SIMULATION STUDY FOR IMPROVING THE PERFORMANCE OF A PRODUCTION LINE IN THE ELECTRONICS INDUSTRY

Sara Costa(a), Ana Luísa Ramos(b), José Vasconcelos Ferreira(c)

(a) DEGEIT, University of Aveiro, Campo de Santiago, 3810-193 Aveiro, Portugal
(b) (c) GOVCOPP/DEGEIT, University of Aveiro, Campo de Santiago, 3810-193 Aveiro, Portugal

(a)costasara@ua.pt (b)aramos@ua.pt (c)josev@ua.pt

ABSTRACT

Due to the complexity of the current production systems in the industrial sector, more complex simulation models are needed. This work describes the study and the analysis of the production process of one of the main products produced by the electronics Company X. For this study, a simulation model was developed to mimic the current operation of the production line. The simulation study key objective was to evaluate the dynamic behaviour of the production process of the Product Y based on some performance measures such as cycle time, lead time, utilization rate of resources and work in process' statistics. They are also presented three scenarios that show improvement suggestions in relation to the system current configuration. The use of computer simulation revealed the importance of this tool in process control and in the analysis of improvement strategies that make the production system more efficient. Therefore, simulation can be used as a scientific basis to help in decision making with the considerable gain of avoiding the interference with the regular operation of the system.

Keywords: cycle time, lead time, simulation, Arena software

1. INTRODUCTION

In order to understand and cope with the challenges that businesses face today, empowered and able people are needed to make decisions in uncertain environments, because the ability of making system analysis and to find constraints or opportunities for improvement can make the difference in the production system performance.

There are several tools that can be used to study a system and to help the decision-making process but simulation is probably the only tool able to mimic dynamic and complex environments with considerable interdependencies and stochastic behavior. With simulation, it is also possible to analyze several scenarios and to consider a wide range of performance measures.

In this case, the production line simulated belongs to an electronics industry, the Company X. Operating in this type of industry has become increasingly difficult, because companies compete with high quality standards, with rapid technological changes and with short production cycles. It is known that electronics products are the most complex to produce. The Product Y was the elected product for simulation because is the representative one. The production process can be divided into six phases: manual assembly 1, welding, rework, manual assembly 2, visual inspection and electrical test and packing.

This paper is organized as follows: Section 2 presents an overview of simulation in order to describe the theoretical work context. Section 3 describes the current state of the system and presents the main steps to develop the simulation model. To create the logical models it was used the Arena simulation software. After verification and validation steps, the main results are presented as well as three proposed scenarios for process improvement. Section 4 presents the key conclusions of this work.

2. SIMULATION OVERVIEW

Over the last thirty years, numerous books and papers have focused on the topic simulation because this has been useful and important as a decision support tool. With simulation, it is possible to build, quickly and almost inexpensively, virtual models of complex systems and to do the analysis of different perspectives before making a decision on the actual system (Seleim et al, 2012).

According to Altiok and Melamed (2007) simulation modelling "is a common paradigm for analysing complex systems". One should also refer that simulation modelling "involves the development of descriptive computer models of a system and exercising those models to predict the operational performance of the underlying system being modelled", according to Smith (2003).

Simulation can be described as the process of building a model that represents a real system and allows users to perform experiments with this model, in order to learn about its behaviour and, thus, evaluate the impact of each alternative operation strategy.

The simulation offers benefits such as low cost, rapid and safe analysis system (Wang et al, 2009) and numerous other advantages, such as (Shannon, 1998):

- the ability to identify bottlenecks in information, material and product flows;
- the study of complex real systems, which would be difficult to represent by analytical models;
- the study of alternative layouts without any cost of implantation.

Nonetheless, simulation has also disadvantages, like (Shannon, 1998 and Banks, 1999):

- the (statistical) simulation results are difficult to interpret;
- the collection of data that shows confidence can become a very slow process;
- the simulation alone does not solve problems, only shows the solutions that can solve the problem, so someone must implement the proposed changes.

Negahban and Smith (2014) provide a comprehensive review on manufacturing simulation studies highlighting the application of DES (Discrete Event Simulation) in this context. Simulation models are used for a wide range of complex manufacturing scenarios, from system design to daily operations, as well as covering an extensive set of manufacturing sectors.

In this work, Arena software (a DES simulator) was used as a modelling and simulation tool to study a production line for an electronic product. This software was developed by Rockwell Automation Company. Using SIMAN processor and its simulation language, this software is commonly used to simulate manufacturing processes or services whose purpose is to study the current system performance (Wang et al, 2009).

In the manufacturing Portuguese context, simulation is not a widespread tool for decision-support. This work intends to contribute to evidence the benefits that Portuguese factories can have when adopting simulation practices.

3. CASE STUDY

3.1. Current state of the system and problem formulation

To start a simulation study is necessary to formulate the problem and define the objectives. Relatively to problem formulation, it is intended to develop a simulation model that represents the production system of Product Y. Regarding the objectives, it is important to identify bottlenecks, identify the lead time and the cycle time (because these two indicators are unknown for the Company X) and look for improvements. So, in order to facilitate the analysis of the simulation model, it is intended to gather the following performance measures: throughput, lead time, cycle time, utilization rates, number in queue and time in queue.

3.2. Data collection and information and conceptual model definition

To develop the initial model, data were collected on the production line. Several observations were made in order to observe and measure the operations and to detect possible failures and/or maintenance procedures (e.g., in the welding machine). These observations were also conducted to better understand the details associated with the line. The first annotations included time measurements of each operation, time between failures on the welding machine, operators' work schedule, rework and product rejection rates, number of daily produced units and product transfer time between different phases. The chosen line has eight operators and a single welding machine.

The data gathered will serve as input to the simulation model and will be treated using the *Input Analyzer* (Arena tool), in order to identify the distributions that best fits the data collected on the shop floor.

The definition of the conceptual model was possible through direct observation of the production process and through process sheet for the product Y. This means that both were analyzed in detail. The conceptual model is illustrated in the following figure and shows, in a simplified and structured way, the sequence of operations required to produce the product. The conceptual model will serve as basis for modeling the real system in the Arena *software*.

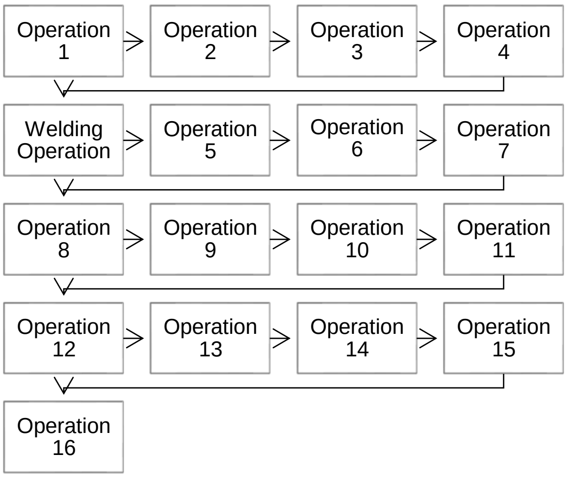

Figure 1: Conceptual model

After several discussions with the area leaders, it was concluded that the conceptual model is correct and complete.

3.3. Logic model construction and verification

After collecting data and some other information, the next step comprises the development of the current logical model. The operation processing times collected on the production line are used in this step.

For the construction of this model, it is intended to codify the conceptual model on a set of logical statements that reflect the real system behavior. The Arena software has several templates that help building the model, such as the *Basic Process*, the *Advanced Process* and the *Advanced Transfer*. To this study, the three templates were used as well as other modules.

An additional relevant fact was the definition of the operators work schedule. For this simulation run, it was considered that a working day has 9 hours, however discounting the lunch break (1 hour) and the snack breaks (20 minutes in total) the production period is 7 hours and 40 minutes. Only the *WeldingMachine* resource is operational during 9 hours, and every 2 hours, this resource stops for, approximately, 5 minutes.

It was decided to simulate a typical planning period of 8 working days. However, it is important to note that the phases are not simultaneously in operation. The following

Gantt diagram (figure 2) shows the days when each phase is being operated. At the end of the day 8, the company has 11 boxes of Product Y.

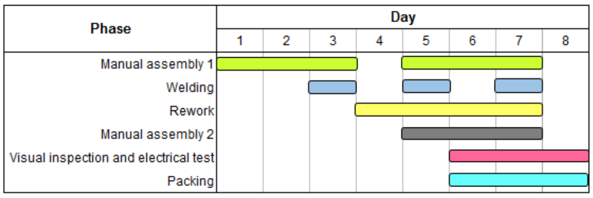

Figure 2: Gantt diagram

To run the model, 50 replications were made. The replication length was 8 days and 9 hours per day. The base time units are minutes. It should be noted that there is a resource, the *SubstituteAF*, which only works in this production in *AF* resource schedule breaks. This resource will not be considered for further analysis.

Manual assembly 1 phase

To build the simulation model, in this first phase, the following modules were used: *create*, *assign*, *batch*, *hold*, *match*, *record*, *process*, *station* and *route*. MF and LB operators carry out the first four operations. The *MF* operator is responsible for *Operation 1*, *Operation 2* and *Operation A*. Two operators perform the Operation 3: *MF* and *LB*.

The model starts with nine *create* modules that create the entrance of the following components: *panels*, *switches B*, *orange cables1*, *coloured cables*, *accessories1*, *accessories2, switches A1, switches A2 and orange cables2.*

The *Operation 1* (*process* module), performed by MF operator, needs *panels* and *switches B*. In one panel are assembled 100 *switches B*. The resulting entity of the group is synchronized by the *match* module ("*Match 1*") to the panel. After the entities being synchronized, a permanent *batch* ("*Batch 1*") was created. The *record* modules were used to collect the number of entities before and after each operation.

In this phase were used two *hold* modules: one before the *Operation 1* and the other after the *Operation 3*. The entities arriving this module wait in the line until the necessary condition to advance for the next module is verified. It is given the example of the "*Hold welding*", where the following condition was defined: *"(CalDayOfMonth(TNOW)==3) || (CalDayOfMonth(TNOW)==5) || (CalDayOfMonth(TNOW)==7)*. The entities locked in this module only advance when the day of month is equal to three, five or seven. Otherwise, the entities wait in the line until the necessary day is confirmed. The remaining *hold* modules used in the model, follow the same logic explained here. The entities that are in this module wait until the necessary condition is verified. When it happens, the panel is transferred to the next phase by the *station* and *route* modules.

Here, the *"Entry time*" *assign* module, along with the *"Lead time" record* module in the packing phase, has the goal to collect the production lead time.

Welding Phase

This phase is constituted by two operations: *Operation 4* and *Welding operation*. The *Operation 4* has two operators: *AF* and *SubstituteAF*. The *Welding operation* has two human resources (*AF* and *SubstituteAF*) and a welding machine (*WeldingMachine*). To represent the operations, two *process* modules were used. Like the previously stage, the *record* modules here were used with the same goals. As once said, in this phase, it is also present a *hold* module ("*Hold Rework"*), that hold the entities until all of the conditions are checked. Once verified, the entities are transferred to the next workstation ("*Station Rework*") through the "*Route Welding_Rework*" *route* module.

Rework phase

In this phase, the *PP* operator is responsible for two operations (*Operation 5* and *Operation 6*). The construction logic is similar to the previous one.

Manual assembly 2 phase

Here, the following modules were used: *record, batch, match*, *process*, *decide, hold, station*, *route*, *dispose* and *separate*. The *RJ* operator is responsible for the *Operation 7* and *Operation 8*. The *Operation 9* includes the *PP* operator and the *Operation 10* contains the *PS* operator. Finally, the last operation in this phase (*Operation 11*) includes the *PS* and *PP* operators. The *PP* operator is also responsible for *Operation 8_1*.

The first operation of this phase is the *Operation 7*. In order to break the entity (panel) in its 25 PCB's units it was used the *separate* module ("*Separate panel in 25").* From now on, the entity name that runs the system is PCB unit or only PCB and not panel. After *Operation 8*, the decide module is introduced. In the "*Rework operation 8?" decide* module, 2% of PCB's units require rework, which means that the remaining units follow for the next operation (*Operation 9*). If the PCB's units need rework, then they go to the *Operation 8_1*. After this operation, another module *decide* (*"Units recovered?"*) is presented. This module is used to decide the path of the units after the *Operation 8_1*. The PCB's units that are rejected, they go out of the system by *the* "*Exit operation 8_1 NOK*" *dispose* module. The recovered units follow to the *Operation 9*.

In this phase, the representative unit became a box containing 25 PCB's units. A temporary *batch* was created and then, immediately, a *separate* module was created too. These two modules ensure that to each operation arrive batches with 25 PCB's units and each batch is separated before being processed, to ensure the individual PCB unit processing.

Visual inspection and electrical test phase

To construct this phase the modules *record, process, decide, dispose, create, match, batch* and *separate* were used. The *PP* operator is responsible for *Operation 12_1* and the *SP* operator executes the remaining operations. To add a new component to the system it is necessary to create a new entity. It was created the "*Labels*" and the "*Accessories3*" entities from *create* modules. Each of these entities is synchronized with the existing entity in the system by the same logic already explained in the previous phases. The *decide* module is used again. This module determines the need of rework after the *Operation 12*. In this case, there are three possible paths for the PCB's units:

- 2% of the units follow to the *Operation 12_1*.
- 3% of the units cannot be reused and so their final destiny is disposal. These units leave the system through the *"Rejection" dispose* module.
- the remaining units follow to *Operation 13*.

100% of the entities that go to *Operation 12_1* are recovered, which means that these entities also go to *Operation 13.*

Packing phase

To construct this last stage, the following modules were used: *create, process, batch, match, record, assign* and *dispose*. The *Operation B* and *Operation 16* are the only two operations in this phase and the operator allocated to them is *SP*. At this time, card boxes enter in the system. It was used a *create* module ("*Card boxes"*) to give the reference to the component input. After the *Operation B* (that consists in assembling the boxes), each box is synchronized with the previous entity through the same construction logic.

According to Sargent (2013), "model verification is defined as ensuring that the computer program of the computerized model and its implementation are correct". The verification was carried out in phases allowing the identification and correction of code errors.

It was also developed a three dimensional animation (3D) for a better analysis of the system. The animation is a very important aspect in this work, because it allows, in a graphical form, to see the whole production process of the Product Y. The animation was also important for model verification and credibility (when showing the results to company managers). Figure 3 depicts a screen shot of the 3D animation model for the current system.

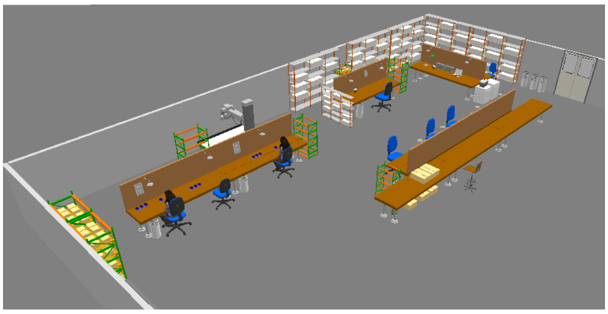

Figure 3: 3D animation model

3.4. Validation and output analysis

Several runs of the model were made. As previously mentioned, to run the model, 50 replications were made, the replication length was 8 days and the working time was 9 hours per day.

In relation to model validation, the author Sargent (2013) refers that the validation is defined "as the substantiation that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model". The existence of historical data contributed positively to model validation. To validate the model was considered the throughput performance indicator. Based on this performance indicator, it was found that the results returned by the simulation model (12.28 ± 0,13 boxes, 95% confidence interval) were similar to the real system (11.25 boxes, in average). It can be conclude that the model contains an acceptable adjustment because the performance indicator referred to validate the model is similar to the reality. Relatively to the unknown lead time indicator, the current simulated value is 4431.02 ± 10,50 minutes, which corresponds approximately to 8 days of work. Concerning to cycle time (also an unknown value), the value is 63.82±1,96 minutes. These results seem reasonable and were validated by working operators.

The simulation results in table 2 show the resources utilization rates. It is possible to verify that in general the resources utilization rates are high, except for *AF* and *WeldingMachine* resources. In relation to *AF* the observed low utilization rate (0.26 ± 0,00) is not relevant because this operator is a polyvalent resource and he gives assistance to other productions. The low utilization rate of the *WeldingMachine* (0.17 ± 0,00) it is not also a concern because this resource is used to weld others PCB's (is not fully dedicated to Product Y). It was noticed that the *RJ* resource is underutilized in comparison with the other resources.

Table 1: Resources utilization rate for current model

Resources	Utilization rate
AF	0.26 ± 0,00
LB	0.92 ± 0,00
WeldingMachine	0.17 ± 0,00
MF	0.93 ± 0,00
PP	0.88 ± 0,00
PS	0.88 ± 0,01
RJ	0.50 ± 0,00
SP	0.71 ± 0,01
SubstituteAF	0.20 ± 0,00

After carefully analysing all operations, it is possible to see in table 2 that the bottlenecks are in *Operation 2* and *Operation 10*, because these operations have the highest number waiting and waiting time of entities in the queue. The *MF* resource (allocated to *Operation 2*) has a utilization rate of 0.93 ± 0,00. The resource allocated to *Operation 10* is *PS* has a utilization rate of 0.88 ± 0,01.

Table 2: Entities waiting time and number waiting in queue

Operation	Number waiting (panels and PCB's)	Waiting time (minutes)
Operation 2	58.94 ± 0,13	1620.77 ± 3,49
Operation 10	189.14 ± 2,22	236.73 ± 3,33

3.5. Conduct experiments

After analyzing the output data, three scenarios were considered which consisted of making deliberate variations in the initial model in order to observe the system behavior. For each simulated model, 50 replications were done, the replication length was 8 days and the working time was 9 hours per day. The three simulated scenarios are now presented.

Scenario A: Act on bottleneck operations

The first improvement suggestion is the elimination of the bottlenecks that were identified. To achieve this scenario, the *RJ* resource was allocated to the bottleneck operations, because this is the resource with the lowest utilization rate (without considering the *AF* and *WeldingMachine* resources). It was possible to verify an improvement in the throughput indicator in relation to the actual system. Although the lead time and the cycle time have slightly increased, it is not considered a concern, because the throughput increased about 35%. In relation to the resources utilization rates allocated to the bottleneck operations, its utilization rates decreased. On the other hand, and as expected, the *RJ* utilization rate increased. The *AF* and *WeldingMachine* utilization rates increased too, although it was not significant. The most significant growth was in the *SP*, *PP* and *RJ* resources. It can be concluded that a better use of resources leads to a productivity increase (throughput=16.56 ± 0,17 boxes). It was also visible a decrease in number waiting and waiting time of entities in the bottleneck operations (*Operation 1* and *Operation 10*).

Scenario B: Reduce from 8 to 7 the production days

In order to analyse the impact that it will have the elimination of a production day, it was tested a scenario with this suggestion. To test this scenario, it was removed the "*Hold visual inspection_et*" *hold* module that was holding the entities immediately before the last two phases of the process. The operations of the last phases were realized on days 6, 7 and 8 being now executed on days 5, 6 and 7 (Gantt diagram in figure 4).

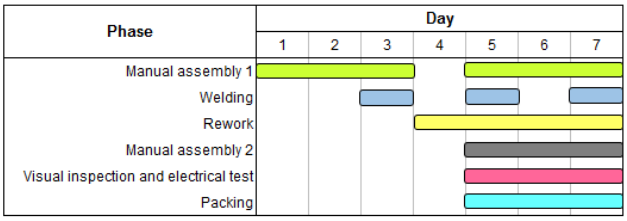

Figure 4: Gantt diagram for scenario B

With this scenario, it was possible to conclude that is viable to decrease one production day leading to better results in lead time (as expected) and cycle time performance indicators. In relation to throughput, the value obtained is good (11.84 ± 0,11) and still acceptable, because the value remains above the production goal (11.25 boxes, in average).

Relatively to the *LB*, *MF* and *PP* resources, it was found that these resources utilization rates increased. *LB* and *MF* presents a utilization rate of 100%, which means that they are well used (perhaps at the limit), such as the *PP* resource whose utilization rate is near to 100%. The other resources utilization rates are similar to the current model.

Scenario C: Situation make-to-stock and make-to-order

The last scenario comprises the make-to-stock and make-to-order logic. In make-to-stock mode the intermediate product is produced for stock and then in a make-to-order phase is when it happens the product differentiation to satisfy the customer's request (Gupta and Benjaafar, 2004). This strategy is known as postponement. With this scenario only the manual assembly 1 phase produces to stock during 7 days. When the company receives the customers' requests, the remaining phases enter in production during the period of 4 days. In order to take advantage of resources utilization rates and maximize the throughput, the following adjustments were made:

- A *hold* module was added after the *Operation 3* and before de *Welding operation*. This module is used to create stock.
- The *LB* resource also supports the *Operation 2*.
- The *Helper1* resource is used to support the following operations: *Operation 6*, *Operation 9*, *Operation 11* and *Operation 14*.
- The *Helper2* is assigned to the *Operation 10*.

With this scenario, the results were interesting as depicted in table 3.

Table 3: Results of scenario C

Throughput (number of boxes)	**29.26 ± 0,13**
Cycle time (minutes)	66.31 ± 0,28
Lead time (minutes)	5177.66 ± 4,78

This scenario takes advantages of resources capacity, because they evidence higher utilization rates, some even close to 100%, with the exception of the *AF* and *WeldingMachine* resources (table 4).

Table 4: Resources utilization rates of scenario C

Resources	Utilization rate
AF	0.27 ± 0,00
LB	1.00 ± 0,00
MaqSoldar	0.19 ± 0,00
MF	1.00 ± 0,00
PP	0.90 ± 0,00
PS	0.88 ± 0,00
RJ	0.88 ± 0,00
SP	0.93 ± 0,00
Helper1	0.91 ± 0,00
Helper2	0.86 ± 0,00
SubstituteAF	0.30 ± 0,00

3.6. Analyze output data

In this step, the results of the current model were compared with the proposed scenarios. In both alternative scenarios, the responses of the system were analyzed. The discussion of the results is based on the elected performance measures.

In figure 5, it is clear that in the three tested scenarios the throughput is above the production objective, which is 11.25 boxes. The scenario A shows that when we act on bottleneck operations, there is an increase in the throughput of about 35%. The scenario B is interesting because it has been found that the reduction in the number of production days does not interfere with the desired throughput (the decrease was approximately 4%). Even in this scenario, there is an improvement on cycle time and lead time. The scenario C shows an increase in the number of produced boxes in the order of 138% over the value obtained by the current model.

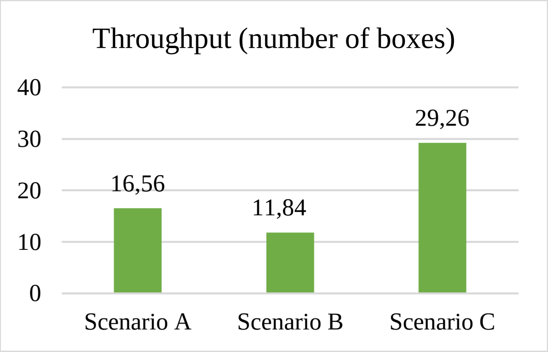

Figure 5: Throughput for the different scenarios

From the analysis of figure 6, it does not exist large discrepancies between the lead times of the different scenarios when compared to the current model. The largest discrepancy occurs in the scenario C, which it shows an increase of around 17%. However, scenario B shows improvements on lead time. The reduction of this performance indicator in relation to the current model is in the order of 6%. On the other hand, in scenario A there was an increase of approximately 7% of this indicator.

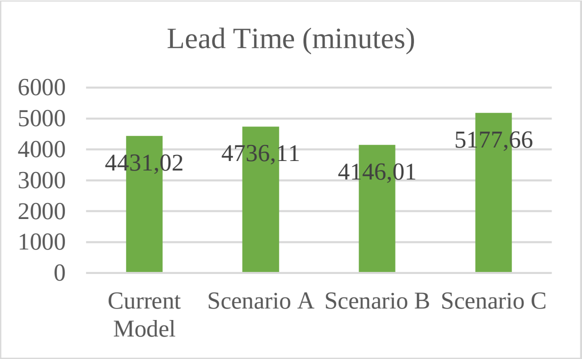

Figure 6: Lead time for the different scenarios

In relation to cycle time, it is possible to verify that just in scenario B was a reduction of this indicator in the order of 4%. This reduction is related to the decrease of a working day. On the other hand, scenarios A and C show an increase in cycle time of approximately 10% and 4%, respectively (figure 7).

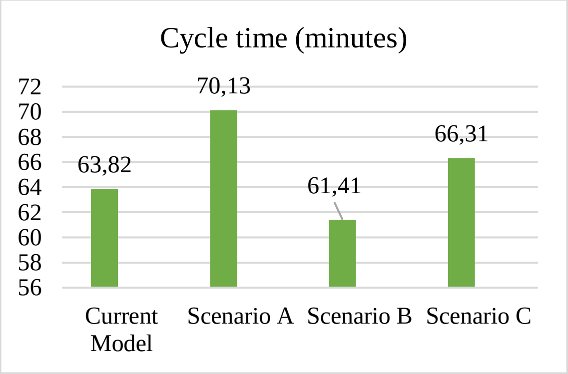

Figure 7: Cycle time

The graph of figure 8 illustrates the resources utilization rates, in percentage, of the current model and of the three considered scenarios. Scenario C is the alternative that shows similar resources utilization rates (with the exception of *AF* and *WeldingMachine*). There are not noteworthy differences and the load is more balanced. Concerning scenario A and B it can be seen that these two scenarios have utilization rates alike to the current model.

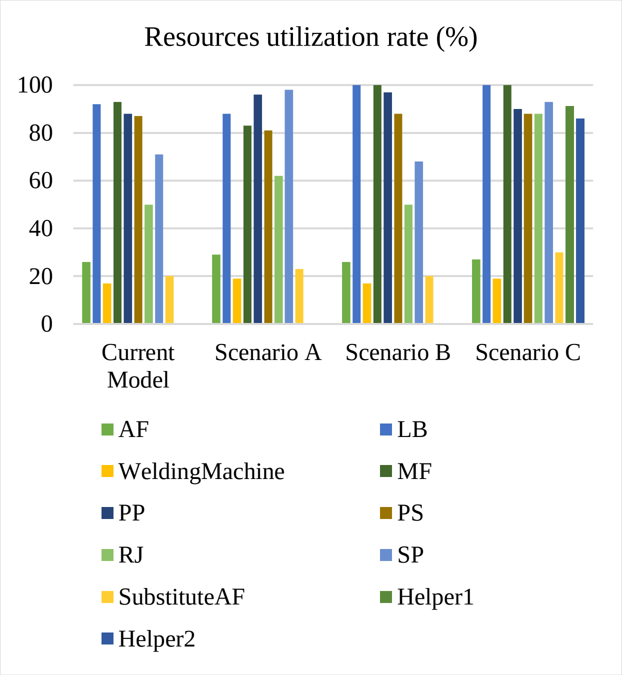

Figure 8: Resources utilization rates

4. CONCLUSIONS

Over the time, simulation has been proving that is one of the most flexible and most used tools in operations management and manufacturing systems, as well as a decision support tool.

In this work, the production system of electronic Product Y was dynamic analysed through modelling & simulation. The quantification of cycle time and lead time values had a huge importance to the Company. The information of cycle time allowed to know the time between the production of successive boxes and the lead time expresses the time that is required for the product Y to go through all process phases, from the beginning to the end. In relation to the three scenarios proposed, it was found that better performances than the current model can be obtained.

The use of computer simulation in a work of this nature, revealed the importance of it in process control and in presenting improvement strategies that make the production system more efficient.

In conclusion, the simulation has proven that is an effective tool for analyzing the production process and to help the decision making process by evaluating several different scenarios and the corresponding impact on a broad set of performance measures. Therefore, simulation can be used as a scientific basis to help in decision making with the advantage that it is not necessary to interfere with the real system. So it is proven the importance of simulation in improving the efficiency of the production process of Product Y. Wherefore, it is justified the use of this tool for analyzing complex systems/processes characterized by numerous interdependencies and stochastic behavior.

The Company X is analysing the simulation results and intends to implement some of the suggested improvements. Other scenarios are also in analysis including different factors such as production volumes. The 3D animation was a critical factor concerning model results' credibility.

REFERENCES

Altiok, T, and Melamed, B (2007). Simulation Modeling and Analysis with Arena. ISBN: 978-0-12-370523-5.

Banks, J (1999). Introduction to simulation. *Proceedings of the 31st conference on Winter simulation*, **1:** 7–13, doi: 10.1145/324138.324142.

Gupta, D and Benjaafar, S (2004). Make-to-order, make-to-stock, or delay product differentiation? A common framework for modeling and analysis. *IIE Transactions*, **36**(6): 529–546, doi: 10.1080/07408170490438519.

Negahban, A., Smith, J. (2014). Simulation for manufacturing system design and operation: Literature review and analysis. *Journal of Manufacturing Systems*, 33(2): 241-261.

Sargent, R G (2013). Verification and validation of simulation models. *Journal of Simulation*, **7**: 12–24, doi: 10.1057/jos.2012.20.

Seleim, A, Azab, A, and AlGeddawy, T (2012). Simulation Methods for Changeable Manufacturing. *Procedia CIRP*, **3:** 179–184, doi: 10.1016/j.procir.2012.07.032.

Shannon, R E (1998). Introduction to the art and science of simulation. *Proceedings of the 30th conference on Winter simulation*, **1**: 7–14.

Smith, J S (2003). Survey on the Use of Simulation for Manufacturing System Design and Operational. *Journal of Manufacturing Systems*, **22**: 157-171.

Wang, T, Guinet, A, Belaidi, A, and Besombes, B (2009). Modelling and simulation of emergency services with ARIS and Arena. Case study: the emergency department of Saint Joseph and Saint Luc Hospital. *Production Planning & Control*, **20**(6): 484–495, doi: 10.1080/09537280902938605.