ otherwise.} \end{cases} \quad (7)$$

$$b_{d,l} = \begin{cases} 1, \text{ pick aisle } d \text{ in UP has pick positions} \\ \quad \text{of order } l; \\ 0, \text{ otherwise.} \end{cases}$$

Finally, sum S_l as $f_t(\mathbf{G})$.

5.2. Time consumption calculation

The travel time can be easily calculated by $f_t(\mathbf{G})/v$. However, the pick time depends on numerous factors, such as the stature of the order-picker, the height of the rack and the weight of the SKUs. For simplification of the mathematical model, the 9th assumption is made to reduce the number of factors in this study. The modular arrangement of the predetermined time standard (MODAPTS) is used to analyse the body movement of picking up SKUs in the different storage locations of the columns, so that the pick time can be quantified. For each picking order, SKUs with the same vertical positions are firstly counted up in order to calculate the weighted sum of pick time. Assuming that a rack has five rows, numbering from bottom to top, the analysis of pick time by MODFAPTS is shown in Table 2.

Table 2: Analysis of Pick Time by MODAPTS

No. \ Row	1	2	3	4	5
1	C4	C4	C4	C4	C4
2	B17	B17	E2	E2	E2
3	E2	E2	M3	M4	M5
4	M5	M4	G3	G3	G3
5	G3	G3	C4	C4	C4
6	C4	C4	M5	M5	M5
7	M5	M5	E2	E2	E2
8	E2	E2	P2	P2	P2
9	P2	P2			
MOD	44	43	25	26	27
Time (s)	5.676	5.547	3.225	3.354	3.483

5.3. Energy expenditure calculation

The energy expenditure of order-pickers is also affected by various factors: complicated body conditions of order-pickers, weight of goods, equipment, working time etc. It changes with so many factors that a general optimal solution of storage location assignment is not available for diverse conditions. Although each specific case can be optimised, it does not make much sense in the practice.

Nevertheless, the statistics of the energy expenditure can be used in the mathematical models as constants, standing for diverse activities, to simply the optimisation problems and find a compromise. In order picking, the activities of order-pickers can be divided into two basic types: travelling and picking, causing quite different energy expenditures per unit time. So two statistical weights k_t and k_p are used in this paper to measure the energy expenditure of these activities with the unit MET (1 MET = 1 kcal/kg/hr). The energy expenditure is therefore calculated as follows:

$$f_{te}(\mathbf{G}) = k_t f_t(\mathbf{G}). \quad (8)$$

$$f_{pe}(\mathbf{G}) = k_p f_p(\mathbf{G}). \quad (9)$$

6. CASE STUDY

In this section, an example of the warehouse and picking orders are presented to illustrate the effectiveness of these algorithms.

6.1. Experiment plan

The single-block warehouse has 10 racks, 30 columns, and 5 rows. Each storage location is 0.5 m wide, 1 m long. The width of pick aisles and the half-width of cross aisles are set as 1m. According to the 5th assumption, the warehouse has 1500 SKUs.

Dong, Block, and Mandel (2004) presented that the energy consumption of a moderate walking and picking activity (shopping for food, putting groceries away) costs 2.8 MET and 2.3 MET respectively. The travel speed of the order-picker is set as 1.67 m/s.

In the experiment, the ABC-classes of SKUs are defined based on the Pareto principle, see Table 3. 3000 picking orders are generated according to the assumption that the discrete distribution of picking frequency approaches three connecting segments (Zhang 2016).

To show the advantages of these multi-objective evolutionary algorithms, both the full-turnover storage and the order-orientated storage assignment strategy are tested, in respect of four routing strategies.

Table 3: Setup of ABC-Classes

Class	Proportion (%)	Popularity (%)
A	10	70
B	20	20
C	70	10

6.2. Result analysis

6.2.1. Analysis of calculation time

The calculation time of four algorithms MIA, MIAS, MEA and MEAS, are shown in Figure 4 and Figure 5, in respect of four routing strategies. Obviously, there is a decreasing sequence of the routing strategies by calculation time: MB, SB, RB and RS, because the more complicated a routing strategy is, the more time it takes.

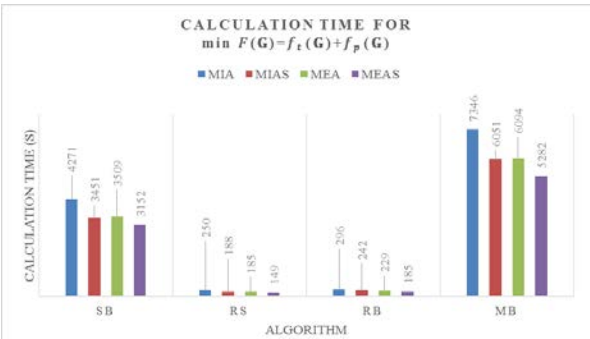

Figure 4: Calculation Time for CSF

For CSF, MIAS consumes 18% less calculation time than MIA on average, whilst the calculation time of MEAS is 12% less than that of MEA. For MF, the average reductions are 19% and 8%. Obviously, the MIAS and MEAS algorithms can improve the calculation efficiency. According to the 7th assumption, there is no change in the actual storage assignment, if the same SKUs are in the same column of the same rack. In this instance, the change of the SKU priority list is limited to a small section within a column of a rack, causing no change in the objective functions. As a result, these kinds of cases can be skipped in the optimisation.

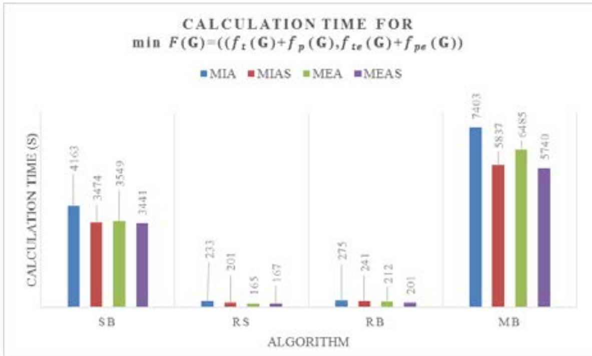

Figure 5: Calculation Time for MF

6.2.2. Improvements in order-picking

On the one hand, the time consumption of travelling and picking is calculated as an index for the converted single-objective optimisation. Figure 6 shows the reduction in time consumption by the four algorithms under diverse routing strategies, compared with the full-turnover storage. In general, MEA and MEAS always perform better than MIA and MIAS. That means the exchange method is better than the insertion method for this optimisation problem.

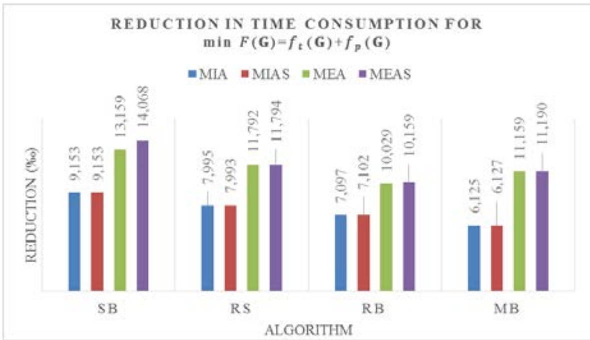

Figure 6: Reduction in Time Consumption for CSF

MEAS in particular can always lead to more reduction in time consumption than MEA. Meanwhile, the improvement of MIAS is not very stable, compared with MIA. On average, the time consumption of MEA is 3.94‰ more than that of MIA, whilst MEAS consumes 4.21‰ less of time consumption than MIAS.

On the other hand, both time consumption and energy expenditure of the picker are considered in the multi-objective optimization problem. In this case, the two indexes converge simultaneously. Figure 7 describes the reduction of time consumption, whilst Figure 8 shows the energy expenditure. Generally, MEA and MEAS perform better than MIA and MIAS at all times.

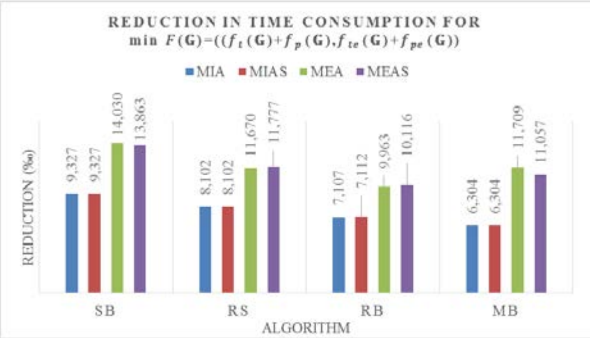

Figure 7: Reduction in Time Consumption for MF

However, MEAS does not always lead to the best improvement. The improvement of MEAS is more than that of MEA under routing strategies RS and RB. Nevertheless, there are negative results of MEAS under routing strategies SB and MB. Statistically, MEA leads to 4.13‰ and 4.18‰ reduction of time consumption and energy expenditure more than MIA. Meantime, MEAS shows 3.99‰ and 4.04‰ more improvement than MIAS.

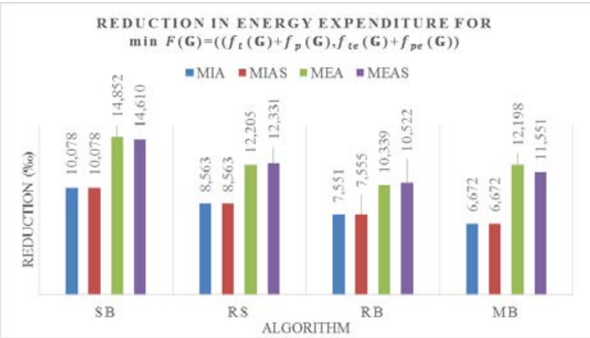

Figure 8: Reduction in Energy Expenditure for MF

7. CONCLUSION

This paper presents the four multi-objective evolutionary algorithms of a correlated storage assignment strategy, to improve the storage location assignment in picker-to-parts order-picking systems under four routing strategies. For the reduction in travel distance and pick time, the multi-objective optimisation problem is converted into a single-objective optimisation. The time consumption and the energy expenditure are further studied in the multi-objective optimisation problem with parallel convergence. In this study, the change of storage locations for single SKUs is considered to develop the algorithms, and the case study shows the advantages of these algorithms in the correlated storage assignment strategy, by comparing with the full-turnover strategy.

However, there is still great potential in the mining of picking orders and the development of effective algorithms for the multi-objective optimisation problems of warehouse management. Firstly, the correlated SKUs may be grouped into itemsets; secondly, the energy expenditure of order-pickers could be more detailed; finally, more objectives can then be set in the optimisation. Furthermore, with the application of picking robots, the energy expenditure can be quantified by power consumption. Thus, the multi-objective evolutionary algorithms should be further developed for these problems.

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BROWSING OR BUYING: ADDING SHOP DYNAMICS AND ADDITIONAL MALL VISIT CONSTRAINTS IN REGIONAL VERSUS CITY MALL SIMULATIONS

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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) and reasons to prolong a shopping trip (such as coffee, snacks and meals), which benefit in an ecological sense other retailers. This paper extends the work by Duncan, Bossomaier, D'Alessandro, & Murphy (2015b) by including different distributions of shops versus entertainment /service options which model the trade-off of a consumer staying longer.
Our results show that smaller regional malls with their distribution of shops biased to larger consumer expenditure are more vulnerable to economic shocks than are larger city malls with a distribution of shops catering for mid-consumer expenditure. The results suggest that the decline in the number of shops in the services category may be a lead indicator for the sudden collapse of regional malls.

Keywords: complex systems, retail shopping malls, regions, cities, tipping points, social networks.

1. INTRODUCTION

Shopping malls, are an important part of any developing and advanced economy. In the United States, for example, there are over 50000 shopping centers and malls, which contribute an estimated 2.3 dollars in sales and 75% of all non-automotive consumer sale (Miller & Washington, 2011). Shopping malls are surprisingly similar across the world: A mall in Rio de Janeiro looks inside just like 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) However, there is evidence that shopping malls have been slowly disappearing in the developed world. Davidowitz (Peterson, 2014) predicts half of all shopping malls to fail within the next 15 to 20 years. Major US retailer Sears closed some 300 stores since 2010 (Peterson, 2014) and the investment in malls fell 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).

2. LITERATURE REVIEW

The choice between online versus traditional retail bricks and mortar buying behavior has been a topic of much debate over the last decade. 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:

1. Risk of fraud (Huang, Feng, Fan, & Lin, 2012)
2. Lack of trust (Toufaily, Souiden, & Ladhari, 2013)
3. and the presence of incomplete information about the retailer (Dennis, Jayawardhena, & Papamatthaiou, 2010).

Reasons consumers 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.

Stores which provide benefits to consumers, and help retain them longer in malls are food and beverage outlets. US research suggests about 7% of consumer 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 on 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 entice 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.

While the economic impacts of malls are well understood malls can contribute to community benefits in regional areas:

- They provide a destination, especially in regional, or poor neighborhoods, 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 also 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 and malls remain in good health. But regional shopping malls like all other shopping centers face increased competition from online retailers.

It is for both economic and social reasons that we have conducted research on previous simulations of mall behavior (Duncan, Bossomaier, & D'Alessandro, 2014; Duncan, Bossomaier, D'Alessandro, French, & Johnson, 2015a; Duncan et al., 2015b). In this study we extend our research with the use of additional empirical data and the further modelling of mall behavior. To start with an accurate representation of the retail landscape, 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.

3. THE SIMULATION MODEL

A Matlab simulation was constructed of a regional mall based around the mall designs from Stockland and Westfield mall chains examined in a previous paper (Duncan et al., 2015b). The model has four development stages:

1. Stage 1 was discussed in (Duncan et al., 2015b). It comprises a model of customers and shops across different retail sectors and examines profitability of mall under different scenarios.

2. Stage 2 increases the model complexity to allow parametrization with spatial data (transport costs etc) and data from the Australian Bureau of Statistics on income distributions and retail preferences.

3. Stage 3 will compare four regional centers: Orange, Wagga-Wagga and Albury with Bathurst. Only Bathurst currently has a significant, purpose built mall.

4. Stage 4 will takes results from the previous stages and develops a general turn- key simulator, which may be used by investors, town councils and other stakeholders in mall development.

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.

After the calculation of all the customer's 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 neighbor's experience is [0-1].

To the social network model we improve on the random decision to visit the mall as follows: The decision to go to the mall is based on two parameters

- The time since last in the mall, t. We use a day as the of unit of t
- The decision to visit the mall is based on the customer experience, denoted by X_j
- The customer experience in the mall is represented by the following equation:

$$X_j(v) = \zeta X_j(v-1) + (1-\zeta)p_j/p_{max} \quad (1)$$

Where:

Xj= customer j experience of the mall.

v = visit to the mall.

ζ= hysteresis factor, momentum factor of the history of past visits to the mall.

P_j = path length (length of a mall visit)

P_{max}= maximum possible path length (maximum possible time in the mall).

Pj and Pmax are the path length for this visit compared to the maximum. The ratio is identical in value to the fraction the daily opening hours the customer is present in the mall. We assume the longer the time spent in the mall therein the positive the experience.

The path length undertaken by an agent in the model depends upon the availability of entertainment, (in this case cafes and takeaway foods). We that a customer / agent would need a break every 4 ticks (one tick representing 15 minutes, or 1 hour in total). Without such an opportunity for refreshment we argue, the customer stops and the path length (time in the mall) terminates, as the agent (customer) gets hungry and thirsty and goes home. This is given by the following equation:

$$P_j = \max(P)\ s.t. \sum_{i=1}^{P} \delta_{ic} \leq floor\left(\frac{P}{b}\right) + 1 \quad (2)$$

Where Pj= Path length of customer j

δ_{ic}= Kronecker delta of coffee shop count.

b= break in the path for refreshments and entertainment, set at 5 ticks.

We generate for each customer in the mall a random path, with a maximum 15 minute visit to trip length, say 20 ticks (5 hours). Now generate a random path, with a step every tick. We define a parameter b (for break) which is the amount of time one can visit shops without a break in the entertainment (ie food, coffee, etc) domain. So we now run cumulative sum of the number of entertainment slots in the path and if the number of ticks divided by b is greater than the number of e stops, then the path terminates. Thus with b=5 then if at tick 19 one has passed 4 e stops then the path continues. 20 is okay (ticks/b=4) but 21 (ticks/b=4.2) and the path terminates.

If the entertainment options (coffee shops) falls too low then the retail sales will fall, because the residence time in the mall will go down. If the customer's experience includes a dead shop, the experience is decreased by a penalty factor β, which is set at 0.95 for all customers through-out the simulation.

The customer also has a bricks and mortar preference $\Psi_j(q)$ for each retail category, q. If the purchase in a shop does not go through it is decreased by β (because the shop is unoccupied or there is bad service). Whether a purchase goes through depends on the consumer profile for category q, denoted by ϕj(q), and the shop service factor sq for shop category q. This is a constant factor representing price, competitiveness, brand range, customer service and so on.

The customer experience is initialized to a value of between 0.8 and 1 according to:

$$X_0 = 0.8 + 0.2r \quad (3)$$

Where r is a uniformly generated random number in [0-1]

Disposable income is incremented every pay period, in this case 14 days.

The probability of going to the mall on any day, $\emptyset_j$ for customer, j is defined in terms of these parameters and the faction of occupied shops in the mall, ς. If some shops in the mall are unoccupied, this decreases the desirability of the mall. The mean of mall experiences in our model is also defined by a social network effect (5).

$$\emptyset_j = \arctan(t_j \bar{X}_j \beta_j\, \varsigma\, \Psi_j) \quad (4)$$

$$\bar{X}j = \lambda Xj + (1-\lambda) \sum_{k \in U_j} X_k \quad (5)$$

Where:
$\bar{X}_j$ = mean of personal and social network mall experiences
X_j = personal mall experiences
λ= weight of personal experience versus that of a social network.
U_j = social network of customer j.

We simplify the shop's behavior to simply requiring it to meet a revenue target, *R*. If this number is not met, the shop collapses. This threshold will be different for the different retail categories. A coffee shop for example, may require more transactions than a clothing / fashion outlet in order to break-even and this is also represented in the model.
The model also included the dynamics of the mall break-even point, centered around the following equation:

$$\alpha P \bar{c} \frac{T_s}{T_v} Nc = RN_S \qquad (6)$$

Where:

α = External financial and economic pressure on the mall. A higher number representing more challenging financial and economic conditions.

P = Maximum path length of the customer in the mall, a path length consisting of 15 minute intervals for shop visits. In this case 40 possible visits in a 10 hour day

$\bar{c}$ = Average item cost, for each of the six types of stores.

T_S = Shop clock rate, or time at the mall over a given period.

T_v = Time between mall visits

N_c = Number of consumers

Ns= Number of shops

R= Revenue target.

In essence, equation three models the effect of online success, which reduces the success of the mall, as a greater number of customers are needed to shop in the mall. The path length in the mall is influenced by the desirability of the mall as shown by the mall random path, which is influenced by the availability of entertainment and shopping options. Of course, equation 1, shows the probability of visiting the mall in the first place a feedback is dependent on the attractiveness of the mall as defined by number of shops, entertainment options and the occupancy rate, which depends on shops meeting the breakeven and therefore number of shops and available attractions. The parameters in the model are shown in table 1

Table 1: Parameters in the model

Variable	Values
α	0.70, 1.4
P	40
N_c	1000, regional mall 6000 for city mall.
Ts	Shop check rate, 90 days.
Tv	30 days
$\bar{c}$	As per the ABS retailing categories these were set at; Food retailing \$150, Household goods/ electrical \$250, Clothing and footwear, \$100, Department stores \$200, Cafes, restaurants and takeaway food \$10, Other retailing services \$50.

Empirical shop distribution and mall size

	City Mall	**Regional Mall**	
Food retailing	2%	7%	2%
Household goods /electrical stores	4%	7%	4%
Clothing, footwear and personal accessory retailing	34%	24%	34%
Department stores	1%	3%	1%
Cafés, restaurants and takeaway food services	21%	18%	21%
Other retailing and services	38%	42%	38%
Mall size	**300**	**50**	

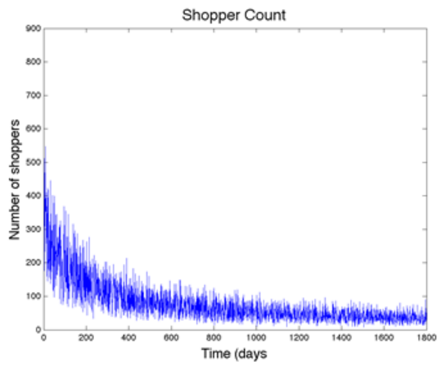
4. RESULTS

The results of the model run for the conditions of a city mall, taken from secondary research compared with that of a smaller regional mall are shown in panels 1 for number of customers, and 2 for types of shops. The large mall simulation was run with 6000 customers, 300 shops and to take into account the different sizes of the mall, the regional mall simulation was run with 1000 customers with 50 shops. All simulations were run until the mall was no longer functioning (it had no customers and therefore no shops). Note that increase in financial difficulty did not alter the results for city malls, so only the higher financial levels of stress are shown here.

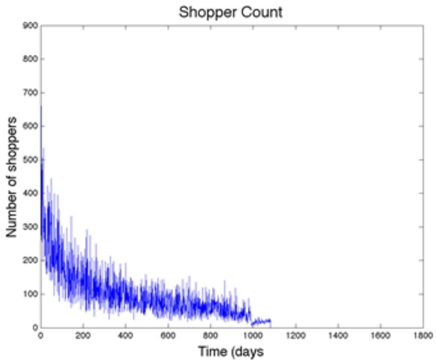
As can be seen in panel 1 and 2, regional malls are very vulnerable to external shocks (greater financial and economic difficulties). The results for α=1.4 showed an early collapse of patronage with other retailing and services (lime green line) falling as the result of reduced customer visits in time 10, followed by the other shop types in time 12, with cafes and takeaway food services surviving a little longer to time 13 at a higher rate (see blue line). The same cannot be said for larger city malls. The results as shown in panel 3, show a stable distribution of shops over time, even with the decline of customers over that time period. These results suggest that larger city malls act more as a sustainable ecosystem for consumers, even in times of financial difficulty. The reason being that the large mall size allows a greater absolute measure of diversity of options and builds greater robustness in the mall, via virtue of the availability of retail options.

Panel 1: Customer results for regional malls for α=0.70,1.4.

Regional mall ($\alpha = 0.70$)

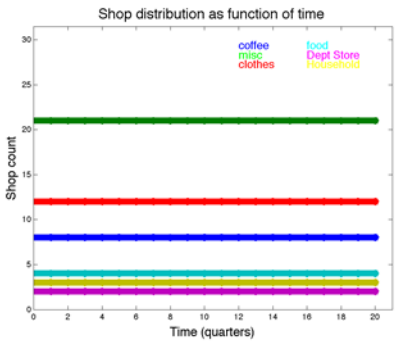


Regional mall (α=1.4)

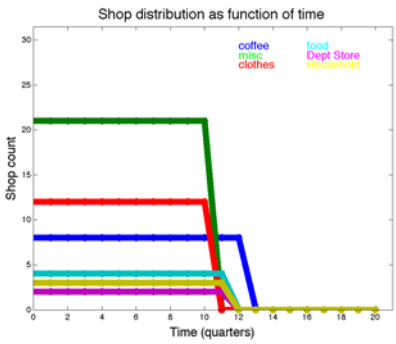


Panel 2: Shop distribution results for regional malls $\alpha = 0.70, 1.4$

Regional mall ($\alpha = 0.70$)



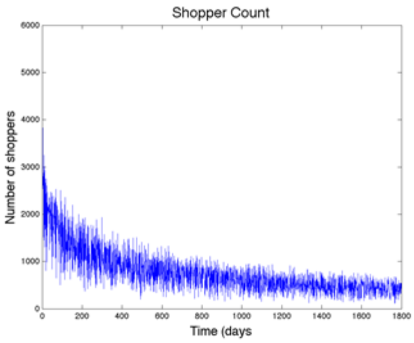
Regional mall ($\alpha = 1.4$)



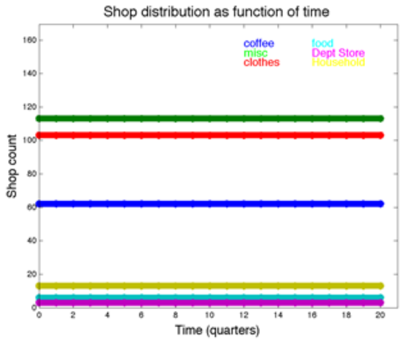
The higher proportion of cafes and takeaway foods in a larger city mall, probably encourages consumers to stay longer, and the personal clothing and fashion stores which exist in city malls in much greater proportions in city malls (34 to 24%) respectively, means purchases that are the mid-level of $100 per trip, make the design of city malls more sustainable to hard economic times. In regional malls, there are higher proportions of shops at the larger end of the consumer expenditure curve, which means that this mall design, is sensitive to any changes in consumer patronage dramatically changing the retail landscape.

Panel 3: Customer and Shop distribution results for City malls ($\alpha = 0.70$ & $\alpha = 1.4$).

Customer results



Store results



5. DISCUSSION

Understanding the dynamics of mall behavior is a good example of the application of complex systems thinking to an issue of great economic and social concern. As suggested in the results, regional malls are more vulnerable to economic shocks. In order to counter this regional malls may wish to become first bigger centers in order to survive. Town planners and regional mall managers need to carefully plan for a mix of shops closer to what would be found if possible in larger city malls. Towns in close proximity may even wish to share the distribution of shops (or specialize) across areas of retailing. The sudden decline in the number of shops in retailing and other services sector in a regional mall may also be an early warning alarm that the mall is in serious risk of dramatic decline.

Of course no simulation model is ever complete and 100% realistic. In this case we have not used empirical data representing the differing consumer expenditure profiles, or market segments that exist in both regional and urban areas. Our categories of retail types, although based on ABS and government classifications are quite broad, and so the model may not yet simulate all the complexities of retailing. We have also not included competition between malls, or centers. Nevertheless we believe this simulation to be an important step in the process of understanding, predicting and then managing the complexities of retailing in both cities and country areas. Future work will add these refinements.

Future research could widen the application of the model developed here to include differing consumer expenditure profiles, a more granular description of retail types, include inter-mall competition and finally could even include changes in nearby population and demographic structure. The challenge here is not only to model these factors in future but also to have access to wide range of parameters (such as a detailed item cost, and shopping behavior of consumers). This may be quite possible in the future in the age of big data.

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OPTIMAL STRUCTURE COORDINATION IN SUPPLY CHAIN (SC): PRINCIPLES, MODELS, METHODS AND ALGORITHMS FOR THE SC STRUCTURE DYNAMICS CONTROL

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ABSTRACT
One of the main features of modern supply chains (SC) is the variability of their parameters and structures caused by objective and subjective factors at different stages of the SC life cycle. In other words, we always come across the SC structure dynamics in practice. Under the existing conditions the SC potentialities increment (stabilization) or degradation reducing makes it necessary to perform the SC structure control and management (including the control of structures coordination). The aim of this investigation is to develop a generalized description of models, methods and algorithms for the SC structure dynamics control.

Keywords: supply chains, control of structures coordination, decision support system

1. INTRODUCTION

Analysis of the main trends for modern complex technical systems (SC) indicates their peculiarities such as: multiple aspects and uncertainty of behavior, hierarchy, structure similarity and surplus for main elements and subsystems of SC, interrelations, variety of control functions relevant to each SC level, territory distribution of SC components.

One of the main features of modern SC is the variability of their parameters and structures caused by objective and subjective factors at different stages of the SC life cycle (Okhtilev, Sokolov, and Yusupov 2006; Peregudov and Tarrasenko 1989; Ivanov and Sokolov 2010; Ivanov and Sokolov 2012). In other words, we always come across the SC structure dynamics in practice. Under the existing conditions the SC potentialities increment (stabilization) or degradation reducing makes it necessary to perform the SC structure control (including the control of structures coordination). There are many possible variants of SC structure dynamics control. For example, they are: alteration of SC functioning means and objectives; alteration of the order of observation tasks and control tasks solving; redistribution of functions, problems and control algorithms between SC levels; reserve resources control; control of motion of SC elements and subsystems; coordination of SC different structures.

According to the contents of the structure dynamics control problems they belong under the class of the SC structure — functional synthesis problems and the problems of program construction, providing for the SC development.

The main feature and the difficulty of the problems, belonging under the above mentioned class is a follows: optimal programs, providing for the SC main elements and subsystems control can be implemented only when the lists of functions and control and information-processing algorithms for these elements and subsystems are known.

In its turn, the distribution of the functions and algorithms among the SC elements and subsystems depends upon the structure and parameters of the control rules, valid for these elements and subsystems. The described contradictory situation is complicated by the changes of SC parameters and structures, occurring due to different causes during the SC life cycle.

Coordination is one of the central issues in supply chain management (SCM) that is applied by companies with the aim to successfully meet the customer needs while improving the performance efficiency (Chen and Hall 2007). The study by Hall and Potts (2003) introduced the consideration of benefits challenges of coordinated decision-making within SC scheduling. Most recently, Agnetis et al. (2006) and Disney et al. (2008) investigated the impacts of schedule coordination on SC performance. Chung et al. (2011) considered minimization of order tardiness through collaboration strategy in a multi-factory production system. In SC schedule coordination, two or more processes are typically considered subject to their mutual coordination. This coordination may be subject to coordinating schedules of different suppliers with some planned schedule changes by one of them, or simultaneous consideration of different interlinked flows (e.g., material and information flows). In practice, due to some re-scheduling activities (i.e., new rush customer orders) at one of the companies, the schedule coordination should be performed again. In this study, we consider two synchronized schedules in the supply chain (e.g., an assembly line schedule at a production company and a supply schedule for a module). This problem is a dynamic scheduling problem where machine capacities are constrained (Ivanov and Sokolov 2012) and a schedule recovery is needed. The body of literature on this issue is limited. Recently, schedule recovery has been considered for situations where one of the suppliers is disturbed (Xiao et al. 2007; Xiao TJ, Qi XT and Yu G 2007). Chen and Xiao 2009 studied an assembly system where suppliers provide parts to a manufacturer. Hall and Liu (2011) investigated the capacity allocation by a manufacturer who faces the challenge of limited resources subject to orders from distribution centers. Similar problems can be found in regard to maintenance scheduling and adjustable machines. The goal of this study is to develop an approach in order to ensure an explicit inclusion of schedule changes in the SC coordinated decisions. The peculiarity of the proposed approach is the dynamic interpretation of scheduling based on a natural dynamic decomposition of the problem and its solution with the help of a modified form of continuous maximum principle blended with combinatorial optimization.

At present, the class of problems under review is not examined quite thoroughly. The new theoretical and practical results have been obtained in the following lines of investigation: the synthesis of the SC technical structure for the known laws of SC functioning (the first direction — Peregudov and Tarrasenko 1989; Ackoff 1978; Aframchuk 1998; Peschel 1978); the synthesis of the SC functional structure, in other words, the synthesis of the control programs for the SC main elements and subsystems under the condition that the SC technical structure is known (the second direction - Okhtilev, Sokolov, and Yusupov 2006; Ivanov 2010; Ivanov and Sokolov 2010; Skurikhin, Zabrodskii, and Kopeichenko 1989); the synthesis of programs for SC construction and development without taking into account the periods of parallel functioning of the existing and the new SC (the third direction — Ivanov 2010; Ivanov and Sokolov 2010; Arnott 2004); the parallel synthesis of the SC technical structure and the functional one (the fourth direction — Ivanov and Sokolov 2010; Okhtilev, Sokolov, and Yusupov 2006).

Several iterative procedures to solve the joint problems, concerning the first and the second directions, are known currently. Some particular results were obtained within the third and the fourth directions of investigation. All the existing models and methods for the SC structure — functional synthesis and for the construction of the SC development programs can be applied during the period of the internal and external design when the time factor is not very important.

The problem of SC structure dynamics control consists of the following groups of tasks: the tasks of structure dynamics analysis of SC; the tasks of evaluation (observation) of structural states and SC structure dynamics; the problems of optimal program synthesis for structure dynamics control in different situations. Therefore, the development of new theoretical bases for SC structure dynamics control is currently very important. From our point of view, the theory of structure dynamics control will be interdisciplinary and will accumulate the results of classical control theory, operations research, artificial intelligence, systems theory, and systems analysis. The two last scientific directions will provide a structured definition of the structure dynamics control problem instead of a weakly structured definition. These ideas are summarized in Figure 1. Here, as the first step to the new theory, we introduce a conceptual and formal description of SC structure dynamics.

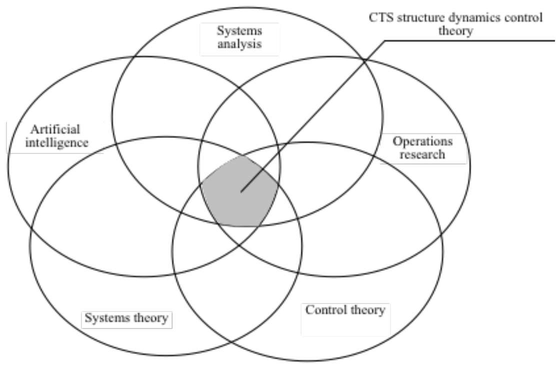

Figure 1: The theory of structure dynamics control as a scope of interdisciplinary investigations

2. CONCEPTUAL AND MULTIPLE-MODEL DESCRIPTION OF SC STRUCTURE DYNAMICS CONTROL

The preliminary investigations have confirmed that the most convenient concept for the formalization of SC control processes is the concept of an active mobile object (AMO). In the general case, it is an artificial object (a complex of devices) moving in space and interacting (by means of information, energy, or material flows) with other AMO and objects-in-service (OS) (Kalinin and Sokolov 1985; Kalinin and Sokolov 1987; Kalinin 2015). Figure 2 shows a general structure of AMO as an object being controlled. AMO consists of four subsystems relating to four processes (functioning forms): moving, interaction with OS and other AMO, functioning of the main (goal-oriented) and auxiliary facilities, resources consumption (replenishment).

The four functions of AMO are quite different, though the joint execution of these functions, the interaction being the main one, provides for SC new characteristics. Thus, it becomes a specific object of investigation, and SC control problems are strictly different from classical problems of mechanical-motion control. The notion of “Active Mobile Object” generalizes features of mobile elements dealing with different SC types. Depending on the type of Active Mobile Objects, they can move and interact in space, in air, on the ground, in water, or on the water surface. The Active Mobile Object (AMO) can be also regarded as a multi-agent system. We distinguish two classes of AMO: AMO – one, namely AMO of the first type. This type of AMO fulfills AMO principal tasks; and AMO – two, which supports functioning of AMO – one. Objects-in-service can be regarded as external AMO.

For example, on the one hand, distribution centers, factories, warehouses can be interpreted as AMO – two, on the other hand, various types of production at different stages of their life cycles may be regarded as AMO – one.

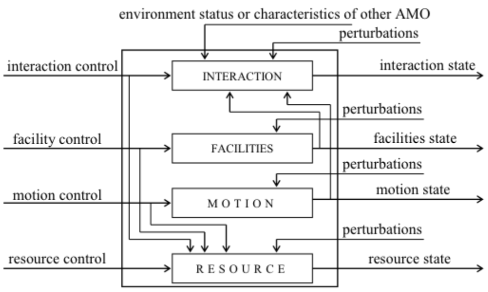

Figure 2: General block diagram of AMO

Thus, at the conceptual level, the process of SC functioning can be described as a process of SC operation execution, while each operation can be regarded as a transition from one state to another. Meanwhile, it is convenient to characterize the SC state by the parameters of operations.

The particular control models are based on the dynamic interpretation of operations and the previously developed particular dynamic models of SC functioning.

In accordance with the proposed conceptual model of SC control, let us introduce the following basic sets and structures: B is a set of objects (subsystems, elements) that are embodied in SC and are necessary for its functioning. $\overline{B}$ is a set of external objects (subsystems, elements) interacting with SC (the interaction may be informational, energy or material). $\tilde{B} = B \cup \overline{B}$ is a set of the considered objects. $\tilde{C} = C \cup \overline{C}$ is a set of channels (hardware facilities) that are used by SC and OS for interaction. D is a set of SC operations. Φ is a set of SC resources. P is a set of SC flows. $G = \{G_\chi, \chi \in NS\}$ is a set of SC structural types, where the main types of structures are the topologic (spatial) structure, the technology (functional) structure, the technical structure, the structures of mathematical and software tools, and the organizational structure.

To interconnect the structures let us consider the following dynamic alternative multi-graph (DAMG):

$$G_\chi^t = \left\langle X_\chi^t, F_\chi^t, Z_\chi^t \right\rangle, \tag{1}$$

where the subscript χ characterizes the SC structure type, $\chi \in NS = \{1,2,3,4,5,6\}$ (here 1 indicates the topologic structure, 2 indicates the functional structure, 3 indicates the technical structure, 4 and 5 indicate the structures of mathematical and software tools, 6 indicates the organizational structure, the time point t belongs to a given set T; $X_\chi^t = \{x_{\chi l}^t, l \in L_\chi\}$ is a set of elements of the structure G_χ^t (the set of DAMG vertices) at the time point t; $F_\chi^t = \{f_{<\chi,l,l'>}^t, l, l' \in L_\chi\}$ is a set of arcs of the DAMG G_χ^t; the arcs represent relations between the DAMG elements at time t; $Z_\chi^t = \{f_{<\chi,l,l'>}^t, l, l' \in L_\chi\}$ is a set of parameters that characterize relations numerically.

The graphs of different types are interdependent, thus, for each particular task of SC structure–dynamics control the following maps should be constructed:

$$M_{<\chi,\chi'>}^t : F_\chi^t \to F_{\chi'}^t, \tag{2}$$

compositions of the maps can be also used at time t:

$$M_{<\chi,\chi'>}^t = M_{<\chi,\chi_1>}^t \circ M_{<\chi,\chi_2>}^t \circ \ldots \circ M_{<\chi'',\chi'>}^t . \tag{3}$$

A multi-structural state can be defined as the following inclusion:

$$\begin{aligned} S_\delta \subseteq X_1^t \times X_2^t \times X_3^t \times X_4^t \times \\ \times X_5^t \times X_6^t, \quad \delta = 1,\ldots,K_\Delta \end{aligned} . \tag{4}$$

Thus we obtain the set of SC multi-structural states:

$$S = \{S_\delta\} = \{S_1,\ldots,S_{K_\Delta}\}, \tag{5}$$

Allowable transitions from one multi-structural state to another can be expressed via the maps:

$$\Pi_{<\delta,\delta'>}^t : S_\delta \to S_{\delta'} . \tag{6}$$

Here we assume that each multi-structural state at time $t \in T$ is defined by a composition (3).

Now the problems of SC structure dynamics control can be regarded as a selection of a multi-structural state $S_\delta^* \in \{S_1, S_2, \ldots, S_{K_\Delta}\}$ and of a transition sequence (composition) $\Pi_{<\delta_1,\delta_2>}^{t_1} \circ \Pi_{<\delta_2,\delta_3>}^{t_2} \circ \Pi_{<\delta',\delta>}^{t_f}$ ($t_1 < t_2 < t_f$), under some criterion of effectiveness. The results of the selection can be presented as the optimal program for SC structure dynamics control. This

program guides the system from a given multi-structural state to the specified one.
Figure 3 presents the interpretation of structure dynamics processes for SC functioning problems.
Here: $\Gamma_{\chi}^{t_1}$ is the functional structure of SC at moment t_1, $\Gamma_{\chi_1}^{t_1}$ is the technical structure of SC at moment t_1.
The dynamic alternative multi-graphs $G_{\chi}^{t_1}$, $G_{\chi_1}^{t_1}$ describe functional and technical structure dynamics. Next figure describes the graphical interpretation of a particular problem of SC structure dynamics control. In this case, the main point of the problem is that a flexible distribution of tasks between the main elements of SC control system (CS) is to be established. This problem is strictly interrelated with a problem of optimal dynamic allocation of limited resources in SC CS. These two problems should be solved jointly. In this case, the problem of SC structure dynamics control can be stated as a problem of an optimal path search in the dynamic alternative multi-graph (Figure 4). Today, different methods and models are used to solve these problems.

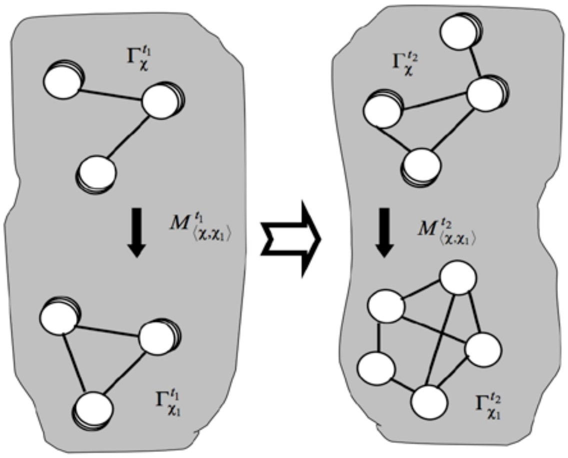

Figure 3: Structure dynamics process for SC functioning problems

The known approaches to these problems are based on the PERT description of scheduling and control problems and traditional dynamic interpretation. The realization of these dynamic approaches produces algorithmic and computational difficulties caused by high dimensionality, non-linearity, non-stationarity, and uncertainty of the appropriate models.
We proposed modifying the dynamic interpretation of operations control processes. The main idea of model simplification is to implement non-linear technological constraints in sets of allowable control inputs rather than in the right parts of differential equations. In this case, Lagrangian coefficients, keeping the information about technical and technological constraints, are defined via the local-sections method. Furthermore, we proposed that interval constraints are used instead of relay ones. Nevertheless, the control inputs take on Boolean values as caused by the linearity of differential equations and convexity of the set of alternatives. The proposed substitution allows using fundamental scientific results of the modern control theory in various SC control problems (including scheduling theory problems).

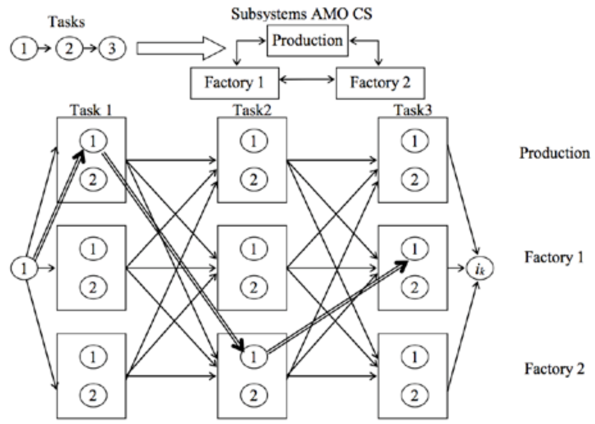

Figure 4: Graphical interpretation for particular problem of SC structure dynamics control

As provided by the concept of SC multiple-model description, the proposed general model includes the particular dynamic model: dynamic model of SC motion control (Mg model); dynamic model of SC channel control (Mk model); dynamic model of SC operations control (Mo model); dynamic model of SC flows control (Mn model); dynamic model of SC resource control (Mp model); dynamic model of SC operation parameters control (Me model); dynamic model of SC structure dynamic control (Mc model); dynamic model of SC auxiliary operation control (Mv model) (Okhtilev, Sokolov and Yusupov 2006; Ivanov 2010; Ivanov and Sokolov 2010).
Figure 5 illustrates a possible interconnection of the models.
Procedures of structure dynamics problem solution depend on the variants of transition and output functions (operators) implementation. Various approaches, methods, algorithms and procedures of the coordinated choice through complexes of heterogeneous models have been developed by now.
SC structure-dynamic control problem has some specific features in comparison with classic optimal control problems. The first feature is that the right parts of the differential equations undergo discontinuity at the beginning of interaction zones. The considered problems can be regarded as control problems with intermediate conditions. The second feature is the multi-criteria nature of the problems. The third feature concerns the influence of uncertainty factors. The fourth feature is the form of time-spatial, technical, and technological non-linear conditions that are mainly considered in control constraints and boundary conditions. On the whole, the constructed model is a non-linear, non-stationary, finite-dimensional

differential system with a re-configurable structure. Different variants of model aggregation were proposed.

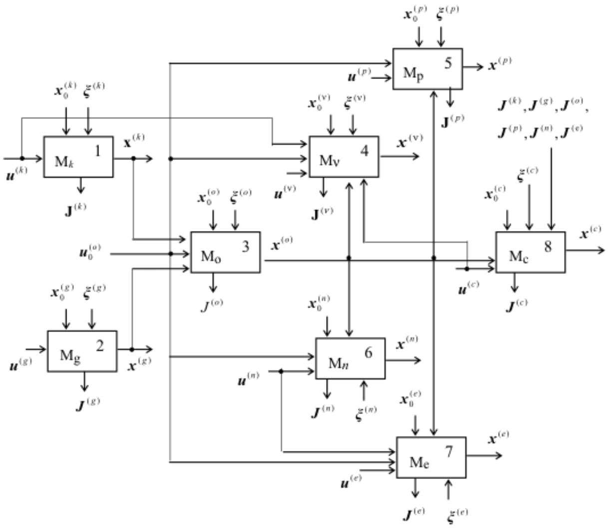

Figure 5: The scheme of model interconnection

These variants produce a task of model quality selection that is the task of model complexity reduction. Decision-makers can select an appropriate level of model thoroughness in the interactive mode. The level of thoroughness depends on: input data, external conditions, and the required level of solution validity.

The proposed interpretation of SC structure dynamics control processes provides advantages of modern optimal control theory for SC analysis and synthesis. During the investigations we described the main classes of SC structure dynamics problems. These problems include: SC structure dynamics analysis problems; SC structure dynamics diagnosis, observation, multi-layer control problems; problems of SC generalized structural states synthesis and the choice problems of optimal transition programs providing the transition from a given SC structural state to an allowable (optimal) structural state. Methodological and methodical bases for the theory of structure dynamics control were developed. Methodological bases include the methodologies of the generalized system analysis and the modern optimal control theory for SC with re-configurable structures. The methodologies find their concrete reflection in the corresponding principles. The main principles are: the principle of goal programmed control; the principle of external complement; the principle of necessary variety; the principles of multiple-model and multi-criteria approaches; the principle of new problems. The dynamic interpretation of structure dynamics control processes allows for the application of the results, previously received in the theory of dynamic systems stability and sensitivity, for SC analysis problems.

During our investigations the main stages and steps of a program-construction procedure for optimal structure dynamics control in SC were proposed.

At the first stage, the formation (generation) of allowable multi-structural macro-states is performed. In other words, a structure-functional synthesis of a new SC make-up should be fulfilled in accordance with the current or a forecasted situation. Here, the first-stage problems come to SC structure-functional synthesis.

The general algorithm of the SC structure-functional synthesis includes the following main steps.

Step 1. Gathering, analysis, and interrelation of input data for the synthesis of SC multi-structural macro-states. Construction or correction of the appropriate models.

Step 2. Planning the solution process for the problem of the SC macro-states synthesis. Estimation of time and other resources needed for the problem.

Step 3. Construction and approximation of an attainability set (AS) for the dynamic system (1). This set contains an indirect description of different variants of SC make-up (variants of SC multi-structural macro-states).

Step 4. Orthogonal projection of a set defining macro-state requirements to AS.

Step 5. Interpretation of output results and their transformation to a convenient form for future use (for example, the output data can be used for the construction of adaptive plans of SC development).

At the second stage, a single multi-structural macro-state is selected, and adaptive plans (programs) of SC transition to the selected macro-state are constructed. These plans should specify transition programs, as well as programs of stable SC operation in intermediate multi-structural macro-states. The second stage of program construction is aimed at the solution of multi-level multi-stage optimization problems. The general algorithm of problem solving should include the following steps.

Step 1. Input data for the problem are prepared and analyzed in an interactive mode. During this step, the structural and parametric adaptation of models, algorithms, and special software tools of simulation system (SIS) is fulfilled to the past states and to the current states of the environment, object-in-service, and control subsystems embodied in existing and developing SC. For missing data simulation experiments with SIS models or expert inquest can be used.

Step 2. Planning the comprehensive modeling of adaptive SC control and development for the current and forecasted situation; planning of simulation experiments in SS; selection of models, selection of model structure; determination of methods and algorithms for particular modeling problems, selection of models and model structure for this problems; estimation of the necessary time.

Step 3. Generating, via comprehensive modeling, the feasible variants of SC functioning in initial, intermediate, and required multi-structural macro-states; introducing the results to a decision-maker; preliminary interactive structure-functional analysis of modeling results; producing equivalent classes of SC multi-structural macro-states.

Step 4. Automatic putting into operation of data of SC functioning variants; analysis of constraints correctness; final selection of aggregation level for SC SDC models, and for computation experiments aimed at SC SDC program construction.

Step 5. Search for optimal SC SDC programs for the transition from a given multi-structural macro-state to a synthesized one and for stable SC operation in intermediate multi-structural macro-states.

Step 6. Simulation of program execution under perturbation impacts for different variants of compensation control inputs received via methods and algorithms of real-time control.

Step 7. Structural and parametric adaptation of the plan and of SIS software to possible (forecasted through simulation models) states of SO, CS, and of the environment.

Here, SC structural redundancy should be provided to compensate for extra perturbation impacts. After reiterative computation experiments the stability of constructed SC SDC plan is estimated.

Step 8. Introducing comprehensive adaptive planning results to a decision-maker; interpretation and correction of these results.

One of the main opportunities of the proposed method of SC SDC program construction is that besides the vector of program control we receive a preferable multi-structural macro-state of SC at the end point of control interval. This is the state of SC reliable operation in the current (forecasted) situation.

The combined methods and algorithms of optimal program construction for structure dynamics control in centralized and non-centralized modes of SC operation were developed too.

The main combined method was based on the joint use of the successive approximations method and the "branch and bounds" method. A theorem characterizing properties of the relaxed problem of SC SDC optimal program construction was proved for a theoretical approval of the proposed method. Different examples (Okhtilev, Sokolov, and Yusupov 2006; Yusupov et al. 2011; Ivanov 2010; Ivanov and Sokolov 2010; Ivanov and Sokolov 2012; Ivanov and Sokolov 2013) illustrated the main aspects of the implementation of the proposed combined method.

3. CONCLUSION

The methodological and methodical basis of the theory of SC structure dynamics control and coordination has been developed by now. This theory can be widely used in practice. It has an interdisciplinary character provided by the classic control theory, operations research, artificial intelligence, systems theory, and systems analysis. The dynamic interpretation of SC coordination process provides a strict mathematical basis for complex technical-organizational problems that were never formalized before and have a high practical importance.

The proposed approach to the problem of SC structure coordination control in terms of general context of SC structural dynamics control enables: common goals of SC functioning to be directly linked with those implemented (realized) in SC control process, a reasonable decision and selection (choice) of adequate consequence of problems solved and operations fulfilled related to structural dynamics to be made (in other words to synthesize and develop the SC control method), a compromise distribution (trade-off) of a restricted resources appropriated for a structural dynamics control to be found voluntary (Okhtilev, Sokolov, and Yusupov 2006; Ivanov 2010; Ivanov and Sokolov 2010).

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MULTI-CRITERIA DECISION SUPPORT SYSTEM COUPLING LOGISTICS AND FINANCIAL PERFORMANCE IN INVENTORY MANAGEMENT

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ABSTRACT
Inventory management, the process of providing the required items in the right quantities, at the right time, at the right place and at the right price, is one of the most critical activities for establishing an effective supply chain. On the other hand, it is a complex problem since measuring inventory management performance is typically a multi criteria decision making problem involving multiple criteria of conflicting nature. In this study, we propose a Choquet integral method to aggregate opinions of decision makers for rating the importance of criteria. We took into account both logistics and financial criteria to measure performance of inventory management. Then, we use optimization of the improvement when the overall performance achieved is deemed insufficient.

Keywords: multi criteria decision making, coupling logistics and financial performance, Choquet integral, performance measurement, Optimization of the improvement.

1. INTRODUCTION
Recently, inventory management has received considerable attention in both academia and industry. After introducing the inventory management definitions and properties presenting the main solutions developed in this area, we end this section by highlighting the aim of the current paper.

1.1. Supply chain and Inventory management
Supply chain management is the process of integrating interdependent actors such as suppliers, manufacturers, warehouses, and retailers, so that goods are produced and delivered in the right quantities and at the right time, while minimizing costs as well as satisfying customer’s requirements (Bottani et al. 2013).
Managing customer and vendor relationships is a critical aspect of managing supply chains. However, a closer examination of supply chain relationships, particularly those involving product flows, reveals that the heart of these relationships is inventory movement and storage (Waller and Esper 2014).
As such, inventory is the main part of any supply chain of a firm that plays an important role in the supply chain decisions. Furthermore, inventory management as defined by (Mitra et al. 2015) refers to the accurate tracking of the flow of goods and the managing of its movement from raw materials to the ultimate consumer.
The main purpose of the inventory management practices is to have the required items ready to be processed right on the required time with the minimum cost (De Felice et al. 2014).
The process of inventory management has to cope with many challenges given the complex environment caused by unpredictable and turbulent demand, requirements on product variety, delivery lead-time and quality of product (Verwater-Lukszo and Christina 2005).
When competing in such complex environment, company must have appropriate and effective inventory management strategies to survive.Consequently, the management of inventory is a challenging topic of interest and it can provide insight into the firm’s performance.
The aim of inventory decision making is to implement a tool that helps managers to make inventory decisions that maintain the optimum level and minimize the total cost of inventory (Cadavid and Zuluaga 2011).

1.2. How to solve inventory management problems?
This section discusses existing solutions dedicated for inventory management outlining their limits.

1.2.1. Analytic models limitations
Although many studies have treated inventory management problems(Braglia et al. 2004, Bottani et al. 2013), most of themuse analytic models. In fact, an analytic model can be defined as a mathematical modeling technique used for simulating, explaining, and making predictions about the mechanisms involved in complex physical processes (OpenEI 2013).
However, the use of analytic models suffers from some limitations. Moreover, in a complex environment characterized by interdependent and dynamic behaviors, it becomes difficult to provide an analytic model of the inventory management system.

In addition, specific approaches for coupling financial and logistics performance in inventory management are limited in literature.

1.2.2. Modeling & Simulation (M&S)

Modeling & Simulation (M&S) can be exploited as a useful alternative to analytic approaches. In fact, given that inventory management requires the management of product flow at various levels as well as the performance assessment of a complex systems and the monitoring of a highly dynamic process, M&S has proved to be a valuable methodology and a highly indispensable tool for complex systems design, performance assessment, management and monitoring (Longo et al. 2015).

The use of M&S in the area of the supply chain is not recent. Indeed, the first applications of this methodology in industry and logistics dates back to 1980 (Longo et al. 2015) and it has allowed "a greater degree of similarity between the model and reality" (Solis et al. 2014). M&S has been widely applied to support supply chains design, management and optimization (Longo 2012).

1.3. Purpose of this paper

The main goal of this research work is to provide a decision support system in order to help managers to identify the parameters that are necessary for coupling logistics and financial criteria for performance measurement of inventory management and to identify the improvement that can be achieved when the overall performance achieved is deemed insufficient by the decision maker by the use of multi-criteria methods and optimization. Coupling can be considered as two different things turn to a system by mutual linked. Every subsystem has a dynamic association relationship based on interdependence and mutual coordination (Wang andLu2015).

The paper is structured as follows: Section 2 presents an overview of the related works of inventory management; section 3 presents the proposed multi-criteria decision support inventory management model. In section 4, we present the experimental results. Conclusions and future work are presented in the last section.

2. RELATED WORKS

2.1. Decision support systems

2.1.1. Decision support systems definition

Decision support systems (DSS) are information technology solutions that can be used to help managers to support decision-making activities and problem solving. Given the scale and complexity of these decisions, it is essential to transforming some inputs in outputs required to make a decision (Cadavid and Zuluaga 2011).

2.1.2. DSS for inventory management

Several research works examined the usage of various DSS to solve a specific set of related supply chain and inventory management problems. In order to present and design their DSS system, various approaches, models, techniques and methods were used.

Modeling approach

Verwater-Lukszo and Christina (2005) propose a modeling approach to improve complex inventory management of many product grades in a multi-product batch-wise industrial plant. The proposed model implemented in a decision support tool assists the decision maker(s) in revealing the performance parameters (inventory level/costs and service level) behavior concerning inventory in order to arrive at potential improvement options for inventory management. Two objectives are considered as the most important indicators: the minimization of the inventory costs and the maximization of the customer satisfaction. Therefore, the problem consists of finding the most appropriate compromise between expected inventory costs and the customer satisfaction level.

Framework

In order to help inventory managers to define the parameters of inventory control policies, Cadavid and Zuluaga (2011) present a decision support system framework for inventory management area by using time series models, ABC classification and inventory management models including a full definition of its parameters. The model allows companies to define all the information that an inventory control model requires to improve the effectiveness of the system. This model requires the definition of several parameters such us: reorder points, order quantities, inventory levels, security stocks, and service levels and presents the behavior that inventory and costs will have with the information defined.

2.1.3. DSS for inventory classification

FSN (Fast-moving, Slow-moving and Non-moving) Analysis

While (Verwater-Lukszo and Christina 2005, Cadavid and Zuluaga 2011) evaluate how parameters affect the inventory levels mainly in terms of service level, inventory level and/or costs, Mitra et al. (2015) analyses the items according to the turnover ratio it possesses by using FSN analysis.

FSN analysis groups materials into three categories as **F**ast-moving, **S**low-moving and **N**on-moving (dead stock) respectively. We note here that the DSS is used to help the decision maker to analyze and classify these articles and to determine the dead stock.

K-means algorithm

Ware and Bharathi (2014) implemented an approach to predict factors affecting the sale of products for a huge stock data mining patterns. For this, it divides the stock data in three different clusters based on sold quantities i.e. Dead-Stock (DS), Slow-Moving (SM) and Fast-Moving (FM) using Hierarchical agglomerative algorithm K-means algorithm and Most Frequent Pattern (MFP) algorithm to find property values frequencies of the corresponding items.

ABC analysis

Another way to classify items into different groups is ABC analysis. The three categories named 'A', 'B', and 'C' respectively, lead to the term ABC analysis. Thus, the items are grouped in order of their estimated importance. 'A' items are the most important items for an organization followed by 'B' items that are important but of course less important than 'A' items followed by 'C' items that are marginally important (Rezaei and Dowlatshahi 2010).

While ABC analysis has an efficient control on a large number of inventory items, it is limited because it uses only one criterion, mostly ‘‘annual dollar’’, for classifying inventory items.

Cross Analysis

To alleviate this shortcoming, Felice et al. (2014) proposes a Cross Analysis based on Analytic Network Process, a multi-criteria approach as modified version of ABC analysis. Cross Analysis suggests different materials management methods, depending on the particular criteria considered. This multi criteria approach, that allows to consider several criteria all at once that include both quantitative and qualitative criteria, is applied to inventory classification in order to propose the most suitable model for material management applied to the considered industrial system.

While Cross Analysis suggests different materials management methods depending on the particular criteria considered, considering all factors at the same time is no univocal and specific choice for the management method.

2.2. Multi Criteria Decision Making methods

Since, inventory management problem is characterized by the inclusion of several dimensions simultaneously like consumer’s preferences, increasing complexity of products, life cycles reduction, quality of associated products and services, occurrence of failure and delay in repairing, making this processes more complex, we believe that multi criteria approaches are the best candidates to cope with this. Hereafter, we detail the most relevant Multi Criteria Decision Making methods.

2.2.1. MCDM Aims

The aim of MCDM is to support decision makers faced with multiple decision criteria and multiple decision alternatives (Toloie-Eshlaghy and Homayonfar 2011). MCDM has proven to be an effective methodology for solving a large variety of multi-criteria evaluation and ranking problems in the presence of numerous objectives and constraints.

According to (Toloie-Eshlaghy and Homayonfar 2011), the development of MCDM methods has been motivated not only by a variety of real-life problems requiring the consideration of multiple criteria, but also by practitioners’ aims to propose enhanced decision making techniques using recent advancements in mathematical optimization, scientific computing, and computer technology.

However, despite this large number of MCDA methods, there is no unique method, which is the best for all kinds of decision-making situations. Consequently, a recurrent question arises of how to choose the most appropriate method in a specific decision situation? To answer such question, we conducted a comparative analysis of the most commonly used multi-criteria decision-making methods.

2.2.2. MCDM categories

According to (Polatidis et al. 2006, Adomavicius et al. 2011), the following categories of global preference modeling approaches can be identified:

- Multi-attribute utility theory (MAUT) approaches: In such approaches, marginal preferences upon each criterion are synthesized into a total value function called the utility function.
- Multi objective mathematical programming (MOMP): Criteria, in such approaches, are expressed in the form of multiple constraints of a multi-objective optimization problem. The goal is to find a Pareto optimal solution for the original optimization problem.
- Outranking models: Preferences, in such approaches, are expressed as a system of outranking relations between the items, thus allowing the expression of incomparability. In such approaches, all items are pair-wise compared to each other, and preference relations are provided as relations “a is preferred to b”, “a and b are equally preferable”, or “a is incomparable to b”.
- Non-classical approaches: Such approaches try to infer a preference model of a given form from some given preferential structures that have led to particular decisions in the past. Inferred preference models aim at producing decisions that are at least identical to the examined past ones.

2.2.3. MCDM for inventory management

In our comparative analysis, we study the most common MCDM methods in each category. Table 1 shows that MCDM methods have been successfully adopted in literature to deal with supply chain management in general, and their use in inventory management, in comparison with other supply chain management problems, is only limited to inventory classification.

In the next sub-sections we focus on identification of the criteria used in the field of inventory management, which may be potentially adopted in the MCDA.

2.3. Inventory management evaluation criteria

In order to determine how each of the criteria influences the decision making process, it becomes necessary to identify and agree on the criteria that will be evaluated (Thokala et al. 2016). Taking into account the specificity of inventory management, we have to highlight the related criteria.

2.3.1. Logistic criteria

In general, properties like inventory costs, costs of stock-out, lead time, service level, turnover ratio, and so on (Verwater-Lukszo and Christina 2005, Cadavid and Zuluaga 2011, Mitra et al. 2015) are likely to be relevant for any set of criteria a firm may want to use to evaluate its operations in terms of overall logistic effectiveness and efficiency.

2.3.2. Financial criteria

Nowadays, a firm evaluates its operations not only in terms of overall logistic effectiveness and efficiency but also in financial terms.

El Miloudi et al. (2015) focus on the links between the trust and the supply chain by studying such flows and their impact on the overall performance and optimization decisions.

Buzacott and Zhang (2004) analyzed the relationship between operations management and production with funding constraints in capital, risky and uncertain market.

Dada and Hu (2008) studied the optimum amount of orders for a retailer with limited cash.

Zhou and Wang (2009) studied the impact of constraints and funding methods on the performance of the supply chain.

Moussawi-Haidar and Jaber (2013) studied the interdependence between financial decisions and operational decisions. They built a model that integrates cash costs and those of the stock. They analyzed the impact of the optimal management of cash on the total cost of the stock.

Tsai (2008) tried to measure the risk of cash flow in the supply chain with regards to some risk factors related to time, including implementation time, periods of accounts receivable, accounts payable and collecting payments.

2.3.3. Coupling Financial and logistics criteria

Few studies have considered both logistic and financial issues in inventory management and supply chain management.

Nakhla (2006) proposed to involve a process of rationalization of supply chains and financial performance of the company to reconcile financial strategy and operational management. It evaluated the implementation of new logistics services driven by new levels of service in terms of impact on the financial performance of the company.

Fenies and Lebrument (2011) proposed an extension of the PREVA approach (process evaluation) on a schedule in three stages. The first step is the evaluation of the performance of the physical flows using models for action coupling discrete event simulation and heuristic or optimization of the physical flows by generating more optimal solutions. The second stage concerns the evaluation of the financial flows having as input variable the elements provided by the action of the physical flow model. The last step for the results of the decision support models in the form of dashboards using the SCOPE process (supply chain operations performance).

2.3.4. Discussion

The state of the art survey highlights that there is a lack of research studies with a combined logistics and financial criteria in inventory management.

While logistics is recognized as a critical dimension of business success, experts believe that stocks represent 25 to 35% of fixed capital of a company (Rossi-Turck et al. 2004).

Only a combined valuation of logistics and financial requirements can assess a company's strategies. Combined financial and logistics performance measurement is vital for any business that wants to survive in an increasingly competitive environment and can lead to new decisions (Estampe et al. 2003).

Hence, coordination between logistic and financial criteria is now needed to ensure the economic profitability, customer satisfaction and to ensure the sustainability of the business. Some studies have underlined the importance of these multiple aspects for a firm (Longo et al. 2015, Kleindorfer et al. 2005, Shrivastava 1995).

Despite the importance of the combination of logistics and financial criteria, only Fenies and Lebrument (2011) took into account both of these criteria in their approach but on sequential manner i.e. the outputs of the logistics performance evaluation are the inputs of financial evaluation.

To solve these disadvantages, we presented a multi-criteria decision support system that combines both logistics and financial criteria for performance measurement of inventory management that will be detailed in the next section.

3. MULTI-CRITERIA DSS PROPOSED MODEL

The model proposed in this paper which is presented in figure 1, relies on a multi-criteria approach for decision support in inventory management.

The main goal of our model is to enable the coupling of logistics and financial criteria for performance measurement of inventory management and thus to identify improvements needed.

The consideration of several criteria at once either logistics or financial justifies the use of multi-criteria approach.

So, as we can see in figure 1, our approach is based on three steps that are detailed in the following paragraphs. But, in order to apply our approach, data collection is a necessary step. In fact, data collection plays a crucial role and affects the development and use of the models (Longo et al. 2015).
So, in order to apply our model, the statement of the global objective of the company by stating associated criteria and information related to these criteria is necessary. To summarize, the following information should be completed:

- Criteria,
- Current measures of these criteria.
- Measures m_{good} of these criteria, which expresses the maximum value that can achieve this criterion.
- Measures $M_{neutral}$ of these criteria, which expresses the minimum value that can achieve this criterion.
- Weight of the contribution of each criterion.
- Interactions between different criteria.
- Cost potentially undertaken improvement actions.

Step 1 consists in associating to any current measure defined on the interval [$m_{neutral}$, m_{good}], a performance expression defined on the interval [0, 1] by linear interpolation (figure 1(a)).
Given that the overall performance is not a simple summation of the elementary expressions already calculated in step 1 but depends on the weight of each criteria and the interactions between the different criteria. Step 2calculates the aggregation of these elementary performance criteria (overall performance) by Choquet Integral (figure 1(b)). Furthermore, in order to improve this overall performance calculated in step2, optimization is applied in step 3 (figure 1 (c)).

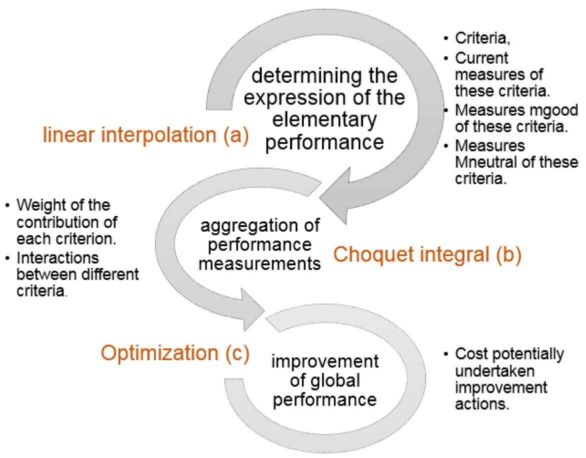

Figure 1: Multi-criteria DSS model

Each step of the model is detailed in the following sub-sections.

3.1. The expression of elementary performance

The performance indicator returns an expression of performance that identifies the level of achievement of each objective expressed in terms of criterion. In fact, it results from the comparison of the objective and physical measurement. This comparison can be formalized by the following function (Sahraoui et al. 2008):

$P: O \times M \rightarrow E$
$(O, m) \rightarrow P\ (o, m) = P$

O, M and E are respectively the universe of discourse of Objectives o, measures m and expressions of the performance P. Note that an essential condition to be met for the aggregation of the elementary expressions of performance is their commensurability which ensures that all values are expressed in the same logic (Sahraoui et al. 2008), i.e. the interval [0, 1] with 0 means no satisfaction and 1 means maximum satisfaction. Two possibilities exist to develop the expressions of performance (Sahraoui 2009):

1. Direct expression of performance in the form of mapping between the physical measurement and the associated performance through Linear interpolation, i.e. a series of points, especially for extremum 0 and 1.
2. Indirect performance expression by human comparisons between different situations, including the two extremum (the worst one and the best one). So, when human knowledge is available and in order to coherently translate this knowledge into numerical assessment, the MACBETH method can be used.

In our work, we use the first method i.e. the linear interpolation. So, to bring all elementary performance to the same scale i.e. the interval [0, 1], the decision maker uses the following expression: let m_2 actual measure of elementary performance and P_2 expression of the performance of that value on the interval [0, 1]. m_1 and m_3 represent respectively the minimum and maximum measures of the elementary performance studied which $P_1 = 0$ and $P_3 = 1$ their respective expressions of the performance on the interval [0, 1]. So, we have (Fouchal 2011):

$$P_2 = \frac{(m_2 - m_1)\,(P_3 - P_1)}{(m_3 - m_1)} + P_1 \qquad (1)$$

3.2. The aggregation of the performance

To evaluate criteria set, an aggregator operator is used as a common method to reduce the multi-criteria problem into a global single criterion problem (Bendjenna et al. 2012). According to the study methods MCDA presented above, we find that these methods differ in the way and the modeling structure of preferences of decision maker. Certainly there is no ideal method. Choosing a MCDA method may depend on the nature of the problem, context cultural and personality of decision makers (Dhouib 2011). A traditional method uses a weighted sum (or weighted mean). Despite its simplicity, this method assumes that the criteria are independent. Indeed, Choquet Integral will be used to take into account the interactions between the criteria. Indeed, the Choquet integral 2-additive generalizes the weighted mean in the sense that it allows one hand to model the relative importance of a criterion. On the other hand, the operator takes into account the mutual interactions between the criteria. The Choquet integral 2-Additive takes into account the interactions pair criteria (Sahraoui et al. 2008):

$$C_{2-\text{additive}}(P_1 \ldots P_n) = \sum_{i=1}^{n} P_i v_i - \frac{1}{2}\sum_{i>j}^{I_{ij}} |P_i - P_j| I_{ij} \quad (2)$$

After we calculate the overall performance, we can evaluate the overall performance according to basic performance. So, we calculated the contribution of each individual performance in overall performance and we use a graphic visualization of the effects and an identification of the factors having a significant impact on the overall performance.

$$\text{Perf}_{\text{agrégée}} = \sum_{i=1}^{n} P_i \times \Delta_i \rightarrow \Delta_i = V_i \times P_i + \frac{1}{2}\sum_{i>j}^{I_{ij}} I_{ij} - \frac{1}{2}\sum_{j>i}^{I_{ij}} I_{ij} \quad (3)$$

with Δ_i is the elementary performance contribution.

3.3. The improvement of the performance

In our work, we treated two optimization problems to improve the performance. The first problem concerns the minimum investment necessary to improve overall performance. The second problem allows to determine maximum expected improvement for a fixed budget increase. Let's look first at the minimum budget necessary to improve the overall performance of an initial performance at an expected final performance. Assumed that the vector of initial elementary performance $P^1 = (P_1, P_2, \ldots, P_n)$ and a final overall performance to reach $P^* \in [0, 1]$, where $P^* > \text{Perf}_{\text{agrégée}}(P_1, P_2, \ldots, P_n)$. Knowing that theimprovement cost to move from the performance P1 to the performance P^* for each criterion i is C_i, then we seek the minimum improvement of the varIouselementary performances will achieve P^* at least cost. The optimization problem noted (P_1) is then stated as follows:

$$(P_1) \begin{cases} \text{Min } C(P, \delta) = \min\left(\sum_{i=1}^{n} C_i(P_i, \delta_i)\right) \\ \text{Under the constraints:} \\ \text{Perf}_{\text{agrégée}}(P_1 + \delta_1, \ldots, P_n + \delta_n) = P^* \\ \forall_i,\ 0 \le P_i + \delta_i \le 1 \end{cases}$$

With C(P, δ): cost of the improvement.
The second optimization problem is to find the maximum expected improvement for a given budget increase θ. The problem then states as follows:

$$(P_2) \begin{cases} \text{Max Perf}_{\text{agrégée}}(P + \delta) \\ \text{Under the constraints: } C(P, \delta) = \theta \\ \forall_i,\ 0 \le P_i + \delta_i \le 1 \end{cases}$$

With $\text{Perf}_{\text{agrégée}}(P + \delta)$: expected aggregate performance.

4. CASE STUDY

Finance and logistics are two organization functions which have always found themselves on opposite sides of each other. While financial performance is dependent on its cash management and profitability, logistics performance is dependent on low inventories, delivery time and delivery quality etc.

4.1. Description of financial and logistics performance

In order to measure logistics and financial performance, both logistics and financial criteria are used (figure 2). Based on literature, financial performance is measured by:

- Return on assets (ROA)characterizing the efficiency of assets in producing income.
- Return on equity (ROE) characterizing the shareholder investment.
- Earnings before interest and tax (EBIT) characterizing the profitability compared to asset-based measures.

Furthermore, for measuring the logistics performance and based also on literature, we use:

- Service level (SL) characterizing the service quality.
- Inventory turnover (IT) characterizing how the company turns over its inventory within a year.
- Logistics costs (LC) characterizing cost efficiency.

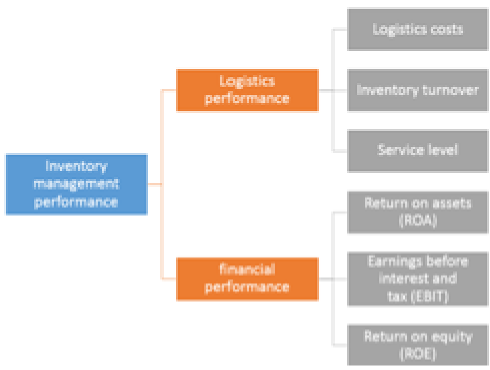

Figure 2: hierarchy of inventory management performance

4.2. Experiments

To illustrate how the proposed method can be used to evaluate the performance measurement, we used a

Table 1: Summary of most commonly used MCDM Methods

Category	Methods	Characteristics: *Support a large number of criteria*	*Hierarchy consideration*	*Ease of use*	*Uncertainty treatment*	*interdependence between criteria*	*Time and resources needed*	*Modeling Decision-Maker preference*	Application areas
Multi objective mathematical programming (MOMP)	*Goal programming (GP)*	High +	Low -	High +	High +	Low -	Moderate +	High +	Logistics distribution network design, Product-driven supply chain selection, Resource allocation in transportation
Multi attributive utility theory (MAUT)	*Analytic hierarchy process (AHP)*	Low -	High +	High -	High -	Low -	Moderate -	Low -	partnership selection, Suppliers and products selection, Selection of partner in logistics value chain, Inventory classification, Global supplier development, Production and distribution, Transportation
	Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS)	High +	Moderate -	High +	Low -	Low +	Moderate +	Low -	Customer evaluation, Performance evaluation, Location site selection, Supplier selection, Selection of partner in logistics value chain, Supplier evaluation in SCM
	Classical Multi-Attribute Utility Theory (MAUT)	Low -	High +	High +	High -	Low -	High -	Low -	Distribution and Logistics Management
	Analytic Network Process (ANP)	High -	Low +	High +	Low -	Low -	Low -	Low -	Purchasing decisions, Stock selection, Supplier selection, order allocation
	Simple multi attribute rating technique (SMART)	Low -	High -	High +	High -	Low +	High -	Low -	Supplier selection, Evaluation of robustness of supply chain information-sharing strategies
Non classical approaches	*Choquet integral*	High +	High +	High -	High +	High +	Moderate +	High +	Evaluation of 4PL (Fourth party logistics) operating models, improving industrial performance
	Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)	Low -	High -	Moderate +	High +	High -	Moderate -	High -	Outsourcer/supplier selection, Stock trading assessment

detailed financial and logistics reports-based data extracted from (Jae 2015; Debt 2013) combined with a sub-sample of interaction data from (Töyli et al. 2008). After determining the values and the weight for each criterion and the interaction between criteria, the overall performance is then determined by Choquet integral (formula (2)). Table 2 and Table 3 show the values, the current value (Cr value) and the weight (W) for each criterion as well as interaction between criteria successively.

Table 2: information of logistics and financial criterion

Criteria	2010	2011	2012	2013	2014	Cr value	W
ROE (%)	29.3	33.8	35.3	30.0	35.4	40.4	0.176
ROA (%)	18.6	22.3	23.7	17.9	17.0	18.6	0.124
EBIT (%)	11.89	9.12	9.96	8.35	11.62	10.11	0.191
SL (%)	93.83	93.95	97.12	95.83	91.88	93.83	0.256
IT (units)	52.51	70.53	112.12	83.45	57.94	62.82	0.145
LC ($)	36.92	40.10	43.76	45.28	45.69	47.23	0.108
							1.000

Table 3: interaction between criteria

	ROE	ROA	EBIT	SL	IT	LC
ROE	1.000					
ROA	0.0690	1.000				
EBIT	0.0466	0.0800	1.000			
SL	-0.1192	-0.1476	-0.0920	1.000		
IT	-0.0332	0.0487	0.1208	0.111	1.000	
LC	-0.0739	-0.066	0.0174	0.252	0.115	1.000

In the next step, contribution for each criterion on the overall performance is then determined. After that, we can calculate performance improvement either by minimizing investment necessary to improve overall performance (P_1) or by determining maximum expected improvement for a fixed budget increase (P_2). Table 4 shows the numerical results.

Table 4: numerical results

Criteria	Elementary performance	contribution of each criterion		Improvement
		without interaction	with interaction	
ROE	1.0	0.176	0.12	1.0
ROA	0.238	0.03	0.097	0.64
EBIT	0.497	0.095	0.045	0.702
SL	0.372	0.095	0.023	0.875
IT	0.173	0.025	0.013	0.775
LC	1.0	0.108	0.014	1.0
		0.529	0.316	0.63
				51 $

5. CONCLUSION AND PERSPECTIVES

In this work, we treated the coupling of logistics and financial criteria problem in inventory management by aggregating the performance for linking elementary performance with the overall expression on the one hand and optimization of the performance improvement on the other hand. The aggregation model is based on Choquet integral to take into account the weight and the interactions between the criteria. However, it is not always easy to the decision maker to provide quantitative data. So, as a perspective, we will make him express his preferences in terms of qualitative information using the concept of linguistic variable which have the advantage of being easily comprehensible by the decision maker. Moreover, it is possible to take into account the opinion of many decision-makers at the same time. Our system will also be integrated into a multi-agent system in order to determine the equity levers that allow the company to achieve its objectives.

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PRIORITISING THE SAFETY MANAGEMENT ELEMENTS THROUGH AHP MODEL AND KEY PERFORMANCE INDICATORS

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ABSTRACT

Safety management is considered a basic component of any firm's safety culture in various models. In fact, accidents at workplace not only provoke a decrease in human capital; they also generate financial losses. Nowadays, the organizations have been searching for continuous improvement within this specific issue. The objective of this work is to develop a multicriteria model to evaluate the performance of process safety management system. More specifically, the purpose of the study is to present a hierarchy decision model for assessing the priority of elements of goals of OHSAS 18001 by using the Analytic Hierarchy Process (AHP) methodology and to select a set of KPIs for measuring safety performance. A real case study is analyzed.

Keywords: OHSAS 18001, AHP, performance measurement, decision support system, KPIs

1. INTRODUCTION

Today, any firms encounter pressure from multiple stakeholders to manage occupational health and safety issues properly, systematically and transparently (Lo *et al.*, 2014). During the last decade academic literature has emphasized the central role of occupational health and safety management as a key long range strategy, as it helps improve health at work and alleviate the different costs of work accidents (Frick, 2011). Pagell *et al.* (2013) argued that safety must be treated as a key operational priority alongside cost, quality, flexibility, delivery and innovation. It is currently recognised that safety management plays an important part in achieving and maintaining a high level of safety (Mitchison and Papadakis, 1999).

Safety systems allow documenting safety processes and aim at minimising occupational risks within the business. Occupational Health and Safety Assessment Series (OHSAS) is the favored certification because the system has to be audited by an independent organization. OHSAS remains the most popular externally certified Occupational Health and Safety Management System - OHSMS (Fernández-Muniz *et al.*, 2012).

Since the certification was introduced in 1999, it has diffused rapidly, growing from 8399 certifications in 2003 to 56,251 in 2009. OHSAS certification improves the firm's sales performance, since certification may meet customers' safety requirements (Law *et al.*, 2006). The standard has been developed to be compatible with ISO 9001: 2008 (Quality) and ISO 14001:2004 (Environmental) management systems standards, in order to facilitate the integration of quality, environmental and occupational health and safety management systems by organizations, should they wish to do so.

OHSAS Standard uses a management approach tool called the PDCA cycle. PDCA is an ongoing process that enables an organization to establish, implement and maintain its health and safety policy based on top management leadership and commitment to the safety management system. The "Plan-Do-Check-Act Cycle," outlined below, demonstrates how safety management systems give operators a tool for constantly evaluating and improving their safety performance.

In this context the present paper aims to examine the connection between the adoption of the OHSAS 18001 standard and performance measurement within an Italian s consulting company. Firstly, the adoption of the OHSAS 18001 standard was analyzed. Secondly, a key performance indicators (KPIs) were developed to evaluate the effect of the safety standard on safety performance. The KPIs were identified using a multicriteria approach based on Analytic Hierarchy Process.

The rest of the paper is organized as follows. In Section 2 a literature review on safety management and multi criteria approach is presented. Section 3 describes the proposed model and a case study is analyzed. Section 4 presents discussion. Finally, in Section 5, conclusions are analyzed.

2. LITERATURE REVIEW

In recent decades, companies have improved the process management of the health and safety to reduce the number of accidents and to improve working condition. In particular, it is necessary to promote measures of continuous improvement to improve working conditions (Lo *et al.*, 2014). The safety management plays an important role in achieving and maintaining a high level of safety (Mitchison and Papadakis, 1999). The interest for the health and safety of workers is extended to all industrialized countries. In the strategy's mandatory form, EU's Framework Directive (89/391/EEC) specifies how employers are to manage the work environment for half a billion Europeans (Frick, 2011). The Eurostat data shows the decreasing trend of accidents in the European Union in the manufacturing sector. In the last five years the decrease of accidents is about 40% in the manufacturing sector. The identification of hazards and their corresponding control measures provides the foundation for a safety program and essentially determines the scope, content and complexity of a successful occupational health and safety management system (Makin and Winder, 2008).

It is necessary to define the appropriate tools for documenting the safety processes and work to minimize the occupational hazards. Certified occupational health and safety management systems (OHSMS) have become an important instrument for companies in their efforts to ensure a healthy and safe work environment (Fernández-Muniz *et al.*, 2012 and Hohnen and Hasle, 2011). The Occupational Health and Safety Assessment Series (OHSAS) 18001 is the dominant international standard for evaluating safety management processes at the firm level (Granerud and Rocha, 2011). Abad *et al.* (2013), argue that businesses characterized by poor working and safety conditions would likely exhibit problems in their operations, and this negatively affects safety outcomes and operational performance. They analyze the relation between the adoption of the OHSAS 18001 and firm performance, as shown in Figure 1.

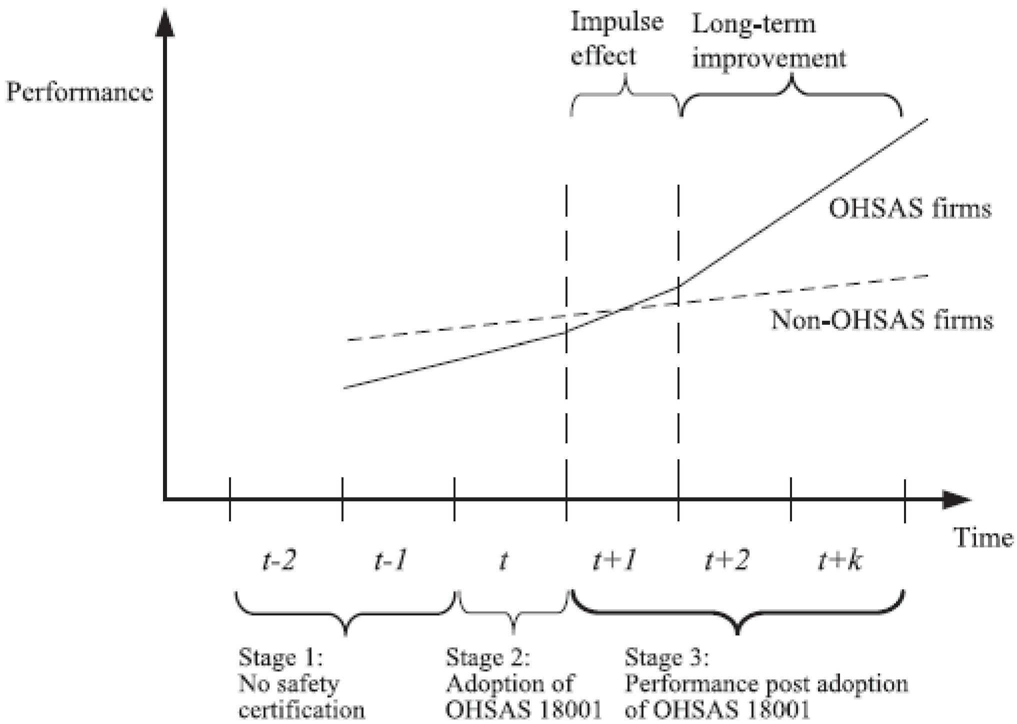

Figure 1: Relation between the adoption of the OHSAS and firm performance (Abad *et al.* 2013)

Vinodkumar and Bhasi (2011), study the impact of management system certification on safety management. The conclusions show that the safety system is closely related to quality ad environmental system, in fact OHSAS 18001 is compatible with ISO 9001: 2008 and ISO 14001.

When managing health and safety systems it is necessary to make choices, the complexity stems from a multitude of quantitative and qualitative factors influencing the choices (De Felice and Petrillo, 2013). It is necessary to identify a decision-making methodology that allows to make the best possible choice. The strategic decision-oriented health and safety includes a range of factors which involve both quantitative and qualitative. Extensive multi-criteria decision making approaches have been proposed such as the Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Case-Based Reasoning (CBR), Data Envelopment Analysis (DEA), Fuzzy set theory, Genetic Algorithm (GA), mathematical programming, simple multi-attribute rating technique (SMART), and their hybrids (Ho *et al*., 2010). Among the above method, one of the most popular is the AHP, used to solve complex decision problems and introduced by Saaty (1977). The strength of AHP is to breaks down a decision-making problem into several levels forming a hierarchy with unidirectional hierarchical relationships between levels. Some applications of AHP are analyzed as following. Law *et al.*, (2006) using a hierarchical decision model (AHP) to evaluate the priority of safety management elements in manufacturing enterprises in Hong Kong. The model proposes a self-regulating system to implement the security features. De Felice *et al.*, 2016 present an integrated approach AHP to quantify the performance and effectiveness of risk management to evaluate emergency alternative problems. Prasad *et al.*, (2013) have proposed a hierarchical decision model to evaluate the priority of elements in view of OHSAS 18001 in the Indian construction sector. The infrastructures are divided into: transportation, urban infrastructure and utilities. Hsu and Wang (2011), define a complete and safety management system in the plans. The study identifies 43 key factors of security and 15 cultural dimensions. The AHP identifies the weights between the cultural dimensions. Podgórski (2015), uses the analytic hierarchy (AHP) to select key performance indicators to measure the health and safety management. In the end you get a KPI ranking. Aminbakhsh et *al.* (2013), manage the priorities of risks with AHP model in the construction sector. The model determines appropriate investments for prevention of accidents considering their costs. The choice is made through the decision-hierarchical methodology. Chang and Lian (2009), develop a safety assessment model of the processes in plants producing paints. The AHP model has defined the weights of the different design attributes. The model showed that companies certified ISO 18001 have a more efficient risk management.

Badri *et al*. (2012), propose an approach for the risk assessment by classifying the risk factors, through a decision-making approach implemented with the expert choiche software. Silva *et al*. (2009), use an AHP model to evaluate the most important organizational management aspects (environment, safety and health, quality) for a manufacturing company.

3. THE METHODOLOGICAL APPROACH

According to some studies a low level of safety performance is related to insufficient knowledge and competence in the domain of OHSAS (Blewett and O'Keeffe, 2011). Furthermore, it seems that companies believe that the only benefit from certification is the ability to "attract" customers. Thus, all other components of operational performance would remain unchanged after certification. The above considerations lead to the conclusion that it is necessary to search for new solutions and arrangements that would improve the performance of OHSAS, which would consequently result in a positive contribution to greater acceptance of these systems among employers, employees and other stakeholders. This study utilized a holistic method to solve the problems in measuring the safety management. The aim of this paper is to demonstrate the application of the AHP to assess the priority of elements of goals of OHSAS 18001 and to select a set of KPIs for measuring safety performance. Figure 2 shows the research framework.

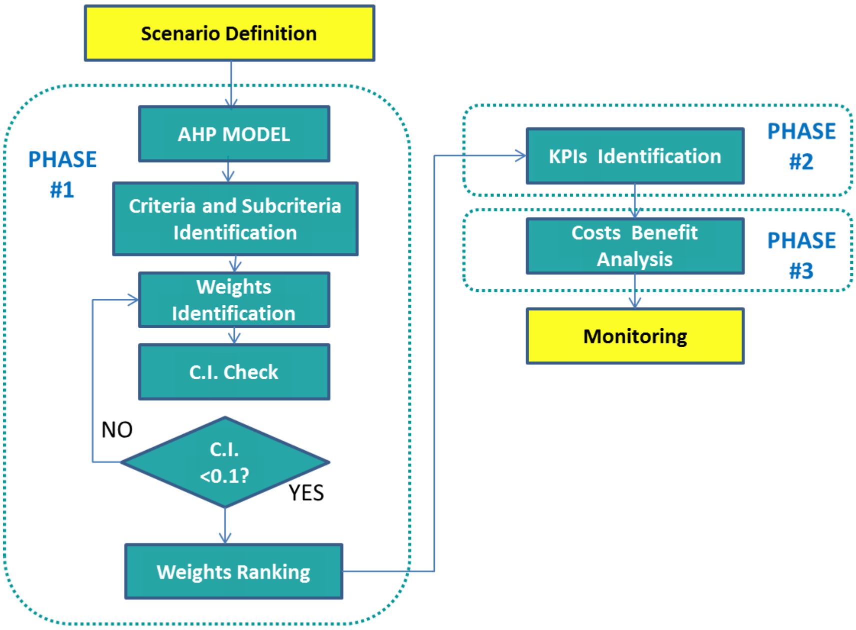

Figure 2: The research framework

3.1. Scenario definition

The case study was developed considering an Italian consulting company with 25 employees that operates in the IT and Engineering sector. The company aims to ensure the prevention, protection, health and safety of its employees. Thus, it decided to adopt an the OHSAS standard. The adoption of OHSAS standard requires a conscious organization and the identification of strategic safety management criteria. For this purpose a decision model was developed.

3.2. AHP Model: Phase#1

The decision model based on AHP framework was developed through a three-level hierarchy, as shown in Figure 3. The top level of the hierarchy is the main goal of the decision problem. The lower levels are criteria and subcriteria that contribute to the goal. The bottom level is formed by the alternatives to evaluate in terms of the criteria. The model is divided into three steps:

- Pairwise comparison and relative weight estimation;
- Priority weight vector calculation (identification of the solution);
- Consistency index estimation to verify the accuracy of the judgments.

The design of hierarchy required experience and knowledge of the specific problem. Thus, an expert team consisting of 1 safety management, 1 risk management, 1 expert consultant in OHSAS was formed. Expert team identified 4 criteria and 18 sub criteria. The model aims to select and to prioritize safety management indicators.

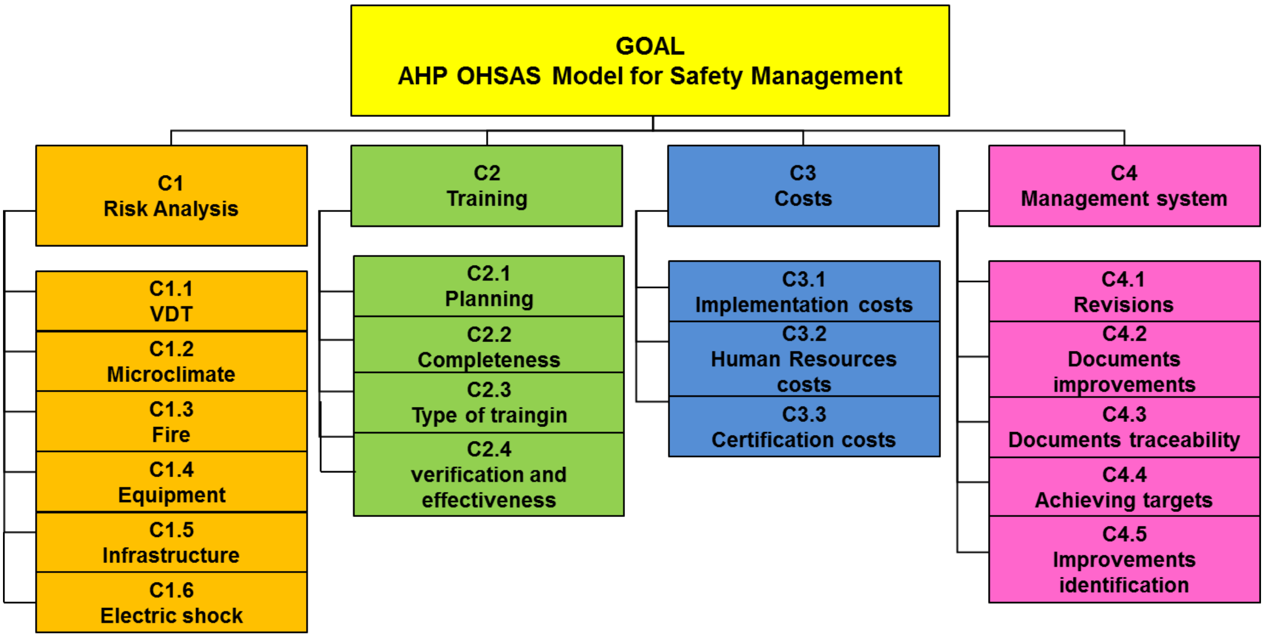

Figure 3: AHP OHSAS Model

After the hierarchy definition, the pairwise comparison matrices were developed in order determine the criteria and subcriteria weights. Table 1 shows an example of pairwise comparison for criteria.

Table 1: Example of pairwise comparison - criteria

	C1	**C2**	**C3**	**C4.**	**Priority Vector**
C1	1	3	2	1/2	0.301
C2	1/3	1	2	1/2	0.170
C3	1/2	1/2	1	1/3	0.117
C4	2	2	3	1	0.410
					CI = 0,061<0.10

Priority vector highlights that the most important criteria is C4 (Management System) with a score of 41%, followed by C1(Risk Analysis) with a score of 30%.

Figure 4 shows a summary of priorities for criteria and subcriteria.

The most important criteria are C1.1 (VDT risk) with a score of 36.9%; C2.1 (Planning) with a score of 46.6%; C3.3 (Certification costs) with a score of 62.5% and finally C4.1 (Revision) with a score of 44.4%.

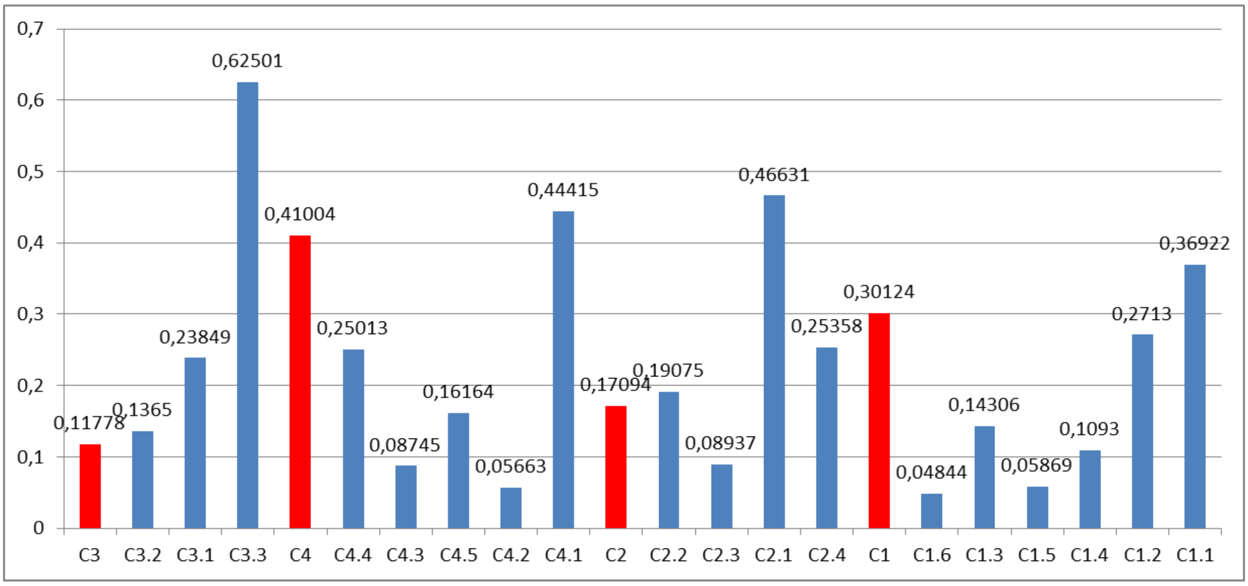

Figure 4: Summary of Priorities for criteria and sub criteria

3.3. KPIs identification: Phase#2

Success is defined in terms of making progress toward strategic goals. Thus, according the above results, KPIs were identified in order to evaluate the success of the company to implement the OHSAS standard. The choosing of the right KPIs was based upon a good understanding of what is important to the organization. Table 2 shows the selected KPIs.

Table 2: Example of selected KPIs

Criteria	KPIs
C1 Risk Analysis 30%	R1 = N° of eligible VDT workstations/ Total N° of VDT workstations
	R2 = N° of occupational diseases due to ergonomic/ Total N° of occupational diseases
	R3 = Total number of accidents/ N° of days of absence
C2 Training 17%	T1 = N° employees trained/Total N° of employees
	T2 = N° training courses executed/ training courses planned
	T3 = N° training courses executed/ N° employees trained
C3 Costs 12%	C1 = costs incurred for new procedures/ initial costs of OHSAS implementation
	C2 = costs for the implementation of the system OHSAS/Total costs
C4 Management system 41%	M1 = N° corrective actions implemented/N° corrective action planned
	M2 = Percentage of internal audits carried out versus plan

3.4. Costs Analysis (CA): Phase#3

A CA can help to make judgements on whether further risk reduction measures are reasonably practicable.
The main interest in assessing CA is to ensure that all the appropriate costs are included.
The total cost (CT) to implement the OHSAS standard is given by the following Equation (1):

$$CT = C3.1+C3.2+C3.3 \qquad (1)$$

According to the weights calculated with the AHP method, the ratio, in percentage terms, for any costs in relation to the total cost is:

- C3.1 is 23.8% CT;
- C3.2 is 13.6% CT;
- C3.3 is 62.5% CT.

The above percentages are subject to change by 20% according to the discretion of the decision makers in the application of AHP methodology.
The next step was the identification of an algorithm to determine the total cost (CT) necessary to implement OHSAS standard taking into account 2 factors or the number of employees and the level of safety risk. At this purpose two coefficients were introduced: α and k.

Table 3 shows the variation of the coefficient α with the varying of the level of safety risk of the company.

Table 3: Coefficient α related to level of risk

Level of risk	Coefficient α
Low	1
Medium	1.5
High	2

The choice of α coefficient is a hypothesis based on the considerations that the costs rise progressively with increasing the level of safety risk. Expert team

established an increase of 50% in the pass between two consecutive levels.
While, Table 4 shows the variation of the coefficient k with the varying of the number of employees. In this case the expert team identified the variation of coefficient k considering that an increase of 25 employees, corresponds on average an increase of 20% of costs (that is, an increase of a factor of 0.2).

Table 4: Coefficient k related to number of employees

Number of employees	k
1-25	1
26-50	1,2
51-75	1,4
76-100	1,6
101-125	1,8
126-150	2
151-175	2,2
176-200	2,4

Therefore, the determination of the coefficients σ and k as a function both of the various levels of safety risk and the number of employees allows to determine the increase of the total cost to implement OHSAS standard.
The final relation is given by the following Equation (2):

$$CT' = CT^* \sigma^* k \quad (2)$$

For case study under study the CT is estimated considering:

- Level of safety risk: Low = 1
- Number of employees: 25 = 1

The estimated CT is shows in Table 5

Table 5: Annual Costs - estimate

Costs	€ (euro)
OHSAS Implementation costs	9.746,00
Human Resources costs	8.514,00
Certification costs	3.718,00
total	*21.978,00*

While if we consider, as an example, a company with:

- Level of safety risk: Medium = 1,5
- Number of employees: 110 = 1,8

The estimated CT' is 57.450,00 €.
The variation is given by

$$\Delta CT = CT' - CT \quad (3)$$

Thus, in the example the ΔCT is 35.472,6 €. Thus, the cost increase is about 60%.

3.5. Monitoring

It is estimated that an injury to the company costs 5 times more than a non-injury. Furthermore, it is estimated that 1 € invested in safety costs ensure 2.2 € in benefits. Benefits include all reduction in risk to workers and to the wider community, such as avoidance of deployment of emergency services and avoidance of countermeasures such as evacuation and post-accident management.

4. DISCUSSION

The goal of implementation of OHSAS is to meet client's requirement and to improve safety and health in both the segments. Thus, it is essential to monitor KPIs over the time. Table 6 shows the set of monitored KPIs.

Table 6: Monitored indicators (%)

KPIs	Last Year 2015	Target 2014	Actual 2016 (I sem)
R1	30	20	50
R2	20	25	18
R3	15	18	7
T1	35	30	40
T2	20	20	15
T3	10	15	10
C1	21	30	25
C2	15	15	10
M1	10	5	8
M2	5	7	5

While Figure 5 and Figure 6 shows an example of monitored KPIs.

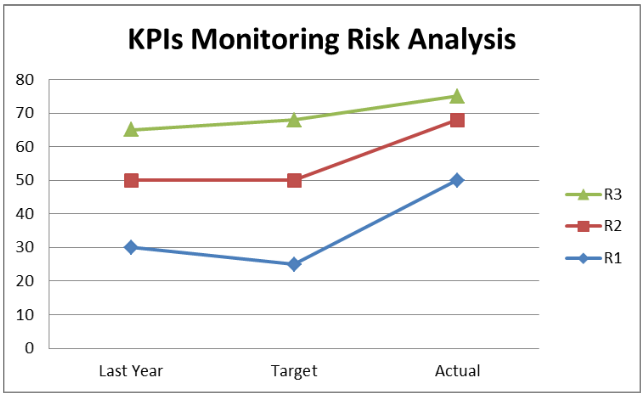

Figure 5: Example of monitored indicators for Risk Analysis

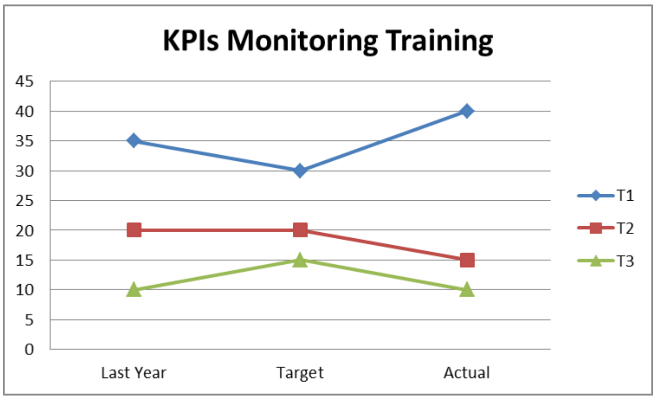

Figure 6: Example of monitored indicators for Training

5. CONCLUSION

The necessity of evaluating the OHSAS standard implementation within an organizations by means of a simple and flexible method has been the main focus of this work. It is important to emphasize the method validity. Its application is worthy as for the diagnosis of the organization performance and contribute for the decision making process, having as objective the continuous improvement of its processes and of the implemented management system.

The results presented demonstrated that the proposed method is an efficient tool to diagnose, in a simple and flexible way, the performance of an organization that implemented or is implementing a quality, environment and occupational health and safety management systems with the purpose of improving the performance of its internal productive processes or of administrative support.

The proposed set of KPIs should be tailored to specific conditions of a company, such as the size, industry sector, types of occurring hazards, or the maturity of safety management processes. The advantages of the model are: 1) Provides a structured approach for managing safety; 2) Existence of a continuous improvement culture and 3) Reduction in incident levels with increased measures of performance.

Future work will focus on soliciting opinions from more experts and testing the validity of this model in other industrial sectors. The ultimate goal is to develop a comprehensive model for all industrial sectors.

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INVESTIGATION INTO ERP-BASED SYMBIOTIC SIMULATION PROJECT IMPLEMENTATION ON FORD ENGINE PRODUCTION LINE: CHALLENGES, OPPORTUNITIES AND PROSPECTS

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ABSTRACT
The paradigm of Symbiotic Simulation describes a close relationship between a simulation system and the physical system. This relationship is usually mutually beneficial, whereby the simulation system benefits from a steady supply of real-time data from the physical system, while the physical system benefits from the optimised decisions arrived at through what-if experiments executed by the simulation system. In furtherance of existing work towards developing symbiotic simulation systems anchored on integration with corporate information systems, this paper presents research into an industrial application of symbiotic simulation to improve the simulation project life-cycles at a major automotive engine production line controlled by a shop floor information system. We discuss inexorable issues associated with the implementation of the relatively novel concept of symbiotic simulation, highlight the challenges to successful implementation in a corporate change-averse culture, suggest solutions for surmounting them and discuss the impact and prospects for symbiotic simulation with ERP integration.

Keywords: Symbiotic Simulation, Corporate Information Systems, ERP, Data Management

1. INTRODUCTION

Symbiotic simulation is a system that interacts with a physical system in a mutually beneficial manner (Fujimoto et al, 2002). The results of what-if experiments performed by the simulation system can be used to provide decision support or to control the physical system. Conversely, the simulation system benefits from the continuous supply of the latest data to validate its outputs. This enables timely response to abrupt changes in the physical system, unlike traditional simulation systems constrained by long lead times for model update and validation.

ERP systems facilitate the corporate management of a business enterprise, seamlessly integrating individual functional systems such as manufacturing, finance, procurement, distribution and human resources. In the manufacturing environment, most operational data are stored in ERP systems, such as cycle times, bill of materials, etc. According to a survey carried out by Robertson and Perera (2002), majority of input data for simulation modelling are stored in ERP systems. This is especially so for the manufacturing sector (Skoogh et al., 2012). Research into the integration of ERP systems with simulation modelling tools has gained reasonable traction, with Moon and Phatak (2005) proposing DES for enhancing the functionality of ERP systems in obtaining more accurate lead times, being a case in point.

As is the case with any program of wide-ranging organisational change initiatives, the successful implementation of symbiotic simulation requires a paradigm shift in the socio-economic system, which in turn is intertwined with technology, task, people, structure, and culture. Organisational resistance to change therefore emerges as a critical success factor. Organisational fit and adaptation are important to the implementation of such an innovative concept that needs to coexist and interact with extant large-scale enterprise systems that were built with a pre-determined business process methodology and purpose.

Considering the benefits inherent in the application of symbiotic simulation systems, this paper analyses the issues associated with its implementation in a major automotive company. The lessons learned would be useful for other manufacturing companies in their efforts to successfully implement symbiotic simulation systems.

2. LITERATURE REVIEW AND RELATED WORK

The following literature review explores the state of the art in symbiotic simulation, ERP data management and interaction with simulation tools and corporate change-averse culture, with a view to identifying and demarcating the knowledge gap relevant to this research.

2.1. Symbiotic Simulation Systems and Applications

Symbiotic simulation has been implemented in various application domains. Low et al. describe a symbiotic simulation system for semiconductor manufacturing backend operation (Low et al. 2005), where upper and lower limits for queue lengths are used to make outsourcing decisions. Optimal limits are determined by analysing different settings using what-if simulations, with each simulation representing a different set of limits. A symbiotic simulation-based problem solver to automatically resolve decision making problems regarding the operations of the various tools in an entire semiconductor manufacturing fab has also been proposed. The problem solver agent detects the physical system and executes what-if scenarios to identify and solve some manufacturing problems (Aydt et al., 2011).

Symbiotic simulation has also been applied in the control of unmanned aerial vehicles (UAVs). Kamrani and Ayani describe how symbiotic simulation can be used for path planning (Kamrani and Ayani 2007), whereby what-if simulations are used to evaluate alternative paths. Mitchell and Yilmaz have also developed a symbiotic simulation system in UAV control (Mitchell and Yilmaz 2008) and described how symbiotic adaptive multi-simulation (SAMS) can be used for real-time decision making under uncertainty. Each what-if simulation is concerned with a combined model ensemble that combines parameters regarding unknown environmental conditions and possible system configurations. Unlike other symbiotic simulation applications, SAMS analyses how a particular system configuration performs under different possible environmental conditions.

Symbiotic simulation has also found application in the large gas turbine manufacturing process, where the architecture of an intelligent assembly quality control solution using symbiotic simulation that combines an ON-line Simulation Module (ONSM) with OFF-line Simulation Module (OFFSM) is introduced (Meng et al., 2013).

Symbiotic simulation model validation has been used in a radiation detection application (Aydt et al. 2009), where a highly accurate model of the environment is used to estimate the radioactivity at certain locations in the environment, given a particular kind of radiation source and its location. Different hypotheses regarding the radiation source are evaluated by means of simulations. The hypothesis which produces the closest results to the actual measurements can be considered as the likely location of the radiation source in the real environment.

An agent-based implementation for a generic symbiotic simulation framework for different applications has been developed by Aydt et al. (2008), that provides standard implementations for the various functional components that can usually be found in a symbiotic simulation system. The framework has been designed with requirements regarding applicability, extensibility, and scalability in mind.

2.2. ERP and Corporate Information Systems

The Corporate Information System is commonly encountered as Enterprise Resource Planning (ERP) systems in most corporate environments. Although simulation practitioners may still need to complement information from ERP systems with data from other sources for simulation modelling, there is a concerted effort towards establishing automated links between simulation models and corporate information systems as the main source of simulation data (Robertson and Perera, 2002; Randell and Bolmsjö. 2001).

ERP systems typically include the following characteristics:

- An integrated system that operates in real time (or next to real time), without relying on periodic updates.
- A common database, which supports all applications.
- A consistent look and feel throughout each module.
- Installation of the system without elaborate application/data integration by the Information Technology (IT) department.

Figure 1: Typical ERP System

Even though ERP systems have already become the dominant management software in manufacturing and distribution systems in today's competitive business environment (Ho and Ireland, 2012), they lack prognostic functionality and the capability of dealing with uncertainty. These are, of course critical factors for decision support in manufacturing and other domains (Addo-Tenkorang and Helo, 2011; Battista et al., 2011). Simulation tools, on the other hand, have the functionality to deal with such issues as decision support, time compression and expansion, what-if experimentation, problem and constraint identification, forecasting, visualisation, and requirements specification (Banks, 1999; Babulak and Wang, 2008; Jovanoski et al., 2013). Recent work to integrate ERP systems with simulation tools in the manufacturing environment have mainly focused in the following two areas:

2.2.1. Data Management within ERP Systems and Simulation Tools

Input data management is a crucial and time-consuming process for both ERP systems and simulation tools (Skoogh et al., 2012a). At the heart of an ERP system is the central database that feeds data into a series of applications supporting diverse enterprise functions (Davenport, 1998). ERP systems typically host most of the operational data, such as cycle times, set-up times, and bill-of-materials. The need for better integration between simulation tools and ERP systems in order to facilitate automation of data transmission between them has been articulated by Robertson and Perera (2002). A survey that investigated input data requirements of simulation tools in 2012 revealed that for manufacturing companies, 40% of the main and 77% of the common sources of data for simulation tools are stored in ERP systems. Results also showed that 77% of participants expected to implement a higher level of automation of input data for simulation tools (Skoogh et al., 2012b).

A framework for automated data transmission between ERP systems and simulation tools was proposed by Robertson and Perera (2002), along with the concept of an intermediary database to automatically extract and store data between ERP systems and simulation tools as shown in Figure 2. The need for an interface to automatically acquire data from ERP systems for simulation modelling has become more compelling and several products have been developed to meet it. A Generic Data Management Tool that automatically collects, processes and outputs critical simulation input data from ERP systems has since been developed and released as open source software by Skoogh et al. (2012a).

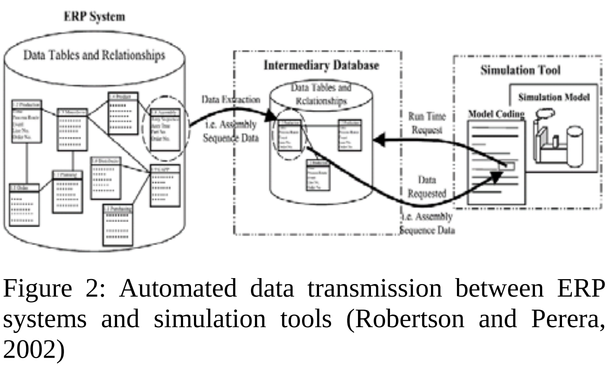

Figure 2: Automated data transmission between ERP systems and simulation tools (Robertson and Perera, 2002)

2.2.2. Interaction of ERP Systems and Simulation Tools

ERP systems are rightly considered as main sources for simulation data. Better integration between simulation tools and ERP systems is therefore not merely desirable but necessary to enable automatic data exchange between them (Robertson and Perera 2002).

A method has been proposed for linking discrete event simulation model with an ERP system to enhance the functionality of the ERP system in determining realistic production lead time data. A pump manufacturing factory test case demonstrated that lead-time data can be determined with a higher degree of accuracy (Moon and Phatak, 2005).

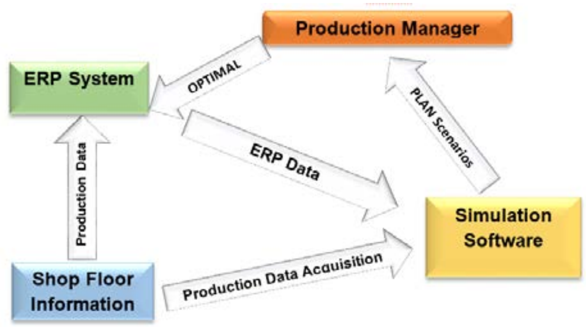

Figure 3: ERP/Simulation system interaction (adapted from Moon and Phatak, 2005)

The simulation tool acquires relevant manufacturing data from the ERP system and outputs simulated lead times. Comparing the simulated results with the actual due date, a production manager changes data by adjusting overtime and executes the simulation model again. This process is repeated until the manager is satisfied with the simulation results. The ERP/simulation system developed by Moon and Phatak uses traditional off-line simulation methods and lacks the facility of automatic validation. Here, optimisation and control of the physical system depends on the production manager, rather than being automatically generated.

2.2.3. Background of Simulation at Ford PTOME

Ford Power Train Operations Manufacturing Engineering (PTOME) has used simulation for over 30 years. In that time, significant progress has been made, not only in process design issues, but in the simulation methodology employed to make these improvements (Winnell and Ladbrook, 2004). The increasing requirement to simulate the effects of logistical and other ancillary operations is having a bigger impact on the work of the simulation team than basic changes to manufacturing procedures. Examples include the frequency of tool changes and the operation of offline metrology routines, which can often cause bottlenecks.

The current trend is towards integration through the construction of complete models in which every process is represented, rather than fragmentation through the addition of extra functionality. Work is already at advanced stages to enable the inclusion in simulation models of information about energy consumption on the shopfloor (Wilson et al, 2015). Another milestone in prospect is the construction of models that incorporate information about manufacturing operations out in the supply chain. This research on symbiotic simulation is a natural progression aimed at continuous improvement and keeping PTME simulation operations at the cutting edge of the latest technology.

The test case assembly line is in a configuration composed of different U-Sections as can be seen from a high level in Figure 4 below. The core component of the line is a moving conveyor with rollers, moving along the path of the bold lines indicated.

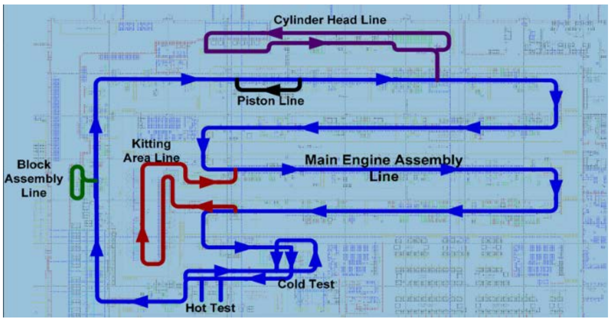

Figure 4: Layout of Test Case Engine Production Line

Details of individual machines and operations on the line cannot be disclosed for commercial confidentiality. The simulation model of the line built using the WITNESS simulation package is shown below.

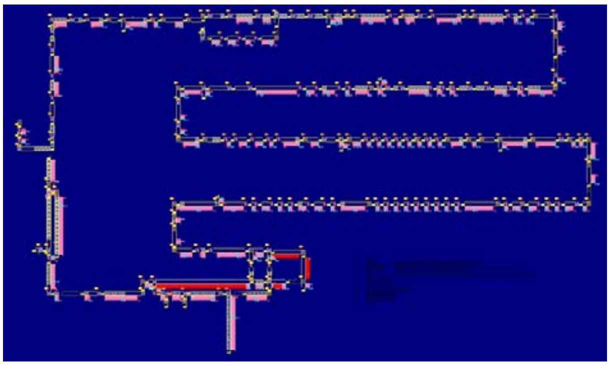

Figure 5: Model of Test Case Engine Production Line built in WITNESS.

3. IMPLEMENTATION FRAMEWORK FOR ERP-BASED SYMBIOTIC SIMULATION SYSTEM

Linking symbiotic simulation systems to manufacturing lines controlled by an ERP system is relatively new. Previous efforts have focused on data exchange and physical interaction between ERP Systems and simulation tools.

In the proposed implementation symbiotic simulation system (adapted from Tjahjono et al, 2015), is composed of three main subsystems:

- Symbiotic Simulation Forecasting System (SSFS)
- Symbiotic Simulation Anomaly Detection System (SSADS) and
- Symbiotic Simulation Decision Support System (SSDSS).

The framework also incorporates triggers and objects. These subsystems, triggers and objects should work collectively to:

- Exchange data from the Factory Information System (FIS, the ERP system)
- Evaluate trigger conditions
- Create and run what-if scenarios
- Optimize and analyse simulated results
- Visualize real-time states
- Forecast the future and
- Recommend solutions to an external decision maker.

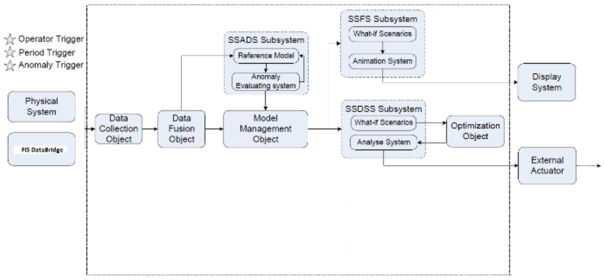

Figure 6: Conceptual Model of the Symbiotic Simulation System

3.1. Data Collection & Data Fusion Objects

The Data Collection Object automatically extracts raw data from Ford Motor Company's proprietary plant monitoring system known as Factory Information System (FIS) and passes it on to the simulation model in an accessible format. Data is extracted from FIS using an Excel interface with SQL queries embedded in VBA. The Data Fusion Object is essentially a collection of functions built in Witness to carry out data loading and manipulations, such as removing data duplication, between the Excel spreadsheet and the simulation model. Parameters are used to represent attributes of the modelled objects, such as machine cycle times. Variables store simulation results or object characteristics that are changing over time, e.g. lead times. Collections store, retrieve and manipulate aggregate data, such as queues or sequences.

3.2. Optimisation Object

The Optimization Object generates the optimum decision parameters that are passed on to an external decision maker. The Optimization Object determines parameter values that result in the maximum or minimum of the objective function, while adhering to constraints. The what-if scenarios generated by the Optimization Object are used to find the optimum decisions for predefined problems.

3.3. Model Management Object

When triggering conditions are met, notifications are sent to the Model Management Object. The MMO manages what-if scenarios and invokes the subsystems as appropriate. At start-up, MMO is used to assign data from the DFO to simulation parameters and update simulation models to the current or defined state. At runtime, MMO continuously delivers dynamic data from DFO to simulation models.

3.4. Symbiotic Simulation Anomaly Detection System

The Symbiotic Simulation Anomaly Detection Subsystem (SSADS) constantly monitors the information in the Data Fusion Object (DFO) and compares it with a reference model in order to detect anomalies. The SSADS detects anomalies from the physical and simulation systems by comparing the simulation model with the actual data in the DFO. In the event of a sharp drop in average weekly JPH, for instance, an anomaly notification would be automatically generated to trigger the MMO to invoke other subsystems. When the discrepancy between the simulation model and actual production data is beyond a certain tolerance, it is considered as an anomaly.

3.5. Symbiotic Simulation Forecasting System

The SSFS generates future prediction and visualization to the display systems. The essential part of the SSFS subsystem is the 'what-if' scenarios that can be used to forecast future events. It may contain animation systems to generate 2D/3D animations. MMO delivers static and dynamic data to the SSFS subsystem and invokes the what-if scenarios.

3.6. Symbiotic Simulation Decision Support System

The SSDSS requests the Optimization Object to generate optimum decision parameters, which are used as alternative decision parameters by an external decision maker. Unlike the Symbiotic Simulation Control System that implements the optimum decision directly on the physical system using actuators, the SSDS simply presents the options to an external decision maker.

4. CHALLENGES ENCOUNTERED

'Driving innovation in every part of our businesses' is a mantra that is trumpeted by most companies that seek to portray themselves as global leaders at the cutting edge of new technology. In practice, however, this is often no more than a slogan honoured more in the breach than in the observance. Novel methods with the potential to significantly enhance performance and positively improve return on investment typically have to contend with a change-averse and risk-averse corporate culture, resulting in overextended project lead times and outright abandonment of otherwise hugely beneficial concepts.

Embarking on the implementation of symbiotic simulation on Ford engine manufacturing lines was no exception. It was conceived by John Ladbrook, Ford Motor Company's Simulation Technical Specialist and designed as a PhD research project in conjunction with the University of East London, a Ford partnership called the High Speed Sustainable Manufacturing Institute (HSSMI) and the UK Engineering and Physical Sciences Research Council (EPRSC). The project has encountered a set of challenges, the most significant of which are outlined below.

4.1. Organisational Culture

In most companies, the cards are heavily stacked against the nurturing of innovation, especially the new ideas and 'disruptive' innovations that generally lead to major changes within the business. At the best of times, things hardly move at the "*speed of thought*" in large corporations steeped in longstanding traditions, especially those that have enjoyed considerable success. But whilst it took up to nine months and several meetings to obtain routine approvals for required access to information systems and databases, the support and enthusiasm from key players never wavered.

4.2. Management Buy-in and Funding

Funding applications and approvals take a minimum of one year, thereby making short to medium term planning extremely difficult for such a project, although it was conceived at the appropriate management level. It is pertinent to acknowledge the sheer size of Ford Motor Company, which has a multi-billion dollar R&D division, in order to situate this project within that context, for a proper appreciation of the gravity of this challenge from that perspective. Working to engender synergy among relevant business units in a multi-disciplinary project is always an uphill task. A periodic review of the business case for the project became necessary, as the rationale for resource allocation against alternative projects came into sharp focus in a climate of fiscal restructuring and budget cuts. Senior management support was decisive in the survival of the project to this stage of implementation.

4.3. IT Governance

Corporate IT governance rules and procedures are enacted for a good reason, with security, availability and robustness at the top of the list of priorities aimed at the alignment of business goals with the technology strategy. There is often a tendency for the IT department to selectively hide behind governance issues as an excuse to delay, deny and frustrate an IT-centric project that did not originally emanate from them. However, Ford IT has demonstrably gone the extra mile to facilitate this research. As curators and administrators of the infrastructure on which the project would be anchored, the IT department's adoption of the project helped to ensure adherence to Corporate IT governance.

4.4. Proliferation of Production Data Sources

Real-time production monitoring, ERP and other manufacturing shop floor information systems collect and store a large amount of data. This data is subsequently stored in a variety of databases, repositories and other proprietary or OEM systems that are not interlinked. Oftentimes these systems are also virtually not interoperable. Whilst this obviously presents a dilemma in the process of streamlining the simulation input data requirements against the variety of data sources, it conversely presents a goldmine of data from which useful knowledge and intelligence can be extracted, leading to the development and building of better models.

4.5. Development and Testing Environment

Notwithstanding the perception of autonomy and decentralisation prevalent in transnational corporations like Ford with global operations, the situation is more fluid in practice, where standardisation takes precedence over localised exigencies. Provision of an offline sandboxed development and testing environment required for the project therefore becomes a sticking point between IT central administration and the specific manufacturing plant hosting the project. The interpersonal skills developed in the course of complex interactions with various interdisciplinary business units have been immensely rewarding, although a decision is still being awaited on the provision of an intermediary simulation-centric database as well as a development environment.

5. EVIDENCE-BASED IMPLEMENTATION STRATEGY

Introducing any technological innovation into an organization presents a unique set of challenges different from competent project administration. Shepherding a technical innovation into routine use requires tact and experience to guide its development and manage its implementation. Although the effectiveness of any strategic framework for surmounting the challenges to the adoption of new technologies must be assessed within the context of organisational climate, lessons learned from this undertaking can have resonance across a wide spectrum of application areas.

In the course of this research into the implementation of an ERP-based symbiotic simulation system on a Ford engine production line, we have adopted an approach of turning stumbling blocks into stepping stones. The summary of our experiences and recommended strategy for surmounting some of the impediments to successful implementation are outlined in three broad steps: 1) First Reaction-Build the Case; 2) Investigate the Technical Performance and 3) Implement – Limit the Risk.

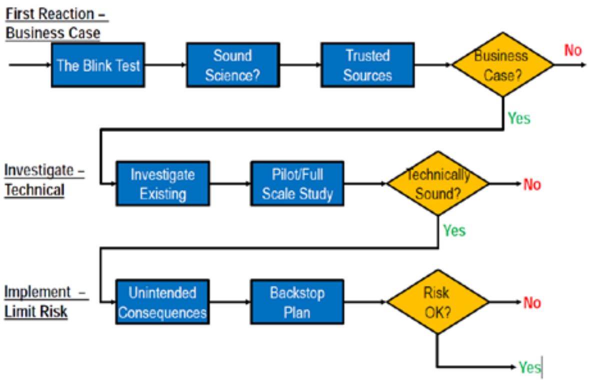

Figure 7: Implementation Strategy (Neethling, 2015)

5.1. First Reaction – Build the Case

1. Apply Malcolm Gladwell's "Blink" test - If it sounds too good to be true, it probably is. Let the factual evidence of the advantages speak for themselves.
2. Check the science/technology – Beware of obsolescence.
3. Check past experiences from trusted sources – Examine evidence from related implementations.
4. Make the business case favourable – Demonstrate the impact on return on investment.

5.2. Investigate the Technical Performance

1. Investigate existing implementations
    - Physical site visit, where possible
    - Question the operators & owners
2. Pilot test and/or Full scale tests
    - Determine site specific conditions
    - Operations assessment
3. Evaluate technology performance

5.3. Implement – Limit the Risk

1. Think of unintended consequences
2. Develop Risk Mitigation Plan for Implementation
3. Have a fallback option.

6. DISCUSSION

Research into symbiotic simulation systems is still relatively new and only a limited amount of literature is available, especially with ERP integration. This is a cross-disciplinary subject area encompassing simulation modelling, decision support, data fusion, man-machine interface and automatic control engineering (Lozano et al, 2006). Whilst traditional simulation has been standard practice in Ford Motor Company for over five decades, symbiotic simulation offers better prospects for enabling real-time planning, foreseeing real-time problems and proffering solutions, delivering performance improvements, making it possible to adapt to sudden and unexpected events, improving aspects of safety and security of the physical system and serving as operational decision support tools.

Although simulation has been identified as the most appropriate technique to generate and test out possible execution plans, it suffers from the drawback of long cycle times for model update, analysis and verification. It therefore becomes difficult to carry out prompt "what-if" analysis to respond to abrupt changes in these systems. Symbiotic simulation solves this problem by having the simulation and the physical system interact in a mutually beneficial manner (Low et al, 2005).

The progress made to date from a project management standpoint is a testament to the agile credentials of Ford Motor Company and its commitment to driving innovation in every aspect of the business, whilst forging meaningful partnerships with academia and other research institutions.

7. SUMMARY AND CONCLUSIONS

Ford Motor Company has a 113 year history and is one of the biggest and most successful automobile manufacturers in the world. It is therefore not difficult to understand why the adoption and implementation of any innovative technological concept would require the utmost diligence in order to surmount the challenges and impediments posed by an organisational culture entrenched by a corporate climate of long-term accomplishments, sheer size and values. The pitfalls inherent in approaching any such endeavour purely from a technical viewpoint without taking into account these characteristics would become apparent very quickly, with the likelihood of this resulting in the abortion of the project, regardless of how well-intentioned and beneficial to the company it might be.

The experiences outlined in this paper are intended to signpost some of these challenges, share the lessons learned and highlight the strategy that has guided the progress of the symbiotic simulation research project at Ford Motor Company. The contribution of this work lies in its value as a case study on the ERP-based implementation of symbiotic simulation on an automobile engine production line. To the best of our knowledge, this has not yet been successfully achieved as at the time of writing.

The scope of this work is limited to Ford Motor Company, but our thesis is that the challenges, opportunities and prospects are generic enough to be deemed applicable to similar project undertakings in automotive engine production in particular and the manufacturing industry as a whole.

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PROCESS DRIVEN FRAMEWORK FOR AUGMENTED REALITY IN A MANUFACTURING ENVIRONMENT

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ABSTRACT

In many domains where VR has proven its value, augmented reality (AR) starts getting recognition as a viable alternative to its more mature predecessor. Unfortunately, it has been suffering from similar challenges that VR needed to overcome. Some application domains, e.g. manufacturing, pose additional barriers preventing AR for widespread. So far in manufacturing, AR applications have been built with a specific task in mind and were mostly prototypes. In this paper, we focus on an AR application for process control with an emphasis on a generic process structure. This approach would allow to reuse the AR application in a range of processes which could be easily defined by a limited number of parameters. To test this approach, we developed an AR application using off-the-shelf components and applied it to a machining process in an actual manufacturing center. We used up to thirteen parameters to define each step of the process and provide input to the algorithm driving the AR application. We established that the experience of developing a process-centric AR tool was feasible and allowed the user to leverage just-in-time information available through the AR display.

Keywords: augmented reality, process control, process monitoring, advanced manufacturing

1. INTRODUCTION

Many domains, including manufacturing, have benefited from the introduction of virtual reality (VR). Before this could happen, researchers and industry had spent decades on maturing the technology to the point where it can now be successfully used, especially in training and education. For many years, however, it was common to oversell VR to the end user despite its very little value which had a significant impact on technology acceptance. Focusing on the technology limitations, rather than on how it could add value was characteristic for many industries. Fortunately in recent years, we have been observing a paradigm shift in the approach to this technology leading to better recognition of its potential and new applications. Unfortunately, augmented reality (AR) has been suffering from similar challenges that VR had to overcome. Promotional materials and concept videos are setting user's expectations too high. They present the technology as being capable of accommodating a variety of specialized scenarios with effortless customization spanning across various domains which in reality has not been achieved yet.

Similarly, computer-based augmentation for manufacturing applications will not follow the one-size-fits-all principle in the near future. First, manufacturing is a broad domain encompassing a large number of processes with a varying range of human activity. Second, an AR system has to be a part of the cyber-physical infrastructure of an enterprise. Since cyber-physical systems (CPS) are themselves in the initial stage of development, there is a need of defining guidelines for their implementation in the industry, taking into account the principles of Industry 4.0 (Kagermann, Helbig et al. 2013). Industry 4.0 assumes CPS integration across the whole manufacturing operation, i.e. logistics, services, and production which requires a unified system framework, which is part of ongoing research efforts (Lee, Bagheri et al. 2015). Eventually, AR systems will have to be abundantly integrated with a unified framework and be a worker's window to CPS (Kagermann, Helbig et al. 2013).

Industry 4.0 recognizes a human operator as the most flexible asset in the manufacturing environment requiring a high level of adaptiveness to ever increasing complexity of the production settings (Schmitt, Meixner et al. 2013). Under the Augmented Operator principle of the fourth industrial revolution, an operator needs to be equipped with tools which allow for monitoring of manufacturing processes from almost anywhere and, if necessary, provide guidance through. Mobile user-centered technologies with intuitive user interface are currently able to potentially fulfill this task since they already provide support when the user tackles a wide selection of problems (Gorecky, Schmitt et al. 2014). However, currently available technologies, i.e. smart-glasses and watches, smartphones, and tablets, in their majority are not designed to meet the requirements of the industrial environment.

Academia alone cannot address these issues and close collaboration with the industry is needed. In recent years, we could observe academia-industry initiatives, started to accomplish a higher level of efficiency through the introduction and adoption of industry-grade

AR, e.g., the Augmented Reality for Enterprise Alliance (thearea.org).
The research approach in this paper focuses on the development of a framework for the integration of AR for industrial process control with the aim to guide the user through a process and visualize relevant information in real-time. To test the framework, we applied it to a machining process executed at the Commonwealth Center for Advanced Manufacturing (CCAM) – an applied research center bringing universities and manufacturing industry together.

2. AUGMENTED REALITY

AR is an enhanced version of reality where digital information is overlaid over a direct or indirect view of a physical environment. Although AR is typically associated with vision, it can also refer to other senses, like audio (Mavor and Durlach 1994) and tactile feedback (Wellner 1993). In the case of visual augmentation, one can argue that only overlaying information over a direct view constitutes real AR. For some applications, however, an indirect view AR may be more beneficial to the end user than a direct. Therefore, we consider both types of AR in this paper.
An AR system typically consists of hardware, i.e. display, input devices, sensors, etc., and software and algorithms, including image, object recognition and registration.
The augmentation process is device and application dependent. Figure 1 shows its generalized version for manufacturing applications. Internal sensors gather information about the current state of the AR device and its surrounding, including visual input.

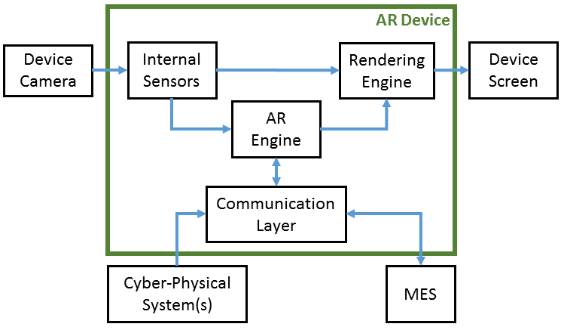

Figure 1: Augmentation Process

The heart of the system is an AR engine responsible for object recognition and registration by the means of computer vision. An AR engine is also typically used to develop an AR experience.
A communication layer is a critical component of an industry-grade AR system enabling two-way data exchange with the CPS, enterprise resource planning (ERP), and/or manufacturing execution system (MES). Connectivity with CPS includes machines and sensors, ideally through MTConnect or Open Platform Communications Unified Architecture (OPC UA). Communication with ERP/MES can be more challenging since those systems tend to be enclosed and an AR system needs to be tailored to accommodate their specificity. Some information may need to be updated at a higher frequency, e.g. machine state, whereas certain information, e.g. CAD model, is not required to be updated at such high frequencies.
The AR engine generates digital content which is then rendered over a video feed or on a semi-transparent surface, depending on the form factor.

2.1. AR Form Factor Classification

There are currently several AR form factors available on the market: head-mounted displays (HMDs), projection-based, and handheld. HMD is a display device worn on the head or as part of protective gear, which has a small optic display in front of one (monocular) or each eye (binocular). HMDs for AR applications come in three forms: Video see-through, where users cannot directly see the physical world, and instead see a live video which is sampled by a camera; A miniaturized video see-through, which allows users to directly see the physical world via a live video sampled by a camera and presented on a miniaturized display; and an optical see-through, which possesses the capability of reflecting projected images on the real world environments as well as allowing the user to see through the display.
A hands-free display is one of the most notable advantages of HMDs. However, interaction with the AR experience may require manual input from the user. Video see-through HMDs provide higher level of immersion than the other two types and controls the user's entire field-of-view (FOV). However, wearing video see-through HMDs may affect a user's visual acuity and cause simulation sickness. This type of HMD may also be uncomfortable for the user due to the hardware's weight and bulkiness. On the contrary, miniaturized video and optical see-through HMDs are typically lightweight and do not cause simulation sickness. However, miniaturized video see-through devices are characterized by lower FOV and require the user to change focus. Limited computational power of this form factor cannot be neglected since this implementation would require to display 3D content and a smooth user-device interaction via a haptic device. Miniaturized displays have also lower resolution when compared to other devices. Optical see-through HMDs, on the other hand, suffer from narrow FOV which requires the user to be looking almost directly at the area of interest. Due to the hardware design, the overlay image is never fully opaque which allows to see the environment behind the computer-generated object (Azuma 1997).
Another AR form factor is projection-based where a projector is used to project information on real objects. This form factor may be beneficial when the environment is large. Similarly to HMDs, it is a hands-free display and the user does not need to switch focus between the image plane and the real environment with optionally multiple users. This form factor, however, requires an environment with low light-intensity and is

not highly mobile. It also requires a physical object for image projection so it may be hard to generate virtual objects midair (Cebulla 2013).
The last form factor, handheld, is very popular since it includes smartphones and tablets where the live video is sampled by the camera. Handheld devices are typically affordable, ubiquitous, do not restrict user's FOV, have multi-sensor and network capabilities, and are rich in on-board computational resources. Unfortunately, such a device needs to be held when in use which limits the user's manipulation capabilities for the task at hand. Special attention to the security of such devices needs to be considered when implementing their use in industrial settings in order to minimize any compromise of the data being used while operating such devices.

2.2. Safety

Safety is a major concern in the manufacturing industry and the magnitude of general industry safety standards can be overwhelming. Although the use of AR is expected to contribute to an increase in safety (McCutcheon, Pethick et al. 2016), it could also be a source of safety violations. Furthermore, AR equipment needs to meet industry safety standards and requirements.
To better illustrate the case, in the US, many organizations require their workers to wear protective eyewear which typically has to be in compliance with industry standards and the Occupational Safety and Health Administration (OSHA) regulations. Currently, the majority of HMDs, especially see-through, are not certified for the shop floor.
View management is another aspect that can negatively influence a worker's safety. Industrial environments are typically dynamic and require situational awareness. It will become even more critical with widespread of autonomous robots and machines. Computer generated content in AR, e.g. 3D models and annotations, can potentially overwhelm a user's view due to the amount of information AR systems can provide. Some researchers have discussed the need of actively managing a user's interface and digital content to avoid confusion and eliminate any safety issues.
Höllerer *et al*. (Höllerer, Feiner et al. 2001) proposed three user interface design techniques, i.e. information filtering, user interface component design, and view management, to provide a more intuitive interaction and better organized digital content. For information filtering, the authors leveraged the concept of a situated user interface that depends on the user's location, physical context, tasks, and objectives, which are also the same three key elements in AR applications for manufacturing.
Motivated by the need to improve readability and intelligibility of the annotations, Makita *et al.* (Makita, Kanbara et al. 2009) developed a system which obtains positions and shapes of target objects, and penalize location of annotations that overlap and/or occlude the target. Not without importance was the distance between the annotation and the object in the current and sequential frames. The system was supplemented, besides a video camera, by an infrared camera to detect people in the scene and calculate how much the region in a frame was occupied by the user. The functionality proposed by the authors would decrease the risk of annotations blocking a user's view in busy environments. However, this approach focuses only on people, whereas an AR system deployed in industrial settings would need to be able to detect autonomous machines and robots.
Tsai (Tsai 2013) recognized a similar problem in AR applications to transportation and proposed a safety view management mechanism to display information on AR devices in a safer manner. In this approach, a region on a device screen where labels or annotations can be displayed without overlapping moving objects is continuously calculated increasing the user's safety.
The aforementioned safety issues are mostly applicable to optical and video see-through HMDs. A video see-through HMD may introduce an additional set of safety problems. Due to the typical characteristics of this form factor, the display takes up virtually the entire user's field-of-view (FOV) with the casing closely adhering to user's face. In this way, a user's peripheral vision is significantly limited, hence he or she may not have full situational awareness.
Another safety concern associated with this form factor is the complete loss of vision if the device runs out of power or malfunctions. The user may not always be able to react immediately, e.g. while performing a manual task.
Misalignment between the camera(s) (typically one camera per eye) and the user's perspective (Kanbara, Okuma et al. 2000, Colgan 2015, Samini and Palmerius 2015), in the case of device-perspective rendering (DPR), can also be a causative factor behind safety issues. When an AR application is being developed, there are typically three camera types, i.e. virtual, physical, and biological, that need to be considered (Colgan 2015). Although placing the cameras at the same height as user's eyes, i.e. biological cameras, is not currently problematic, separation between two cameras of each type, except virtual cameras, cannot be freely changed. This discrepancy can lead to a user's incorrect conviction concerning his or her position in the physical world. Therefore, video see-through form factors should not currently be used in industrial settings.
User's safety while using AR in industrial settings is an undisputable concern. However, safety of CPS should also be considered by the stakeholders. We can expect that AR devices used in the manufacturing domain will be connected to CPS under the Internet of Things (IoT) paradigm. However, there is no consensus how to best implement security in IoT at any IT level (River 2015). Daniels (Daniels 2014) discussed cybersecurity implications of AR applications from the perspective of an end user, i.e. geo-location services, always-on data input, and social networking and media. However, these implications have been known since the introduction of

modern mobile devices. They are also inherited by AR especially as far as the general audience is concerned. Since AR in manufacturing is information driven, it would be more appropriate to look at factors that could lead to data compromise.

3. METHODS & MATERIALS

An AR system typically consists of a hardware and a software component. In this section, we focus on the devices used and the AR application we developed to accommodate a manufacturing process.

3.1. Hardware

To better understand how various form factors fit modern manufacturing environment, we chose a Nexus 7 (ver. 2013) and an Epson Moverio BT-200, both powered by Android, which represent a handheld and HMD optical see-through form factors, respectively. The camera and user input method are one of the most important factors influencing the performance of AR applications. The tablet camera has 1920x1200 resolution, whereas the glasses is limited to 640x480. In the tablet's case, the user interacts with the system mainly through the touchscreen, whereas the glasses are equipped with a separate touchpad. Additional input is possible through built-in sensors and microphone. The glasses are also characterized by a limiting 23º FOV.

3.2. Software

The AR application was developed in Unity (Unity Technologies, San Francisco, CA, USA) – a cross-platform game engine, supplemented by Vuforia (PTC, Needham, MA, USA) – an AR Software Development Kit (SDK). The application consisted of four main components: a rule-based process control framework, communication, pattern recognition, and GUI.

In the application, each manufacturing process is defined by a set of steps that need to be executed in a particular order. Each step is defined by up to thirteen step parameters depending on its type and can be triggered by either manual input, recognized feature, and readings from a machine. Some process steps may consist of a sub-process which does not have any major implications on the algorithm other than for time reporting purposes. The parameters are as follows (optional and dependent parameters marked with an asterisk):

- Step name (string)
- Subprocess (integer)
- Displayed text (string)
- Object to display (2D/3D object)*
- Manual input required (y/n)
- Sensory input required (y/n)
- Sensory input name (string)
- Parameter type (string/number)*
- Triggering values (string/number)*
- Operation type (less than, greater than, equal)*
- Name of the object to track (string)*
- Text over the indicator (string)*
- Indicator position (vector)*
- Next step (integer)

To reduce the number of parameters, some of them can inform the processing algorithm by their mere presence how to proceed. For instance, if the sub-process parameter has any value, it indicates that the entry is part of the process step.

In addition to the parameters, the data structure stores the step completion time which can be uploaded to MES for further manufacturing process analysis.

Since some steps rely on object recognition, we used Vuforia's capability to recognize and track planar images, also known as image targets. A set of images corresponding to equipment and other significant locations on the shop-floor was taken and converted to image targets. The conversion process extracts salient features that are later tracked within the camera's frames. The target will be tracked as long as the target is at least partially visible and tracking is lost once not enough target features are available. However, Vuforia allows the application to continuously learn its environment by detecting other features beyond those in the image target, also known as extended tracking. However, not every image can serve as a stable target. Each target is rated from 0 to 5 based on its quality. To achieve a high rating, images should be rich in detail, have good contrast, and exclude repetitive patterns, because the system looks for sharp, spiked, and chiseled details. **Error! Reference source not found.** shows examples of high (left) and poor (right) target quality with identified salient features.

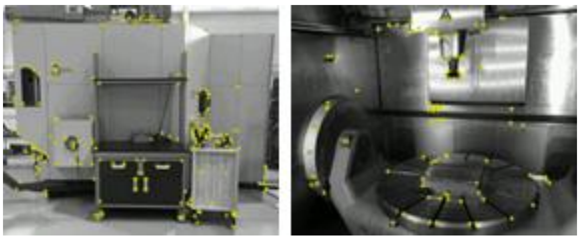

Figure 2: Target Quality of AR Image Targets: High (left) and Poor (right)

To better understand limitations of image tracking, we performed simple tests using the aforementioned devices. In the first test, we gradually covered an image target of high quality with uniformly distributed features and measured the amount of the target covered when tracking was lost. In the second test, we gradually uncovered the image target and measured the amount of the target uncovered when tracking was established. We also measured the angular position of the camera with respect to the target when tracking was established and lost.

The tests indicated that tracking was lost when 80% (tablet) and 70% (glasses) of the image target was covered, respectively. The image target was detected when between 20% (tablet) and 45% of the image target was uncovered, respectively (**Error! Reference source not found.**). To detect an image target, the camera needed to be approximately perpendicular with ±15º deviation.

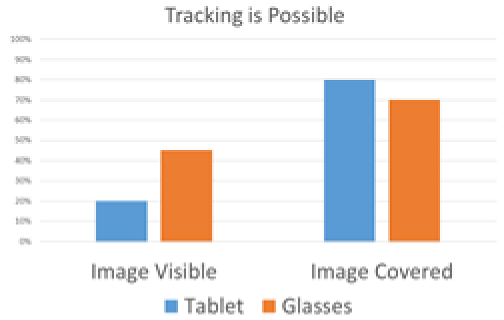

Figure 3: Range of Tracking Ability Between Tablet and Glasses

A simple 3D model of the shop-floor can be used to place the image targets matching the locations of interest around the facility. For items that are mobile, like shop carts or parts, object targets can be created by scanning physical objects. This step allows for registration of the physical and virtual environment. Unless new equipment is added, this task has to be performed only once. A 3D model is used for better user's spatial perception and the whole process can be executed at run-time by providing spatial relative correspondence between image targets. Image target themselves can be stored in a remote location which allow for the ability to edit and substitute image targets without any action from the user.
Since AR applications typically run on mobile devices with limited computing power and storage, communication with databases and sources of data is an important feature. We leverage Extensible Markup Language (XML) for data exchange since it is both human- and machine-readable, readers and writers are easy to implement, and used by MTConnect. We set up a simple web server *in lieu* of MES to store process information and to which real-time machine data was sent.
When the application starts running, the user is prompted to choose an outstanding order. Each order has an associated list of steps that needs to be executed by the worker. Then, the processing algorithm (**Error! Reference source not found.**) reads in the first step in the process. Based on the process step parameters, the type of the step is identified and the algorithm utilizes related parameters to run the scenario. To avoid false step completion reporting, steps utilizing tracking require the user to provide confirmation.

3.3. Case Study

To test whether the application and chosen form factors, and, to be more precise, the chosen hardware can accommodate work in a manufacturing environment, we applied the proposed tools to a machining process at CCAM. The process was augmented to accommodate the specificity of CCAM members' operations. The process was developed with assistance of an experience machinist and consisted of the following steps:

1. Choose order (manual)
2. Localize raw part pickup area (tracking)
3. Localize raw material (tracking)
4. Localize assigned machine (tracking)
5. Fixture part (manual)
6. Choose program file (manual)
7. Start machining (sensory)
8. Machine (sensory)
9. Remove from fixture (manual)
10. Inspect part (manual)
11. Metrology lab (tracking)
12. Generate report (manual)

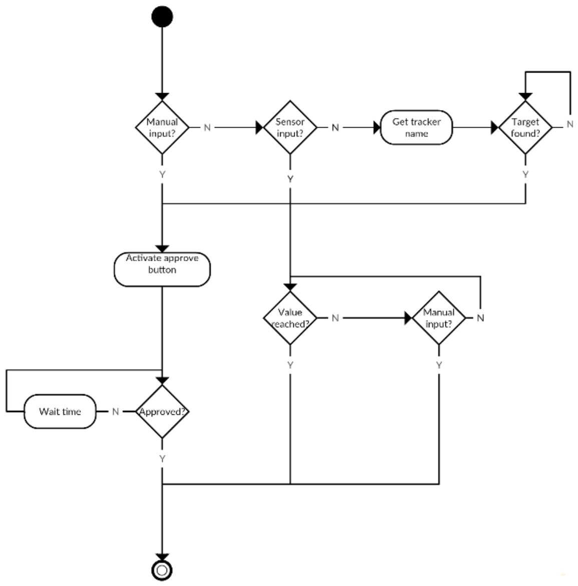

Figure 4: AR Application Algorithm

Process step #8 consists of sub-steps triggered by M01 program stops, included in the CNC program generated to mill a pocket in a cube. Two M01 commands are related to tool wear measurements and one in between requires the machinist to adjust the fixture. All stops were introduced to the program for testing purposes but the user is required to take action based on the system's recommendation and to resume program execution. Additionally, process step #10 consists of three sub-steps requiring the machinist to measure indicated features in the finished part.
A section of the shop-floor was modeled using simple geometric solids indicating location and bounding box of equipment and shop-floor important features (**Error! Reference source not found.**). Respective image targets were created by taking photographs of the equipment. All image targets had the augmentation rating of four and up. The image targets were placed at their respective locations. It is important to indicate that neither the image targets nor the shop-floor model is visible to the user while using the application.
For the purpose of this project, we set up a remote server to store all process-related information including live machining data obtained through an OPC server connected to a Hermle c42 – a high-performance 5-axis CNC machining center.

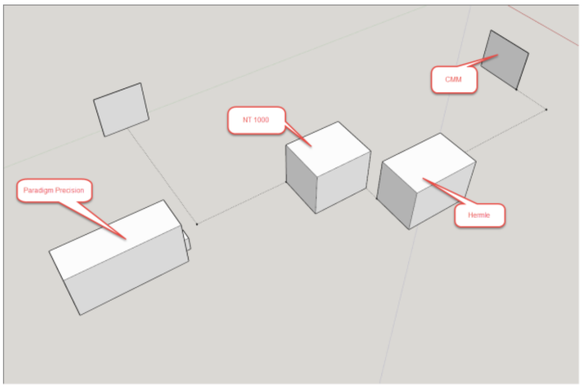

Figure 5: Simplified 3D Model of the Environment

4. RESULTS & DISCUSSION

In this section, the performance of the application and form factors is analyzed. The focus is on tracking and communication in industrial settings, identifying opportunities and gaps in the implementation of AR technology. We ran the application multiple times at different times of day to investigate the influence of lighting conditions.

4.1. Tracking

The majority of image targets were recognized almost instantaneously when the tablet was used. The glasses required shorter distance and almost perpendicular position of the camera to the object. The tablet also provided more stable tracking. This difference in performance can be attributed to the much higher resolution of the tablet's camera.

The image target recognition approach is also sensitive to lighting conditions. Since the illumination of the CCAM's shop-floor is provided by lamps and sunlight, the conditions can change throughout the day. In some cases, during sunny days, the camera was blinded if a window was in the current camera's frame. Again, this phenomenon was more prevalent on the glasses.

Since the image target tracking relies on searching for known patterns in the current camera's frame, shop-floor elements used in this process need to stay relatively invariant. Additionally, if several pieces of the same equipment are available across the facility, an incorrect one can be falsely recognized.

Figure 6: AR Display Using Image Tracking

Radio-frequency identification (RFID) tags as supplementing, and in some cases replacing visual tracking could improve object tracking since for some cases only the general user's proximity is needed to detect what information to display.

4.2. Communication

To enable data exchange, we leveraged the existing communication network at CCAM. Machining data was obtained via an OPC server and converted to XML format, and streamed to the server we had set up for this project. We also implemented an MTConnect data reader and connected it to the test server for testing purposes. The user can see a parameter of his choice (**Error! Reference source not found.**) even when he or she is away from the machine.

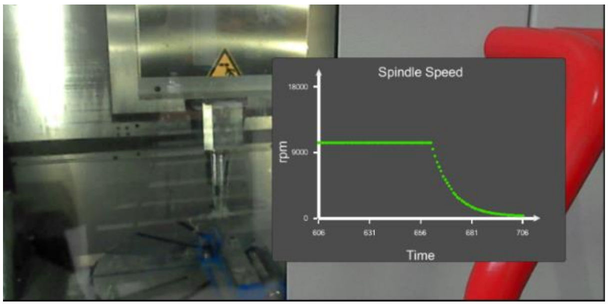

Figure 7: Live Process Information on AR Display

The machinist can also receive critical process-related information once available on the server. In our case study, the application retrieved images of tool wear and the related measurement during M01 stops (**Error! Reference source not found.**).

Figure 8: Server Provided Process-related Information on AR Display

4.3. Content

Providing digital content and information under the just-in-time paradigm is one the most important benefits of using AR in industrial settings. Our application mostly relies on live process information in a textual and numerical form, which is relatively easy to manage in AR. Also, retrieving images is not problematic since there is a lot of widely accepted formats, e.g., jpeg and png. A challenge arises when it comes to handling CAD data. There are many CAD packages being used in the manufacturing domain, each having its own method of describing geometry. In our case, a 3D model of the raw part was created in Siemens NX which uses its own proprietary format which we later converted to FBX – a common format for the Autodesk software family.

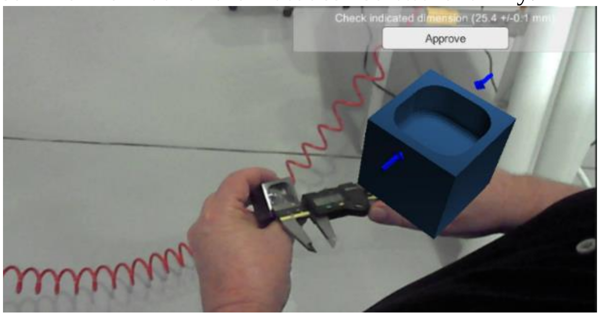

Figure 9: CAD-based 3D Content on AR Display

Businesses incorporating AR will need to provide at least geometric models in one of the standardized file formats, e.g. VRML/X3D. Providing 3D models in these formats is already being practiced by some organizations. This way, workers on the shop-floor can view the part through a regular internet browser. This approach can be also leveraged by AR applications.

4.4. Form Factors

Tests showed that both, handheld and optical see-through HMD, form factors have the potential for industrial applications. They also present limitations to the extent AR could be used.

The majority of the users found the tablet easier to work with since they were already familiar with this form factor. The glasses, on the other hand, required the user to spend some time on learning how to interact with the hardware through the touchpad.

The tablet provided better screen resolution with easier to read text and much better contrast than the glasses. Because the glasses provided a smaller area to display information and digital content, when there too many items displayed, it obstructed the user's view even with limited opacity which can be an issue when used in industrial settings.

The tablet allowed the user to wear safety eyewear, whereas it was not possible to fulfill safety requirements while wearing the HMD.

Both devices require recharging every several hours depending on how much they are used which can be a limiting factor for extended use on the shop-floor.

As far as the glasses are concerned, the scale of the digital content does not match the FOV scale of the real environment, impacting how much information may be displayed at one given time. It is not possible to apply a fixed scaling factor since this phenomenon depends on the distance between the camera and the augmented feature. This is also true for the tablet, however, since the real and augmented world is viewed through the tablet's camera FOV and shown through the tablet's higher resolution display, this issue is not as evident. Newer generations of HMDs could benefit from being equipped with depth cameras, which can greatly compensate for this problem.

5. CONCLUSIONS

In this paper, we investigated the use of AR in industrial settings due to the growing popularity of this technology. We identified several challenges that can affect AR adoption in the manufacturing domain, i.e. robust tracking, communication, content, form factor, and safety.

We developed an AR application for process control using Unity, Vuforia AR SDK, and off-the-shelf hardware to test whether it is possible to provide the user with additional information and content under a just-in-time paradigm, he or she would not have access to otherwise.

Our focus was also on creating a generalized framework for encoding process steps which would allow quick process definition and execution within the AR application. Each process step is defined by up to thirteen parameters which are also input parameters for the algorithm driving the application.

We tested our application at CCAM by applying it to an existing process – machining. The application guided the machinist through the process and provided live process information through an AR form-factor.

Both form factors used during testing exposed associated potential benefits and drawbacks. However, with a rapid progress in AR devices a lot of challenges will be mitigated in the near future.

Advances in enterprise interoperability and ontological context-awareness, which is the next step in our research, will have a major impact on integration of AR with a manufacturing organization.

ACKNOWLEDGMENTS

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A BUFFER ALLOCATION PROBLEM IN AUTOMOTIVE BODY SHOP

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ABSTRACT
Body shop in an automotive factory consists of many sub-lines which are highly automated transfer line, and the sub-lines are merged in many assembly operations. To design a body shop, the layout concepts based on welding technologies, the part transfer policies in sub-lines, and the buffer allocation problems should be considered and optimized. In this study, we will suggest guide lines for designing a body shop using simulation experiments. The major concerns are which sub-line should be decoupled and how to distribute the limited total buffers in the layered build layout to increase the production rate near to that of modular build layout.

Keywords: workstation design, work measurement, ergonomics, decision support system

1. INTRODUCTION
The body shop of an automotive factory is the typical manufacturing system which consists of many assembly operations and the concept of layout is a flow lines (or transfer lines). Moon et al. (2006) explain that the body shop is divided into 15~20 sub-assembly lines in general. In each sub-line many welding operations are processed and the welding operations are assigned to many serial stations considering the line balancing. Thus, more than one welding operations are assigned to a station.
Generally, no buffer is allowed in a sub-line because available space is limited and they want to reduce WIP (Work in Process). On the other hand, finite buffers are allowed between two successive sub-lines for reducing the risk caused by and unexpected blocking and starving. The electric monorail system (EMS) is usually installed in the body shop for conveying and storing parts.
Moon et al. (2006) describe the design processes for body shops of automotive factories. Some decision makings are encountered at the initial phase of designing the body shop. The first decision is which welding method is adopted for constructing car-body (see Wang, 2014; Kim et al., 2015). There are two types of welding methods used in body shops and they are “layered build method” and “modular build method”. Figure 1 is the concept of layered build method and Figure 2 is the concept of modular build method, respectively. Some say that the strength of welded body is higher when it is assembled by the layered build method, and it also has the merit of the accessibilities of robot guns. However, the layered build method has the weakness of the over-load in the main body sub-line, and thus the longest line length is increased (Kim et al., 2015). Figure 3 and Figure 4 are the abstract layout models which adapt the layered build method and the modular build method, respectively (Wang, 2014; Kim et al., 2015; Moon et al. 2016). In their articles, the throughput of the modular build layout is higher than that of the layered build layout when transfer policy is synchronous.

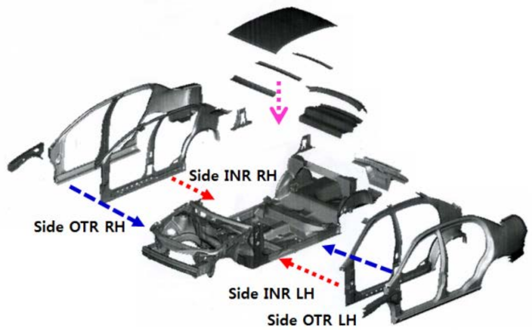

Figure 1: Concept of Layered Build Method (Kim et al. 2015; Moon et al. 2016)

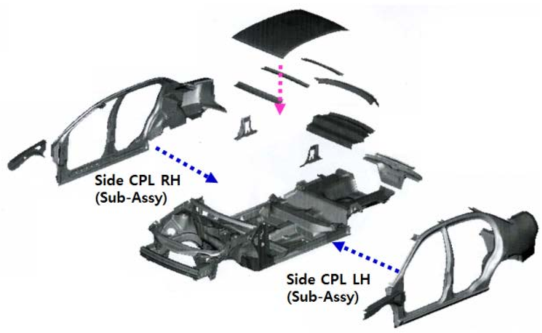

Figure 2: Concept of Modular Build Method (Kim et al. 2015; Moon et al. 2016)

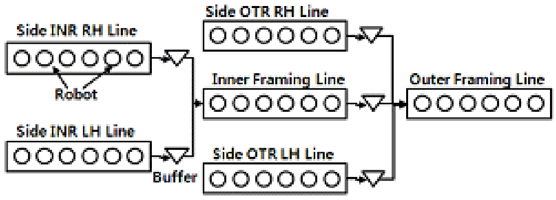

Figure 3: Abstract Layout of Layered Build Method (Wang, 2014; Kim et al., 2015; Moon et al. 2016)

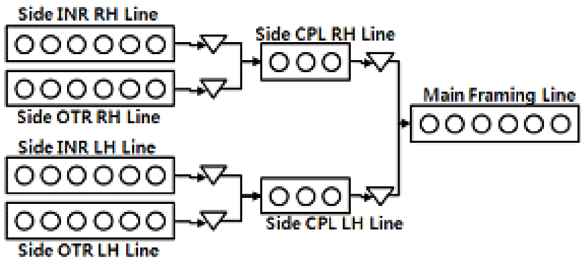

Figure 4: Abstract Layout of Modular Build Method (Wang, 2014; Kim et al., 2015; Moon et al. 2016)

The second decision is for the sub-line design and it is to determine the part transfer policy in a sub-line. Moon et al. (2016) explained that there are two types of part transfer policies which can be applied to the sub-lines with no buffer. The first one is the ‘synchronous transfer” and the second is the “asynchronous transfer”. In the synchronous policy stations are coupled perfectly by a transfer device and all parts on the stations of a flow line move to the next stations at the same time. In the asynchronous policy the transfer operation of a particular part to the next station is independent from others. There have been many researches considering transfer policies in flow lines such as Dallery and Gershwin (1992), Kalir and Sarin (2009) and Bertterton and Cox III (2012). Moon et al. (2016) compare the transfer policies in two different layouts of the body shop and assessed that the asynchronous transfer is better with respect to the throughput. However, it is known that the investment cost of synchronous transfer is cheaper and easy to control.

The third decision is how many buffer positions are required and how to allocate total buffers to buffer positions. There have been many works dealing the optimal buffer allocation problems in flow lines and assembly lines, but most of them focus on determining buffer size when buffer positions are predetermined (Powell and Pyke, 1996; Papadopoulos et al., 2013; Demir et al., 2013; Nahas et al., 2014). They considered various types of objective functions such as maximizing profit or maximizing throughput. To optimize the problem various optimization algorithms have been used such as genetic algorithm, search algorithm and heuristic algorithms.

In this study we suggest a strategy how to increase the production rate of the layered build layout by splitting a subline and allocating buffer between the split sub-lines.

2. SYSTEM DESCRIPTION

To evaluate the buffer allocating strategy the two systems introduced in Figures 3 and 4 are considered and the following assumptions are applied to these systems:

① The total numbers of welding operations (number of stations) are the same and they are assumed to be 36.
② Each sub-line has six stations, and there is no buffer between stations in each sub-line. However, in Figure 4, the Side_CPL_LH line and the Side_CPL_RH line are assumed to have only three stations for balancing the total workloads.
③ There are buffers between two sub-lines, and the total number of buffers is assumed to be the same in both models. The number of buffer locations in Figure 3 is five and in Figure 4 there are six. Thus, we assume that the buffer capacity of each buffer is six in Figure 3 and five in Figure 4, respectively, when the total number of buffers is set to 30.
④ The cycle times of all welding operations are known and constant as one time unit (minute) because a body shop is a highly automated manufacturing system.
⑤ There is only one mode of time-dependent failure for all operations and the distributions of uptime and downtime are known and the same. Exponential distributions are assumed.
⑥ There is no starvation in the first stations and there is no blocking in the final stations. The first station denotes the station that does not have predecessors, and the final station is the station that does not have successors.

An automotive manufacturer want to change its body shop layout from the modular build layout to the layered build layout because they believe that the strength of car-body is stronger and the flexibility to the model change is better when the layered build method is applied. However, Kim et al. (2015) show that the production rate of the modular build layout is slightly better than that of the layered build layout, when synchronous transfer policy is applied and the total capacities of buffers are the same. Although they assume that the total workloads of two layout systems are the same, some engineer insist that the total workload of layered build layout is greater than that of modular build layout, about 5~10% in the main welding lines. If additional welding stations are added to the current layered build layout, it is clear that the production rate must decrease.

Then, how can we increase the production rate of layered build layout to be close to that of the modular build layout? To solve the problem, we will test decoupling the Inner Framing Line (or Outer Framing Line) of the layered build layout. Figure 5 shows the example of Decoupling the Inner Framing Line in Figure 3. In Figure 5, Inner Framing Line is evenly divided into two sub-lines and the numbers of stations are three.

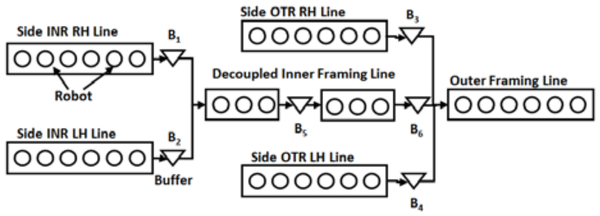

Figure 5: Decoupling Sub-line in Layered Build Layout

3. SIMULATION EXPERIMENT

For investigating the effects of transfer policies on the two layout structures, the following experimental conditions are selected: (the efficiency of isolated station is defined as in equation (1), where MTTF denotes the mean time to failure and MTTR denotes the mean time to repair.

$$e = \frac{MTTF}{MTTF+MTTR} \tag{1}$$

- The failure distribution is the exponential and MTTF and MTTR are 190 and 10, respectively, and thus, the value of e is 0.95
- Total buffer capacity (TB) is set to 30, 60, 90 and 180
- Synchronous and asynchronous transfer policies
- Layered build and modular build layouts

Simulation models are developed with ARENA™. Simulation run time is set to 330,000 time units including a 30,000 unit warmup period and the number of replications is 20. Table 2 shows the results of simulation with respect to the production rates and their 95% confidence intervals.

3.1. Decoupling Sub-line

As explained in section 2, the first scenario (S1) is to decouple the Inner Framing Line of the layered build layout (Figure 3) into two sublines (Figure 5). The second scenario (S2) is decoupling the Outer Framing Line in Figure 3. Then, the number of buffer positions is six and it is the same to that of the modular build layout. The buffer capacity of each buffer location is five. These two scenarios are referred to Latered_S1 and Layered_S2, respectively in Table 1 and Table 2.
Table 1 shows the simulation results when applying the asynchronous transfer policy, and Table 2 is the results of the synchronous transfer policy. In these tables 'Moon' is the results obtained in Moon et al. (2016). Dev1 and Dev2 mean the deviation between two scenarios and calculate as follows.

$$Dev1 = \frac{(PR_{Layered\_Moon} - PR_{Modular\_Moon})}{PR_{Modular\_Moon}} \times 100$$

$$Dev2 = \frac{(PR_{Layered\_S1} - PR_{Modular\_Moon})}{PR_{Modular\_Moon}} \times 100$$

Table 1: Production Rates (Asynchronous)

Scenario (Layout)		Total Buffer Capacity 30	60	90	180
Modular	Moon	0.4154	0.4943	0.5439	0.6212
Layered	Moon	0.4086	0.4835	0.5308	0.6054
	S1	0.4122	0.4905	0.5396	0.6155
	S2	0.4034	0.4805	0.5300	0.6082
Dev1		-1.63%	-2.18%	-2.41%	-2.55%
Dev2		-0.76%	-0.76%	-0.80%	-0.92%

Table 2: Production Rates (Synchronous)

Scenario (Layout)		Total Buffer Capacity 30	60	90	180
Modular	Moon	0.3756	0.4709	0.5279	0.6137
Layered	Moon	0.3643	0.4562	0.5112	0.5949
	S1	0.3744	0.4680	0.5238	0.6074
	S2	0.3597	0.4540	0.5112	0.5981
Dev1		-3.02%	-3.13%	-3.17%	-3.06%
Dev2		-0.33%	-0.62%	-0.78%	-1.03%

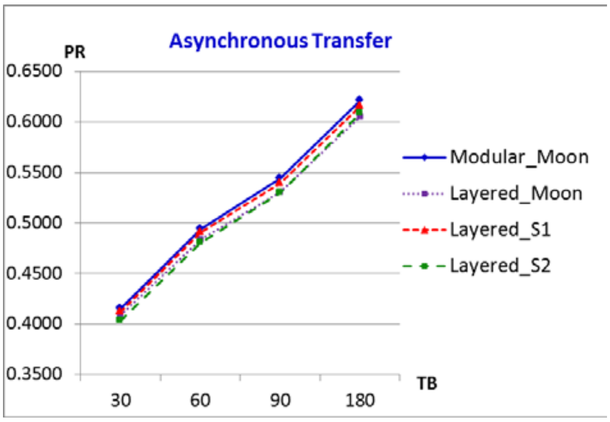

Figure 6: Behavior of Production Rates (Asynchronous)

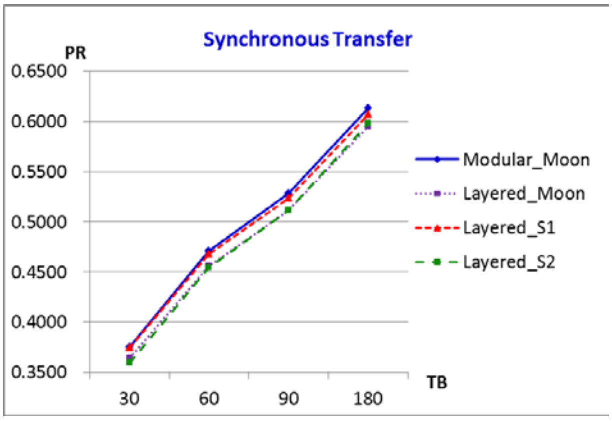

Figure 7: Behavior of Production Rates (Synchronous)

From the simulation experiments we observed that Layered_S1 is effective on the increasing production rate. The production rates become close to those of Modular_Moon. The improvement is higher in the synchronous transfer policy than in the asynchronous transfer policy. However, the decoupling strategy for Outer Framing Line (Layered_S2) shows negative effect. It means that the production rates are rather lower than those of Layered_Moon scenario when the values of TB are 30, 60 and 90. Thus, we don't have to consider Layered_S2 anymore. Figures 7 and 8 show the behaviors of production rates clearly.

3.2. Additional Station

As mentioned in Session 2, there is an opinion that the total workload of layered build layout is greater than that of modular build layout, about 5~10% in the main welding lines. Thus new scenarios are designed for simulation experiments. At first four workstations are assigned to two decoupled sub-lines (scenario S3) and then five workstations are assigned (scenario S4) based on Layered_S1and the same total buffer capacities. The total workloads of S3 and S4 are 38 and 40, respectively. The simulation results are shown in Tables 3 and 4.

Table 3: Effect of Additional Stations (Asynchronous)

Scenario (Layout)		Total Buffer Capacity			
		30	60	90	180
Modular	Moon	0.4154	0.4943	0.5439	0.6212
Layered	S1	0.4122	0.4905	0.5396	0.6155
	S3	0.3970	0.4757	0.5261	0.6063
	S4	0.3849	0.4620	0.5123	0.5942
S1-S3		0.0152	0.0149	0.0135	0.0092
S3-S4		0.0121	0.0137	0.0138	0.0121

Table 4: Effect of Additional Stations (Synchronous)

Scenario (Layout)		Total Buffer Capacity			
		30	60	90	180
Modular	Moon	0.3756	0.4709	0.5279	0.6137
Layered	S1	0.3744	0.4680	0.5238	0.6074
	S3	0.3571	0.4519	0.5095	0.5975
	S4	0.3408	0.4357	0.4941	0.5850
S1-S3		0.0173	0.0160	0.0143	0.0098
S3-S4		0.0163	0.0163	0.0154	0.0125

We anticipate that the assignment of additional stations to the decoupled sub-lines will not critically influence on the production rate because the number of stations is increased to four from three and the maximum number of stations in a sub-line is six. However, simulation results show that the effect of increasing station is not negligible. The decrements of production rates are slightly bigger in the synchronous policy rather than asynchronous policy.
Figures 8 and Figure 9 show the behaviors of production rates for scenarios S1, S2 and S3 when the total buffer capacity increases from 30 to 180 and two different transfer policies are applied.

4. CONCLUSIONS

In this study we considered the possibility that could make the production rate of the modular build layout and that of the layered build layout equivalent by simulation experiments. We tested a decoupling strategy to the main assembly sub-lines in the layered build layout, e.g., Inner Framing Line and Outer Framing Line. The decoupling of the Inner Framing Line and allocating additional buffer location between the decoupled sub-lines was an alternative for improving production rate of the layered build layout. We also investigated the behaviors of production rates when additional station is assigned to the decoupled sub-lines, because there is an opinion that the total workload of the layered build layout is greater than that of the modular build layout.

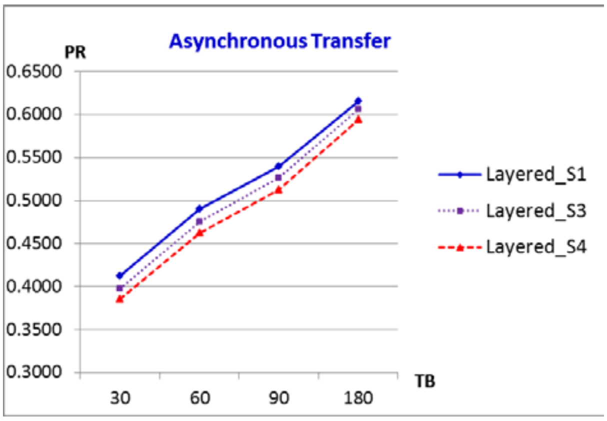

Figure 8: Effect of Additional Stations (Asynchronous)

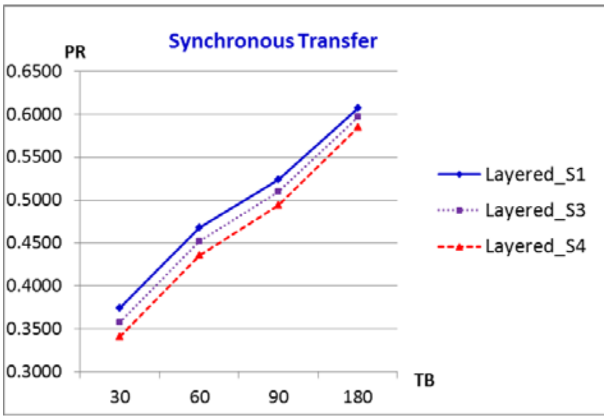

Figure 9: Effect of Additional Stations (Synchronous)

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Modelling Trauma Physiology for Large Crisis Management

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ABSTRACT

In recent years, there has been a rise in Major Incidents with big impact on the citizens health and the society. Without the possibility of conducting live experiments when it comes to physical trauma, only an accurate in-silico reconstruction allows us to identify organizational solutions with the best possible chance of success, in correlation with the limitations on available resources (e.g. medical team, first responders, treatments, transports, and hospitals availability) and with the variability of the characteristic of event (e.g. type of incident, severity of the event and type of lesions).

Utilizing modelling and simulation techniques, a simplified mathematical model of physiological evolution for patients involved in physical trauma incident scenarios has been developed and implemented. The model formalizes the dynamics, operating standards and practices of medical response and the main emergency service in the chain of emergency management during a Major Incident.

Keywords: predictive models for adverse outcomes; personalized patient treatment; health monitoring applications

1. INTRODUCTION

It is today clear that the occurrence of Major Incidents (MIs) – situations where available resources are insufficient for the immediate need of medical care – has increased significantly parallel to the technical and economic development in the world (Lennquist S., et al., 2012). The World Disaster Report 2007 showed a 60% increase in the occurrence of incidents defined as major during the decade 1997-2006 (Klyman, Y., Kouppari, N., Mukhier, M., 2007). During the last decade, the reported deaths from such incidents increased from 600,000 to more than 1,200,000 and the number of affected people increased from 230 to 270 million (Klyman, Y., Kouppari, N., Mukhier, M., 2007). MIs have previously been considered as low probability events that might inflict bodily harm, incapacitation, or even fatalities, and generally have a big impact on the citizens and the society (Smith, E., Waisak, J., Archer, F., 2009). The main causes of this increase have been recognized in (Frykberg, E.R., 2002): the increase of global population; the escalation of natural disasters, due to global warming and climate change' ; the significant amounts of flammable, explosive, chemical, and toxic agents which are produced, transported on roads and railroads, and used every year; the global terrorism (e.g., chemical warfare agents (CWA), biological warfare agents (BWA), and radiological and nuclear particulate hazards); the continuing urbanization, which has resulted in an increasing number of people living or gathering together for public events in crowded areas. Such areas are also potential targets for terrorist attacks or constitute a risk in themselves, because, it can be difficult and time-consuming to evacuate a large number of people from physically constrained areas (e.g., in case of structural collapse or fire).

Parallel to the significant increase of MIs, the vulnerability of our health care system to such situations has increased: increasing demands on efficiency reduce or eliminate the "resilience capacity" for high loads of casualties (Lennquist S., et al., 2012).

The goal of the health care system during the occurrence of an MI is to reduce or eliminate loss of life and health, and subsequent physical and psychological suffering (Lennquist, S., 2003a).

The achievement of such a goal requires two actions (Lennquist, S., 2003a):

1) Relocation of available resources to where they are most needed, and rapid mobilization of additional resources (personnel and materials);
2) Optimal utilization of available resources through accurate priorities between patients

and measures and through the use of simplified methods for triage, treatment and transport (Lennquist, S., 2003b).

Relocation and mobilization of resources can be enhanced through the introduction and proliferation of good and accurate mathematical models to manage incident medical response (Walter F., Dedolph R., Kallsen G., et al., 1992), for example to simulate physiological value, predict adverse outcomes and personalize the treatment of the patients.

Advanced simulation models can illustrate all components in the chain of MI management (e.g., patient evolution, triage, treatment, transport, and hospital) and aim at developing and ensuring resilience capacity. The improvement of resilience and the better integration of health care systems in real operations will enhance the safety and security of citizens.

2. METHODS

Utilizing modelling and simulation techniques, we have developed and implemented a mathematical model for the physiological patient evolution during/after physical trauma. The assessment of the peculiarities of the patient response of individual patients to medical intervention by mathematical and computer modelling techniques is a quite recent approach (O. Bouamra, M.M. Lesko, 2014), which underwent a dramatic development over the past few years (M. Hill, 2010), due to the technological progress allowing widely available computing power.

From the mathematical point of view, the patient condition is described in terms of continuous physiological variables, and the state of the system can assume infinitely many values. As illustrated hereafter, the evolution is governed by systems of Ordinary Differential Equations (ODEs) which determine the "trajectory" of the physiological (state) variables.

2.1. Taxonomy

For the implementation of a mathematical model of physiological patient evolution during a MI, the following taxonomy has been used, which involves the following classes:

- Events: an event is an accident or an incident that involves a certain amount of people. We have built an Event Library, which contains physical trauma incidents (Frykberg, E.R. 2002, Bertazzi, PA, 1989, Kales, S.N., et al., 1996, Nutbeam, T., Boylan, M., 2013):
    - motorway accident;
    - bridge collapse;
    - ship explosion;
    - train crash;
    - stadium crush;
- Lesions: a lesion is a damage or an injury that can afflict in general all the systems of the human organism. An event is liaised to a set of lesions with a conditional probability of occurrence. A Lesions Library has been built, containing physical lesions (Alywin, C.J., 2006, Moreira, L.B., et al., 1999, Binder, S., Bonzo, S., 1989, Burgess, J.L., et al, 1997, Ellis, D., Hooper, M., 2010, Greaves, I., Porter, K., 2007):
    - head trauma;
    - facial trauma;
    - chest trauma;
    - spinal trauma;
    - abdominal trauma;
    - pelvic trauma;
    - extremity trauma.
- Physiology: in agreement with the ABCDE Primary Survey and Resuscitation (Alywin, C.J., 2006), there are only five main ways to die, from fatal complication involving:
    - Airway (A);
    - Breathing (B);
    - Circulation (C);
    - Disability Nervous System (D);
    - Extra Damage or Exposure with Environmental Control (E).

  Accordingly, the patient dynamics can be described by a set of physiological variables, based on ABCDE paradigm. The set of physiological variables consists of 10 variables:
    - A1 (i.e., intact, at risk, partially obstructed, or completely obstructed airway);
    - B1 (i.e., respiratory rate);
    - B2 (i.e., tidal volume);
    - B3 (i.e., oxygen saturation, SpO2);
    - C1 (i.e., heart rate);
    - C2 (i.e., Mean Arterial Pressure, MAP);
    - D1 (i.e., Glasgow Coma Scale, GCS);
    - D2 (i.e., seizures);
    - D3 (i.e., cholinergic activity);
    - E1 (i.e., trauma, burns, and contamination).
- State Variables: the patient dynamics is described by:
    - $x(t)$, which is the current state of each variable;
    - $v(t)$ (i.e. $dx(t)/dt$), which is the speed at which each variable changes its state.
- Therapeutic maneuvers: there is a set of therapies (according to the ABCDE treatment) repairing the damage that afflicts the physiological variables. We have built a Therapeutic Maneuvers Library, which contains (Nutbeam, T., Boylan, M., 2013,

Wyatt, J.P., et al., 2012, Waldmann, C., Soni, N., Rhodes, A., 2008, Singer, M., Webb, A.R., 2009, Cone, D.C., Koenig, K.L., 2005):

- decontamination;
- oxygen;
- intubation;
- ambu-bag;
- Hyperbaric Oxygen Therapy (HBOT);
- saline;
- blood;
- vascular surgery;
- neural surgery;
- orthopedic surgery;
- tourniquet;
- respiratory drugs (e.g., bronchodilators, respiratory stimulants);
- cardio drugs (e.g., β-adrenergic agonist as adrenaline, chronotropes as atropine);
- neuro drugs (e.g., anticonvulsant drugs as benzodiazepines).

- Lesions/Maneuvers delta-alpha matrices: each lesion affects one or more physiological variables with a maximal initial damage (delta$^-$) and a maximal worsening rate per unit time (alpha$^-$); symmetrically, each therapeutic maneuver repairs one or more physiological variables with a maximal initial improvement (delta$^+$) and a maximal improvement rate per unit time (alpha$^+$). Tables 1 and 2 contain some parameter values for delta and alpha for a subset of lesions and maneuvers.
- Assets: an asset is characterized by a collection of therapeutic maneuvers. An Assets Library has been built, which contains:
  - ambulance;
  - emergency room;
  - decontamination team;
  - operating theatre;
  - police car;
  - on the scene (i.e., the absence of therapies).

The assets link the patient model to a future logistic model, which takes into account the real-time availability of the resources.

2.2. Mathematical Model

The mathematical model describes the physiological patient evolution in terms of piecewise-linear trajectories in the state space, where the patient dynamics is described by means of normalized physiological values (see previous section for more details). In the normal form of first order, the evolution of each variable satisfies the following differential equation:

$$\frac{dx(t)}{dt} = -\alpha + u(t) \qquad t \geq t_0 \qquad (1)$$

starting from the initial condition:

$$x(t_0) = 1 - \Delta \qquad (2)$$

where:

- t_0 is the start of the event;
- x(t) is the value assumed by each physiological variable at time $t \geq t_0$, when the damage of each variable starts. Each variable takes values in [0,1], where 1 is the initial healthy value, and has a lower-bound value under which the patient's health is compromised;
- $x(t_0)$ is the value assumed by each physiological variable at time $t = t_0$;
- dx(t)/dt = v(t) is the speed at which each variable changes its state;
- Δ: $\Delta \in [0,1]$ is the maximal initial damage at time t_0;
- α: $\alpha \in \mathbb{R}_0^+$ is the maximal worsening rate [relative damage/unit time];
- u(t) is a non-negative therapy component. Symmetrically to what happens for lesions, it provides instantaneous improvements Δ [relative damage] and positive healing rates α [relative damage/unit time] for some therapies and some physiological variables.

However, the event starts affecting the patient's status at (possibly) different times for each individual, causing lesions, namely reductions in the value of one or more physiological variables.

	B1 Delta	B1 Alpha	….	C2 Delta	C2 Alpha	….	E Delta	E Alpha
Head/Neck	-0.3	-1.2	….	0	-0.6	….	-0.1	-0.3
Face	-0.2	-1.2	….	0	-0.6	….	-0.1	-0.3
Chest	-0.9	-0.6	….	-0.9	-1.2	….	-0.1	-0.3
Abdomen	-0.2	0	….	-0.9	-1.2	….	-0.1	-0.3
Extremities	0	0	….	-0.5	-1.2	….	-0.1	-0.3
External	0	0	….	-0.4	-0.6	….	-0.9	-0.6

Table 1: Effects of some lesions on the physiological variables in terms of instantaneous maximum damage (in fraction) and maximum rate of worsening (in fraction/hour)

	B1 Delta	B1 Alpha	….	C2 Delta	C2 Alpha	….	E Delta	E Alpha
Oxygen	0	0.06	….	0	0	….	0	0
Intubation	1	60	….	0	0	….	0	0
Ambu bag	0.5	30	….	0	0	….	0	0
Saline infusion	0	0	….	0.2	6	….	0.2	3
Blood infusion	0	0	….	0.4	6	….	0.1	3
….	….	….	….	….	….	….	….	….

Table 2: Effects of some therapies on the physiological variables in terms of instantaneous modifications (in fraction) and of variation of the rate of change (in fraction/hour)

3. IMPLEMENTATION

To run simulations, the following functions have been preliminarily implemented in Matlab and then made available as webservices:

- GeneratePatients: this function randomly generates patients, affected by different lesions. The degree of severity of each patient can be sampled according to different (choosable) distributions: gaussian, uniform or triangular;

The architecture follows a simple client-server paradigm: the models have been implemented by means of web-services, running on a LAMP (Linux-Apache-MySQL-Php) server running on a workstation in the CNR-IASI Biomathematics Laboratory, located in the Gemelli Hospital in Rome, Italy.

- EvolvePatients: this function simulates the patients evolution from (1)-(2), with and without therapeutic maneuvers;
- TimeToDeath: this function calculates the time to death for each patient, if there is not a medical treatment with therapeutic maneuvers;
- TriagePatients: this function simulates a patients triage, based on the time to death, and gives the color code according to literature review (Jenkins, J.L., et al., 2008, Partridge, R.A., et al., 2012).

The syntax and the input-output description of each service, in terms of number and type of input-output parameters, is contained in the Web Services Description Language (WSDL), publicly available at the web address http://biomat1.iasi.cnr.it/webservices/master/webservice.wsdl. An example of Java Client calling some of the functionalities offered by the web-service is illustrated in Fig.2.

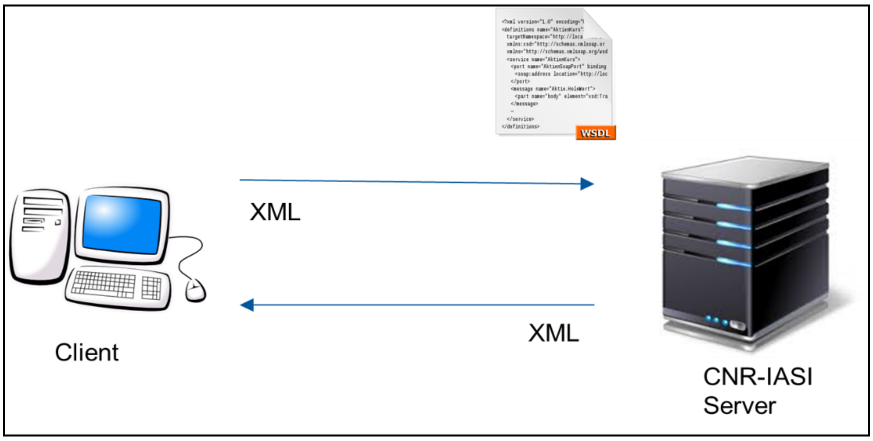

Figure 1: Scheme of the architecture used for the modeling web-services

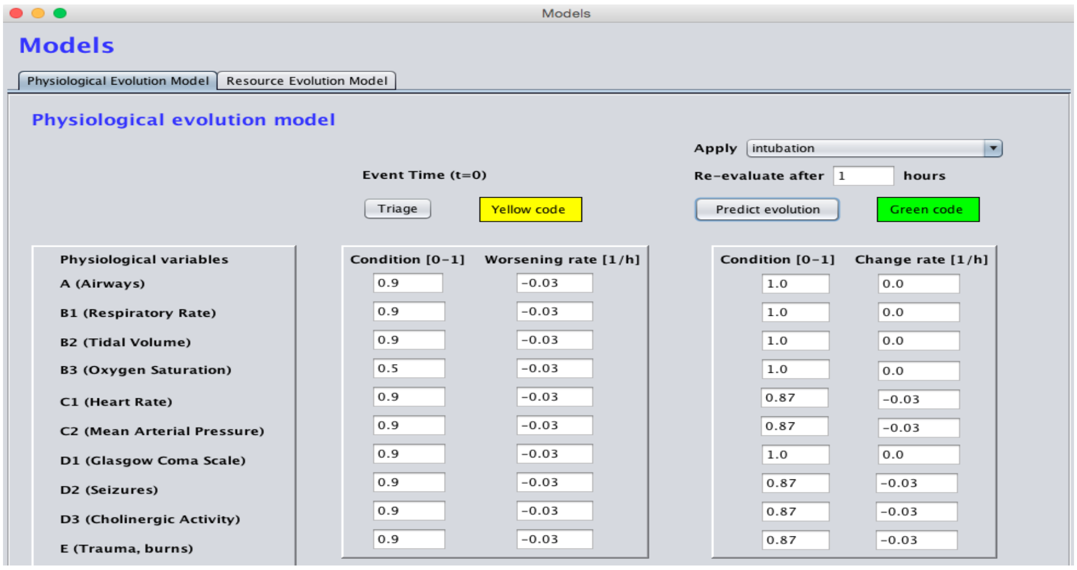

Figure 2: A Java client calling the mathematical model, involving also the TriagePatients functionality

4. DISCUSSION

We have developed and implemented a mathematical model of the physiological patient evolution during/after physical trauma events. The evolution of the value of 10 physiological variables (i.e., A1, B1, B2, B3, C1, C2, D1, D2, D3, and E1) is simulated in different physical trauma incident scenarios; the ultimate goal is to predict adverse outcomes with simplified methods for triage and personalize the treatment of the patients with available therapeutic maneuvers.

The results could provide a benchmark for potential introduction and proliferation of applications to be employed in real operation during MIs medical response, with potential improvements on the safety and security of citizens. In particular, it will allow the development of health monitoring applications aiming at: saving data remotely; producing reports on the health status of each patient; supporting decision-making during MIs, where medical staff act in limited time, under pressure, without having a second decision-making chance, outside their own medical specialties, and with high load of casualties.

The future perspective is to link this physiological patient-evolution model to a logistic model in order to: handle/request stockpiles and available resources during emergency; plan them in the preparedness phase for particular events, as mass gatherings; analyze old and new vulnerabilities (e.g., the overpopulation and how this effects healthcare) to enhance the resilience capacity and the better integration of healthcare systems. These models will be implemented in telemedicine tools to insure an interoperability standardization for medical response during MIs. Such tools could be used also during interactive training by emergency medical practitioners (which cannot be trained in real situations as MI) in order to “learn by doing”.

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DISCRETE EVENTS SIMULATION TO IMPROVE MANUFACTURING PROCESS OF JACKETS OFFSHORE STRUCTURES

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ABSTRACT
Certain measures for optimization of jacket offshore structures manufacturing are presented in this paper. By using Discrete Events Simulation, various simulation models will be developed in order to reduce flowtime per jacket, identify bottlenecks, adjust manufacturing time to due dates and minimize probability of breaking them. This simulation model will be referred to a company with limited resources involving space and work-stations.

Keywords: Offshore energy, jacket, scheduling, Discrete Events Simulation, optimization, Assembly job shop scheduling, Lean Manufacturing.

1. INTRODUCTION
Wind power has a promising future but, nowadays it is really difficult to find places with high wind speed rates without being exploited. As a solution to this problem, offshore energy causes important advantages. In an offshore wind farm, energy production is 20% larger than in land, and this is because wind speed at sea is 1 m/s bigger and surface rugosity is considerably lower.
According to EWEA (2015), a growing tendency is clearly observed when it comes to offshore energy installed in the last years, 3,019 MW of net installed, grid-connected capacity was added in 2015, 108% more than in 2014. A net addition of 754 new offshore wind turbines in 15 wind farms were grid-connected from 1 January to 31 December 2015. It is also remarkable that 3,230 turbines are now installed and grid-connected, making a cumulative total of 11,027 MW.
From every kind of offshore structures, jackets are expected to be the most used ones. According to EWEA (2015), jackets structures could have a 40-50% of market share by 2020.
It is important to mention that costs derived from this kind of structures represent a 28% of the cost of the whole wind turbine. As reported by Sun, Huang, & Wu (2012), a substantial cost reduction can be expected over the long-term through economies of scale, learning effects and R&D efforts. The experience curve concept has been widely applied to predict the future trend of offshore wind energy costs, which expresses cost reduction as a function of increased cumulative installed capacity.
As reported by Blanco (2009), when total installed offshore wind power doubles, it is estimated that the costs per kWh can decrease by between 9 and 17%. In addition, a reduction of about 40% in the manufacturing of monopiles structures is forecasted.
Levelized cost of energy of larger turbines (6 MW) supported by jackets is around 11.1 cent/kwh while 3 MW turbines with monopile structures represents a LCoE of 13.4 cent/kwh; and a LCoE of 9 cent/kwh is the offshore target by 2020.
This could only be accomplished by using new technology, specifications optimization, standardization and big volumes in supply chain as well as maintain supplier cost-out.
When it comes to jackets manufacturing, traditional construction methods are based on point-to-point strategies and big painting cabins have to be replaced with new construction strategies based on optimized installations and mass production with assembly-based fabrication (prefabricated joints, optimized weldings…). Apart from that, innovation plays also a big role involving Lean Manufacturing which derives to the optimization of the assembly process.
As stated by Kolberg & Zühlke (2015), Industry 4.0 aims for optimization of value chains by implementing controlled and dynamic production. What´s more, main processes in Lean Production are standardized, transparent and reduced to essential work. As a result, they are less complex and support the installation of Industry 4.0 solutions.
A simulation model will be developed in order to represent and optimize the construction strategy. The study case will be referred to the construction of these structures in a company with limited space, in which the fact of storing the parts of the jacket (Transition Piece TP, Jacket Upper Block JUB and Jacket Lower Block JLB) in different workshops makes it vital to analyze and schedule production activities involved. Minimizing flowtime per jacket, identify bottlenecks, adjusting manufacturing time to due dates and reducing probabilities of breaking them are the main goals of this

study. Discrete Events Simulation will be used in order to achieve this.
As a result, an important reduction will be obtained in terms of resources (workstations) and time, and, as a consequence, manufacturing costs.

2. MANUFACTURING PROCESS OF A JACKET

Manufacturing process of a jacket can be performed by means of traditional construction methods which are based on point-to-point strategies or by means of innovative methods such as fabrication by joints, which will be the one studied in this model.
This construction strategy is suitable to mass production since it consists of prefabricated joints assembled with pipes. In addition to this, manufacturing process will be modelled as a pull-system since milestones will cause fabrication to start. Moreover, main solutions of Lean Manufacturing have also been performed in the model.

2.1. Parts of a jacket

Next figures show main parts of a jacket:

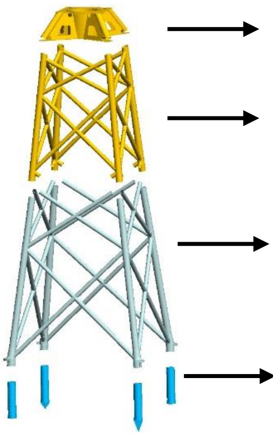

Figure 1: Parts of a jacket

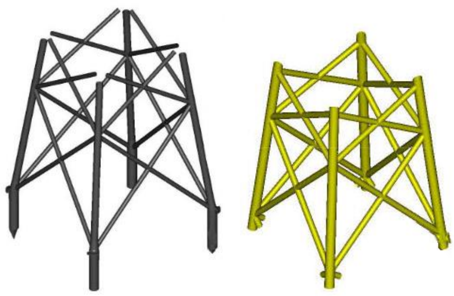
Figure 2: JLB & JUB

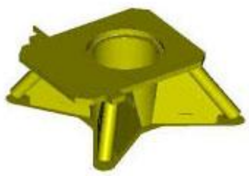
Figure 3: TP

2.1.1. Sub-parts of a jacket.

Next figures show main sub-parts of a jacket:

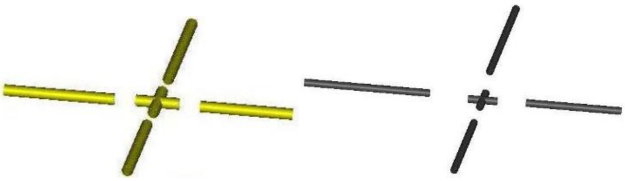
Figure 4: Bracing JUB & JLB

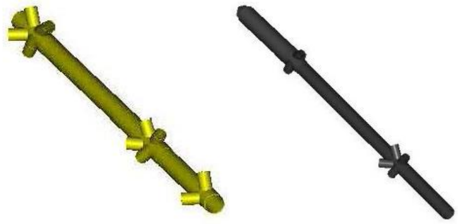
Figure 5: Leg JUB & JLB

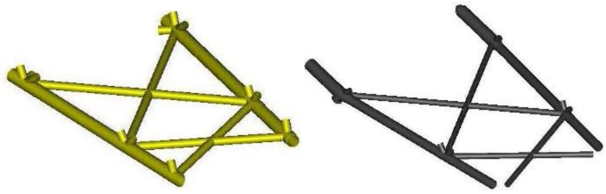
Figure 6: Row JUB & JLB

2.2. Construction strategy.

Main tasks involved in the manufacturing process of the jacket consist of assemblies of the sub-parts and painting of TP and JUB.

3. METHODOLOGY

3.1. Simulation Model.

This figure shows the flow chart of the simulation model. It basically consists of two inputs (drawings and material) which are necessary to start fabrication. Then, jackets are produced according to the construction strategy explained before and load-out of jackets is made according to different milestones for each cluster.

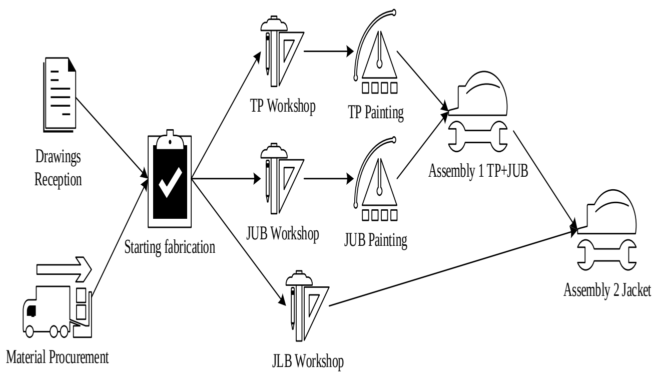

Figure 5: Flow chart of the simulation model

TPs, JUBs and JLBs are processed simultaneously assembling their sub-parts. Then TPs and JUBs are painted and after that, they are assembled (Assembly 1). Once Assembly 1 is carried out, the jacket is finally obtained after making Assembly 2, which consists of adding JLB to TP+JUB as shown in next figure:

Figure 7: Assembly 1 (TP+JUB) and Assembly 2 ((TP+JUB) + JLB).

Apart from representing the construction strategy, this simulation model is used to measure flowtime per jacket, identify bottlenecks by analyzing utilization of the main processes, quantify available space to buffer items as well as studying cost in terms of working hours for each part of the jacket. These will be the main indicators used to take into account when implementing measures to optimize the manufacturing process. Next figure illustrates main measures and goals taken into account:

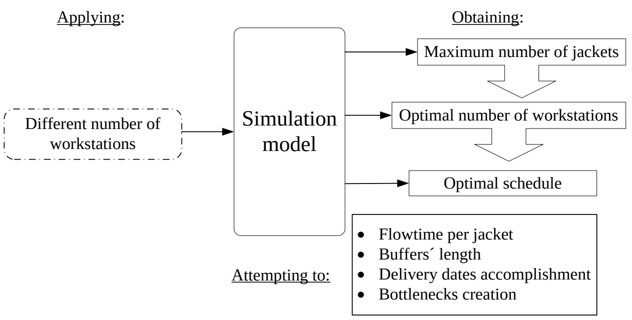

Figure 8: Measures, goals and indicators

3.2. Scheduling.
Scheduling of the project was made by means of a generic schedule consisting of clusters of jackets which are associated to the main payment milestones.

3.3. Discrete Events Simulation.
Due to the required detailed level in this work, Discrete Events Simulation has been chosen. This kind of Simulation has the following characteristics:

- Discrete (items flow, which are the parts and sub-parts of the jacket).
- Dynamic.
- Stochastic.

We used ExtendSIM Simulation software due to its versatility to represent any process, to its usefulness presented in terms of results and implementation and its easy use which avoids to using specific language coding. Next figure shows a screenshot of the simulation model developed:

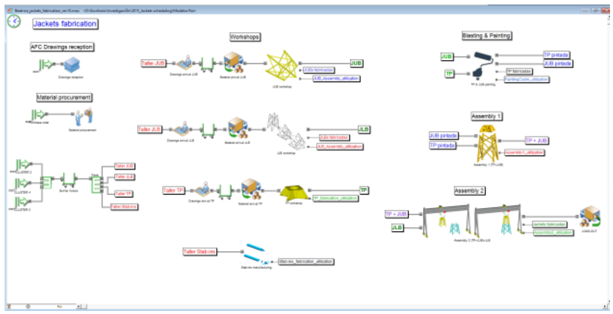

Figure 9: Screenshot of the simulation model.

3.4. Problem description.
According to the construction strategy, this problem applies to an assembly job shop scheduling, since the assembly of the final product (jacket) can only be conducted after all sub-components are finished. The components of the final product are processed by different machines according to a predetermined process plan.
Assembly job shop scheduling is different from job shop scheduling. The main difference is that assembly job shop scheduling not only involves the string type scheduling decision but also coordination of the assembly operations.
As it is a space-limited company, buffers capacity will be a constraint, especially those located before the painting cabins and assembly 1 and 2 areas. It will be particularly important to quantify queue´s length in the painting cabin as TPs and JUBs concur at this point so as flowtime will be minimum.
In addition to this, bottlenecks will also play a big role in the fabrication process so they will have to be identified and avoided by increasing workshops´ resources.

4. STATE OF THE ART.
The problem of an assembly job shop scheduling can be treated by means of different methods. In the next paragraphs, there is a brief summary of the most relevant studies related to the problem considered:
Thiagarajan & Rajendran (2005) used dispatching rules as a way to minimize the sum of weighted earliness, weighted tardiness and weighted flowtime of jobs by incorporating the costs related to earliness, tardiness and holding of jobs in form of scalar weights.
Natarajan et al. (2006) modified some existing dispatching rules to take into account different weights for holding and tardiness of jobs. However, it can be said that this study is limited when it comes to processing time (it is assumed as a constant value), queue length (it does not represent a constraint in the model) and assembly operations duration (the same for all levels).
Lui & Ponnambalam (2012) applied a Differential Evolution-based algorithm in solving a flexible assembly line scheduling problem. They proved the superiority of Differential Evolution variants in comparison with the current work.
Cheng, Mukherjee, & Sarin (2013) studied the so-called “lot-streaming” technique, which consists of accelerating the flow of a product through a production system by

splitting its production lot into sublots that are simultaneously processed and, as a result, work-in-process and cycle-time is reduced. They applied this method to an assembly environment. By implementing a polynomial-type algorithm to obtain optimal sublot sizes to minimize makespan. Later, Mortezaei & Zulkifli (2013) developed a mixed-integer lineal mode for multiple products lot sizing and lot streaming problems. This formulation enabled to find optimal production quantities, optimal inventory levels, optimal sublot sizes and optimal sequence.

Dai, Hu, & Chen (2014) developed a Genetic Algorithm based on a heuristic approach in order to obtain the optimal block sequence in shipyards. This study paid much attention to the minimization of uncertainty of processing times, as well as the minimization of makespan. They found that there is a negative effect between makespan and spread of processing uncertainty, with a non-linear relation.

Wan & Yan (2014) analyzed the problem of an integrated assembly job shop (AJS) in which scheduling and self-reconfiguration was very important to minimize the weighted sum of completion cost of products, the earliness penalty of operations and the training cost of workers. They simultaneously optimized the assembly of components and the capacity of workstations. A heuristic algorithm was proposed to reconfigure the manufacturing system to meet the changed demand at the minimum production and reconfiguration of cost. Their results were analyzed by numerical experiments and they show that the proposed algorithm promises lower total cost and desirable simultaneous self-reconfiguration costs in accordance with scheduling.

Jia, Bard, Chacon, & Stuber (2015) combined the used of Discrete Events Simulation with heuristics approaches to evaluate dispatching rules for assembly operations. Their main goals were minimizing makespan, the number of machines used and the weighted sum of key devices shortages.

Komaki & Kayvanfar (2015) studied the optimal sequence of jobs so as makespan is minimized in a two-stage assembly flow shop in which not all jobs are available at time zero. Several heuristic techniques and also a meta-heuristic algorithm called Grey Wolf Optimizer are applied.

5. EXPERIMENTAL RESULTS.

5.1. Generic schedule.

Once construction strategy is modelled according to a generic schedule, first results can be obtained:

According to delivery dates associated with main cluster milestones, next table points out finishing fabrication dates for each cluster of jackets and its corresponding milestone date with the gap measured in days between each date:

Table 1: Differences between delivery and finishing fabrication dates (generic schedule).

Cluster	Cluster milestone date	Finishing fabrication date	Gap
1	24/04/2017	22/04/2017	2 days
2	22/06/2017	18/06/2017	4 days
3	02/11/2017	18/10/2017	15 days
4	28/01/2018	01/01/2018	27 days

As shown, the generic schedule implemented in this model accomplish main cluster milestone dates but gaps related to last clusters are too high so a reduction in terms of resources could be carried out.

Once differences between delivery and finishing fabrication dates were analyzed, throughput of main parts of the jacket was measured:

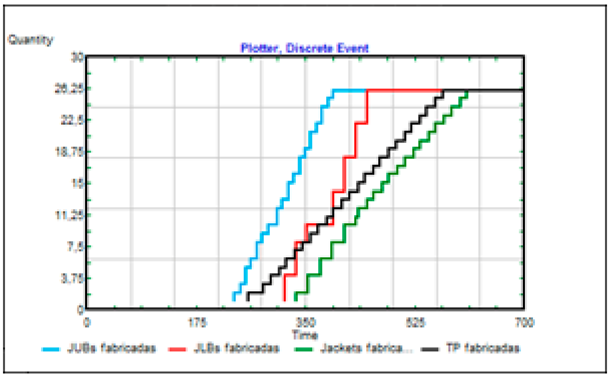

Figure 10: Throughput of main parts of the jacket (generic schedule).

As it can be seen, jackets manufacturing is strongly dependent on TPs manufacturing especially for the last ones.

Apart from that, JUBs seem to be constructed faster than JLBs so a line balance is needed.

Flowtime per jacket was measured as the difference between starting and ending fabrication dates for each jacket.

Next figure illustrates its evolution:

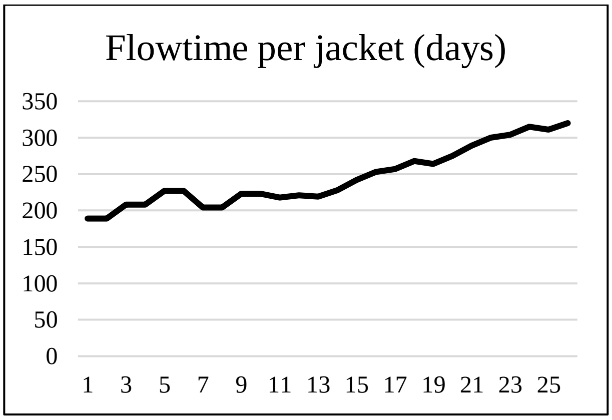

Figure 11: Flowtime per jacket evolution (generic schedule).

Flowtime per jacket increases according to project progress, what implies that jackets manufacturing lasts more when the project is ending than at the beginning. This can be produced because of the over-occupation of some workstations in certain stages of the project so as a consequence, fabrication has to be adjusted to due dates by means of a better assignment of resources.
Bottlenecks will be identified by analyzing % utilization of different workstations. Once detected, it will be important to optimize resources so as fabrication will not be blocked. The table below indicates average value of flowtime per jacket:

Table 2: Average flowtime per jacket (generic schedule).

Average flowtime per jacket	245,62 days

As it can be perceived, it will be particularly important to reduce flowtime per jacket.
Next figure shows utilization coefficients of the most important workstations:

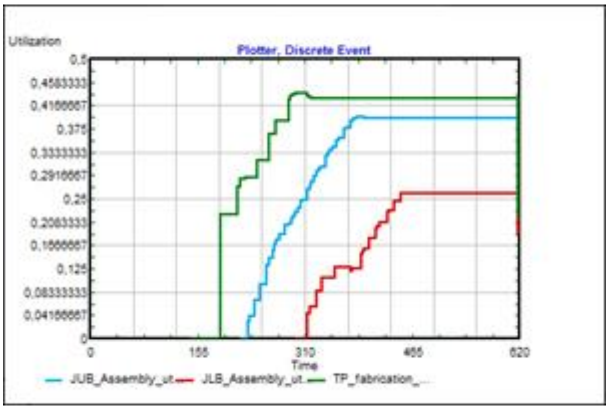

Figure 12: Utilization JLB, JUB and TP workshop (generic schedule).

As it can be seen, workshops seem to be not fully-exploited since coefficient of utilization is quite low, what implies that number of workstations is oversized.
On the other hand, it is important to avoid too high utilization since fabrication could be blocked if a certain machine gets damaged. Next figure shows evolution of utilization of painting cabins and assembling workshops:

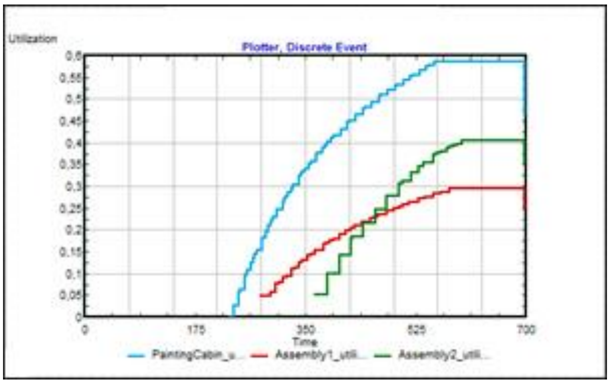

Figure 13: Painting cabin and assembling utilization (generic schedule).

As space is a limited resource in the company, it is vital to analyze the evolution of the buffers´ capacity in order to determine whether or not queues´ length are suitable for space available. Apart from that, if space required is reduced, another project could be carried out so profitability would increase. Most critical buffers in the process are the ones located before assembly operations due to the size of the parts of the jackets and painting cabins, in which JUB´s and TP´s wait to be painted.
When it comes to buffers located before assembly operations, next figure illustrates its evolution:

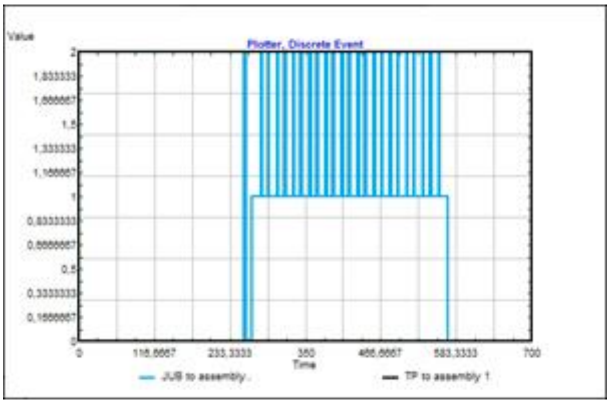

Figure 14: Buffer assembly 1 (generic schedule).

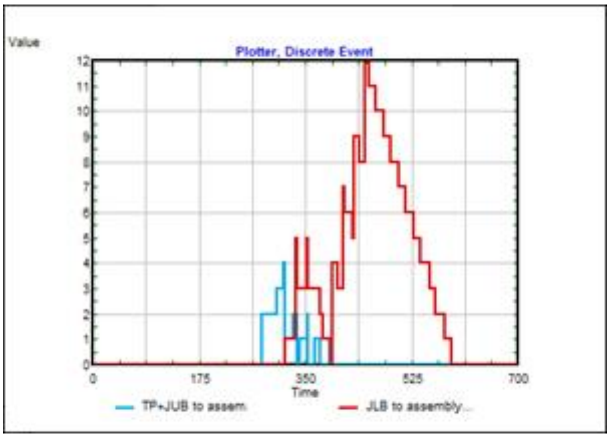

Figure 15: Buffer assembly 2 (generic schedule).

Concerning JUB´s and TP´s waiting to be painted, next figure shows their evolution during the project:

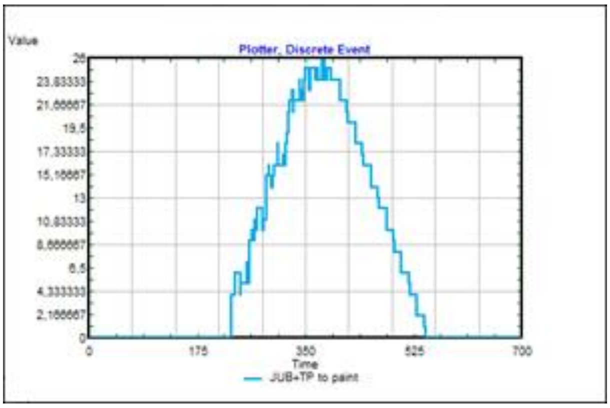

Figure 16: Buffer painting cabin (generic schedule).

According to results showed in previous figures, buffers located before assembly 2 and painting cabin have the highest queue lengths, so an especial attempt should be made to decrease them.
With reference to assembly 1 queue, it is interest to remark that there is not any single TP waiting to be processed so this also indicates that here it is an important bottleneck to consider.

5.2. Different number of workstations.

As throughput of main parts of the jacket was clearly unbalanced, number of workstations was modified to get the production process well-adjusted by creating multiple scenarios taking into account different number of workstations as variable factors and gaps to milestones and buffers´ length as response factors.
Next table shows best combination obtained in terms of reduction of workstations:

Table 3: Workshops modifications.

Decrease in:
-1 JUB Assembly
-2 JLB Assembly
-3 TP Manufacturing
-1 Assembly 1

As throughput rate was unbalanced, number of workshops of JUB, JLB and TP was modified in order to get the production line well-adjusted. Besides, as queue length of assembly 1 was not too long and assembly 1 utilization was also quite low, the number of workstations devoted to carry out assembling of TP and JUB was also reduced.
With reference to milestone dates accomplishment, next table shows results obtained with these new measures:

Table 4: Differences between delivery and finishing fabrication dates (different number of workstations).

Cluster	Cluster milestone date	Finishing fabrication date	Gap
1	24/04/2017	22/04/2017	2 days
2	22/06/2017	21/06/2017	1 days
3	02/11/2017	26/10/2017	7 days
4	28/01/2018	09/01/2018	19 days

As it can be seen, main milestones are accomplished even with the reduction in terms of resources made.
Throughput of main parts of the jacket obtained with new schedule is shown in the next figure:

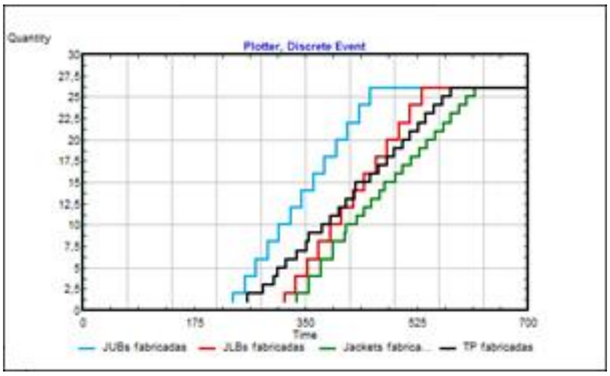

Figure 17: Throughput of main parts of the jacket (different number of workstations).

As shown, throughput rate is much more balanced in comparison with the one obtained by means of the previous schedule.
Regarding flowtime per jacket with the new schedule, an important reduction regarding average value is achieved. In addition, its evolution along project progress is much more regular than before:

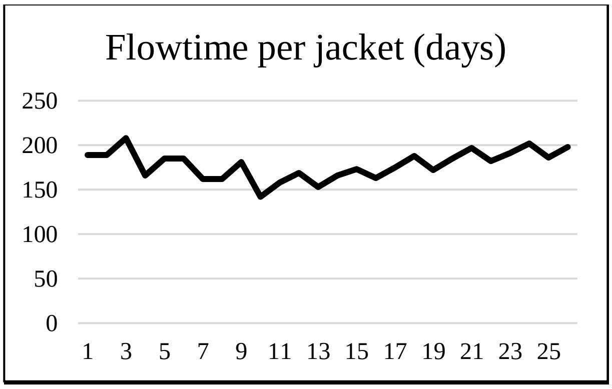

Figure 18: Flowtime per jacket evolution.

Table 5: Average flowtime per jacket.

Average flowtime per jacket	177,96 days

Next figure illustrates utilization coefficients of the main workstations involved in the manufacturing process:

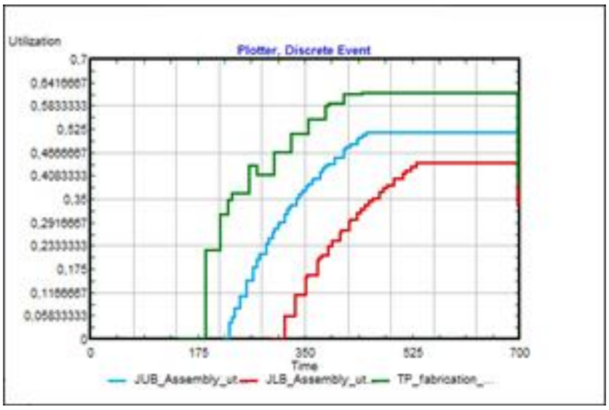

Figure 19: Utilization JLB, JUB and TP workshop (different number of workstations

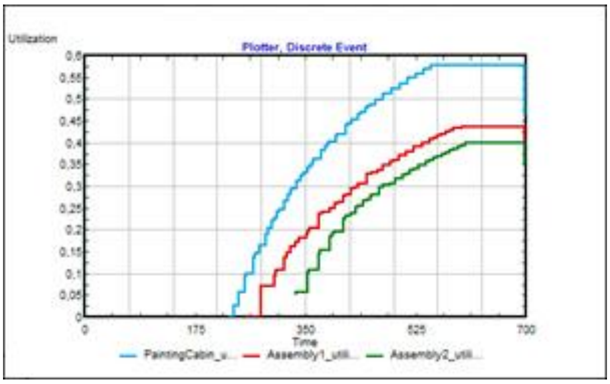

Figure 20: Painting cabin and assembling utilization (different number of workstations).

As a consequence of changes explained before, coefficients of utilization of main workshops have changed and now, workstations seem to be better-exploited.
Next figures show lengths of queues located before Assembly 1, Assembly 2 and painting cabin:

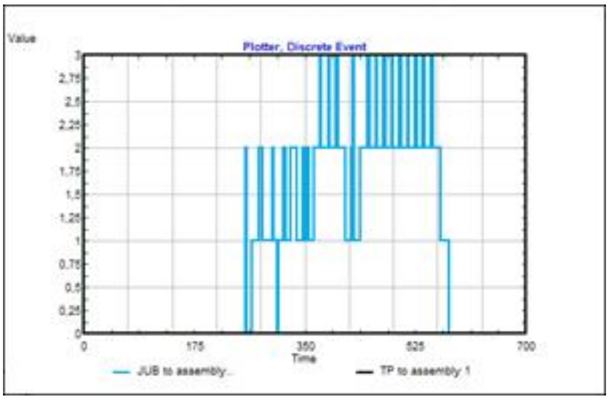

Figure 21: Buffer assembly 1.

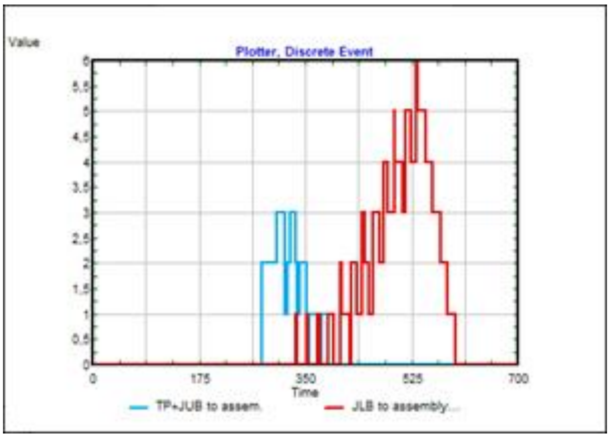

Figure 22: Buffer assembly 2.

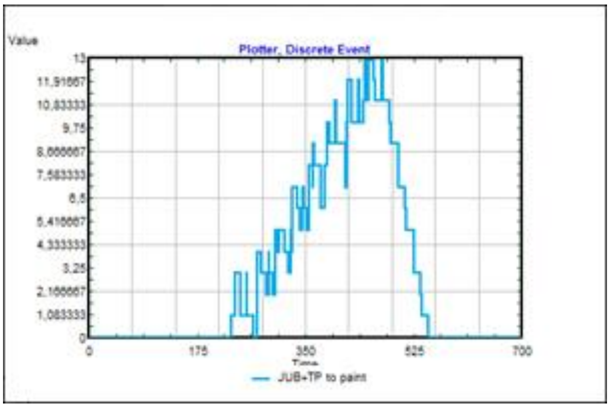

Figure 23: Buffer painting cabin.

With reference to assembly 1, as number of assembling workstations was reduced, its length has increased but not considerably. However, assembly 2 operation queue length has decreased as a result of the new measures carried out. When it comes to painting cabin buffer, it has also been reduced.
Results achieved in terms of queue lengths are going to be considered as suitable for space limitations as they have been reduced considerably in comparison to the ones obtained by means of the generic schedule.
As it can be observed, clusters milestones dates are accomplished even with this important readjustment in terms of resources. Besides, length of the main buffers is not so high when it is compared with results obtained with the generic schedule and main workstations are better exploited so the modifications implemented in the generic schedule seem to be suitable to the manufacturing process.

5.3. Maximum number of jackets with generic schedule.

As gap between finishing fabrication dates and clusters milestones for the generic schedule was too high especially for last clusters (see table 1), maximum number of jackets than can be produced was calculated. Results show that 2 more jackets can be fabricated (1 for cluster 3 and 1 for cluster 4). Gap days are shown in the table below:

Table 6: Differences between delivery and finishing fabrication dates (maximum number of jackets).

Cluster	Cluster milestone date	Finishing fabrication date	Gap
1	24/04/2017	22/04/2017	2 days
2	22/06/2017	18/06/2017	4 days
3	02/11/2017	01/11/2017	1 days
4	28/01/2018	26/01/2018	2 days

As it can be seen, fabrication dates are better-adjusted to milestones when more jackets are produced with the generic schedule.

5.4. Dynamic change in number of workstations.

Another measure that can be carried out consists of modifying the number of workstations during the project progress. As it has been explained before, milestones associated with cluster 3 and 4 are less restrictive so a reduction in the number of workstations from this date seems to be suitable.

Space needed will also decrease so the possibility of carrying out another project simultaneously will appear and as a result, profitability could be higher.

Next table illustrates changes made:

Table 7: Changes made in the number of workstations from fabrication of cluster 3.

From cluster 3, decrease in:
-1 JUB Assembly
-2 JLB Assembly
-4 TP Manufacturing
-1 Assembly 1

Results obtained in terms of differences between milestones and fabrication dates are shown in the table below. Gap days for clusters 1 and 2 will not be modified as changes are implemented for clusters 3 and 4:

Table 8: Differences between milestones and fabrication dates (dynamic change in number of workstations).

Cluster	Cluster milestone date	Finishing fabrication date	Gap
1	24/04/2017	22/04/2017	2 days
2	22/06/2017	18/06/2017	4 days
3	02/11/2017	26/10/2017	9 days
4	28/01/2018	09/01/2018	21 days

As it can be observed, gap days for clusters 3 and 4 have decreased in comparison to the generic schedule as a consequence of changes made in number of workstations.

5.5. Costs expressed in working hours.

Next figures show accumulated cost expressed in terms of working hours achieved with the 3 scenarios developed (generic schedule, different number of workstations and dynamic change in number of workstations) for JLB and JUB assembling operations. As working hours needed for each part are the same for each scenario since the same quantity of pieces are produced, final result will be equal but the evolution will be different for each situation.

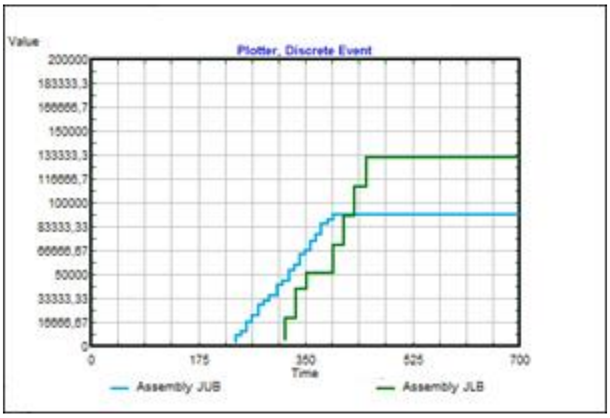

Figure 24: Evolution of cost expressed in working hours (generic schedule).

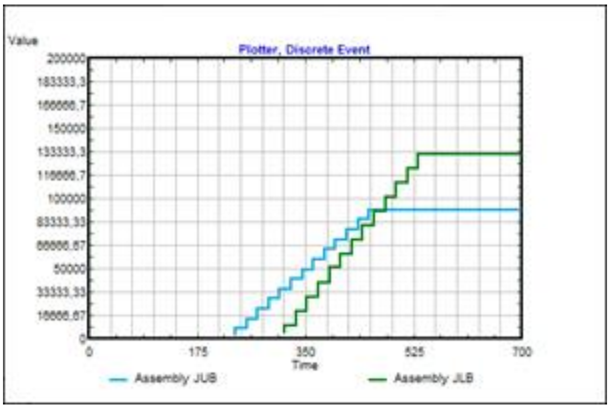

Figure 25: Evolution of cost expressed in working hours (different number of workstations).

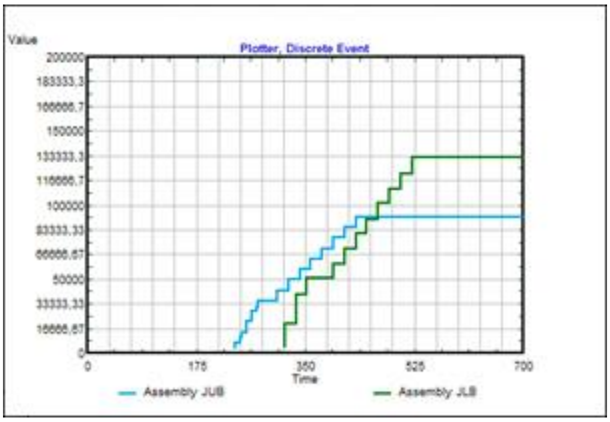

Figure 26: Evolution of cost expressed in working hours (dynamic change in number of workstations).

When it comes to manufacturing cost, it is preferable that its evolution was the less fast as possible in order to avoid big alterations in terms of cash-flow.

Consequently, the most suitable scenario according manufacturing costs is the one in which different number of workstations was considered as its slope is the lowest one. In addition, an important reduction will also be obtained as less workstations are used.

6. CONCLUSIONS.

The problem of an assembly job-shop scheduling is presented in this paper by means of a jacket manufacturing company with space and workstations as limited resources.

First results obtained by a generic schedule were analyzed and some limitations were detected. As a consequence, new measures were implemented to minimize flowtime per jacket, optimize workstations´ utilization and decrease buffers´ length as well as taking into account manufacturing costs expressed in terms of working hours.

Main improvements carried out involve solutions of Lean Manufacturing since the optimal number of workstations to accomplish main milestones was achieved and a balance in the line production was obtained by analyzing different scenarios. Regarding this study case, an important reduction in terms of workstations was achieved, what implies that space required to the manufacturing process has enormously been reduced so that more projects could take place simultaneously.

In addition, maximum number of jackets that can be produced with the generic schedule was determined.

Moreover, a dynamic change in the number of workstations was also performed as last clusters are less restrictive than the first ones.

Furthermore, this paper highlights how useful it is the tool of Simulation since certain simple measures taken into account and evaluated in these models allow companies to increase their profitability without involving too much investment.

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HEURISTIC AND METAHEURISTIC SIMULATION-BASED OPTIMIZATION FOR SOLVING A HYBRID FLOW SHOP SCHEDULING PROBLEM

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ABSTRACT

This paper solves the hybrid flow shop (HFS) scheduling problem of a printed circuit board assembly. The production system investigated consists of four Surface-Mount Device (SMD) placement machines in the first production stage and five Automated Optical Inspection (AOI) machines in the second production stage. The objective is to minimize the makespan and to minimize the total tardiness. This paper describes and compares four approaches to solve the HFS scheduling problem: an integrated simulation-based optimization (ISBO) and three metaheuristics, simulated annealing, tabu search and genetic algorithm. All approaches lead to an improvement in terms of producing more jobs on time while minimizing the makespan compared to the decision rules used so far in the analyzed printed circuit board assembly. The integrated simulation-based optimization delivers results much faster than the metaheuristics. The metaheuristics lead to slightly better results in terms of total tardiness.

Keywords: Simulation-based optimization, hybrid flow scheduling problem, simulated annealing, tabu search, genetic algorithm, Meta-heuristics

1. INTRODUCTION

This paper describes the solution of a hybrid flow shop (HFS) scheduling problem with major and minor sequence-dependent setup times based on an industrial case of a printed circuit board (PCB) assembly. The objective was to minimize the makespan and the total tardiness. This paper is an extension and further analysis of the work of the authors, which will be presented in the Winter Simulation Conference 2016.

An HFS production environment consists of k production stages in series. Each production stage comprises m identical parallel machines. Each job j has to be processed on each production stage on one of the identical machines (Pinedo 2012). This problem is NP-hard (Lenstra et al. 1977). The paper proposes four different solutions to this HFS problem: an integrated simulation-based optimization algorithm (ISBO) developed by the authors and three widely used metaheuristics, simulated annealing, tabu search and genetic algorithm.

Scheduling is the deployment of resources in order to complete a set of tasks during a determined time span (Baker and Trietsch 2009). Scheduling problems have been extensively investigated in different fields of academia due to its essential role in manufacturing environments and different service sectors (Ruiz and Vázquez-Rodríguez 2010). Efficient allocation of resources supported by the appropriate sequencing is considered to be a major mathematical optimization problem (Lenstra et al. 1977). Johnson (1954) presented an optimal schedule for the two machine flow shop with sequence-dependent setup times, which is not as complex as an HFS problem. Direct optimization approaches have been previously implemented to solve HFS problems. Wittrock (1990) adopted a branch and bound algorithm to address the problem of identical parallel machines with major and minor sequence-dependent setup times, which can be considered as a simplified form of an HFS, and reported a near optimal solution. The branch and bound approach requires long computational time, even for small instances. Dynamic programming represents another direct optimization approach, which can be applied to solve HFS problems divided into smaller sub-problems (Baker and Trietsch 2009). The recursive behaviour of a dynamic programming approach facilitates the investigation of the whole solution space of a moderate size problem in reasonable computational time (Pinedo 2012).

Heuristics are used to obtain good solutions in reasonable computational time when the problem domain gets more complex (Allaoui and Artiba 2004). Priority Dispatching Rules (PDRs) are widely used in practice to define scheduling policies in manufacturing environments. PDRs are the simplest form of heuristics due to their ease of use and intuitive nature (Andersson et al. 2008). Shortest Production Time (SPT) and Earliest Due Date (EDD) are typical PDRs. They are often implemented to solve problems with a single objective function and they lack on solution quality as soon as the objective function gets more complex (Andersson et al. 2008). More sophisticated heuristics are adopted to deal with HFS scheduling problems. Voß

(1993) and Gupta (1988) used heuristics based on local search algorithms to solve a special case of an HFS with exactly one machine on the second stage and with the objective to minimize the makespan. This problem is still NP-hard (Gupta 1988). Local search algorithms are improvement procedures based on an initial feasible solution for the problem. They recursively search in the neighborhood of the initial solution for a better solution until a terminating condition is met.

Metaheuristics are often used to solve scheduling problems and are powerful solution approaches. Metaheuristics are guided local search algorithms. They are based on local search improvement algorithms and a general optimization or control strategy. The control strategy is used to guide the local search algorithms (Voudouris and Tsang 2003). The idea of metaheuristics is motivated by the fact that a local search algorithm often only obtains a local optimum from the solution space (Ross 2005). Simulated Annealing (Allaoui and Artiba 2004; Mirsanei et al. 2011), Tabu Search (Wang and Tang 2009) and Genetic algorithm are widely used metaheuristics.

2. SYSTEM DESCRIPTION

Any scheduling problem can be described and formulated based on the machine environment and configuration α, the job characteristics β and the objective function γ (Graham et al. 1979).

2.1. Machine environment and configuration

The analyzed production system is a hybrid flow shop, which consists of two production stages (see Figure 1). The first production stage contains four identical parallel surface mounting technology (SMT) assembly lines. The critical resource in the observed production lines is usually the surface mount device (SMD) placement machines (Csaszar et al. 2000). Consequently, we focused our analysis on the SMD placement machines. The second production stage contains five identical parallel automated optical inspection (AOI) machines. Each job j has to be processed on each production stage on one of the identical machines as it is shown in Figure 1.

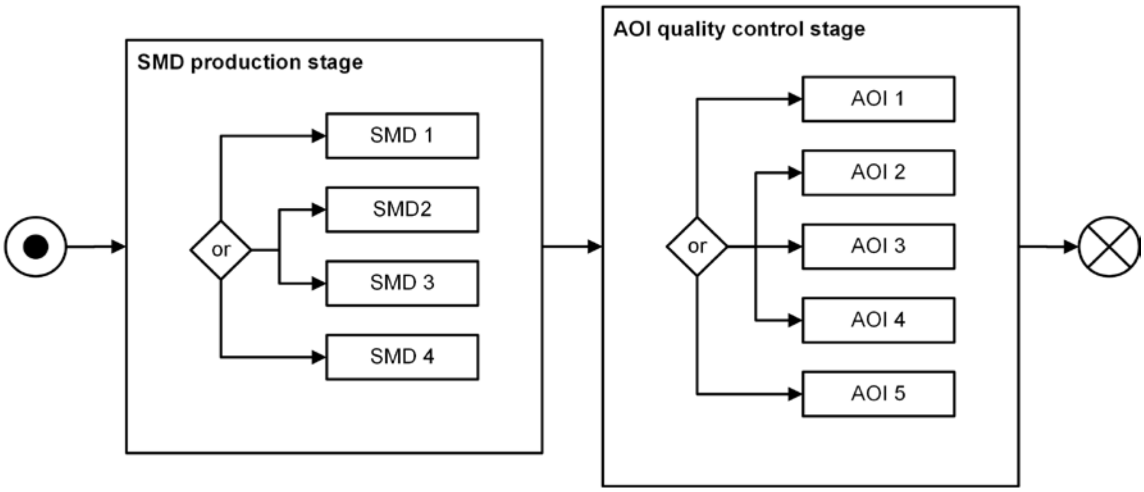

Figure 1: Two stages hybrid flow shop

2.2. Job characteristics

Jobs of the analyzed HFS scheduling problem can be characterized as follows:

- The number of jobs in a certain time period and the number of products per job are known and fix.
- Part types are very heterogeneous.
- The family type of a job depends on the used raw materials.
- The processing time $p_{j,m,s}$ of each job j on the machine m of stage s is known and fix.
- The priority of a job represents the delivery date to the customer.
- The sequence-dependent setup time $s_{j,k}$ is the time to setup the machine when changing from job j to job k.
- Machine breakdowns are not taken into consideration.
- Buffer size between production stages is unlimited.

In the first production stage (SMD), jobs are scheduled with sequence-dependent major and minor setup times on the machines. In the second production stage (AOI), jobs are scheduled incurring sequence-independent setup times on the machines. The concept of major and minor setup time was introduced by Wittrock (1990) as well as by So (1990) to describe sequence-dependency. As an illustration of this concept, jobs which share common raw materials, are grouped into families. On the one hand, a minor setup time will be inquired, if the machine switches from one part type to another inside the same family. On the other hand, a major setup time will be inquired, if the machine switches from one part type to another from a different family. In the first production stage job splitting is not permitted. More precisely, a production process of a job, once started, is not allowed to be interrupted for producing another job due to the fact that a major setup time is inquired to reconfigure the machine. Job splitting is allowed in the second production stage.

2.3. Objective functions

Accomplishing a balance between production system efficiency and the job's due-date is a trade-off decision. For this reason, tardiness has been frequently used as a major supplementary performance criterion along with the makespan (Lenstra et al. 1977). The objective functions of the analyzed HFS problem are to minimize the makespan C_{Max} and the total tardiness T. The makespan is the necessary time to complete all released jobs (Wittrock 1990). To minimize C_{Max} it is important to minimize the number of major setups. Tardiness is the difference between the completion time of a job C_j and its due date d_j as shown in (2).

$$C_{\max} = \max C_j \ \forall \ j = 1, \ ..., \ n \qquad (1)$$

$$T = \sum_{j=1}^{n} T_j, \ T_j = \max \ (C_j - d_j, \ 0) \qquad (2)$$

3. SOLUTION APPROACHES

The problem to minimize the makespan of a two stage hybrid flow shop is NP-hard (Gupta 1988). The development of a polynomial algorithm, which can provide an optimal solution in a reasonable time, is unlikely possible. Thus, breaking down the problem could be the key to obtain a near optimal solution by solving smaller sub-problems. It is often easier to solve the allocation and the sequencing independently (Baker and Trietsch 2009). Initially, jobs are allocated to the machines on each production stage. Four single machine problems with sequence-dependent setup times emerge on the first production stage and five single machine problems with sequence-independent setup times arise on the second production stage. A heuristic and metaheuristics were used to solve the allocation problem. A dynamic programming approach was used to develop a sequencing algorithm that builds a near optimal sequence of jobs on each machine.

The first solution strategy presented is an integrated simulation based optimization (ISBO). The ISBO integrates a heuristic and a sequencing algorithm into a simulation model. The second, the third and the fourth approach use metaheuristics: Simulated Annealing (SA), Tabu Search (TS), and Genetic Algorithm (GA) respectively. All metaheuristics are combined with a sequencing algorithm. Simulation models were used to assess the quality of the metaheuristics' solutions.

3.1. Integrated Simulation Based Optimization

In the integrated simulation Based Optimization (ISBO) (see Figure 2), the simulation is a part of the solution rather than an evaluation method for it. The allocation and sequencing algorithms are integrated in the simulation model. The simulation model was built with ExtendSim 9. The discrete-rate and discrete-event simulation-libraries were used to implement a hybrid mesoscopic simulation approach to avoid a long computation time (Reggelin and Tolujew 2011). The SMD and AOI production processes are modelled using the discrete-rate library. Flow rates differ depending on the current part type, being produced by the machines. The dispatching and decision making processes are modelled using the discrete-event library in order to ensure a high level of accuracy. The flow of a job is changed to a single object at decision points. When a job is released for processing, it is again modelled with a flow rate.

Product families and their jobs are initially allocated to the machines before the simulation starts. The shortest process time (SPT) discipline determines the initial allocation of the product families on the first production stage SMD. The earliest due date (EED) discipline initially allocates the jobs on the second production stage AOI. During the simulation, the interaction between the allocation and the sequencing algorithm leads to a sustainable production strategy with a near optimal sequence being continuously generated on each machine. The allocation algorithm ensure a balance of the production load between the machines.

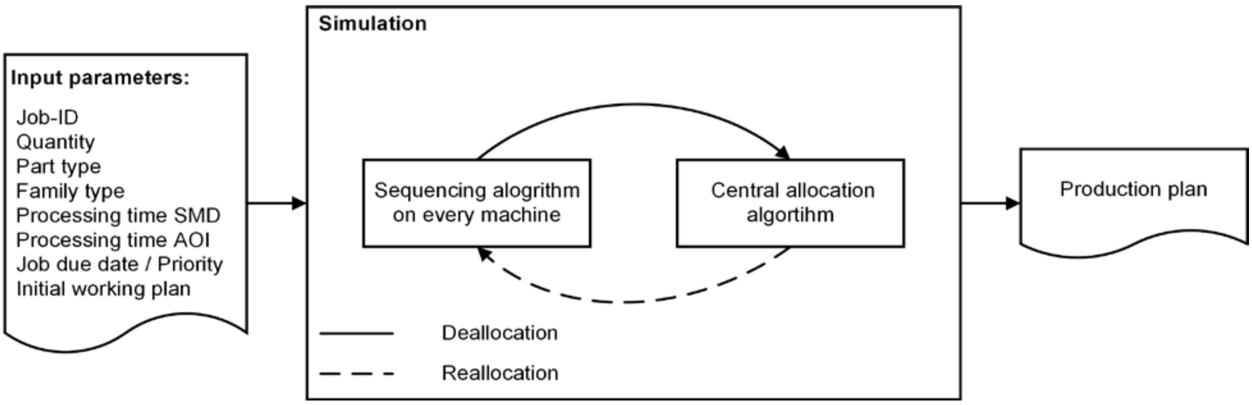

Figure 2 : Integrated Simulation Based Optimization

In order to minimize the makespan, all jobs of a product family should ideally be manufactured successively on the same SMD machine to avoid major setups. However, this would lead to delivery time violations of many jobs. The sequencing algorithm operates on two levels, the product family level and the job level (see Figure 3). On the family level, the smallest family, which contains at least one of the highest job priorities is chosen. Then, the sequencing algorithm switches to the job level. On the job level, the algorithm tends to dispatch jobs from the same family according to the priority of jobs using the EDD rule. The sequencing algorithm keeps operating on the job level until jobs of the family are completely produced or a critical point is met. The critical point describes a situation, when it is no longer possible to produce a job from the same product family without violating the delivery date of other jobs from different families. Choosing the smallest family increases the chance that the chosen family is completely produced before reaching a critical point. This behavior avoids a later major setup.

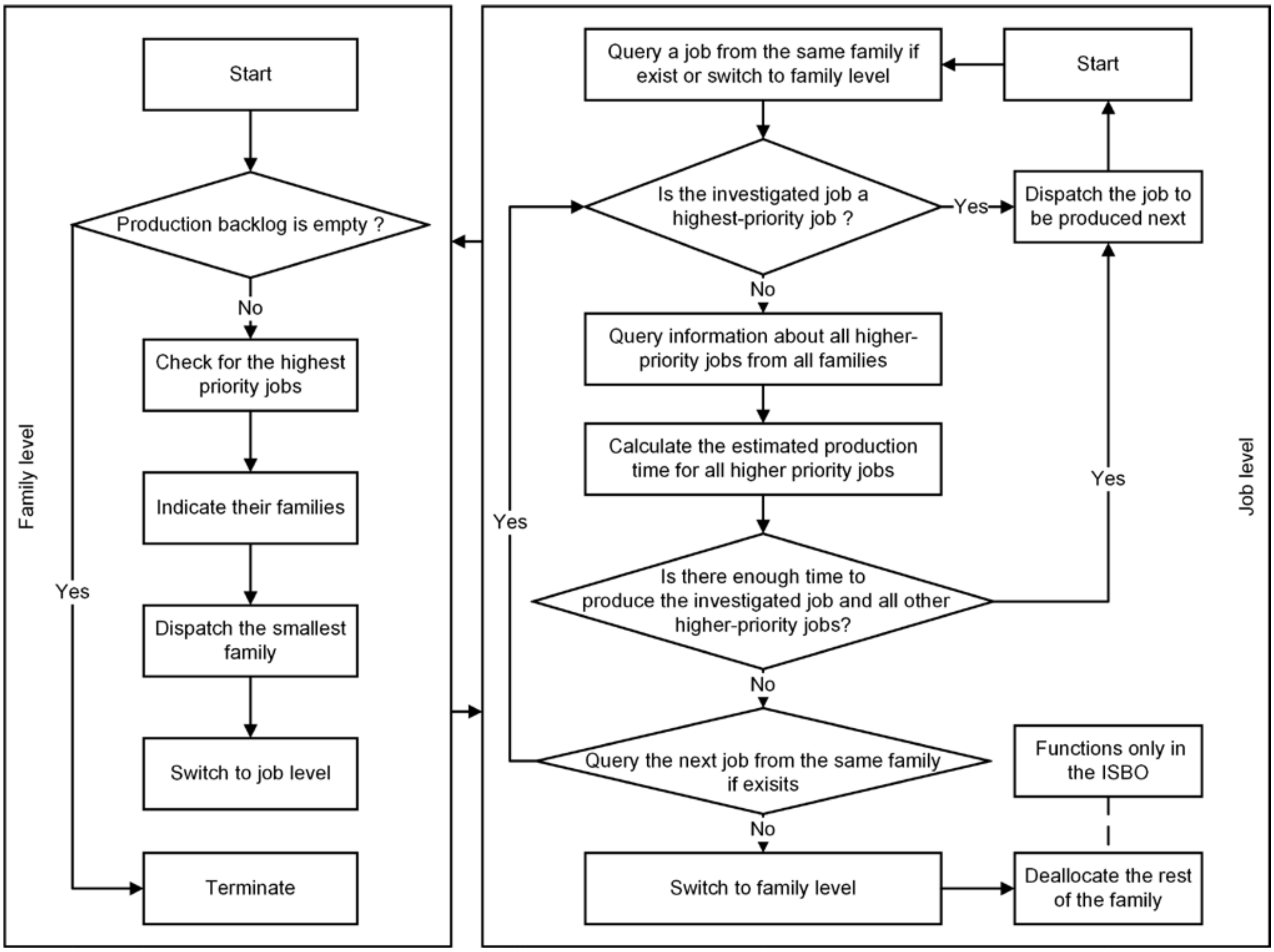

Figure 3: Sequencing Algorithm

The allocation algorithm tries to sustain a balance of the production load between the machines on each production stage. It performs two types of allocation, event-based allocation and pre-defined allocation. The event-based allocation is triggered by the sequencing algorithm (see Figure 2 and Figure 3) when critical points are reached. It checks for the least loaded machine and reallocates the remaining jobs of the family to this machine. The pre-defined allocation is performed each day to balance the production load of the next highest three priorities. All families except the one in production are deallocated. The allocation algorithm starts reallocating families to the least loaded machines during the next three simulated working days. It tends to balance the amount of must-be-produced jobs in the next three days according to their delivery date between the machines. The pre-defined allocation processes tries to avoid major setups by sustaining a balance of the must-be-produced jobs between the machines by avoiding critical points. Manipulating the allocation of families during the simulation better explores the solution space of the problem after significant changes in the production load. Producing from different families changes the form of the production load and therefore, finding an enhancement in the allocation is possible during the simulation despite a perfect initial allocation.

3.2. Simulated Annealing

Simulated annealing (SA) was combined with a discrete-event simulation model to solve the allocation. For the sequencing, the algorithm shown in Figure 3 was used again. Simulated annealing is derived from the concept of physical annealing of a solid substance. It was first introduced in the early eighties by Kirkpatrick et al. (1983) to solve combinatorial optimization problems. Annealing is the process of melting a solid substance and cooling it slowly down until the particles arrange themselves in the solid state (Aarts et al. 2005; Kirkpatrick et al. 1983; Mirsanei et al. 2011). When the temperature is high the particles are free to move randomly since they hold a high energy. In this state, the simulated annealing shows a very random behavior and is more likely to accept a worse solution than the current best solution (Mirsanei et al. 2011). When the cooling process starts, the solid state reduces the random behavior of the simulated annealing. The algorithm starts to search for a better solution in the same region of the solution space, rather than jumping from one region to another region.

Simulated annealing is used to solve the allocation problem on the SMD placement machines. The approach starts with a feasible solution to the problem as depicted in Figure 4. Then, the neighborhood search of the simulated annealing tends to find randomly a better solution in the current region of the solution space. The neighborhood search is based on a random single point operator (Naderi et al. 2009), in which a random family is picked and reallocated randomly to a different SMD placement machine. The number of changes (number of reallocated families) was restricted to one to avoid the simulated annealing behaving like a random search. After all families being allocated, the sequencing algorithm starts to build the production schedule of each SMD placement machine. After that, the jobs are allocated to the AOI machines based on their expected finishing time on the SMD placement machines. The allocation to the AOI machines tries to achieve a balanced production load between the machines and tries to consider the priorities of the jobs (due dates). The generated schedule is evaluated by using the discrete-event simulation model. The production sequences on the AOI machines are determined with the help of the EDD rule during the simulation run.

After passing the result of the simulation run back to the simulated annealing algorithm, three cases can be differentiated:

1. The new schedule dominates the old one in both objective values. The solution is accepted and used as the next start solution.
2. The old schedule dominates the new one.
3. Neither the old schedule nor the new one dominates.

For case two and case three, the Boltzmann distribution is used to decide whether to accept a new solution or not (Naderi et al. 2009). A weighted sum of the observed objective values was used since the Boltzmann distribution contains only one value. The probability of accepting a worse solution depends on the current temperature of the simulated annealing. The setup of the parameters of the simulated annealing strongly impacts its quality (Pirlot 1996). The parameters are initial temperature, the number of iterations before changing the temperature and the cooling rate. In this implementation, the simulated annealing starts with an initial temperature between 20 and 30 degrees. Each temperature contains 10 to 20 iterations. The implemented cooling schedule is linear and the cooling rate deviates between 0.1 and 0.25 degrees.

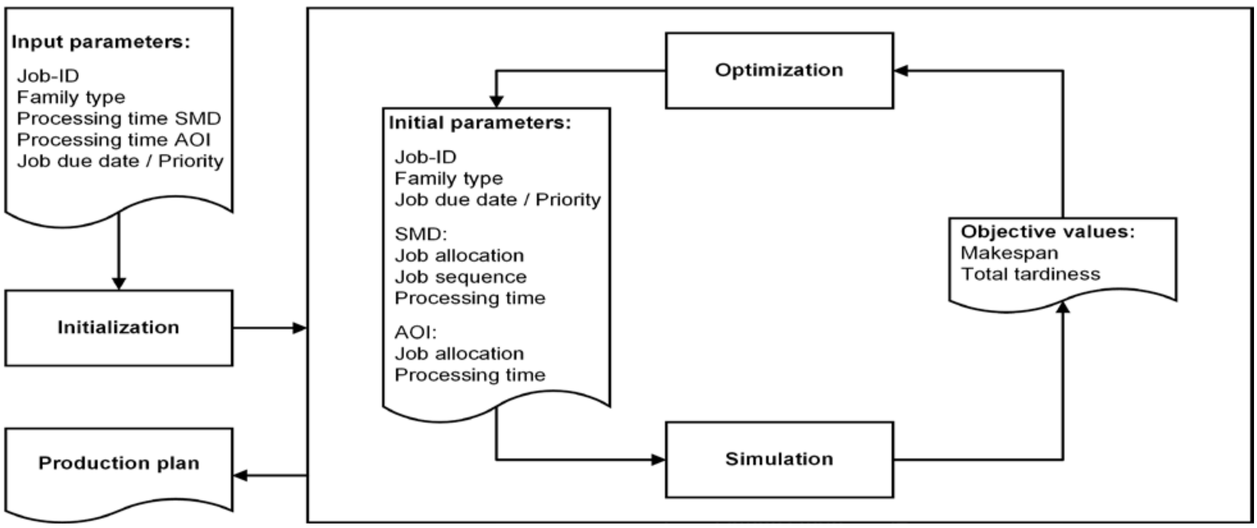

Figure 4: Metaheuristic simulation based optimization

3.3. Tabu Search

The Tabu Search (TS) algorithm was combined with the same discrete-event simulation model, which was used for the simulated annealing. For the sequencing, the algorithm shown in Figure 3 was used again. Tabu search is one of the oldest metaheuristic approaches, which was introduced by Glover (1986) to solve combinatorial optimization problems. In contrast to simulated annealing, tabu search is based on a deterministic solution mechanism, in which the neighborhood of the initial solution is build based on a set of specific moves, which are conducted on the initial solution to obtain new solutions. The current neighborhood is then investigated to identify the best solution. The initial solution is replaced by the best solution found, before starting the next iteration. The move which led to the current solution is stored in the tabu list and cannot be used again in order to avoid cycling. The aspiration function of the tabu search is used independently to evaluate the quality of the generated solutions of the moves from the tabu list to decide they can be used again (Nowicki and Smutnicki 1996).

The implementation of the tabu search in this paper is based on a single point operator neighborhood search. A single move is committed by picking a family and reallocating it to another machine. Each family is associated with three moves that generate three different solutions in the neighborhood. The solutions represent the possible allocations of each family to all considered SMD placement machines. For each generated new allocation, the sequencing algorithm is used to build the new production schedule on each SMD placement machine. Then, the jobs are allocated to the AOI machines, based on their expected finishing times on the SMD placement machines. Finally, the quality of each production schedule is evaluated using simulation. The results of the simulation runs are stored to identify the best solution and add its SMD allocation to the tabu list. The length of the tabu list is limited either to 10 or 15 solutions. Since two objective functions (makespan, tardiness) are considered, a weighted sum was used to identify the best solution before starting the next iteration. The forbidden schedules from the tabu list are evaluated using the aspiration function. If a dominant solution is found, it is used to start a new iteration.

3.4. Genetic Algorithms

The Genetic Algorithm (GA) was used to deal with the allocation problem. The sequencing part of the problem was solved also with the same algorithm shown in Figure 3. Genetic algorithms are guided random search techniques that are often used to solve scheduling problems (Andersson et al. 2008). They are categorized under evolutionary algorithms. The concept of genetic algorithm is based on mimicking the process of natural evolution (Ross 2005). Natural selection as well as genetic inheritance are fundamental element of a genetic algorithm. It maintains a population of candidate feasible solutions of the problem. A problem is first encoded in a genetic representation (Cheng et al. 1996). Each candidate solution is represented by a genome. Then, it simulates an evolution process of the candidate set of solutions to choose the best set. After the evaluation process, the best solutions are selected to evolve a new generation (offspring) of candidate solutions. The evolution process is usually performed by crossing-over the genomes of parents and/or combining them (Mutation), to indicated the genomes of the children solutions (Zheng and Wang 2003). It keeps iteratively performing these steps until some stopping criterion is met.

The genetic algorithm was implemented using ExtendSim 9. A discrete-event model was built and the optimizer of ExtendSim 9 was used. This optimizer is based on genetic algorithm. The allocation problem was encoded and passed to the optimizer as a genome. Then the optimizer starts generating candidate solution, which represents different allocation possibilities of families to the SMD placement machines. For each generated new allocation, the sequencing algorithm is used to build the new production schedule on each SMD placement machine. Then, the jobs are produced on AOI machines according to the priority of jobs using the EDD rule. By the end of a simulation run, the objective values are send back to the optimizer to continue the evolvement process of the next generation of solutions. The general functionality of genetic algorithm can be also derived from Figure 4. In this implementation, the population size of the candidate solutions is 50.

4. COMPUTATIONAL RESULTS

The experiments have been performed on four different datasets, which were provided by the company. The datasets are heterogeneous in terms of the considered number of families, number of jobs and their associated part types as shown in table 1. A large number of families and over 650 different product types have been taken into consideration in all datasets. The major setup time averages 65 minutes and the minor setup time 20 minutes.

Table 1: Input datasets

	Dataset 1	**Dataset 2**	**Dataset 3**	**Dataset 4**
Number of jobs	164	170	175	143
Number of families	41	37	36	35
SMD processing time interval (min)	4 - 3,142	2 - 3,736	4 - 3,293	4 - 3,209
Accumulated SMD processing time (min)	54,685	62,345	61,274	56,250
AOI processing time interval (min)	4 - 4,351	3 - 5,590	5 - 3,528	3 - 4,300
Accumulated AOI processing time (min)	72,528	88,702	74,738	79,294
Quantity of PCB (parts)	40 - 109,920	20 - 143,040	21 - 186,960	20 - 216,000

Table 2 shows the computational results of the approaches used to solve the HFS problem. The Family Production (FP) scenario is a batch production strategy, which has been so far adapted by the company to set scheduling policies for their production. In the FP, a machine, once started producing jobs from a family, is not allowed to be switched to another family until the family is fully produced. Consequently, this scenario point out the minimum number of inquired major setup times to produce all jobs of any data set presented. As it was expected, the reported results of the standard priority dispatching rules didn't meet the required performance criteria. Although, the shortest production time rule is often used to minimize the makespan, the indicated sequence-dependent setup times radically impacted their results and reported inefficient results for both objective values. The earliest due date rule also didn't meet the requirements of minimizing the total tardiness and reported, in addition to the high number of inquired setup times, a violation in the delivery dates of jobs in most of the datasets.

Table 2: Computational results of the different solution approaches

	Makespan (minutes)	**Major-Setup (number)**	**Penalty (number)**	**AVG Tardiness (minutes)**
Dataset 1				
FP	23,513	37	39	5,097
SPT	23,586	126	30	2,883
EDD	21,154	104	0	0
ISBO	19,354	43	1	148
SA	21,930	45	0	0
TS	19,669	45	0	0
GA	17,786	43	0	0
Dataset 2				
FP	25,447	33	52	5,225
SPT	26,662	135	31	4,811
EDD	26,226	136	9	537
ISBO	21,819	53	0	0
SA	23,108	55	0	0
TS	25,142	55	0	0
GA	22,458	53	0	0
Dataset 3				
FP	23,626	32	62	5,060
SPT	25,756	131	36	4,143
EDD	22,603	139	8	750
ISBO	19,979	56	2	268
SA	23,059	59	0	0
TS	22,507	60	0	0
GA	22,671	53	1	28
Dataset 4				
FP	23,539	31	48	5,362
SPT	20,507	113	26	4,430
EDD	21,145	113	2	482
ISBO	18,806	42	3	213
SA	20,562	58	0	0
TS	21,610	57	0	0
GA	22,569	45	0	0

The ISBO, the Simulated Annealing (SA), the Tabu Search (TS) and the Genetic Algorithm (GA) have reported significant improvements in terms of the makespan and the total tardiness in comparison to the currently conducted scheduling polices in the company. The ISBO delivers for all datasets an improved production schedules, which are more concentrated on the efficiency of the production system. The ISBO slightly outperformed TS, SA and GA in terms of the makespan. This is caused by the dynamic behavior of the allocation algorithm implemented in the ISBO, which tends to balance the critical jobs and their families instantly during the simulation. The behaviors of the TS and the SA are relatively identical towards the considered system. Both solutions strategies reported production schedules without recording any penalties and slightly outperformed the ISBO in terms of total tardiness. GA slightly outperformed both SA and TS in terms of the number of major setup times.

The makespan optimization with sequence-dependent setup time requires reducing the inquired setup times as well as the achieving a balance in the production load between machines. Those two goals tend to be often conflicting goals in any system and optimizing one of them would lead to deteriorating the other (Wittrock 1990). For this reason, the obtained results from the SA as well as from the TS optimized the total tardiness, whereby the makespan witnessed an increase in all datasets. However, minimizing the inquired number of major setup times in a dynamic system, where the production backlog is never empty, leads to minimizing the makespan.

The reported results from the ISBO have been obtained from a single simulation run, which required approximately 1 minute computation time. The SA has been configured to run 1500 simulation runs and reported the results for the datasets after approximately 3 hours computation time. The TS was configured to run between 20 to 30 TA iterations, which roughly correspond to 2100 and 3150 simulation runs respectively. The number of simulation runs in the TS depends on the number of the considered families in the dataset. The genetic algorithm is configured to run 6000 to 8000 simulation runs. The experiments have been conducted on a computer with the following characteristics: CPU 4 x 2.6 GHz, RAM 8 GB and windows operating system.

5. CONCLUSION

The paper has shown that the four applied solution approaches integrated simulation-based optimization (ISBO), simulated annealing (SA), tabu search (TS) and genetic algorithm (GA) could solve the hybrid flow shop (HFS) scheduling problem better than the decision rules used very often in practice in the printed circuit board assembly. All approaches lead to an improvement in terms of minimizing the makespan and producing more jobs on time. The ISBO delivers results much faster than the three metaheuristics SA, TS and GA. The metaheuristics lead to slightly better results in terms of total tardiness.

The dynamic allocation as applied in the suggested ISBO allows for a very deep investigation of the solution space during the simulation and thus achieves very good results in terms of minimizing the makespan compared to the metaheuristics SA, TS and GA. The experiments with four real data sets have revealed one major challenge of solving HFS scheduling problems: Big jobs can lead to difficulties in finding a good solution.

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METHODOLOGICAL AND TECHNICAL BASIS FOR INTERDISCIPLINARY INVESTIGATION IN THE FIELD OF CYBER-PHYSICAL-SOCIO SYSTEMS

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ABSTRACT
The main objects of our investigation are cyber-physical-socio space and systems (CPSS). The cyber-physical-socio space is the fusion of the physical space, the cyber space, and the socio space. The problem of CPSS complexity management and control is modern and current. The solution of this problem involves interdisciplinary research studies by specialists in mathematics, economics, sociology, biology, physics, and computer technologies. However, the founders of cybernetics imparted to its laws much more universality than is really considered in today's social and business systems. Therefore, the paper presents the results of the methodological and technical basis for interdisciplinary investigation and development in the field of CPSS, which are interrelated with a new scientific branch named neocybernetics.

Keywords: interdisciplinary research, cyber-physical-socio space and systems, neocybernetics, control and management, integrated modelling and simulation.

1. INTRODUCTION
As a result, of the continuing scientific and technical revolution, which began in the middle of the XXth century, a significant amount of complex objects appeared (nuclear power plants, space equipment, electronics, computers, etc.). Their research, description, design and management presents important difficulties and problems. Cyber-physical-socio space and systems (CPSS) are striking examples of complex systems. So today, we witness a transformation from industrial society, which is based on cyber-physical space to informational society, which is interrelated with cyber-physical-socio space and systems (Zhuge H. 2011; Zhuge H. and Xu B. 2010). The technologies to control this transformation need regulation and structuring at the macro and micro levels. This inspires a renewed interest in the theoretical background of control problems. Unfortunately, the logically relevant chain of fundamental notions: Cybernetics – Control – Informational processes – Universal transformer of information (computer, cybernetic machine) was split. The expansion of computer technologies created an illusion of their ability to solve any problem. Imperfections of these technologies have already caused catastrophes that led American and European scientists to proclaim establishment of "Risk society" rather than "Informational society" one (Gerasimenko V.A. 1993; Okhtilev M.Yu., Sokolov B.V., and Yusupov R.M. 2006; Zhuge H. 2011).
Two main reasons stimulate the importance of the new cybernetics in the modern world. The first one concerns the problem of complexity, which has various applications and aspects (structural complexity, complexity of functioning, complexity of decision making, etc).
For example, (Okhtilev M.Yu., Sokolov B.V., and Yusupov R.M. 2006), CPSS attributes are characterized by the following properties: high complexity and dimensionality with such features as redundancy; multi-functionality; distributed elements; unification; uniformity of main elements, subsystems and inter-relations; structure dynamics; non-linear uncertain behavior; hierarchical network structure; non-equilibrium; uncertainty of observer selection and interaction with them; dynamic rules and regulations; counteracting and amplifying relationships with self-excitation; possible chaotic behavior; no element has enough information about the whole system; selective sensitivity to input actions (dynamic robustness and adaptation); the response time is greater than the time between input actions, and it is greater than the time of supervention; the real object of control cannot have a complete and reliable description (in accordance with Bremerman's limit and Godel's theorem).
Moreover, if we want to interpret CPSS as a socio-humanitarian cyber-system, some media-culture attributes were proposed. Understanding the CPSS media as the objects and technologies providing transfer of experience by creating specific forms of interaction based on the

transfer of culture mechanisms, we investigate media culture — as stages of evolution of various forms of mediation. The phenomenon of a media environment allows speaking about the formation of the new sociocultural and philosophical outlook based on the recognition of the special "reality" defining strategy of life, perception and understanding, reality of cyber-physical-socio systems.

Addressing the question of morphology of virtual art, it should be noted that prompt distribution digital, and, in particular, computer technologies of creation of virtual projects of reality, have received lighting in a set of the scientific directions and spheres of life, the majority of which are far outside the sphere of art. From the theory and history of art artists move in the direction of the analysis of "art science" (Gran O. 2003) as the practice of immersion to systems of communications of various media forming the existential grids catching fluctuations of the field of reality and turning them into elements of art projects. Such experiments become steps on the way of "a projection of computer ontology in culture" (Manovich L. 2002). The close interlacing of real-virtual-cultural-social under a common denominator media in the modern world gives a clear understanding of the expanding sphere of influence of art, its invasion into external and internal limits of the viewer (Manovich L. 2002).

The second reason is the lack of holistic (system) thinking in the IT industry. The problem of complexity control and management involves interdisciplinary research studies by specialists in mathematics, economics, biology, physics, and computer technologies. However, the founders of cybernetics imparted to its laws much more universality than is really considered in today’s social and business systems. Therefore, the paper presents the results of interdisciplinary research in the field of computer modeling and decision support systems in socio-cybernetics objects (Gerasimenko V.A. 1993; Okhtilev M.Yu., Sokolov B.V., and Yusupov R.M. 2006; Zhuge H. 2011; Heikki and Hyötyniemi 2006).

At the beginning of the XXIst century, the specified objective circumstances, which are connected with CPSS resulted in need of a formation of a wide range of experts on system outlook and the relevant system branch of scientific knowledge.

It has been shown in many works (Gerasimenko V.A. 1993; Okhtilev M.Yu., Sokolov B.V., and Yusupov R.M. 2006; Yusupov R.M. and Zabolotskii V.P. 2000) that when speaking about the interdisciplinary branch of system's knowledge, it is expedient to select in it two big sections (block) — the block of fundamental system info - cybernetic knowledge and the block of applied system info - cybernetic knowledge. In the first of the listed blocks, the defining role is played by three scientific directions — the general theory of systems, cybernetics and informatics.

General theory of systems (sistemologiya). This scientific direction sets the task to construct the general scientific bases for systems of any nature. The central concept of the general theory of systems is the concept of open system, i.e., the system, which is implemented by a two-sided interaction with the environment. Mathematical basics of the general theory of systems can be reasonably considered an interpretation of the bases of mathematics, mainly theories of the relations (the concept of the relation is fundamental both in mathematics, and in system researches), theories of mathematical structures, and the theory of categories and functor (Okhtilev M.Yu., Sokolov B.V., and Yusupov R.M. 2006). However, except for a number of recognized general provisions in general for the present there is no uniform understanding of in what way this theory has to be submitted.

Informatics. This scientific direction connected with the development of methods and means of collecting, storage, transfer, representation, processing, and information security.

Speaking about processes of interaction of cybernetics with informatics, it should be noted, first, that historically the last one developed in a subsoil of traditional cybernetics, actually on a uniform technical base — computer facilities and means of communication and data transmission, and, secondly, cybernetics, being science about the general laws and regularities of management and communication. In recent years, the second round of rapprochement of cybernetics and informatics has been noted. There is an active terminological and substantial interpenetration of these scientific directions, issues of use of information for the benefit of management

Therefore, the methods, technologies and means developed in informatics actively take root in cybernetics within such new scientific directions as: information management, different types of intellectual management (situational, neuro-management, the management based on knowledge, on the basis of evolutionary algorithms, multi-agency management and control, etc.). These types of intellectual management are based on the appropriate intellectual information technologies (IIT) focused on symbolic information processing.

It is accepted to refer to the specified information technologies (Gorodetskii V.I., Kotenko I.V., and Karsaev O.V. 2000; H. Wong and K. Sycara, 2000; Yarushkina N.G. 2004; Omatu S., Khalid M., and Yusof R. 1996; Vasiliev S.N., Zherlov A.K., Fedosov E.A., and Fedunov B.E. 2000; Timofeev A.V. and Yusupov R.M. 1994): technologies of expert systems (Expert Systems) or systems based on knowledge (Knowledge-Based Systems); technologies of fuzzy logic (Fuzzy Logic); technologies of artificial neural networks (Artificial Neural Networks); technologies of displaying, based on precedents (Case Based Reasoning, CBR) CBR technologies; technologies of natural language systems and ontology; technologies of associative memory; technologies of cognitive mapping and operational coding; technologies of evolutionary modeling.

General theory of management (cybernetics). Initially, the founder of cybernetics, N. Winer, in 1948 in the book

"Cybernetics or Management and Communication in an Animal and the Car" emphasized that this science is science about management, communication and processing of information in systems of any nature (Wiener N. 1948, Wiener N. 1950). At the same time, the main goal of the research conducted within the specified science consisted in the identification and establishment of the most general laws of functioning to which the operated objects, and the corresponding managing directors of a subsystem irrespective of their nature are submitted. The classical cybernetics has reduced all earlier existing views of management processes in a uniform system and has proved its completeness and generality. In other words, it has shown in detail the raised power of system approach to the solution of complex problems. The most developed direction in cybernetics was the theory of management of dynamic technical systems within which numerous outstanding fundamental and applied scientific results have been received by domestic and foreign experts.

In turn, cybernetic terminology gets into informatics and computer facilities. Today, in particular, concepts and the strategies of adaptive and pro-active computer systems, adaptive management and the adaptive enterprise are very popular in the IT industry. These strategies are intensively developed by the companies IBM, Intel Research, Hewlett Packard, Microsoft, Sun, etc. (Chernyak L. 2003, Chernyak L. 2004, Dmitrov A. 2006). At the same time, the material basis for the realization of technologies of the operated self-organization is created. In the modern business systems (BS) only those organizations obtain success in which development of IT of architecture is focused on the Web services and technologies allowing effective decentralization of traditional systems of decision-making, turning them into self-regulating subsystems. Interaction of cybernetics (neocybernetics) and informatics with the general theory of systems is carried out in several directions. The first of these is directly connected with the generalized description of objects and subjects of management on the basis of the new formalistic approaches developed in a modern systemology to which it is possible to refer, for example, structural and mathematical and category-functor approaches (Okhtilev M.Yu., Sokolov B.V., and Yusupov R.M. 2006). In this regard, it is also possible to note interesting scientific results, which have been received in a qualimetry of models and multiple-model complexes and can be used in informatics and cybernetics. The methods and algorithms of decomposition (composition), aggregation (disaggregation), and coordination developed in the general theory of systems in relation to objects of any nature are widely used in cybernetics and informatics also to solve problems of collecting, storage, transfer, representation, processing, information security, and also management of complex objects. On the other hand, it has been shown in several studies (Vasiliev S.N., Zherlov A.K., Fedosov E.A., and Fedunov B.E. 2000; Timofeev A.V. and Yusupov R.M. 1994) that the approaches developed in the classical theory of management and control of technical objects and also in modern informatics can be applied successfully to the organization of processes of management of quality of models and multiple-model complexes, and also their structural and parametric adaptation.

2. METHODOLOGICAL AND TECHNICAL BASIS OF NEOCYBERNETICS

The analysis of the neocybernetic fields has shown that this theory is an inter-disciplinary science oriented at analysis and synthesis of intellectual control systems for complex arbitrary objects (Okhtilev M.Yu., Sokolov B.V., and Yusupov R.M. 2006; Zhuge H. 2011; Heikki and Hyötyniemi 2006). These systems operate with both deviation-counteracting and amplifying mutual casual relationships and are able to model the environment and themselves in the environment (the cybernetics of the observer enclosed in the system). The subject of neocybernetic investigation is scientific basics of structure-functional analysis, monitoring, and synthesis of adaptive self-organizing intellectual control and management technologies for cyber-physical-socio systems (CPSS).

A few words about neocybernetic history. The renovation of cybernetics has two sources. The first source lies in the attempts to revise methodological backgrounds of cybernetics. As early as in 1963 Magorah Maruyama focused on the systems in which the mutual causal effects are deviation-amplifying. Economic, social and biological examples were considered (Maruyama M. 1963). In contrast to Weiner's cybernetics with deviation-counteracting systems, the studies of deviation-amplifying mutual casual relationships were called "the second cybernetics" (Foerster, von H. 1987, Foerster, von H. 1974). In 1974, Heinz von Foester defined "the second-order cybernetics" with the awareness that an observer is an element of the system. The studies considered processes resulting in increased biological and social complexity (Heikki and Hyötyniemi 2006). Stafford Bear in his works starting in 1974 emphasized that investigations into complexity problems should evolve Ashby's law of requisite variety (Bir S. 1963).

The analysis of modern cybernetics has allowed proposal of several directions respecting this law and establishing concepts of neocybernetics (Okhtilev M.Yu., Sokolov B.V., and Yusupov R.M. 2006; Sokolov B.V. and Yusupov R.M. 2008; Sokolov B.V. 2010) (see fig. 1).

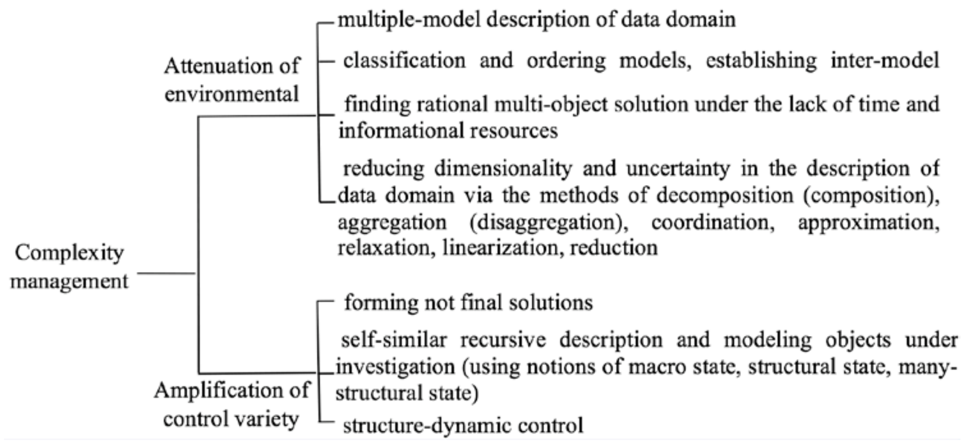

Figure 1: Directions For Realizing The Law Of Requisite Variety

The second source of renovation in cybernetics is the interaction with other scientific disciplines within the system concept. The leading role in establishing neocybernetics belongs to informatics and general systems theory.

In recent years, a new stage of convergence between informatics and cybernetics has occurred. Thus, methods, technologies, and tools of informatics are widely used within new branches of cybernetics such as informational control, evolutionary algorithms, multi-agent control, etc. In turn, cybernetic notions are widely used in the IT industry: adaptive and proactive computer systems; adaptive control and adaptive enterprise.

Now let us consider preliminary composition, structure, main objects, goals, tasks, unsolved problems, and subjects of the XXIst century cybernetics. The peculiarities of control systems, and environmental impacts require sufficiently new approaches to methodological basis of cybernetics. In order to emphasize this novation, the term neocybernetics should be used.

Goals of neocybernetics lie in the creation of cybernetic systems of new generation with the following features: proactive control; abilities of self-actualization, self-reconfiguration, self-perfection, self-optimizing, self-treatment, and self-preservation; public behavior; sociability; kindness; honesty.

The main notions of neocybernetics include complexity, structure dynamics, emergent property, macro states, structural states, many-structural states, proactive control, integrated modeling, and qualimetry of models and multiple-model systems.

The main tasks of neocybernetics are the following: Complexity management including attenuation of environmental variety; amplification of control variety; the tasks of decomposition (composition), aggregation (disaggregation), coordination, approximation, relaxation, linearization, reduction in modeling, analysis and synthesis of CPSS; structure dynamics control for CPSS; models qualimetry; traditional tasks of the first-order cybernetics.

The main unsolved problems of neocybernetics include organization and conducting interdisciplinary investigations for CPSS development; examining basic characteristics of for CPSS (self-configuring, self-service, self-optimizing, fault tolerance, self-preservation) and influences upon these characteristics; construction of methods, algorithms, and models for analysis and synthesis for CPSS; analysis of user interaction for CPSS; analysis of biological analogues for synthesis of CPSS.

Methodology and technique of neocybernetics for CPSS control and management are based on the concept of proactive monitoring and control, which assumes incident prevention through creating radically new forecasting and preventing opportunities when forming and implementing the control actions. Table 1 presents the main scientific results, which we have obtained in the field of neocybernetics by now (Kalinin V.N. and Sokolov B.V. 1995; Okhtilev M.Yu., Sokolov B.V., and Yusupov R.M. 2006; Sokolov B.V. and Yusupov R.M. 2006; Yusupov R.M. et al. 2011).

Table 1 presents opportunities of proposed methods and algorithms, which constitute the description of integrated intellectual decision support systems for proactive management and control of CPSS, as well as combined methods of operative synthesis of hierarchical network structures of decision support systems for proactive management of CPSS as part of managing complex organizational and technical objects.

Table 1: The Main Achievements of the Proposed Methodology and Technique

Achievements	Shortcomings	Opportunities
1. Dynamic multiple-model description of CPSS functioning at the different stages of their life cycle [	1. Different types of models (analytical-simulation, logical algebraic, logical-linguistic models) are used for the description and study of main CPS attributes.	1. Joint use of diverse models in the framework of poly-model systems, allows improvement of the flexibility and adaptability of CPSS, as well as compensation for the drawbacks of one class of models by the advantages of the others.
2. Combined methods and algorithms of models coordination and adaptation.	2. Now several procedures and techniques are proposed to arrange and conduct integrated modeling, which may be different in the methods of generating admissible alternative, solutions, the rules for testing constraints given in the analytical or algorithmic form, and the methods of transition from one step of interactive restriction of the set of admissible alternatives to another.	2. The adaptive plans (programs) of CPSS functioning include transition programs as well as programs of stable CPSS operation in intermediate multi-structural macro-states. One of the main opportunities of the proposed method of CPSS SDC program construction is that besides the vector of program control we receive a preferable multi-structural macro-state of CPSS at the end point of control interval. This is the state of CPSS reliable operation in the current (forecasted) situation.
3. Methodological and technical basis for the synthesis and intellectualization of monitoring technology and systems for complex technical objects.	3. Flow-oriented knowledge-representation models, methods, and algorithms for monitoring and control of CPSS are widely used in different applied areas now (power grid system, virtual enterprises, applied areas of space).	3. The proposed methods of monitoring automation and modeling allow switching from the heuristic description of telemetry analysis to a sequence of stages of monitoring program contraction and adaptation, from unique skills to unified technologies of software. These methods are based on the conclusion that a functional description of monitoring and control process is much less complicated than a detailed examination of software realizations.

3. EXAMPLE OF CPSS MODELLING AND SIMULATION

As an example of the integrated modeling and simulation based on the CPSS, we developed an analytical model for time-table of trains, a simulation program (Fig. 2) and an experimental stand (Fig. 3) with a transport network (for example, railroad); additionally, some production and warehouse facilities are currently under development. The railroad is provided with multiple sensors, for example the RFID, which provide information about the position and the speed of the bypassing locomotives. We note that the RFID experimental environment is not intended (at least, in its current version) for a full implementation of the developed models. It is much simpler as a modeling framework and serves to gather experimental data for the modeling complex. The modeling complex itself is implemented in a special software environment, which contains a simulation and optimization (analytical) engine of planning and execution control, a Web platform, an ERP system, and APS system, and a SCEM system (Morozov V.P. and Dymarskii Ya.S. 1984; Chernyak L. 2003; Chernyak L. 2004; Dmitrov A. 2006). The cornerstone of the computational framework is the decision modeling component, that is, the simulation and optimization engine. The schedule optimization is based on an optimal control algorithm that is launched by a heuristic solution, the so-called first approach.

The seeking for the optimality and the transport network control system (CS) scheduling level is enhanced by simultaneous optimizing and balancing of interrelated CS functional, organizational and information structures.

We note that the RFID experimental environment is not intended (at least, in its current version) for a full implementation of the developed models. It is much simpler than the modeling framework and serves to gather experimental data for the modeling complex. The modeling complex itself is implemented in a special software environment, which contains a simulation and optimization engine of CS planning and execution control, a Web platform, an ERP system, and APS system, and a SCEM system. The kernel of the computational framework is the decision modeling component, that is, the simulation and optimization engine. The schedule optimization is based on an optimal control algorithm that is launched by a heuristic solution, the so-called first approach. The search for the optimality and the CS scheduling level is enhanced by simultaneous optimizing and balancing of interrelated CS functional, organizational and information structures.

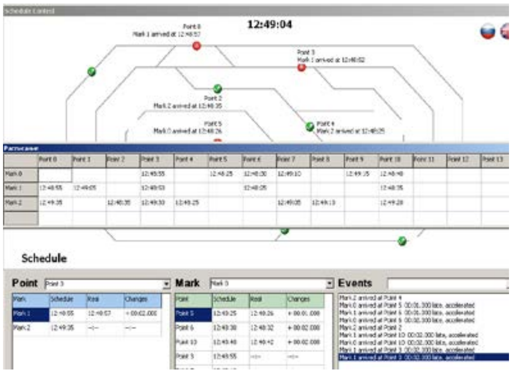

Figure 2: Screenshot from the Transport Network Simulation Program

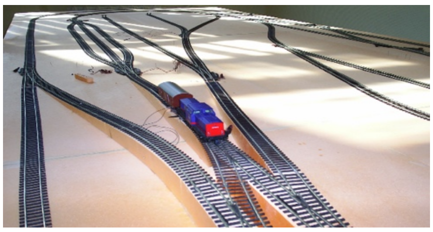

Figure 3: An Experimental Stand

The schedules can be analyzed with regard to performance indicators and different execution scenarios with different perturbations. Subsequently, parameters of the CS structures and the environment can be tuned if the decision-maker is not satisfied with the values of performance indicators. In analyzing the impact of the scale and location of the adaptation steps on the CS performance, it becomes possible to methodically justify the requirements for the RFID functionalities, the stages of a CS for the RFID element locations, and the processing information from RFID. In particular, possible discrepancies between the current needs for the wireless solution of CS control problems and the total costs of ownership regarding RFID can be analyzed. In addition, processing information from RFID can be subordinated to different management and operation decision-making levels (according to the developed multi-loop adaptation framework). Pilot RFID devices with reconfigurable functional structure are developed (Okhtilev, M.Yu., Sokolov, B.V., Yusupov, R.M. 2006). In order to simulate the RFID-based transport network, we have created a prototype of a simulation model that reproduces a real railway network. To do this, we could use different approaches, but the most suitable is the multi-agent system modelling (Gorodetskii, V.I., Kotenko, I.V., and Karsaev, O.V. 2000, H. Wong, K. Sycara, 2000). To realize the simulation model we could use different tools developed for modeling a multi-agent system (M.A.S) but most of them have a restrictive or a paid licensing policy. So, we managed to develop from the bottom a prototype of a simulation environment based on the C++ programing language and the M.A.S. approaches. The first step in creating a simulation model is to define the time framework, implemented in the form of the main event loop. In the loop, we have two functions; the first may or may not create a random disturbance in the locomotive speed and the maximum speed. The second function simulates the agent behavior. This system enables us to simulate a basic railroad network, and test the RFID infrastructure using a realistic model. Of course, as any system, this one has its advantages and disadvantages. As regards advantages, they include: the technologies used to create this model (C++ language), it provides us with a great flexibility in terms of functionality, allowing for modification and implementation of any kind of logic we want; agent based modeling is a powerful method allowing a large number of enhancements in the behavior of the system. Additionally, it enables us to define a logic of each individual locomotive, which is close to how decisions are made in a real system; define the system behavior by an independent entity allows great scalability, as the complexity of the system is linear to the number of entities.

4. CONCLUSION

Thus, summarizing the aforesaid, it should be noted, first of all, that one of the main tendencies in the development of information technologies and systems (IT and IS) in the XXIst century will be connected, in our opinion, with the solution of the problem of comprehensive integration of these technologies and systems with the existing and future industrial and socio-economical structures and the corresponding control systems. To solve successfully this interdisciplinary problem, it is necessary to solve a number of scientific-and-methodological and applied problems.

One of such urgent and interesting scientific-and-methodological problems arising at the turn of modern cybernetics and computer science, is the problem of justifying composition, structure, quantitative and qualitative characteristics of information that is necessary both for effective control of CPSS and for the control of information systems that provide for successful realization of business processes. In this connection, the following problems can be listed among primary tasks that need to be solved: formation and justification of a system of indices to measure information that is necessary for effective operation with adaptive CPSS (for various classes of customers and applications); development and justification of methods and algorithms for determining values of the information measure indices; development and justification of the structure of regular information measurement; development and justification of analysis and design methods for adaptive technologies and realization of processes of generation, registration, gathering, transmission, accumulation, storage, search, processing and release of information to end users with account for objective needs for information and objective prerequisites of the above-listed processes; development and justification of models, methods and algorithms of adaptive control of information quality.

Dynamic multiple-model descriptions of CPSS functioning at the different stages of their life cycle are proposed in the paper. Different types of models (analytical-simulation, logical algebraic, logical-linguistic models) are used for the description and study of the main attributes of CPSS. The joint use of diverse models in the framework of multiple-model systems allows for improved flexibility and adaptability of CPSS, as well as compensation for the drawbacks of one class of models by the advantages of the others.

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AUTOMATED EXCHANGE SYSTEM BETWEEN SIMULATION, VISUALIZATION AND CONSTRUCTION TOOLS

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ABSTRACT

In today's planning processes, it is necessary that assembly processes, component transport to the production facility and the use of components are optimally matched. To realize this matching, these processes must be carried out as detailed as possible. This is where the conflict between the least possible effort in the bidding phase, in which the focus is on the fast creation of a basic factory layout and an appealing communication of the planned system.

By increasing costs, lack of time and cost-intensive physical hardware devices production industry respond to these increasingly with digital planning tools in product development. Through the development of an automatic exchange system between simulation, visualization and construction tools a possibility should be developed to combine intralogistics systems from any planning tools of the digital factory. The use of open source standard AutomationML forms the basis of the automatic exchange system.

Keywords: modern automation system, system planning, AutomationML, automatic model creation

1. INTRODUCTION

Due to ever shorter product life cycles, the versatility, speed and flexibility of origination, production and logistics processes becomes a stronger focus (Schenk 2014). The use of digital tools of simulation, visualization and design increases the quality of planning, increases the efficiency and shortens the product development and launch (Schenk 2014; Daft 2016; Klepper 1996; Lüder and Schmidt 2015). All these benefits can only be fully exploited if it is possible to combine all relevant and previously isolated digital methods, tools and models into an integrated planning system (Faltinski 2011; Schreiber and Zimmermann 2011). The used digital tools in the areas of simulation, visualization and construction provide a comprehensive range of solutions to various problems. The long-term use of simulation, visualization and construction tools in the planning of intralogistics material flow systems clearly shows that over time individual and specialized tools were developed. They have only limited possibilities to offer and share planning data in a heterogeneous system landscape (Faltinski et al. 2012; Rawolle et al. 2002).

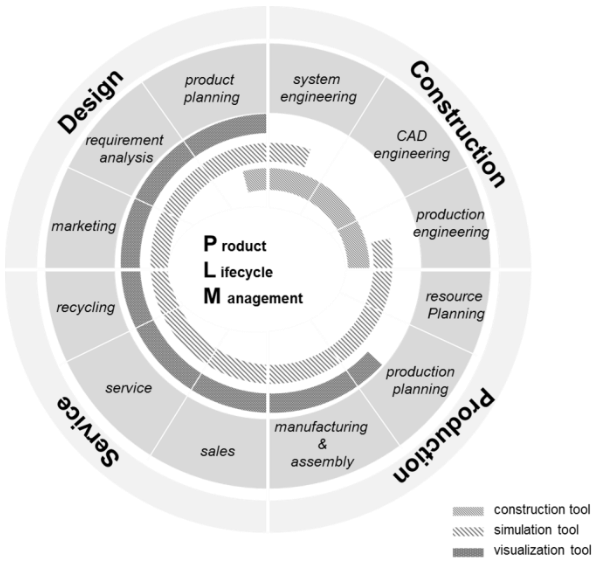

Figure 1 Application of simulation, visualization and construction tools in the PLM cycle

The existing digital tools are partially only for certain functional areas of PLM-cycle as shown in Figure 1. In practice, therefore is no comprehensive, computer-assisted planning of intralogistics systems and production areas. It lacks a neutral exchange format for the mapping of simulation data, geometric construction drawings and visualization of current detailed production and logistics processes. A tool which relates the three most important tools of the digital factory represents the automatic exchange format, which will be explained in detail in the following sections.

2. LITERATURE REVIEW

The complexity and the cost pressure in the PLM are constantly increasing (Eigner and Stelzer 2009). The standardisation of systems, processes, and components is an important means to cope with the future challenges (Drath 2008). The PLM is defined by the overall process of product development with its various steps. A target State of the process, as well as the control of all necessary steps to set and planned (Sendler 2009). The previous focus was the combined planning phases to shorten the time-to-market of products through the integration of product, process and production system planning, the present claim is consists of early reliable data product development for the integrated production, to use factory system development and design (Schenk 2014; Schenk and Schumann 2008). The idea of combined planning phases is described for years by modern and powerful tools (Dangelmaier 2013). There is here a number of special cases. These include individually prepared solutions and are sufficient for concrete problems. However, the lacks comprehensive planning approach to take part in processes to promote an integration of all. A first approach was developed for continuous digital planning and controlling with the enterprise application integration (EAI) and the service-oriented architectures (SOA).

The EAI represents integrated business processing along value chains. Corporate applications of different generations and architectures can interact through a common network (Aier 2004, 2006; Kaib 2004). The SOA describes a method encapsulates the existing computerized components such as databases, servers, and sites in services and coordinate so that their services can be grouped together to higher services and made available to other departments of the Organization (Bieberstein 2008; Liebhart 2007). Goals are the long term reduction of costs in the development of production plans and a greater flexibility of business processes by reusing existing services. The costs of future developments are reduced, because all necessary services are already available and these must only be set should be. Reason for the sluggish development is due to the high requirements for data security, continuity of the tool development and uncertain systems and product development (Fay 2006; Drath 2008; Raupricht et al. 2002).

The combined, continuous flow of information between the used tools has emerged in view of increasing shortening and linking the phases as valuable. Therefore, a comprehensive planning tool in the areas of planning, implementation and realisation is gaining in importance. The interplay of different digital planning tools within the product life cycle is summarized often under the term "Digital Factory". Here, the term describes a comprehensive network of digital models and methods of including the simulation and 3D visualization. Its purpose is the holistic planning, implementation, control and continuous improvement of all major factory processes and resources in conjunction with the product (VDI 2008; Wenzel et al. 2003).

A combination of different planning tools is also known. According to the current state of science no consistent and open source system exists to exchange data between the tools properly, efficiently and effectively. The use of continuous planning tools lacks. The motivation for the use of a common tool can be the reduction of costs for the planning, control, and operation and maintenance of equipment.

3. REQUIREMENTS AND IMPLEMENTATION

Three individual tools are linked by an automatic exchange system. Figure 2 shows the cross-section functions of the individual tools.

Tool for: / **ability to:**	simulation	visualization	construction
simulate		◐	○
visualize	○		◐
construct	○	○	

○ low ◐ medium ● high

Figure 2 Overview of the tools and their abilities

The expert knowledge and the complexity of each tool are very high. By separate cross functions of the individual tools, it is difficult to find a common level. The presented development is an application-oriented middleware and thus represents no additional tools. While the visualization tool offers the possibility of simple stochastic influences but cannot depict a classical discrete event material flow simulation. Another example is the construction tool. The construction tool cannot represent a material flow simulation, but constructed models can be shown in three-dimensional view, that can be interpreted as a simple visualization. The following are the benefits of the automatic exchange system:

- **Lossless and accelerated modeling and conversion:** within the three different tools
- **Avoid new investments:** used simulation, visualization, and construction tools in the company will remain
- **Neutral Exchange format:** leads to any figure of the models and access to different tools

With the simulation tool, software solutions are referred to the discrete event, continuous or discrete-rate modeling and simulation of material (Reggelin 2011). A 3D visualization and animation to the validation refers to the visualization of design planning, interdisciplinary communication and sales presentations of production and logistics systems. The construction tool describes a software solution for the computer-aided technical drawing to create virtual models of three-dimensional objects.

3.1. Exchange format AutomationML (AML)

To enabling the exchange of information between the tools, it is necessary to use an open, non-proprietary and standardized language. By Format AutomationML (AML) (Automation Markup Language) is the internationally standardized in the IEC62424 data format CAEX (Computer Aided Engineering Exchange) as well as the implementation platform and independent Data exchange format XML (Extensible Markup Language) used (Figure 3).

The standard AML supports the definition of semantic roles and classes. Since AML indeed possesses the technical requirements for the modeling of production, intralogistics and material handling systems, however so far mainly in the field of virtual commissioning, robot systems and the general geometry of exchange used to exist only few and rudimentary provided with properties AML descriptions Material flow and logistics systems (Hoernicke et al. 2016; Hundt et al. 2009; Lüder and Schmidt 2015). Existing intralogistics material flow systems as CAD drawing can thus be passed into the visualization tool without create additional elements. This is done by linking role profiles. In addition to the geometry of an element the thereon objects, technical parameters and environment variables are passed. Here the developed standardization serves to link the properties of an element, object or the parameters within a tool with the AutomationML environment.

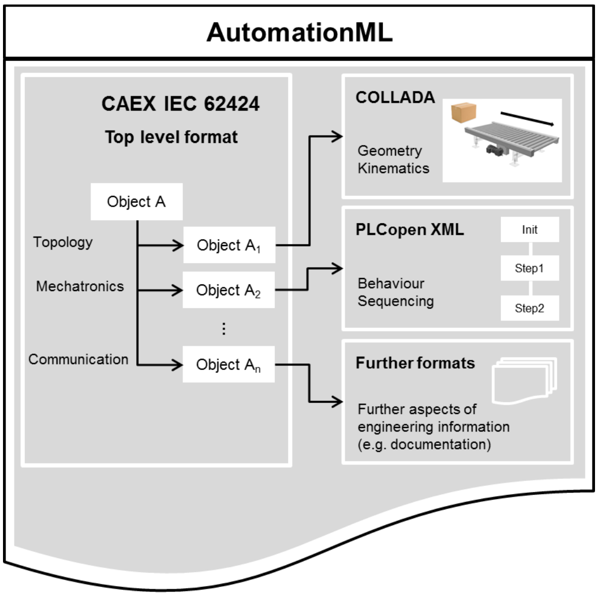

Figure 3 Content and function of AutomationML

4. AUTOMATIC EXCHANGE SYSTEM

Linking the tools in the automatic exchange system allows visualization models in simulation models to convert. A comprehensive up to date step, since the discrete event simulation allows a very detailed and custom modeling. The discrepancy between the implementation of visualized simulation-based models will be reduced by the development. The figure shows the interaction of the participating tools with automatic exchange system. The objective is to provide this omnidirectional appearance and parameters for different tools. A time-consuming and multiple modeling and setting should be avoided. The core functions of the automatic exchange system describing the export of data from the tool in the automatic exchange system, the processing of data in the AutomationML format and import into the target tool. This all takes place automatically and is supported in conflicts through a guided conflict resolution. The specificity of development is this ability formats in the AutomationML format to convert to transfer existing data from the tools and to guide the user through the import and export. By working completely different software environments can be passed this false or nonexistent model elements and other parameters or missing. The user can complete missing content in addition. This function is used particularly in the exchange between simulation and visualization. Due to the different levels of detail and parameter in these two tools here is increased potential for conflict in the Exchange of models and parameters (Figure 4).

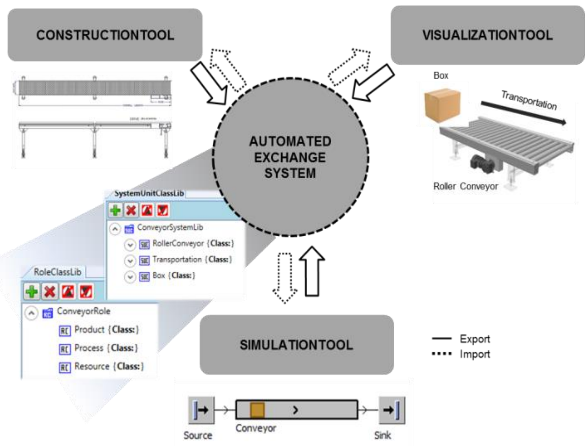

Figure 4 Overview of the integration of the automatic exchange system

To obtain the high degree of customization of simulation and design tools, rules are initialized around objects, parameters and descriptions without error to transfer. Since it is not possible to see all user-specifiable elements before and after an image in the AML Exporter, and from AML in the importer predefine, a tool was developed, with which he can provide the necessary information for a picture itself. The basis for the picture one created by the user rules for mapping between objects or object hierarchies and their attributes. In preparing this set of rules, the user is supported and guided by the developed software. The Figure 5 shows the conceptual approach to the data transfer of the three tools on AML.

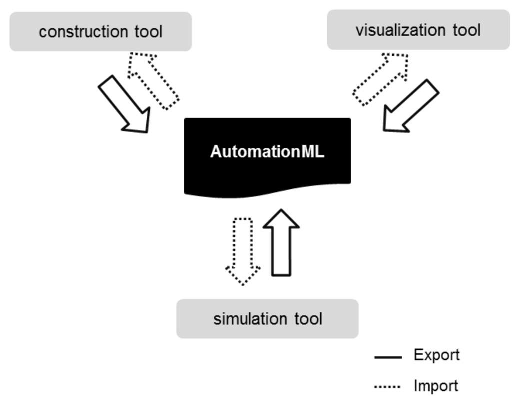

Figure 5 Transfer of data from the tools in AutomationML

The data transfer process essentially consists of two steps, the export in the AML environment and importing into the target tool.

4.1. Import function

The Import describes the transmission from the AutomationML file into the target tool (s. Figure 6). In the simplest case, the data from a source tool that already used for producing the data set a block catalog with an existing set of rules derived. This rule set may have been either created by the user himself at an earlier time, or by a third party as part of a service.

In this simple case, the user selects in an import dialog from the one to use ruleset and then start the import process, which is then completed according to the defined rules. If the imported data does not contain all the information necessary for a complete and unambiguous generation of the target record from the perspective of import target tools, so be where possible defaults assumed and the user then referred to this in order to facilitate a manual review. If no block of mapping rules consists for the data to be imported, the user is given the possibility to create this itself. The functions of the importer in detail:

1. **SourceDataReader:** Captures the attributes of the trainees from object from AML-file
2. **Rule-Interpreter:** uses object attributes to the illustration in the target system
    - matching library item
    - matching Parameters of the object (speed, length, etc.)
3. **TargetDataWriter:** After successfully mapping of the Rule-interpreter, he creates an instance of the appropriate library element or group of elements in the target system

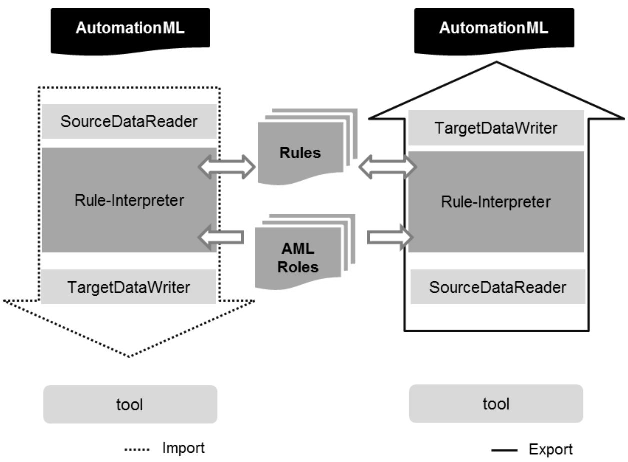

Figure 6 Functioning and structure of the Importer and Exporter

4.2. Export function

The export function is used to exchange data from the source tool in a AutomationML file. The Exporter is designed similarly to the Importer (s. Figure 6). Here, however, the implementation is less complex because the Exporter cannot make assumptions about the target system and thus largely the tool-internal data format can be used as basis for the exported AML structure. The only adjustment is the unique creation of mapping rules of the internal objects on elements of the AML standards, namely the allocation of system Unit Classes, Role Classes and Interface Classes from the standard libraries previously defined, where possible. This is especially the transfer of semantic information between tools and thus greatly increases the quality of data exchange and to simplify the mapping rules on the import side of the data exchange. The functions of the Exporters in detail:

1. **SourceDataReader:** recorded attributes of the object from the source system
2. **Rule-Interpreter:** searches based on object attributes to the figure in AML
    - Matching system-unit-class (SUC) (E.g. rotary table)
    - Matching AML role definition (E.g. conveyor, Rotary element...)
    - Matching Parameters
3. **TargetDataWriter:** by the Rule-interpreter, a corresponding AML-file is written after successfully matching

5. USE IN MATERIAL FLOW SIMULATION

In addition to exchanging the system description and structure, it happens during the design phase of a plant as well as later adaptations that a virtual system image with data from real or simulated production processes to be linked. Applications include for example:

- Visualizing a simulated production layer for communication bottlenecks and opportunities for improvement
- The reproduction of recorded live production data for problem analysis
- The visualization of the modified plant behavior in adjustments in intralogistics

In the above cases, in turn, a data exchange of simulation or production monitoring systems to planning and visualization systems is necessary, but not the investment structure has to be communicated, but the temporal change of the material flow. It was joined by the previously known tools as well as the proposed AutomationML formats to its limits, because it was designed for the description of the plant structure. For this reason, a new data format and transmission method for communication of runtime data of a system must be developed (Figure 7).

The following transfers are to be made possible:

- Date and type of goods recorded in the system
- Time at which a good leaves the considered system
- Changes of the product position over time
- Changes the position of mobile Anagenkomponenten over time (operator, fork-lift trucks, etc.)
- Dates of transfers of goods from one system component to the next station
- Changes to the product (Assembly, damage, packaging, etc.)
- Data editing processes such as Start- and end times and duration of the process
- In General, concrete values are needed for the modeled sizes for everyone in the plant model with distributions or random numbers

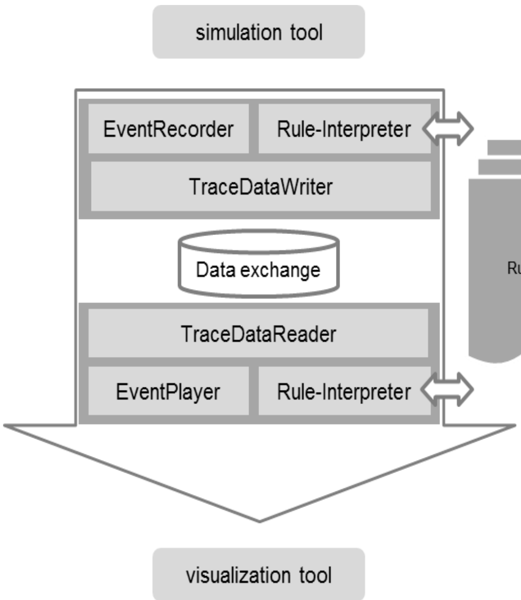

Figure 7 Detailed description of the function in the exchange / feedback between visualization and simulation.

6. THE AUTOMATIC EXCHANGE SYSTEM ON APPLICATION EXAMPLE

To test the development of an automatic exchange system, different examples were developed. Here, the first attempts at exchange of visualization tools were made for simulation tool. The exchange between visualization and simulation is one of the most difficult tasks in the exchange system. This is due to the different levels of detail and different parameterizations within the tools. Where visualizing a detailed reproduction of features, the simulation tool requires a detailed parameterization of the system states.

First, a conceptual model to be visualized the, modeled and simulated system was created. The concept model is the basis for the visualization and simulation. This ensures that both visualization and simulation represent identical models. This facilitates the verification and validation of the models created in the course.

The next step is conceptualized model is transferred to the visualization tool.

The visualization allows a first virtual evaluation of the model. In visualization tool, the system can be shown extensively, but only simple calculations and statements about the system status over time are possible. In order to remedy these drawbacks of the visualization tool, in the next step, a simulation model is created. As a remodeling in the simulation tool is time consuming and a new modeling effort would arise, should be done through the automatic exchange system of this step.

Here, the content is exported from the visualization tool and transmitted in compliance with roles and classes, geometry and kinematics of the elements and objects used in the simulation tool. The transfer of the content was carried out via the interface AutomationML and additional adjustments to the automatic exchange system. The simulation tool the program Tecnomatix Plant Simulation was used. This software for discrete event simulation, analysis and optimization of production processes, material flow and logistics processes is part of Siemens Product Lifecycle Management Software.

6.1. Conceptual model

The basis for the application example is an intralogistics system. The example is based on an existing material flow system and thus describes the common elements of intralogistics. The concept model of the plant is used as a basis for further steps. The logistical objects are transported on conveyor lines (CO) and turntables (RT) to the following stations:

- Processing station (PS) 1,2,3 (Manual picking station)Processing station (PS) 6 (post processing)
- Processing station (PS) 4,5 (Storage in the high-bay warehouse)
- High rack (HR) (Storage of objects)

In addition, read the objects and their properties stored using radio frequency identification (RFID). The figure shows the conceptual model of the system and thus describes the basic function and the relationships of the elements to each other (Figure 8.).

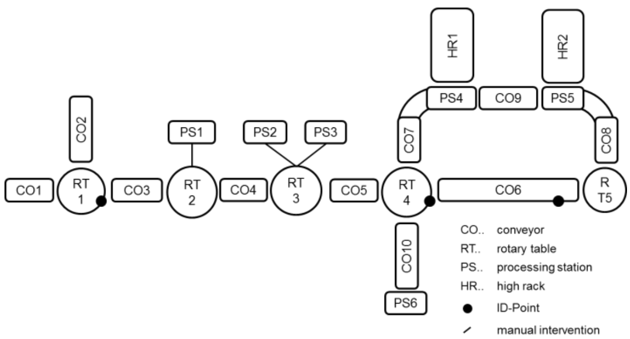

Figure 8 Conceptual model of intralogistical system

6.2. Model in the visualization tool

According to the conceptual model, the intralogistics system was created in the visualization tool. The illustration shows in Figure 9 reaction exemplified in the visualization tool taraVR. The visualization allows a first virtual design of the system and controls with simple priority rules the material flow. Due to the high level of detail, the system can be modeled with a few steps and understandable.

However, there is the possibility of repeated simulation experiments to perform other statements about being able to enter the system.

Table 1 Considered logistical objects in the system

Visualization	Simulation	Sim-Type
ContainerRed	BoxRedFull	Entity
Euro pallet w. raw material	EurPalettFull	Container
Euro pallet w/o. material	EurPalett0	Container
Euro pallet w. material	EurPalett1	Container

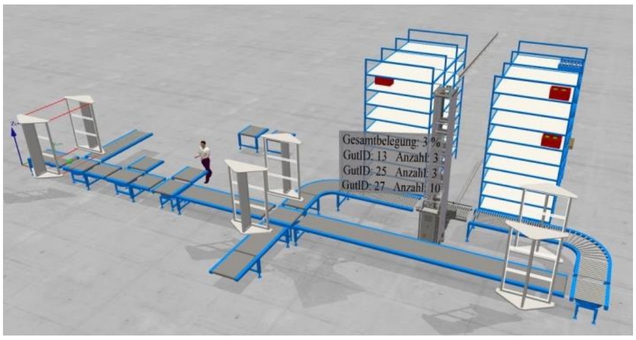

Figure 9 VR of intralogistics system in visualization tool (1)

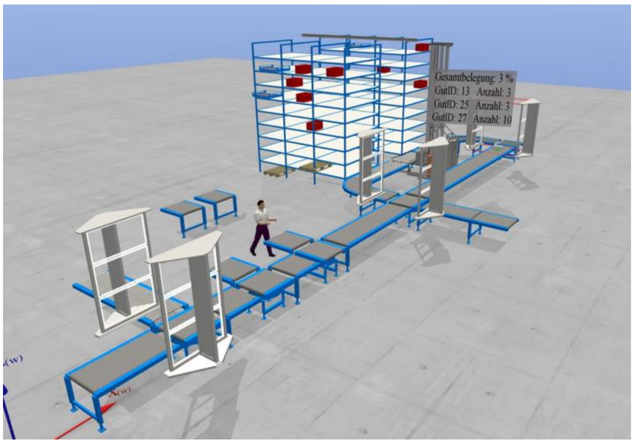

Figure 10 VR of intralogistics system in visualization tool (2)

6.3. Model Description in the automatic exchange system

If a transfer from the visualization in the simulation tool made without the automatic exchange system, a repeated modeling would be necessary. The automatic exchanging system allows a workload by repeated modeling to avoid as a simulation model. The Exports from the visualization create a hierarchy in AutomationML. This hierarchy includes another description of the components, processes and products from the visualization and geometric and kinematic relationships of the content (Figure 9 and Figure 10).

The items from the visualization tool are exported via the developed AML interface in the automatic Exchange System. In the Exchange system, the classes and roles of the objects are created, modified or retained. In this example were created for the project "Blocks", "Processes" and "Products". Then edited and formatted the system the data as described in the chapter 4. Here, all other properties of the objects are applied (location, speed, color, etc.).

After this step, the prepared data on import into the simulation model are passed. Thanks to a programmed surface is enables the user of the modeling process to understand. Furthermore, it is possible when you enter to support. The system can provide work to the user in fact that difficult situations in the creation and parameterization can be solving itself. It comes to a conflict, for example, when creating a new model where is not known whether the problem on conveyor lines or blocks can be depicted, the user support in the selection. He knows how he makes the parametrization of the virtual system. The methods in the simulation tools, networks, and devices create the corresponding model during initialization of the program. This means that subsequent modelling will be as slow as possible.

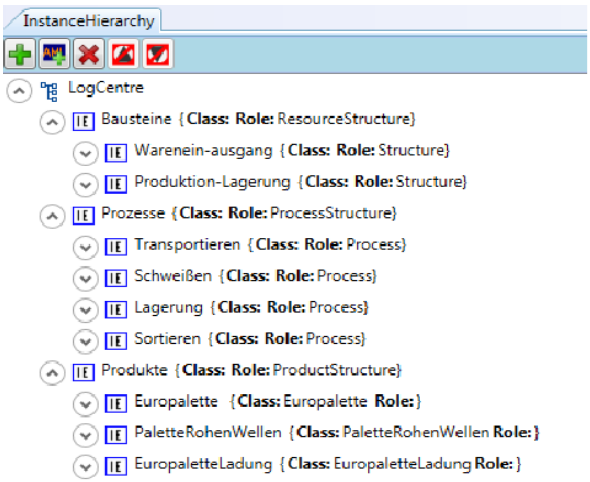

Figure 11 Hierarchies in AutomationML

6.4. Model in the simulation tool

The next step is to convert the model from the visualization tool in the simulation tool. The automatic exchange system helps here in faster modeling. Figure 12 shows the fully converted model from the visualization.

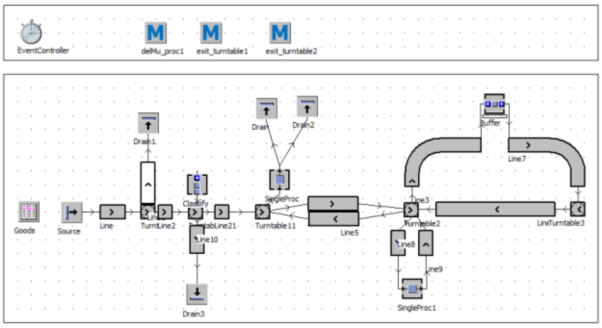

Figure 12 Simulation Model of the intralogistics system after the transfer

The existing settings will provide an initial quantitative images of the model in the simulation tool. Many parameters could be transmitted via the automatic exchange system. It is obvious that a 1: 1 relationship at the moment can never be fully achieved. For this purpose, individual parameterization of the models are too many available. The necessary changes have been covered by the rule interpreter, as well as the user interface.

For the implementation of the model in the simulation tool, the following problems were identified in the prototypical implementation:

- Settings of the transport systems in the simulation tool much more extensively to parameterize as in the visualization tool
- Generating multiple, complex goods from the source must be mapped on a table. A 1:1 relationship of the sources thus not possible
- Parameterization of the employees much more extensively in the simulation tool. Flexibility of staff was carried out via additional method control

The problems could be solved through further parameterization of the respective modules.

Table 2 shows an excerpt from the representation of the different objects of visualization and simulation. Some objects could be easily applied as a component; other objects had to be described by module and method. It is clear that with the high degree of individualization of visualization and simulation model different ways exist to transfer a model from one tool to the next tool. The following table shows extracts the possible combinations for the established example.

Table 2 Excerpt about possible illustrations, and combinations of blocks

Visualization	Simulation	Sim-Library
RT 01	Rotary Table	Materialflow
CO 01	Line	Materialflow
RT 02	Rotary Table + Method	Materialflow + Informationflow
PS 01	PlaceBuffer + Method	Materialflow + Informationflow
HR 01 / 02	PlaceBuffer + Method	Materialflow + Informationflow

7. CONCLUSION

The prototypical example of a first potential and limitations of development outlined. The use of AutomationML enables open source exchange of different tools. In conjunction with an intelligent system for importing and exporting new type of mutual model building can be made possible. The following advantages can be combined with the use of an automatic exchange system.

- Used visualization, design and simulation tools in the company will remain, this avoids heavy new investment
- Synergy effects can be achieved through the use of an Exchange system that combines the individual benefits of the tools
- Visualization, modeling, and simulation of real-world intralogistics systems can be accelerated because of the mostly manual and expensive modeling effort will be reduced
- Multiple implementations of a problem in various tools reduced which results in shorter processing times and increased productivity

The example makes clear how extensive the import and export function must be programmed. In addition, the reference model cannot show all possible errors in the implementation of visualization of the simulation. The overall results of the first phase of development suggest however major advantages. There exists a time advantage over the comparatively new modeling in the automatic conversion. The overall results of the first phase of development suggest however major advantages. There exists a time advantage over the comparatively new modeling in the automatic conversion. Through the implementation of the model from a single source, incorrect or faulty disclosure avoids planning error descriptions and parameterizations. The developed reference models are available following the development for the repeated use of the available. The user interface is developed steadily through constant feedback in the development processes.

8. OUTLOOK

The development of the automatic exchange of information is to facilitate a high potential model building in different tools. The sample results show that the implementation is successful possible. A first approach to the automated model building is managed by automatic Exchange System. Here, no proprietary software solutions were used.

The use and adaptation of open source tool AutomationML is used as a neutral interface between simulation, visualization and construction. With the creation of any model in one of the three tools in the future, it will be possible to produce accurate and rapid models from a single source. This eliminates the costly, error-prone and time-consuming multiple creation of models. The special feature of the coupling with the simulation tool shows that it is possible also in plant simulation is to be able to create an automatic model creation with existing elements.

The example in the implementation of visualization and simulation is one of the most difficult work packages. The used elements are mostly known in the construction. Thus, a simple parameterization and transfer into the automatic exchange system is possible. The construction of intralogistic equipment or the construction of a new element represent only marginal problems of import and export for the system. However, the simulation tool stands for high customization. The Modeler has the choice between different components, networks and methods. A real-world situation can be modeled in the simulation tool on many different levels and adapted. Depending on the goal of the simulation are some items of greater importance and must be modeled more detail than others.

Here, the automatic exchange system offers the possibility of creating a guided model. Conflicts are detected and can be changed by the user. The stronger the user the system interacts with, the more accurate the way of working in the reference libraries of AML is filed. However, for the simulation tool the future issues that should be examined further in the course of the work. Among other things how the illustration can be summarized better standardized elements, how the computing time and computational load may be reduced for larger models, how reference libraries can better portray the intralogistical questions and to what extent in addition to discrete event simulation tools other simulation paradigms and their tools can use for import and export the developed functions.

The described development is a first step for the automatic model creation. This meets the requirements for an integrated planning tool. It is now possible to create joint AML libraries for simulation, visualization and construction, to share and to individualize a repeated use. Future steps are the more detailing and standardization of automated Exchange System.

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USING THE HLA STANDARD IN THE CONTEXT OF AN INTERNATIONAL SIMULATION PROJECT: THE EXPERIENCE OF THE "SMASHTEAM"

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ABSTRACT

To understand, predict and optimize the behavior of systems, several M&S techniques are emerging. A well-known and mature standard is the IEEE 1516-2010 - High Level Architecture (HLA) that is a general-purpose architecture to support the reuse and interoperability of distributed simulation components. In this context, the paper presents a concrete experience in using the HLA standard in the context of an international project, the Simulation Exploration Experience (SEE), organized by the Simulation Interoperability Standards Organization (SISO), in collaboration with NASA and other industrial partners, and involving several university teams in the distributed simulation of a Moon base.

Keywords: Modeling and Simulation, High Level Architecture, Distributed Simulation, Model-based Design; 3D visualization

1. INTRODUCTION

Modeling and Simulation (M&S) represents a pillar supporting the acquisition of knowledge so as to understand, predict and optimize the behavior of systems on which to perform experiments and theoretical analyses (Banks 1998; Falcone, Garro, Tundis, 2014; Fortino, Garro, Mascillaro, Russo 2007; Fortino, Garro, Russo 2004; Fujimoto 2000; Kuhl, Weatherly and Dahmann 1999).

The increasing complexity of modern systems makes their design, development and operation extremely challenging and therefore new M&S methods, techniques and tools are emerging, also to benefit from distributed simulation environments. In this context, one of the most well-known and mature standard is the IEEE 1516-2010 - High Level Architecture (HLA) (IEEE Standard for Modeling and Simulation - High Level Architecture) that attempts to handle this complexity by providing a specification of a distributed infrastructure in which simulation units (called *Federates*) can run on standalone computers and communicate with one another in a common simulation scenario (called a *Federation*) through a Run Time Infrastructure (RTI) that is a sort of service bus that provides information, synchronization, and coordination services to the connected *Federates* (IEEE Standard for Modeling and Simulation - High Level Architecture).

To promote the adoption of distributed simulation practices, standards, and technologies, since 2011, the Simulation Interoperability Standards Organization (SISO), in collaboration with NASA and other research and industrial partners, has been organizing an annual event, named Simulation Exploration Experience (SEE) (The Simulation Exploration Experience project). The main objective of SEE is to provide undergraduate and postgraduate students with practical experience of participation in international projects related to M&S and, especially, to gain expertise in developing distributed simulations based on the HLA standard and compliant tools, by involving them in the simulation of a space exploration scenario.

This paper presents the experience of the "SMASHTeam" of the University of Calabria in the 2016 edition of the SEE project with the aim to highlight the exploited software engineering solutions as well as lessons learned and future research directions. In particular, three HLA Federates developed by the "SMASHTeam" through the use of the *SEE HLA Starter Kit* software framework (The SEE HLA Starter Kit project) will be presented: a *"Command and Control center"*, and two astronauts, one operating on the Moon surface and the other engaged in a EVA (Extra Vehicular Activity), *ASTROUNI*, and *OrbitASTROUNI* respectively.

The rest of the paper is organized as follows. An overview of the IEEE 1516-2010 - High Level Architecture (HLA) standard and a brief description of the SEE HLA Starter Kit software framework are presented in Section 2. In Section 3, the SEE project is described with particular focus on its mission and main objectives. Sections 4, 5 and 6 describe, with emphasis on their objectives, behaviors and 3D models, the *Command and Control center (C2C), ASTROUNI* and *OrbitASTROUNI* Federates, respectively. Finally, conclusions are drawn and future research directions are presented.

2. THE IEEE HIGH LEVEL ARCHITECTURE AND THE SEE HLA DEVELOPMENT KIT

HLA is an IEEE standard (IEEE 1516) for distributed computer simulation systems (IEEE Standard for Modeling and Simulation - High Level Architecture). It was developed by the U.S. Modeling and Simulation Coordination Office (M&S CO) (Modeling and simulation coordination office) in 1995, as a general-purpose simulation systems architecture so as to facilitate the reuse, interoperability and integration of distributed simulation components within a common simulation environment. Although it was initially developed for purely military applications, it has been widely used in non-military industries for its many advantages related to the interoperability and reusability of distributed and heterogeneous distributed simulation modules.

In the HLA standard a distributed simulation is called *Federation*. A *Federation* is composed of several HLA simulation entities, each called a *Federate,* that share a common specification of data communication which is defined in Federation Object Model (FOM) (IEEE Standard for Modeling and Simulation - High Level Architecture). A *Federate* is defined as an application that is conforms to the HLA standard. *Federates* consume and support the interfaces that are specified in the HLA Federate Interface Specification, thus can participate in a distributed simulation execution interacting one another by using the Run-Time Infrastructure (RTI).

Figure 1 shows a generic HLA Federation with the services provide by the RTI.

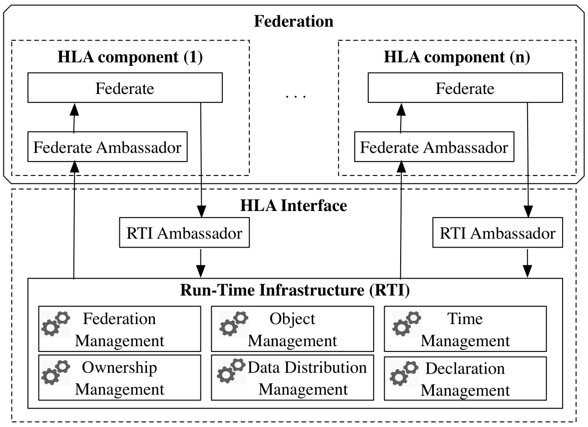

Figure 1: A generic HLA Federation.

The HLA standards defines a set of specifications that can be organized in three major core components:

- *Interface specification*, which defines an interface specification between the Federate and the RTI, which provides communication and coordination services to the Federates;
- *Object model template (OMT)*, which specifies the format of simulation data in terms of a hierarchy of object classes, attributes, and interactions among Federates running in a Federation execution;
- *HLA Framework and Rules*, which outlines the rules that a Federate must follow in order to be compliant to the standard (IEEE Standard for Modeling and Simulation - High Level Architecture).

The RTI represents a backbone of a Federation execution that provides a set of services to manage the inter-Federates communication and data exchange. They interact with RTI through the standard services and interfaces to participate in the distributed simulation execution. It supports the HLA rules and provides a set of services over the interfaces specified in the *Interface Specification*. More in details, the *Federation Management* keeps track of the execution state of both Federation and the joined Federates that are running on an RTI; the *Object Management* defines and handles how the running Federates can register, modify and delete object instances and to send and receive interactions once they have ownership of them; the *Time Management* service manages the logical time of a Federation including delivery of time stamped data and advancing of the Federates time; the *Ownership Management* regulates acquiring and divesting ownership of registered objects; the *Data Distribution Management* manages the distribution of state updates and interaction information in a simulation executions. It limits and controls the volume of data exchanged during the simulation among Federates so as to relay data only to those requiring them; finally, the *Declaration Management* manages data exchange among Federates according to a Federation Object Model (FOM) and by using a publish/subscribe scheme. For each Federate, this service keeps track of types of objects, attributes, or interactions that it has published/subscribed. In this way, the RTI is able to deliver data from publishers to subscribers.

2.1. The SEE HLA Starter Kit

Building complex and large distributed simulations systems, based on the IEEE 1516-2010 standard, is generally a challenging task and requires a considerable period of training to ensure a better understanding of its basic principles and function; as a consequence, the development of HLA *Federates* is complex, error-prone and time consuming because developers cannot focus on the specific aspects of their Federates but have to deal with the underlying HLA functionalities, such as the management of the simulation time, the connection on the RTI, and the management of common RTI exceptions. As a result, they cannot fully focus on the specific aspects of their own simulations.

In order to overcome the above mentioned issues, and helps teams in developing their HLA simulation components in the context of the SEE project, the the SMASH-Lab (System Modeling And Simulation Hub - Laboratory) of the University of Calabria (Italy) working in cooperation with the NASA JSC (Johnson Space Center), Houston (TX, USA), developed a software framework called *SEE HLA Starter Kit*.

The *SEE HLA Starter Kit* aims at easing the development of SEE Federates by providing: (i) a Java-based *software framework* (*SEE-SKF*) for the development in Java of SEE Federates; (ii) a *technical documentation* that describes the *SEE-SKF*; (iii) *user guide* to support developers in the use of the framework; and (iv) some *video-tutorials* that show how to create both the structure and the behavior of a SEE Federate (The SEE HLA Starter Kit project).

The *SEE HLA Starter Kit*, released under the LGPL licence, has been successfully experimented in the SEE project since the 2015 edition. In the 2016 edition, the Universities of Calabria (Italy), Bordeaux (France), Brunel (London, UK) and the Faculdade de Engenharia de Sorocaba, FACENS (Brazil) developed their SEE Federates by using the Kit (Anagnostou, Chaudhry, Falcone, Garro, Salah and Taylor. ACM/IEEE DS-RT 2015; Anagnostou, Chaudhry, Falcone, Garro, Salah and Taylor. ACM SIGSIM PADS 2015; Falcone, Garro 2016); the provided features improved the reliability of their SEE Federates and reduced the problems arising during the final integration and testing phases of the SEE.

3. THE SIMULATION EXPLORATION EXPERIENCE (SEE) PROJECT

To promote the adoption of distributed simulation practices, standards, and technologies, since 2011, the Simulation Interoperability Standards Organization (SISO), in collaboration with NASA and other research and industrial partners, has been organizing an annual event, named *Smackdown* and, now renamed *Simulation Exploration Experience* (SEE) (The Simulation Exploration Experience project).

The main objective of the SEE project is to offer a practical experience of participation in international projects related to M&S and, especially, to the HLA standard and compliant tools to undergraduate and postgraduate students so as to increase their skills in M&S techniques.

The 2016 edition took place during the 2016 Spring Simulation Multi-Conference (*SpringSim'16*) in Pasadena (CA, USA) from 3rd to 6th April 2016 where nine universities took part: University of Liverpool, University of Nebraska, University of Bordeaux, University of Munich, University of Brunel, University of Genoa, University of Alberta, University of Calabria and the Faculdade de Engenharia de Sorocaba FACENS (Brazil).

The team of the university of Liverpool contributed with three HLA Federates: (i) an area of the moon that is designated as a surface mining zone (*Regolith Mining Area*); (ii) a flight vehicle with six degrees of freedom (*Lunar Buggy*) that operates above the moon base; and (iii) a surface explorer that is able to inspect the lunar surface searching for caves and deep craters (*Sub-surface Feature Explorer*).

The University of Nebraska team created a vehicle that can transfer both cargo between facilities and fuel to other vehicles on the lunar surface (*Rover*).

The team of the Bordeaux University created a facility to store the supplies (*Supply Depot*).

The team of the Munich University developed an outpost located at Libration Point Two (*L2-Outpost*).

The University of Brunel team developed an agent based simulation of lunar regolith mining based on REPAST (*Excavator*) (Taylor, Revagar, Chambers, Yero, Anagnostou, Nouman and Chaudhry 2014).

The University of Genoa team produced: (i) an asteroid defense system (*IPHITOS*), which include an asteroid detection system and a missile base, and (ii) a medical facility (*SISMA*) that constantly checks the health status of astronauts.

The team of the university of Alberta developed a construction site on the lunar surface (*Modular Construction*) where some excavators are making a facility (*Modules 3D Printing*).

The *University of Calabria*, contributed with two teams that produced four Federates.

The *"SMASHTeam"* developed: (i) the Command and Control Center (*C2C*) that offers a flexible communication services to the other entities involved in the simulation scenario; (ii) an astronaut, called *ASTROUNI*, that operates in the oxygen factory placed on the moon surface and is constantly monitored by the Astronaut Health Monitoring System; (iii) an astronaut, called *OrbitASTROUNI*, that operates in orbit mainly in proximity of a "Space Exploration Vehicle" and, as well as *ASTROUNI,* is constantly monitored by the Astronaut Health Monitoring System (Falcone, Garro, Longo, Spadafora 2014).

The *"University of Calabria – Team 1"*, developed (iv) a drone called *DREDIS*. It proposes an innovative solution based on using drones inside the lunar base for reconnaissance and exploration missions, thus considering drones as a lifesaving resource that increases safety for a traditionally hazardous situation.

The team of FACENS developed the Lunar habitat (*LuHA*) that provides to the astronauts housing, shelter, and a place to fulfill their basic needs, as well as communicate with the mission control center placed on earth.

All the teams developed for their Federates a 3D model so as to interact with the *Distributed Observer Network* (*DON*) environment (The Simulation Exploration Experience project). *DON* is a real-time 3D visualization environment, which is based on Unity3D, (3D Game Engine, Unity3D) developed by the NASA team that tracks all the SEE Federates and displays their updates on the 3D environment during the simulation execution through the *DON Visualization Tool* (*DON-VT*).

The following sections describe in detail, the three Federates developed by the *"SMASHTeam"* for the 2016 edition of the project. The Federates have been built in Java by using the capabilities provided by the *SEE HLA Starter Kit* (see Section 2), whereas their 3D models were designed through the use of Autodesk 3DS MAX (Autodesk 3DS MAX).

4. THE COMMAND AND CONTROL CENTER FEDERATE

The Command and Control Center (*C2C*) provides flexible communication functionalities to the other entities participating in the simulation scenario. It works as a mediator and manage all the communication among entities. To provide its services, the *C2C* is equipped with: (i) an *antenna* mounted on a tower for managing surface-to-surface communications among the entities populating the moon base; and (ii) a *parabolic antenna* for managing surface-orbit communications (see Figure 5).
The *C2C* Federate define a compact and effective way to interact from/to entities. In particular, a standard packet format has been defined as showed in Figure 2.

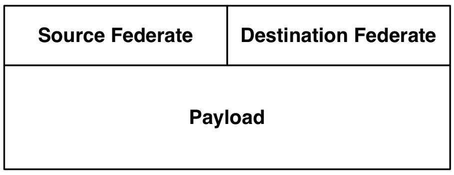

Figure 2: The Command and Control Center (C2C) packet format.

The *Source Federate* field contains the identification of the sender of the packet.
The *Destination Federate* field contains the identification of the receiver of the packet.
The *Payload* field represents the data portion of the packet.
The *C2C* Federate defines two interaction classes created by using the *@InteractionClass* class provided by the SKF to declare a HLA InteractionClass (IEEE Standard for Modeling and Simulation - High Level Architecture; Möller 2013). More in details: (i) the *C2CMessageTx* interaction class manages the communication from the C2C to another entity; and (ii) *C2CMessageRx* handles the communications coming from an entity (*Source Federate*) to the C2C.
Upon the receipt of the data packet, the C2C inspects and forward it by using a "*C2CMessageTx – data*" message to the destination entity (*Destination Federate*).
The behavior and 3D model of the C2C is described in the following subsections.

4.1. Behavior

The SKF provides, through the *SKFAbstractFederate* class, a life cycle to a SKF-Based Federate.
In this way, developers can focus on the specific *proactive* and *reactive* behavioral aspects of the Federate by defining the action to perform (Falcone, Garro 2016; Falcone, Garro 2015; The SEE HLA Starter Kit project).
The *proactive* behavior of the C2C federate is shown in Figure 4 through a UML Activity Diagram.

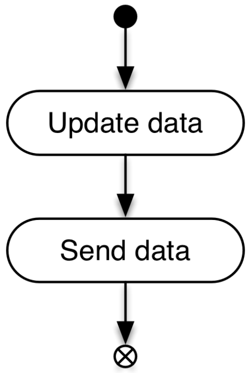

Figure 3: The proactive behavior of the C2C federate.

In the *Update data* activity, the attributes related to the C2C Federate such as position, attitude, height and power are updated whereas, in the *Send data* activity, they are published on the RTI.
The *reactive* behavior of the C2C federate is shown in Figure 4 through a UML Activity Diagram that presents all the activities performed.

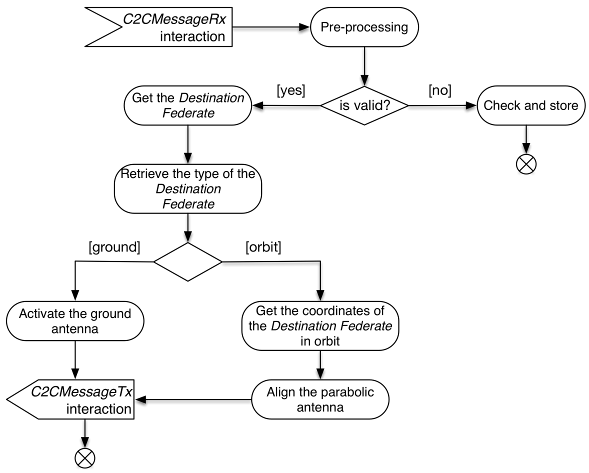

Figure 4: The reactive behavior of the C2C federate.

Upon the receipt of a *C2CMessageRx* interaction, the C2C federate pre-processes it so as to verify if the incoming interaction is valid or not (*Pre-processing*). If not, the C2C performs a check to track down both problems and errors occurred during the *Pre-processing* activity and then stores the results (*Check and store*). Otherwise, the information related to the destination entity is gathered (*Get the Destination Federate*) as well as its type that can be either *ground* or *orbit* (*Retrieve the type of the Destination Federate*). This information is used by the C2C Federate so as to use the right antenna for forwarding the data packet. If it is a *ground* entity, the antenna used for managing the surface-to-surface communications is activated (*Activate the ground antenna*), and then an "*C2CMessageTx – data*" interaction is sent. Otherwise, the C2C gets the coordinates of the destination entity (*Get the coordinates of the Destination Federate in orbit*), positions and orientates the *parabolic antenna* (*Align* *the parabolic antenna*), which is used for managing surface-orbit communications, and then sends an "*C2CMessageTx – data*" interaction.

4.2. 3D model

Figure 5 shows the 3D model of the C2C Federate created according to the specifications provided by the DON team (The Simulation Exploration Experience project) in order to allow the visualization of the model with the DON visualization environment. More in details:

- The size of the 3D model must be less than 20k polygons;
- The 3D model must be exported as a Wavefront (*.obj*) file with only one Material Template Library (*.mtl*) file for the textures and materials;
- A *.txt* configuration file containing some information related to the visualization of the model need to be created.

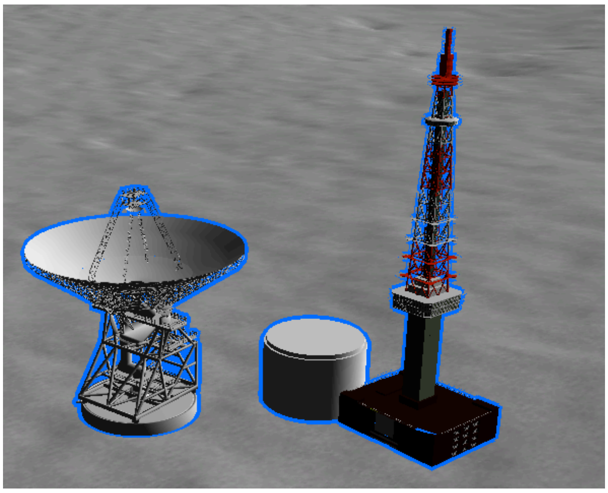

Figure 5: The 3D model of the C2C Federate.

The following code listing defines the information enclosed in the *.txt* configuration file:

```
id= "<entity_name>":
    filename= "<modelname.obj>":
        position: (0, 0, 0)
        orientation: (0, 0, 0, 1)
        scale: (1, 1, 1)
```

The <*entity_name*> tag contains the identification of the *ObjectClass* (IEEE Standard for Modeling and Simulation - High Level Architecture; Möller 2013), which is published by the Federate. The name of the 3D model file (*.obj*) is defined in the <*modelname.obj*> tag.

The *position*, *orientation* and *scale* define the default values for the 3D model. These attributes are self-explanatory, therefore they do not need insights.

5. THE ASTROUNI FEDERATE

ASTROUNI is an astronaut that operates in the oxygen factory placed on the Moon surface and is constantly monitored by the Astronaut Health Monitoring System (AHMS) (The Simulation Exploration Experience project).

The simulation scenario in which ASTRUNI is involved as well as its behavior and 3D model are described in the following subsections.

5.1. The "Suit-Alert" Scenario

The reference simulation scenario of the SEE Project (The Simulation Exploration Experience project) concerns a human settlement called Moon base composed of scientific equipment, storage buildings, rovers, and other elements to allow astronauts to live and work on the Moon.

Part of the SEE 2016 scenario is an emergency situation in which the AHMS detects a malfunction of the ASTROUNI's suit.

In particular, when the AHMS detects that malfunction, it sends (through the C2C) an interaction with payload "*suit-alert-ongoing*" to ASTROUNI that, to avoid health risks, walks toward and enters the oxygen factory room where it shelters awaiting for help.

When ASTROUNI is in the factory, it sends a *C2CMessageRx* interaction with payload "*request-room*" to the *LuHa* Federate (see Section 3) so as to receive help.

The *LuHa* Federate asks the *Rover* (see Section 3), through a *C2CMessageRx* interaction with payload "*astronaut-pick-up*", to pick up and take ASTROUNI to the medical center.

Once *LuHa* receives positive feedback from the *Rover*, it sends a *request-room-ok* message to ASTROUNI that exits the oxygen factory room and gets in the *Rover*.

Note that all the above introduced communications are mediated by the C2C Federate (see Section 4).

5.2. Behavior

The life cycle of the ASTROUNI Federate has been developed by using the functionalities provided by the *SEE HLA Starter Kit*, as well as the C2C Federate (see Subsection 4.1).

The *proactive* behavior of the ASTROUNI federate is shown in Figure 6 through a UML Activity Diagram.

In the *Get target's information* activity, the information related to the *target* component that needs to be repaired is retrieved. If the *target* is empty, which means that the repair activities have been completed, ASTROUNI reaches the Moon base (*Reach the moon base*) and its life cycle ends. Otherwise, the component is repaired by ASTROUNI (*Repair the component*) and the information related to the astronaut such as the position, attitude and health state are updated and published on the RTI (*Update data*).

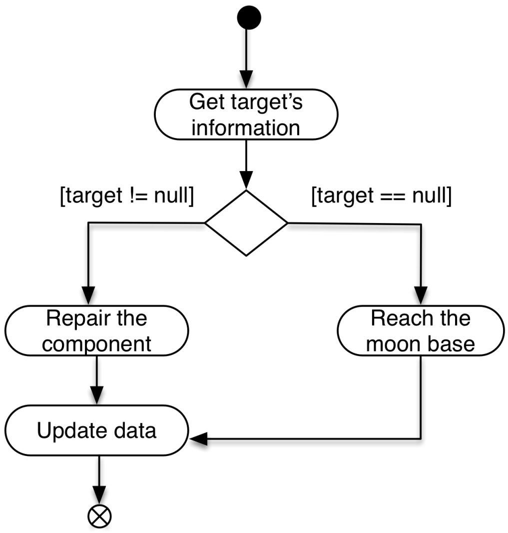

Figure 6: The proactive behavior of the ASTROUNI Federate.

The *reactive* behavior of the ASTROUNI Federate is shown in Figure 7 through a UML Activity Diagram that presents all the performed activities.
Upon the receipt of a *C2CMessageTx* interaction, the ASTROUNI Federate pre-processes it to get the payload of the message (*Pre-processing*). If it is *"suit-alert-ongoing"*, ASTROUNI goes to the oxygen factory where it waits for help. A request message is created (*Create a request message*) and sent to the *LuHa* Federate when the astronaut reaches the room.
Otherwise, if the payload is *"request-room-ok"*, ASTROUNI exits the oxygen factory room (*Leave the oxygen factory*) and gets in the *Rover* (*Reach the Rover*).

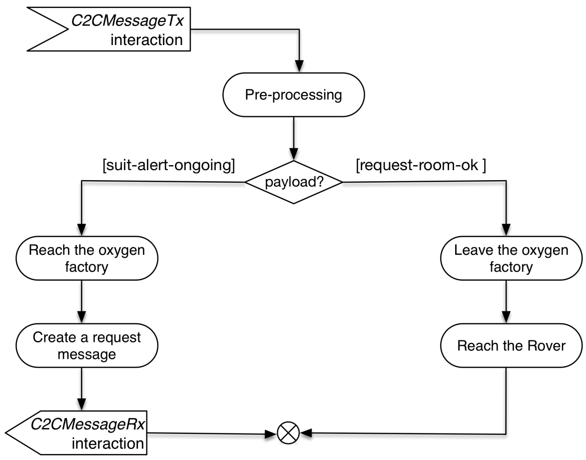

Figure 7: The reactive behavior of the ASTROUNI Federate.

5.3. 3D model

Figure 8 shows the 3D model of the ASTROUNI Federate.

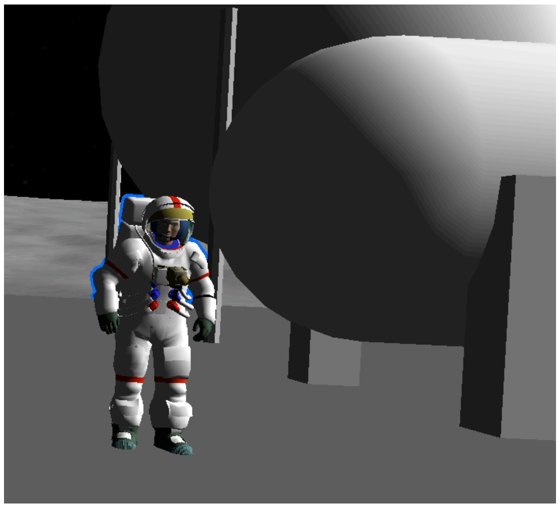

Figure 8: The 3D model of the ASTROUNI Federate.

As well as the 3D model of the C2C federate, it has been created according to the specifications provided by the DON team (see Section 4.2).

6. THE ORBITASTROUNI FEDERATE

OrbitASTROUNI is an astronaut that operates in orbit, mainly in proximity of a "Space Exploration Vehicle" engaged in a EVA, and, as well as *ASTROUNI,* is constantly monitored by the AHMS.
The behavior and 3D model are described in the following subsections.

6.1. Behavior

The *proactive* behavior of the OrbitASTROUNI Federate is defined by using the capabilities provided by the *SKFAbstractFederate* class of the SEE-SKF (Falcone, Garro 2016; Falcone, Garro 2015).
Figure 9 shows the *proactive* behavior through a UML Activity Diagram.

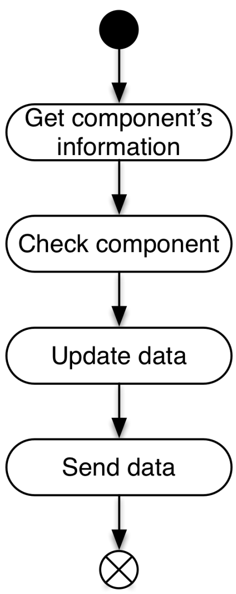

Figure 9: The proactive behavior of the OrbitASTROUNI Federate.

In the *Get components's information* activity, the information related to the *component* that needs to be checked is retrieved. After that, the component is checked by OrbitASTROUNI (*Check component*) and the information related to both the astronaut (e.g. position, attitude, health state, etc.) and status of the component are updated (*Update data*) and published on the RTI (*Send data*).
The *reactive* behavior of the ASTROUNI Federate is shown in Figure 10 through a UML Activity Diagram that presents the all activities performed.
Upon the receipt of a *C2CMessageTx* interaction, the OrbitASTROUNI Federate pre-processes it to get the information related to the component that needs to be checked (*Pre-processing*). In the *Add component* activity the information retrieved in the previous one is added in the check list of the astronaut.

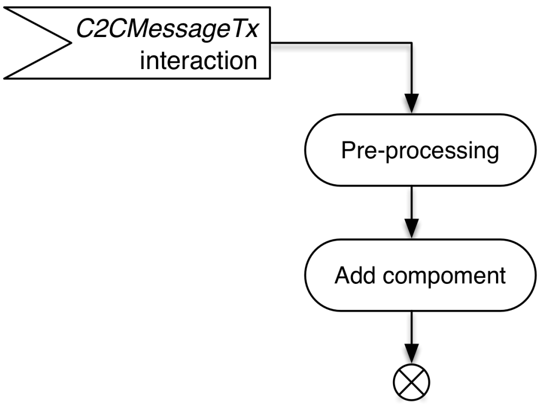

Figure 10: The reactive behavior of the OrbitASTROUNI Federate.

6.2. 3D model
Figure 11 shows the 3D model of the OrbitASTROUNI Federate.

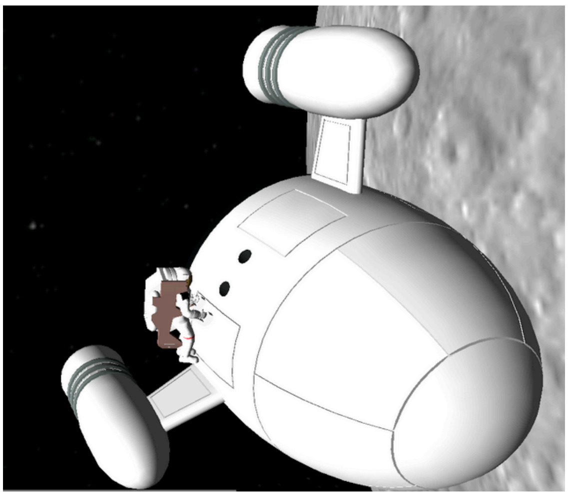

Figure 11: The 3D model of the OrbitASTROUNI Federate.

As well as the other federates, it has been created by using 3DS MAX following the advices provided by the DON team (see Section 4.2).

DISCUSSION AND CONCLUSIONS
The paper has presented the experience of the "SMASHTeam" of the University of Calabria in participating to the 2016 edition of the SEE (Simulation Exploration Experience) event (formerly named *"Smackdown"*). Specifically, the Team has been in charge of the development of the *Command and Control Center* (*C2C*) able to provide flexible communication services to the other entities populating a Moon base simulated scenario as well as two astronauts: *ASTROUNI*, which operates in the oxygen factory placed on the Moon surface and that is constantly monitored by the Astronaut Health Monitoring System (AHMS); and *OrbitASTROUNI*, which operates in orbit mainly in proximity of a "Space Exploration Vehicle" and, as well as *ASTROUNI,* is constantly monitored by the AHMS. Moreover, the team developed for each Federate a 3D model so as to interact with the *Distributed Observer Network* (*DON*) environment.
To achieve the results presented in the paper, the "SMASHTeam" team has faced with several difficulties mainly related to the coordination and collaboration issues that inevitably arise when several and geographically distributed teams are jointly involved in a project with tight deadlines.
The "SMASHTeam" as well as the teams of the universities of Bordeaux (France), Brunel (London, UK) and the Faculdade de Engenharia de Sorocaba, FACENS (Brazil) developed their SEE Federates by using the *SEE HLA Starter Kit*. Through the features provided by the Kit, the teams were able to improve the reliability of their SEE Federates and reduce the problems arising during the final integration and testing phases of the SEE event.
Moreover, the "SMASHTeam" offered support to the above mentioned teams, during all the steps of the SEE project, by providing ready-to-use examples, video tutorials and technical documentation for using the Kit.
The Team is currently working on the further experimentation, refinement and enhancement of the proposed solutions with the aim to participate to the next edition of SEE. Furthermore, the Team is focusing on the new version of the SEE HLA Starter Kit in which new services, such as the transfer of ownership of Objects and communication protocols over the standard Publish and Subscribe (P/S) mechanism, will be developed.
Hopefully, the experience and related solutions shared by the "SMASHTeam" of the University of Calabria Team could encourage and guide the participation of new teams to the next editions of this exciting and challenging event.

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DEVELOPING AN ENTERPRISE OPERATING SYSTEM (EOS) WITH THE FEDERATED INTEROPERABILITY APPROACH

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ABSTRACT
Furthermost of enterprises have chosen to implement ERP solutions or multiple systems in order to facilitate the data orchestration by connecting several software and hardware together at the operational level [1]; Nevertheless this solution may constraint the business due to the top down "enclosing" methodology. Another approach may take place by setting loose coupled connections between enterprise's software in the idea of federated interoperability with only one simplified central orchestrator component. The cooperating parties must accommodate and adjust "on-the-fly" to ensure quick interoperability establishment, easy-pass, and dynamic environment update. In that objective, developing an Enterprise Operating System (EOS) is seen as one of the key steps towards the future generation enterprise manufacturing systems based on IoT and Cyber Physical System principle. This paper tentatively presents at first a set of requirements and functionalities of EOS. Then a survey on existing relevant works is presented and mapped to the requirements. After that the existing models related to the Federated Enterprise Interoperability are presented. The architectures of envisioned EOS and the federated interoperability are outlined. The last part draws some conclusions and gives future perspectives.

Keywords: Operating system, Architecture, Model, Infrastructure, Interoperability.

1. INTRODUCTION

This paper aims at presenting an ongoing research activity carried out at IMS laboratory of University of Bordeaux to develop an Enterprise Operating System (EOS) based on the federated enterprise interoperability concept in order to strengthen the performance and competitively of small and medium manufacturing enterprises and improving the effectiveness of collaborative environments. It presents the requirements and architecture of an Enterprise Operating System (EOS) and the technical architecture of the Federated Interoperability framework.

The proposed EOS will behave in the same way as an Operating System of the computer, but under enterprise context. This EOS will act as a system-wide interface between enterprise business managers and enterprise operational resources performing daily enterprise operations.

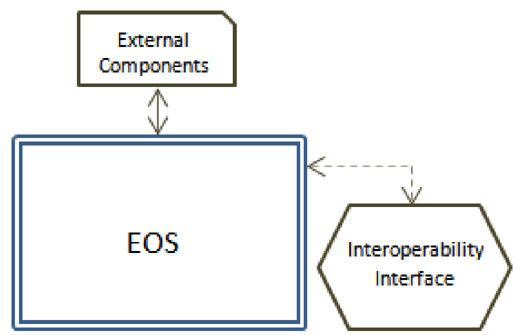

Figure 1. The Enterprise Operating System, Interoperability Interface and the external peripherals

To make this highly flexible, dynamically configured and real time controlled enterprise a reality, a sound Enterprise Operating System (EOS) capable of (real time) monitoring enterprise resources and operations in order to dynamically allocate resources to required activities is more than a necessity but a pre-condition. In this context, the massive use of sensors, actioners and robots coming from different vendors will also require an EOS that is capable of connecting them together to work as a 'one'.

Today, enterprise operational management is largely dominated by integrated solutions like ERP. It has been estimated that 78% of enterprises have chosen ERP solutions or multiple systems in order to facilitate the data orchestration by connecting several software and hardware together at the operational level [1]. Nevertheless this solution may constraint the business due to the top-down "enclosing" methodology.

An alternative approach would be to provide loosely coupled connections between enterprise's software applications (federated interoperability) with the support of only one 'core central orchestrator' (EOS). It will interpret content of enterprise models defined by business managers, trigger various enterprise operations with dynamically allocated enterprise resources, and monitor the status of enterprise resources (Human, Machining, Computing) through various sensing devices and front-ends [2][3].

In other words, EOS and ERP have similar objectives but different approaches. ERP is a top-down integrated approach incorporating in its framework all enterprise applications and needed enterprise operating functions (at least they intend to do this); While EOS is a bottom-up federated approach only providing enterprise operating system (functions) that allows various heterogeneous applications from different vendors to connect to EOS and to work together.

From what have been stated above, we believe that EOS ‘s approach presents the better perspective for the future in the context of Internet of Things (IoT) and Factory of Future (FoF). It also provides an alternative for those enterprises with a tailored solution, especially for SMEs (Small and Medium-sized Enterprises). A SME equipped with an EOS (cost much less than ERP) will be able to only purchase the applications they need (possibly from different vendors). Once EOS is adopted in the industry with the Federated Interoperability approach, a foreseen ecosystem would be developed in consequence to provide varieties of enterprise applications compatible to EOS, just like what happened with Apple’s ecosystem to IOS (iPhone Operating System) and Google’s one to Android. To make this happen, the envisioned EOS needs to be recognized as a standard so that enterprise solutions vendors develop their applications according to the specifications of the EOS.

2. REQUIREMENTS AND FUNCTIONALITIES OF EOS

This section presents an outline of the requirements and functionalities for developing an Enterprise Operating System.

2.1 Enterprise Resource Management “ERM”

Enterprise Resource Management is essential for EOS in order to monitor enterprise resources system-wide (available, occupied, out-of-order…) [4]. It provides a real-time and global view of the use of those resources in a company. Main required functionalities of ERM are: checking, searching, reporting and selecting the availability of resources; matching the required capabilities to the capabilities of existing available resources; allocating and de-allocating resources; and ensuring that the right resources are allocated to the right place at the right time.

2.2 Enterprise Process Management “EPM”

Enterprise Process Management is required for EOS to execute enterprise processes defined by the business managers and other EOS internal process in order to carry out enterprise operations. Main functionalities of EPM include: sending commands triggering the starting of processes, recording ending status of processes (done, not done, fail…); monitoring the activity and state of individual enterprise processes and key performance indicators; and interacting with the Resource Management in order to send commands, interpret and receive resources statuses [4].

2.3 Enterprise Information Management “EIM”

Enterprise Information Management supports information and data exchange between all entities connected to the EOS such enterprise resources and business managers [4].

Main required functionalities of EIM are: ensuring the centralized management of reference data used; excluding data duplicates; ensuring and maintaining system-wide consistency as well as integrity of enterprise data exchanged; providing transparent access to data sources and an appropriate data storage facility needed for running EOS; ensuring information and data confidentiality and security to protect from non-authorized access.

2.4 Presentation Management “PM”

Presentation Management is concerned with the interface between internal and external worlds of EOS. It is mainly required to organize and coordinate the communication and information flow between Enterprise Resources and internal entities of EOS including the Human, Machine and Applications Dialogue services [5].

2.5 Interoperability Management “IM”

Interoperability Management is a utility service of EOS. Interoperability is a precondition for a successful development and implementation of the Enterprise Operating System by ensuring that EOS can interoperate with both Business Software Applications and the Embedded Software provided for device controllers and sensors. The federated approach may be helpful for EOS by allowing quick interoperability establishment, easy-pass, and dynamic environment update in the heterogeneous and multi-partners environment.

3. EXISTING WORKS RELEVANT TO EOS

Since the beginning of 80’s, a lot of works has been done to develop IT infrastructures and platforms to support enterprise activities. Some of them are relevant to EOS.

3.1 Existing Works

CORBA (Common Object Request Broker Architecture) was designed to facilitate communication of systems deploying on divers- platforms, written in different languages and executed on different operating systems. CORBA is seen more as an enterprise application integration platform rather than an Enterprise Operating System [5]. Compared to CORBA, ENV 13550 moved a step towards an EOS. ENV 13550 is a pre-European standard based on CIMOSA enterprise modeling and integration concepts. It aimed at supporting business process monitoring and control [4]. ENV 13550 focused on Enterprise model execution; integration of divers’ heterogeneous applications is not well supported as CORBA [7]. Another well-known work similar to CORBA is EAI

(Enterprise Application Integration) that is an integration framework defined by Gartner Group. It is composed of a collection of technologies and services to provide integration of systems and applications that reside on different operating systems and use different database solutions across an enterprise (SCM, ERP, CRM, payroll…). As CORBA, EAI was not dedicated to enterprise process and operation monitoring and control that are to be supported by EOS [8]. Concerning this last point, we must mention the work of WfMC (Workflow Management Coalition) to define standards for the interoperability of Workflow Management Systems [9]. Similar to ENV 13550, WfMC aims at process model execution that is one of the main functions in EOS. It is worth mentioning two other early works to support integration and interoperability of heterogeneous enterprise systems: OSF/DCE and ODP. OSF/DCE is used to allow different operating systems to distribute processing and data across the enterprise by providing a coherent environment for developing and running applications [10]. ODP is an international standard published in 1990 to describe and build widely distributed systems and applications in a multi-vendor environment [11]. Both ODP and DCE are similar approaches aiming at supporting system-wide distributed communication and sharing of information that is also a core functionality to be provided by EOS.

Further to the above-mentioned works, service orientation has gained interest in the middle of 90's and has been used as a basic principle to develop enterprise integration and interoperability platforms. To this end, the most well-known are ESB (Enterprise Service Bus) and SOA (Service Oriented Architecture). ESB is a software architecture model defined in 2002 as a set of rules and principles to enable interoperability between heterogeneous environments [12]. While SOA is an architectural style defined by the Open Group to support service orientation including service-based development and outcomes services. Both ESB and SOA cannot directly be used as an EOS but they provide interesting concepts and principle to develop and build the EOS [13].

3.2 Efficiency of existing Techniques for EOS

Considering Enterprise Resource Management, most of the existing approaches only focus on IT resource management (monitoring and control). Only ENV 13550 and to a lesser extent the WfMC deal with other non IT enterprise resources such as 'Human' and 'Machine'. SOA allows discovering and matching required capability to existing available resources; this is a useful approach for EOS [14, 15, 16, 17, 18, 19].

Referring to Enterprise Process Management, most of the existing approaches include Process Management. However, distinction should be made between 'Business Process' defined by business users and 'Process' that is orchestrated to ensure internal working of platforms. In an EOS, both the two types of processes will exist but the focus is on the business process execution. In this sense, ENV 13550 and WfMC provide the most interesting concepts and principles to define EOS [20, 21, 22, 23, 24, 25].

For Enterprise Information Management, information exchange between all entities connected to an EOS is essential function. All existing approaches support this function. However due to the heterogeneous data sources in an enterprise, interoperability is fundamental to support this function [26, 27].

Concerning the Presentation Management being not a core function for an EOS but necessary to interact with all resources and business users connected to an EOS, ENV 13550 presents the most interesting concepts, as it allows to dialogue with all types of enterprise resources (human, machine and IT) [28, 29, 30].

For Interoperability Management, existing approaches focused on Enterprise Integration rather than loosely coupled interoperability. In most existing approaches interoperability is not developed to a mature and satisfactory level. A set of interoperability utility services needs to be developed to support the use of the EOS [31, 32, 33, 34, 35].

In conclusion, the existing works studied are all relevant to developing an EOS but they don't cover all the requirements and functionalities. Each of them has its own objectives with specific focuses. The results of the comparison have been quantified and summarized in the figure 2.

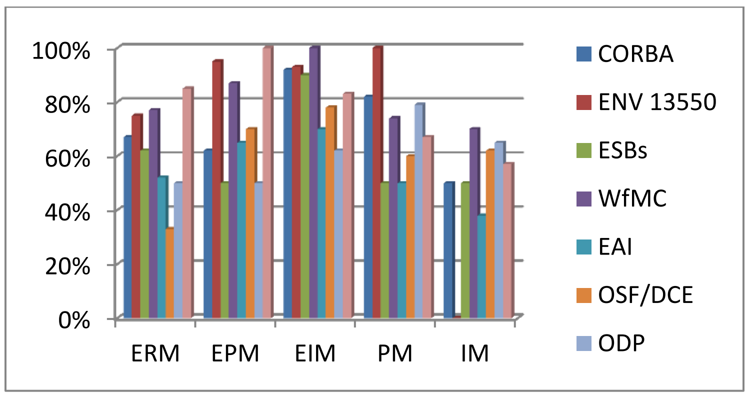

Figure 2. Summary of the existing Techniques' services and efficiencies based on the EOS requirements

4. MODELS RELEVANT TO FEDERATED ENTERPRISE INTEROPERABILITY

Several models mentioned in this section have achieved some success in developing Systems Interoperability based on the federated approach. However, none of them proposes the complete solution for all the interoperability issues in order to develop an Interoperability Interface for ensuring the inter federates communications and the data connection between the components of the EOS and the external peripherals.

4.1 Existing Models

LISI focuses on technical interoperability and the complexity of interoperations between systems. But LISI model does not address the environmental and organizational issues that contribute to the construction and maintenance of interoperable systems. OIM can be seen as the evolved LISI model in the context of the layers developed in the command and control support (C2S) Study by extending LISI into the organizational layer [36]. The Database interoperability & Inverted-V model is an overall architecture to merge information comprised in heterogeneous data sources into one technically consistent and semantically coherent information space. However, it is only for data but not procedure or architecture [37]. The LCIM model has been carried out successfully in simulation domain, but the basic premises apply to many complex sets of interoperating systems [38]. The SOSI model extends the existing models by adding a focus on programmatic, constructive and operational issues which must be managed across the life cycle [39].

The MDA approach contributes on building an interoperable ICT model, from enterprise models to technology models. Those models are able to be aligned by using common meta-model. MDA also provides flexibility and adaptability to accommodate changes at a higher abstraction level. However, several studies doubted that MDA will follow the old way of Integrated Computer-Aided Software Engineering to ruin, to spend 10 percent effort to generate incomplete and useless code (80 to 90 percent), but spend 90 percent effort on struggling in tracing down the rest part to achieve perfection. In addition, the information is losing during the model transformation, such as details of system behaviours [40]. The soundness of the MDI methodology has been demonstrated in the current researches, but no full industrial scale validation has been yet achieved. Only some projects have been especially carried to demonstrate these concepts in an industrial real world significant application [41]. ADM shows its strong power in obtaining information from the legacy systems. But, many people doubt on the validity of this information for achieving federated enterprise interoperability. ADM met the same model transformation problems as MDA [42].

The RMI, DIS and ALSP simulation and application distribution frameworks can support distributed system interoperability, but in varying degrees. None of them can fully satisfy the requirement of the federated approach and especially as concerned with the component coupling, time management, ownership management, environment flexibility and data distribution services [43][44][45][46].

The ontology can fully support the conceptual enterprise interoperability. However, enterprises require more and more dynamic, complex, and advanced interoperability, this kind of architectures independently can hardly handle the updated requirements [47].

4.2 Efficiency of Models for Federated Interoperability Concept

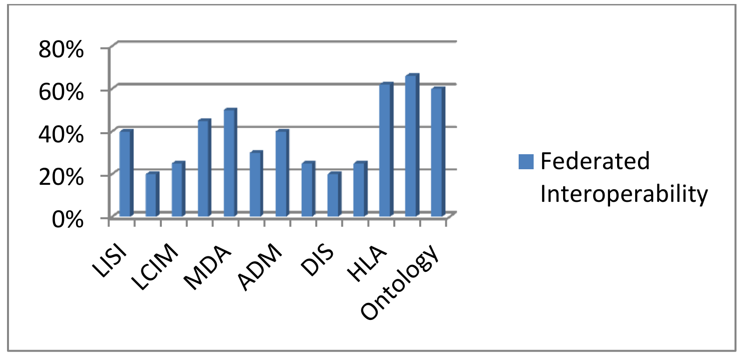

Figure 3. Summary of the Models' services and efficiencies based on the Federated Interoperability concept

Due to the fact that enterprises require more and more dynamic, complex, and advanced interoperability, these methodologies, technologies, and architectures independently can hardly handle these requirements any more. A harmonized and reversible HLA based methodology is being implemented for developing model driven federated enterprise interoperability. This methodology will creatively combine the excellences of some of these existing methodologies, technologies, and architectures, and propose an innovative way to tackle enterprise interoperability at service and data levels through a federated approach.

5. ARCHITECTURES

This section outlines the conceptual architecture of EOS, technical architecture of EOS and the technical architecture of the Harmonized/reversible development framework in order to meet the requirements and functionalities identified in section 2 and 3.

5.1 EOS Conceptual Architecture

Figure 4 describes the EOS Conceptual Architecture. This EOS is a distinctive system-wide platform that allows the business managers to communicate and operate through the systems' (hardware, software, network, machines…) in an efficient and effective way [2].

Unlike ERP, the Enterprise Operating System EOS will mainly be developed and implemented as one simplified central orchestrator component connected to several peripheral devices and external components.

Business users and the three types of resources are outside EOS. They are connected to EOS to send and receive information (data, command...).

Human type resources are human operators to be monitored and controlled by EOS. They are commercial and purchasing agents, product designers, production managers, shop floor operators etc...

IT type resources include computer and other data processing and storage devices, enterprise applications such as MRPII planning software, shop floor scheduling software, CAD, sale forecasting software, CRM software, inventory management software etc…
Machine type resources are material transformation and processing devices and equipment such as automated/manual transfer lines, conventional and NC machines, robots etc...
Business users are not monitored and controlled by EOS; they define what and how enterprise operations will be done and send commands to resources via EOS.
Interoperability Interface is the interface that enables business interoperability between EOS executed systems and the external components related to the EOS.

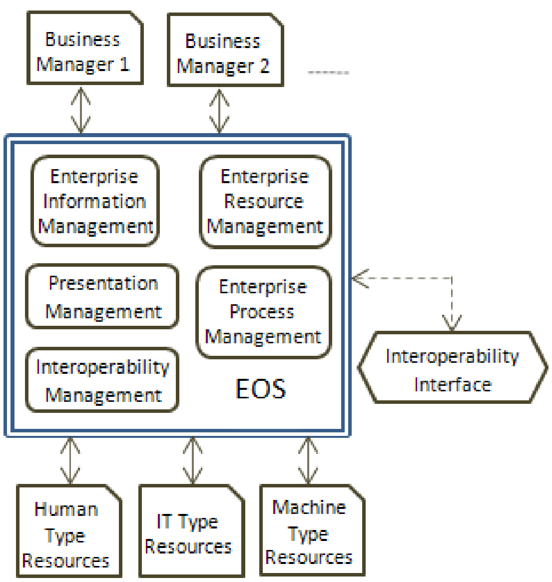

Figure 4. EOS Conceptual Architecture

As shown in figure 4, EOS is an interface between business users defining what/how business is to be done, and the three types of enterprise resources performing defined operations.
Enterprise resource management dynamically monitors the status of enterprise resources, search and allocate suitable resources to operations that must be done.
Enterprise process management executes business processes defined by business users, coordinates and executes EOS internal processes/operations.
Enterprise information management manages, protects and supports information and data exchange of all kinds between the enterprise's resources connected to the EOS.
Presentation management is a set of services with appropriate interfaces that allow business users and other enterprise resources to connect to EOS and receive/send information.

Interoperability management is a set of services that provide necessary mapping between heterogeneous resources to make them interoperable through EOS.

5.2 EOS Technical Architecture

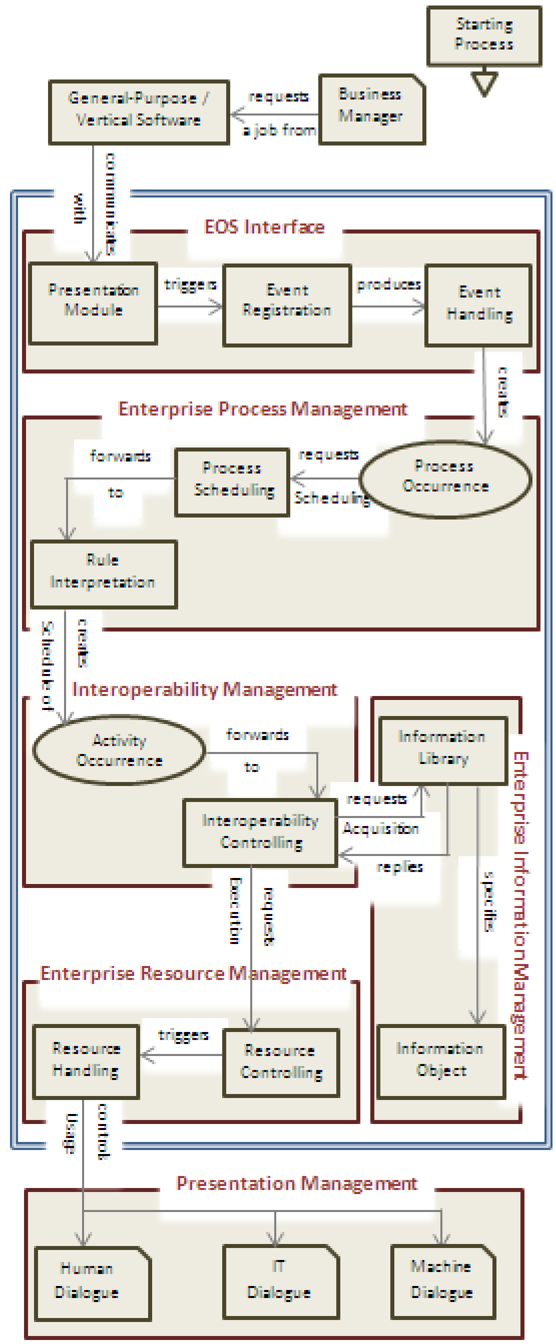

Figure 5. EOS Technical Architecture

As shown in figure 5, the enterprise activities are executed and generated through the EOS internal components at beginning from the starting phase.

At first, each Business Manager accesses the General-Purpose and Vertical software's' interfaces in order to request the day-to-day activities and operations. The related software send special commands to communicate with the EOS Front-End interface called Presentation Module in order to execute the requested job.
After that, the Presentation Module interprets the run-time entities and triggers the event which will be registered with their associated information through the Event Registration Component using the Run-Time Repository Service.
Next, the Event Handling - manages the events' priorities, queues and traceability, -provides the Order Identifier, and creates the Process Occurrence. The Process Occurrence requests scheduling from the Process Scheduling component which interprets the Process Behavioral, Information and Resource requirements. This sub-service checks the authorization to execute the Process, retrieves Process descriptions from the Run-Time Repository, invokes the Enterprise Resource Management to allocate the required Resource capabilities, and forwards the details to the Rule Interpretation.
Later, the Rule Interpretation component provides functionality to retrieve the sequencing and conditional rules associated with the identified Enterprise Process, maintain a state record of all Enterprise activities, and respond to detected Events in order to initialize or terminate the activity.
Subsequently, the Activity Occurrence schedule created by the Rule Interpretation is forwarded to the Interoperability Component which is responsible of requesting from the Enterprise Resource Management to assign resources allocated by the Process Scheduling Component, invoking the Enterprise Information Management to acquire the Object States and specify the Information Object required, requesting from the Enterprise Resource Management to release the involved Resources when terminating an activity, and signaling the termination of the current activity to the Rule Interpretation Component.
The Resource Controlling checks the availability of the Resources and pre-assigns it when available, responds to the Interoperability Controlling requests in order to assign agents, and responds to the Process Scheduling requests to allocate and de-allocate resources. The Resource Handling component select the appropriate resource after matching the capabilities required and by taking into consideration the time, performance and priority.
The Presentation Management services are controlled by the Resource Handling Component for handling Human, Machine and IT Dialogues.
The Human Dialogue provides functionality for presenting in graphical format the current status and the past history of events, allowing authorized personnel to intervene manually in order to modify the contextual parameters at run-time.
The Machine Dialogue supports the necessary features in order to provide access to the various functional capabilities of the machine. It provides the functionality required for receiving and interpreting responses from the machine.
The IT Dialogue provides functionality for interrogating application program interfaces to determine its capabilities, providing support for the integration of the functional entities implemented by existing IT application programs.

5.3 Case Study: Bank's Operation

A simulation system in the Banking and Finance environment is presented, validated and being progressively implemented as a real-world system. The exchange rate is defined as a rate at which a country's currency will be exchanged in terms of another currency. A Bank's exchange rates are constantly changing once every business day based on current market conditions.
Figure 6 and 7 describe the Conceptual and Technical Architectures of the Bank's daily Exchange Rate update.
As shown in figure 7, the first federate is the Core Banking System which is developed using Java language and SQL based database. The second one is the EOS Interface Java based platform which plays the role of the presentation module of the EOS. The third federate is the Enterprise Process Management presented as a Java module. The three federates are connected together through a HLA Federation in order to update the Exchange Rate in the "Start of Day" stage.
Each one is composed of two blocks: 1) The Code Block which contains the Federate Ambassador that uses pure virtual functions to send messages and requests to the RTI (Run Time Infrastructure). 2) The Local RTI Ambassador provides the services for the related federate through communication with poRTIco RTI application which play the role of the RTI component in this HLA Federation.
poRTIco RTI component is the fundamental component used to implement the High Level Architecture in order to coordinate federates' operations and exchange data. This middleware contains a Central RTI component "CRC" connected to the Local RTI component "LRC" of each federate in order to convert requests into messages to be sent between federates. It supports HLA simulation development to greatly expand the use of distributed simulation between the Core Banking System, the EOS Interface, and the Enterprise Process Management.
The Core Banking System sends the Exchange Rate job to the Run Time Infrastructure through the Core System Code Block. The LRC1 transmits the job to the EOS Interface by notifying the LRC2. The EOS Interface creates the process of Exchange Rate's update and sends it to RTI through the EOS Interface Code Block. The RTI notify the LRC3 about the new event and then the Bank's Process Management checks the privileges of the Bank's Manager, retrieves the Exchange Rate's information and sends it to the RTI.
The Central RTI Component manages the federation by communicating with the LRC of each federate in order to update, reflect, send and receive data between federates.
This Technical Architecture is fully implemented in the Java language based on the Interoperability and Uniformity principles in order to provide a set of domain-independent

APIs used to access capabilities and features, and to exchange data between federates using the XML format.

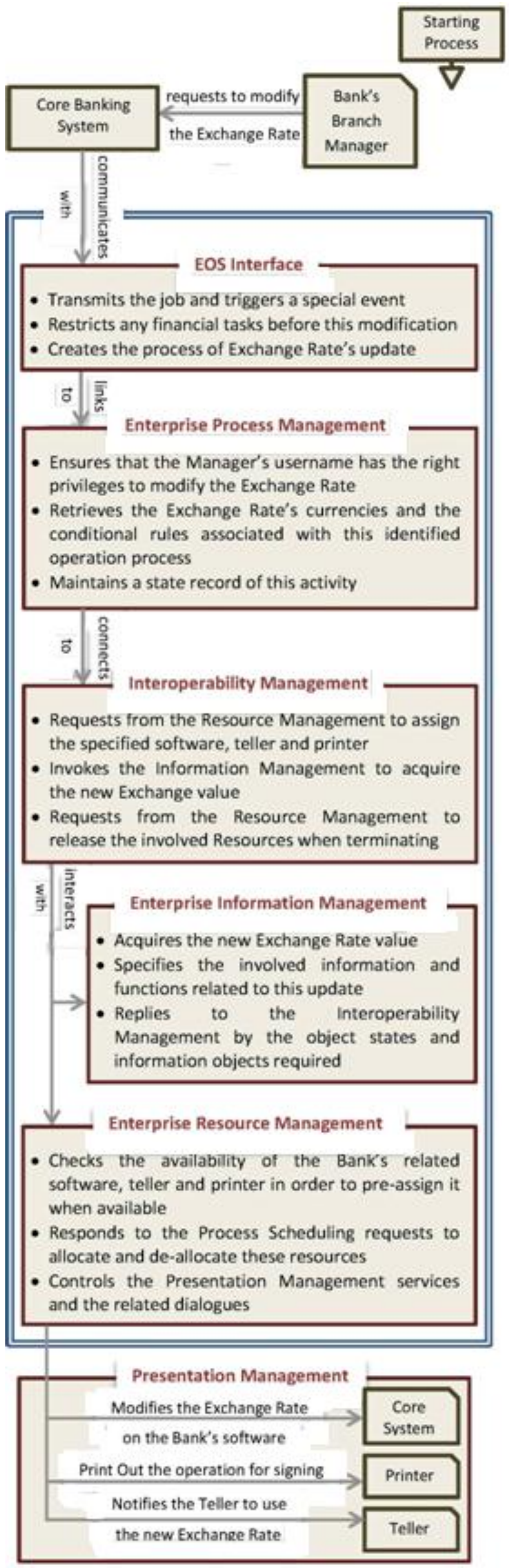

Figure 6. Conceptual Architecture of the Bank's Exchange Rate update

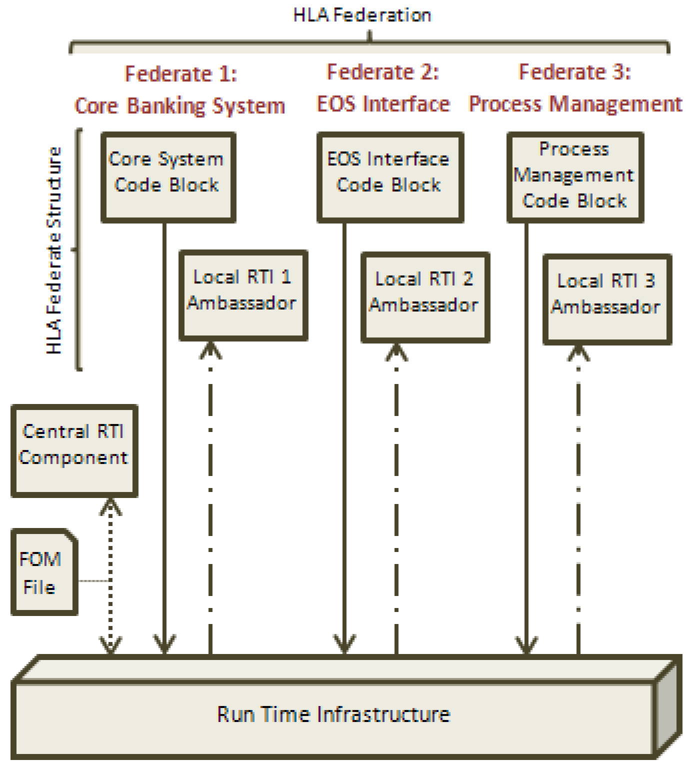

Figure 7. Technical Architecture of the Bank's Exchange Rate update

5.4 Harmonized and Reversible Development Framework – Interoperability Interface for EOS

A new framework is presented and will be used as an Interoperability Interface connected to the Enterprise Operating System in order to set up interoperability rapidly among existing enterprise information systems. This framework will use the existing models benefits for creating a novel way to support the development of federated approach of enterprise interoperability. Thus, the methodology presented will utilize MDA to clarify the system architecture and relationship among systems, and apply Model reverse engineering to reuse and align different EOS components and federates to initiate a Federate Enterprise Interoperability environment, and use the HLA and SOA functionalities as technical support.

This framework is mainly used in order to rapidly develop HLA based interface for achieving federated enterprise interoperability.

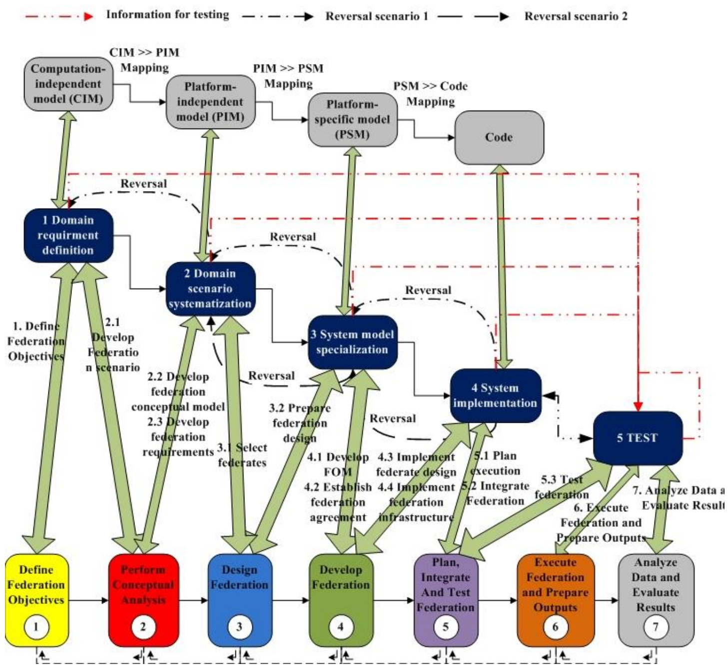

Figure 8. Harmonized and reversible development framework for HLA based Application

Primary concepts are separately presented as follow:

- Harmonized: means this framework is a synthetic framework, which consists of several techniques. As the framework in figure 8 shows, we propose a new five steps development life cycle which aligns MDA and HLA FEDEP. MDA is easy to use and understand, and tightly bounded with Unified Modelling Language, Meta-Object Facility (MOF). It appears to be an appropriate choice to overcome the interoperability barriers, which is mentioned in the MDI framework [41]. HLA FEDEP is the standard for development and execution of HLA federation. It is quite similar to the waterfall development but with look-back test phase. MDA and HLA FEDEP can be easily aligned, because they have several similar steps. In addition, this framework uses web services to improve the flexibility and compatibility of the HLA. The Web Services allows potential external systems to discover the existing HLA Federation, and then connect to it.

- Reversible: means that this framework uses model reverse engineering technique to discover part of the models from the legacy system. Model reverse engineering technique aims at avoiding rebuilding the complete legacy system for a new reuse. The objective is to accelerate the development and reduce the cost. As figure 8 illustrates, there are two kinds of dotted arrows, which have opposite directions to the five steps development life cycle. These two kinds of arrows represent two different scenarios of model reversal in this framework. Section 3.3 will present the method of using model reverse technique

- HLA: means that this framework dedicates to the development of HLA based application. The RTI used in this approach is an open source RTI, poRTIco [48]. The reason of choosing it is not only because of the software price, but also the objective of initiating a global open framework and receiving comments from contributors who can be interested in this idea. In addition, as mentioned earlier in Harmonized part, Web Services will be used to improve the limitation of the traditional HLA.

The goal is to achieve the interoperability among those existing federates in a common project context. The steps of this approach are presented as follows:

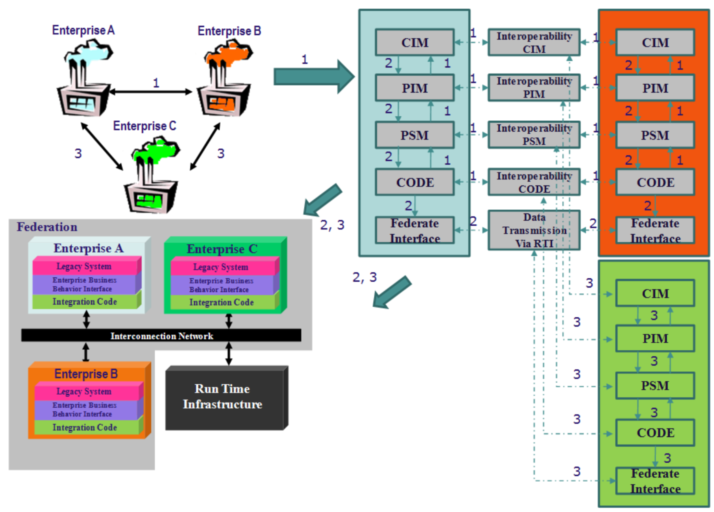

Figure 9. Scenario Description

- Step 1 (arrows numbered with "1"): model reverse engineering is used to discover the models from the legacy system. The model discovery is guided by the enterprises new requirements and interest. Then, these discovered MDA conceptual models go down again along the alignment of MDA and HLA FEDEP. It means models are generated from code to PSM then PIM and CIM level. At each level of the MDA models the interoperability problem is tracked according to the principle of the MDI framework.

- Step 2 (arrows numbered with "2"): a test of the final models obtained by model reverse engineering is carried out. After that, the correct models are transformed from CIM to code, and generate a Federate Interface, which can plug into the HLA platform and transmit the information with other processes' information systems via RTI.

- Step 3 (arrows numbered with "3"): if other federates want to join this ongoing cooperative project, they also need to follow the step 1 and step 2, to rewind their legacy system into MDA conceptual models, and select part of them that can be used for interoperability, then generate the Federate Interface, finally, synchronize with other systems.

6. CONCLUSION

This paper has tentatively presented the requirements and architecture to develop an Enterprise Operating System (EOS) for the new generation enterprise systems such as for example envisioned in Industry 4.0. On the other hand, it presents the technical architecture of the Reversible Model driven and HLA based framework and methodology for implementing federated approach under the Enterprise Interoperability Framework used in order to ensure the inter federates communications and the data connection between the components of the EOS and the external peripherals. This framework has the main role to support establishing enterprise interoperability dynamically in a heterogeneous and multi-partners environment, facilitate re-use of models and re-engineering sub-systems based on models, and allowing extracting from legacy systems and software applications relevant information/data for EI engineering or re-engineering.

The proposed EOS tends to reconciliate two different but complementary initiatives for enterprise management and control that exist in the market: IT platforms /infrastructure and ERP based application packages.

The requirements presented in the paper is based on and inspired from some existing relevant approaches, in particular ENV13550 with necessary generalization and extension to focus on the core functions of an Operation System for enterprise. The proposal is challenging and its success mainly depends on two factors. One is the acceptance of EOS in industry as a standard to develop an ecosystem providing varieties of enterprise application compatible to EOS; the other one is the 'Interoperability' service that allows other heterogeneous non-EOS compatible applications to run on EOS.

Future work planned is to refine both requirements and architectures at the one hand, and on the other hand to develop a prototype to test the EOS against two use cases in both manufacturing and service sectors using the Federated Interoperability Approach for allowing quick interoperability establishment, easy-pass, and dynamic environment update.

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