SIMULATION MODELING AND ANALYSIS OF THE MANUFACTURING SYSTEM OF A PLANT IN MINAS GERAIS – A CASE STUDY

Arthur Ferreira Rezende Delfim, arthurdelfim@me.com[1]
Gabriel Mendes Carvalho de Almeida, gmendescarvalho@gmail.com[1]

[1]Universidade Federal de Minas Gerais – UFMG
Escola de Engenharia da UFMG – Galpão da Mecânica – Departamento de Pós-Graduação
Av. Presidente Antônio Carlos 6627, Belo Horizonte, MG, Brasil.

Abstract. Nowadays, simulation models that can provide accurate approximation of real plants are helping the industry to identify bottlenecks, operator allocation distribution improvement and increase efficiency as a whole. The present paper shows a case-study of the processes analysis that compose a real manufacturing production plant in Minas Gerais and aims to develop a simulation model using the Software ProModel and run several tests in order to point processes errors or unproductive tasks. In this work, it was plotted the total throughput rate over replications to obtain a trustable result and it was able to identify bottlenecks, indicate the need of hiring new operators or training deficient skills, revealed resources overuse detailing the utilization, factory organization and sustainable technologies substitution were indicated resulting on a maximized factory productivity.

Keywords: Manufacturing; Engineering; Simulation; Model; Analysis

1. INTRODUCTION

It is only recently that the production planning and scheduling problems encountered in the industrial environment have begun to be addressed using engineering and operations research techniques. These problems have several features that make them difficult and challenging: random yields and rework, complex product flows, and rapidly changing products and technologies. Hence their solution will contribute considerably to die theory and practice of production planning and control (Uzsoy, 1992).

Simulation models have had extreme value in many companies, being used as decision-making and planning tools by managers in supply chain related areas. ProModel is successful in providing an accurate representation for many players involved in a single product line. The players may consist of suppliers, warehouses, customers, retailers, and transportation vehicles. Such issues facing the players of the organization are fleet sizing, inventory reduction, and shutdowns and outages. ProModel allows to create a model, which addresses these issues in a single model (Benson, 1997).

A supply chain may be defined as an integrated process wherein a number of various business entities (i.e., suppliers, manufacturers, distributors, and retailers) work together in an effort to: (1) acquire raw materials, (2) convert these raw materials into specified final products, and (3) deliver these final products to retailers. This chain is traditionally characterized by a forward flow of materials and a backward flow of information. For years, researchers and practitioners have primarily investigated the various processes of the supply chain individually. Recently, however, there has been an increasing attention placed on the performance, design, and analysis of the supply chain as a whole. From a practical standpoint, the supply chain concept arose from a number of changes in the manufacturing environment, including the rising costs of manufacturing, the shrinking resources of manufacturing bases, shortened product life cycles, the leveling of the playing field within manufacturing, and the globalization of market economies. The current interest has sought to extend the traditional supply chain to include "reverse logistics", to include product recovery for the purposes of recycling, remanufacturing, and re-use. Within manufacturing research, the supply chain concept grew largely out of two-stage multi-echelon inventory models, and it is important to note that considerable progress has been made in the design and analysis of systems (Benita, 1998).

Until recently, manufacturing companies have not fully benefited from simulation in making continuous improvements because of the time, programming expertise, and cost involved in getting useful results. ProModel is designed for manufacturing companies to fully achieve the benefits of simulation technology at an affordable price. ProModel is directed toward making simulation a standard tool in the hands of engineers, managers and systems analysts just as spreadsheet software is in the hands of accountants and financial analysts. Especially challenging issues in supply chain applications include capturing the behavior of continuous flow systems with stochastic conditions. Onscreen variables and output statistics modules provide guidance to make decisions on tank sizing, capacity analysis and impact of variability of supply on manufacturing units. Benefits include the ability to analyze complex systems with a holistic perspective, reducing inventory levels by modeling continuous flow systems at both manufacturing and consumer sites and determining the needs of campaigning of differing products on the same unit (Benson 1997).

The ProModel Optimization Suite is a powerful yet easy-to-use simulation tool for modeling all types of manufacturing systems ranging from small job shops and machining cells to large mass production, flexible manufacturing systems, and supply chain systems. ProModel is a Windows based system with an intuitive graphical interface and object-oriented modeling constructs that eliminate the need for programming. It combines the flexibility of a general-purpose simulation language with the convenience of a data-driven simulator. In addition, ProModel utilizes an optimization tool called SimRunner that performs sophisticated "what-if" analysis by running automatic factorial design of experiments on the model, providing the best answer possible (Benita, 1998).

Some factors are crucial for building valid and credible simulation models. Ideas to be discussed include the importance of a definitive problem formulation, discussions with subject-matter experts, interacting with the decision-maker on a regular basis, development of a written assumptions document, structured walk-through of the assumptions document, use of sensitivity analysis to determine important model factors, and comparison of model and system output data for an existing system (Averil, 2008).

Taking this point of view, this paper aims to analyze a real manufacturing plant in Minas Gerais that preferred to keep its name preserved, simulate the entire process utilizing the afore mentioned ProModel Software, detailing each of the variables, and finally, modify some parameters of the simulation model while testing its results in a trial to identify factors like: bottlenecks, need of hiring new employees, training deficient skills and revealing the overuse of machines. To increase the relevance of the present work, the total throughput rate was plotted over the number of replications, and all those simulation techniques were capable to acquire enough data that was used to successfully identify and solve a bottleneck and overuse of machines and employees problem. After some adjusts in the manufacturing model, it was able to increase significantly the plant efficiency and reduced the operation cost with the rise of the productivity.

2. DEVELOPMENT

A simulation is the best attempt to bring most characteristics of a real life system into a computer representation, called model. The ability to develop a model from a working plant is known as modeling, and everything starts from the construction of a reliable one.

After that, simulation takes place, and analyzing skills are brought to its maximum utilization. The simulation tries to statistically predict the future of a plant, and is able to do it, changing an infinite number of variables, providing data for engineering decisions, such as new machines purchases, hiring new operators, changing factory organization and logistics, revealing bottlenecks, resources overuse and system unexpected behavior. It provides important data to be combined with cost analysis and in the end, determine the best changes that can maximize the productivity of the factory.

Based on the following process description of a industrial plant in Minas Gerais that preferred to keep its name and final activity from being published, a suitable simulation model should be created covering all its specifications:

The process is able to produce two types of products, called Type1 and Type2. It consists of six operations: turning, milling and drilling machines; assembly, inspection and packing station, which are all single capacity – can manufacture one single part at a time. The blank parts arrive at the input-pallet able to hold up to 5 parts, following an exponential distribution with a 20 minutes mean.

Each manufacturing process performs a specific operating time: for turning and milling, it is approximated by triangular distributions of (6,8,10) and (9,12,14), respectively. For the others (drilling, assembly, inspection and packing), the operating time is represented by normal distributions with means of 5, 7, 5 and 3 minutes, respectively, while the standard deviations shows to be 1, 1, 2 and 0.5 minutes, respectively.

The percentage of entering parts in the system is the same for types 1 and 2 - 50% for each. Each type follows one specific way in the production line: Type1 parts are served at turning, then move to milling, drilling, inspection and finally packing. Type2 parts are served at milling, then move to drilling, assembly, inspection and finally packing. In other words, the turning machine is exclusive for Type1, while only the Type2 parts needs to go for assembly.

At the assembly stage, a bought-out aluminum cover, taken from the store, is joined with Type2 parts before it moves to inspection. This aluminum cover is supplied to the storage area, to meet the required demand.

There is one accumulating roller in front of each machine and station, which provide space for finite buffers. All conveyors can hold up to 3 parts, with a length of 10m and speed of 50 meters per minute.

To operate the system, employees were classified into 3 categories according to their salary: the skilled operator serves turning, milling and drilling machines; the semi-skilled operator serves the assembly, inspection and packing stations; and the transport operator moves parts from any machine or station to the conveyor of any other machine. The transport is divided in two types: one is associated with the transfer of parts from the machines to the conveyors and the other one is for transporting the rejected parts from inspection to scrap. There is a 5% probability chance for both types of parts to fail at inspection and there is no priority for any part within the system at any station or machine.

3. RESULTS AND ANALYSIS DISCUSSION

3.1. Experiment 1

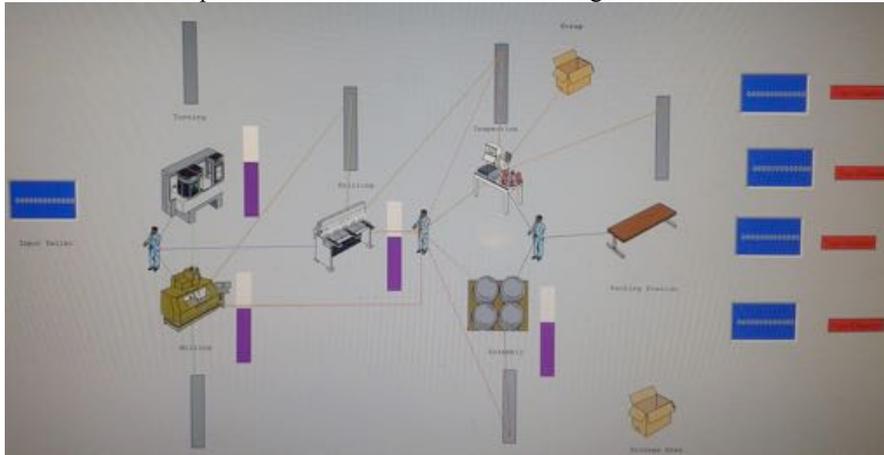The simulation model for the first experiment was created as shown In Fig. 1:

Figure 1. Minas Gerais Plant Simulation Sketch (ProModel Software)

The model should run for 40 hours and all essential performance measures are shown by Tab. 1:

Table 1. Experiment 1 results

Part	Total Exits	Current Quantity In System	Average Time In System (Min)
Blank Part	0.00	1.00	0.00
Type I	61.00	0.00	107.90
Type II	0.00	1.00	0.00
Type II covered	69.00	0.00	99.59
Rejected Type I	4.00	0.00	91.06
Rejected Type II	2.00	0.00	110.64

The model is able to run without any sign of processing errors, but some points require deeper analysis.

The number of finished "Type2" parts is analyzed by the "Type2 covered" ones, because at the assembly stage, Type2 parts were joined with the aluminum cover, becoming, therefore, a new entity, named as "Type2 covered". Its production was more than 13% higher than Type1 parts, even though the entering blank parts for each type in the system was the same, 50% for each side. This could indicate a series of causes.

One possible cause could be the operating time for each machine. The turning machine (strictly related to Type1) performs a higher operating time than the assembly machine (strictly related to Type2). To provide a clearer comparison and identify the superficial information that turning operation lasts longer than assembly, the statistical curves were plotted below for each type of distribution on Fig. 2. Another result that agrees with it is the "average time in system"- Type1 parts took, in average, 8.35% more time to be manufactured than Type2 ones.
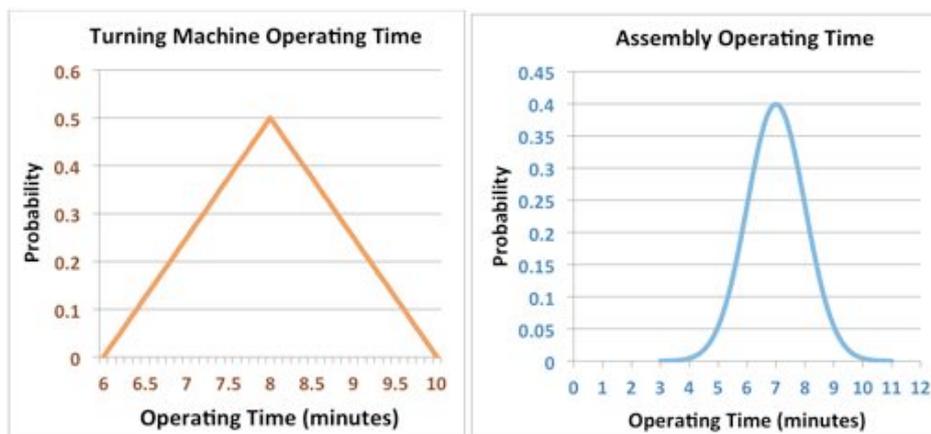
Figure 2. Experiment 1: Turning and Assembly statistical distributions for operation time

The transport operator works in the "first ready" state, in other words, it gets the first available part and carry it to its next destination, does not matter which machine it comes from. So, combining this to a quicker operation, this could amplify its effect to the final production. It would indirectly make Type2 parts as priorities and, accordingly to Fig. 3 (shown below), the transport operator is overloaded – it works 72.9% of the time when each machine operator works less than 10 times this amount.

Figure 3. Experiment 1: Resources Utilization

Another reason for that difference could be the path networks format, created for the transport operations. It might have been more convenient to the order and the machines that the Type2 parts go through.

An eventuality also contributed to this effect in the results. Type1 parts failed twice the number of Type2, even with the same probability of being rejected. However, as previously said, it merely represent an event, and does not interfere in the determination of model parameters to improve the system, it just shows that a more reliable result should be obtained, according to Fig. 4.
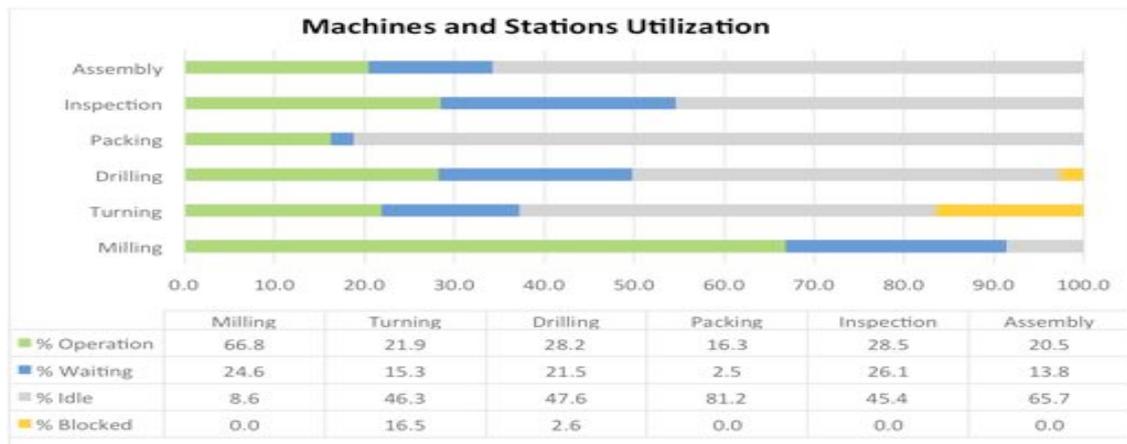

	Milling	Turning	Drilling	Packing	Inspection	Assembly
% Operation	66.8	21.9	28.2	16.3	28.5	20.5
% Waiting	24.6	15.3	21.5	2.5	26.1	13.8
% Idle	8.6	46.3	47.6	81.2	45.4	65.7
% Blocked	0.0	16.5	2.6	0.0	0.0	0.0

Figure 4. Experiment 1: Machines and Stations Utilization

All the causes described before could certainly affect the result, however, the most evident cause that might have led to a bigger throughput rate of Type2 parts was that the Turning machine kept blocked 16.5% of the time by the Milling Conveyor. It means that Type1 parts that had already completed their turning process, sometimes, could not have been moved from there because its next destination (milling conveyor) was full (reached maximum capacity). This fact caused a delay to the manufacturing time of that specific part, and also delayed the next Type1 part that would arrive at turning, being stopped by the other one that was still there waiting for a space to move from there to the milling conveyor.

This fact, combined with the high utilization of the Milling machine (66.8%) - more than twice the utilization compared to the second most used machine – indicates a bottleneck in that machine. It was overused, stopped the production flow by blocking the Turning machine and delayed the throughput time of both parts.

3.2. Experiment 2

Changes were made in the system configuration of the experiment 1, in order to reduce bottlenecks, maximize throughput and minimize work-in-progress.

To solve the bottleneck issue, another milling machine was added to the system and its conveyor capacity was doubled (from 3 to 6) to avoid blocking the turning machine. For the transport operator path network - that could have been more convenient to Type2 parts - two separate paths were created, one following the Type1 parts manufacturing route, and the other one doing the same for Type2 parts. To improve the manufacturing flow and reduce the transport operator overuse, another transport resource was added to the system. Now Type1 parts have its own transportation path network and operator, same thing applies to Type2 parts.

As provided by the Tab. 2, the throughput rate of Type1 parts increased from 61 to 75 (almost a 23% raise). This fact proves that the assumptions of the system configuration problems were correct. The transport path network, overuse of milling machine and the turning machine blockage were actually hampering Type1 parts manufacturing processes. In the other hand, the throughput rate of Type2 parts remained exactly the same as the previous experiment. This shows that it had already achieved good production flow and does not need an exclusive path network. As Type2 parts goes directly to the milling machine, the overuse it was suffering was not interfering in the final production result.

Table 2. Experiment 2 results

Part	Total Exits	Current Quantity In System	Average Time In System (Min)
Blank Part	0.00	0.00	0.00
Type I	75.00	1.00	58.46
Type II	0.00	1.00	0.00
Type II covered	69.00	0.00	53.21
Rejected Type I	2.00	0.00	66.01
Rejected Type II	0.00	0.00	0.00

The only point that does not make sense is the higher production of Type1 parts compared to Type2, even when the average time in system result, shows that Type2 parts takes less time to be manufactured. This does not indicate a system configuration problem, but a reliability issue might be affecting the results. The resources utilization for this case are shown in Fig. 5. For the semi skilled operator, the utilization was raised by 11.3% due to the increase of Type1 parts that passed through inspection and packing station. For the skilled operator, who now have to work on another milling machine and had the demand increased at the turning machine (as it is no longer blocked according to Fig. 6), its usage, as expected, had a higher raise (about 16.4%).

Figure 5. Experiment 2: Resources Utilization

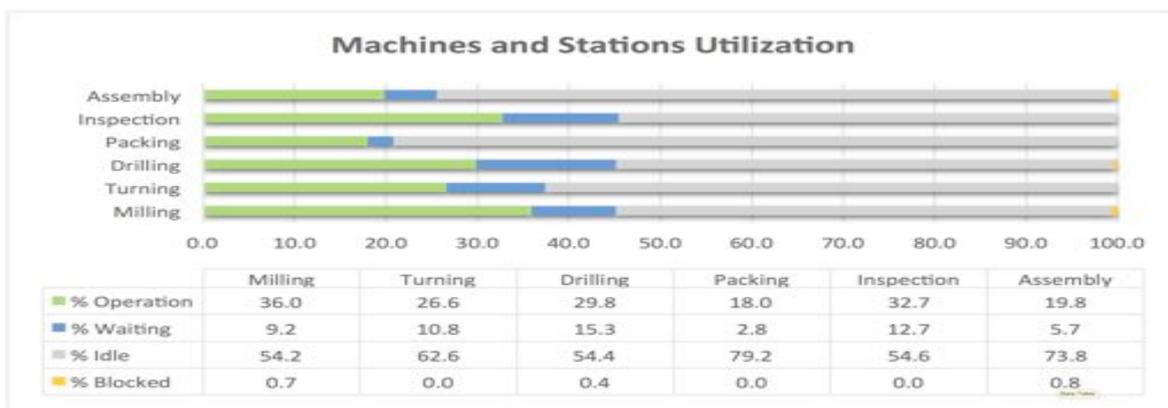|	Milling	Turning	Drilling	Packing	Inspection	Assembly
% Operation	36.0	26.6	29.8	18.0	32.7	19.8
% Waiting	9.2	10.8	15.3	2.8	12.7	5.7
% Idle	54.2	62.6	54.4	79.2	54.6	73.8
% Blocked	0.7	0.0	0.4	0.0	0.0	0.8

Figure 6. Experiment 2: Machines and Stations Utilization

According to Fig. 6, the turning blocking issue was 100% solved by the actions taken. Now with a higher capacity of the milling conveyor (it never reaches its maximum capacity during the simulation) and an increased potential of the milling operation due to the new acquisition, not even one single Type1 part is delayed after being processed by the turning machine. By the Fig. 7 is easily noticed that the transport operator utilization was decreased by more than half, after adding another operator and dividing them into 2 distinct path networks.
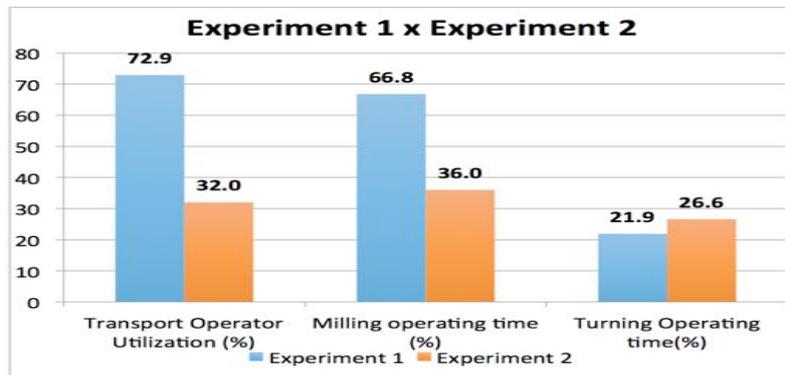

Figure 7. Experiment 2: Detailed bar chart comparison

The milling operating overuse problem was eliminated reducing its operating time by 46%, almost half, by adding another machine. While the turning machine proved to be rid of the blockage, as its operating time increased by 21%, enabling the higher Type1 throughput rate.

Although the prosperous results, an important study should be made before applying the changes to a real industry plant. The cost analysis should result in a profitable operation. By the acquired data, the key improvements were that the Type1 production increased by 23% and the new system configuration is able to perform a better production flow. This can justify the budget raise by a new transport operator, the growth of the milling conveyor capacity and the purchase of a new milling machine.

3.3. Experiment 3

For this experiment, the model should be simulated with the appropriate warm-up period. This concept represents a certain time that the simulation will run before starting to record the results. It allows aspects in the simulation (like queues) to get into normal conditions and typical operating behavior, approximating, even more, the simulation model to the real manufacturing plant. Aiming to find the time (working days) the system will take to produce in a stable rate, the model was run for 80 working days (work day considered 8 hours), the throughput rate results are shown by Fig. 8:
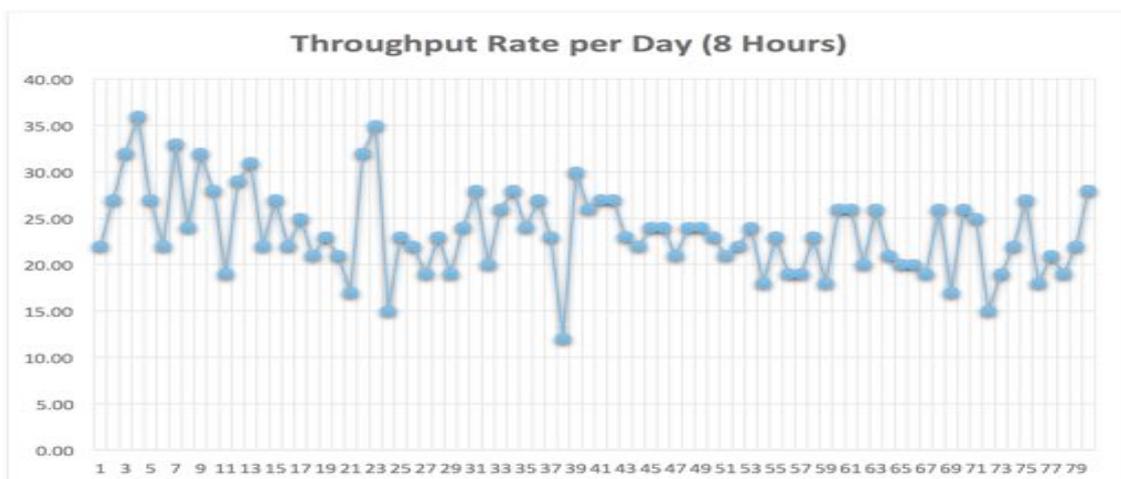

Figure 8. Experiment 3: Warm-up period determination

The system stabilization clearly occurs after the 45th day. By the 25th day, the stabilization starts to show up, and it could be even used as the warm-up time. However, to avoid the high 38th day peak, 45 days is the warm-up period defined for the system and the chart is not as smooth as it could be, because no replications were applied to the system.

Using the warm-up period, and running the system again, new results are shown by Tab. 3:

Table 3. Experiment 3 results

Part	Total Exits	Average Time In System (Min)
Type I	56.00	52.08
Type II covered	60.00	48.76
Rejected Type I	1.00	41.66
Rejected Type II	1.00	43.50

Approximating the model to the reality reduced the throughput rate, and, consenquently, the system productivity. Type1 production was reduced by a quarter, revealing the variability of the system. However, it is a much more reliable result, revealing the point that was not making sense on experiment 2. As Type1 parts take longer time to be manufactured, their production tend to be smaller. That is perfectly what happens now, and the rejection probability no longer causes direct influence in the final result, it was the same for both types, as it should be over a long period. The machines and stations utilization and resources utilization are shown in Fig. 9.
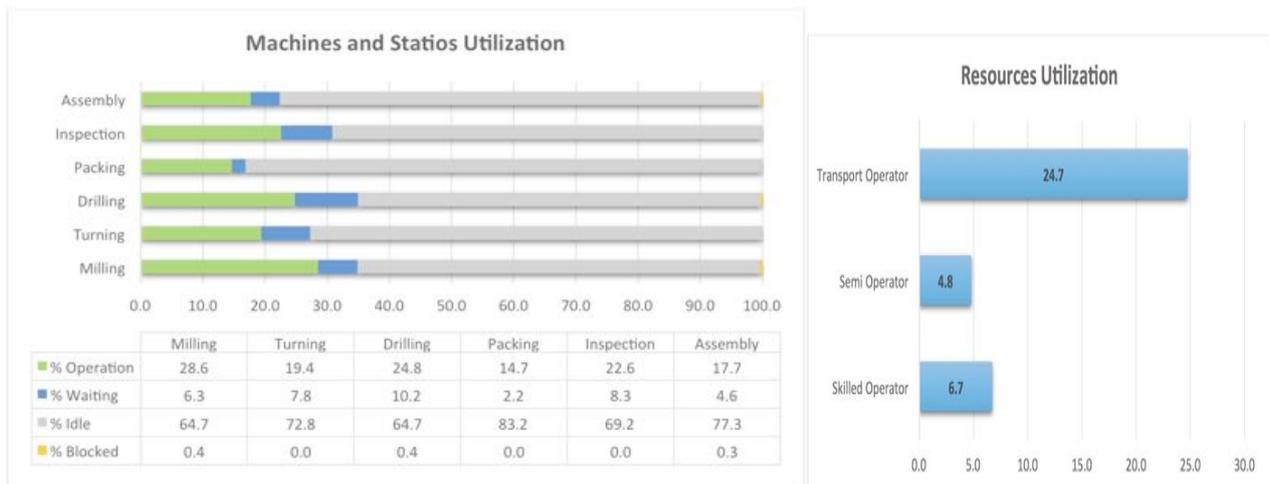

	Milling	Turning	Drilling	Packing	Inspection	Assembly
% Operation	28.6	19.4	24.8	14.7	22.6	17.7
% Waiting	6.3	7.8	10.2	2.2	8.3	4.6
% Idle	64.7	72.8	64.7	83.2	69.2	77.3
% Blocked	0.4	0.0	0.4	0.0	0.0	0.3

Figure 9. Experiment 3: Machines, Stations and Resources Utilization

The machine and resources utilization followed the production curve and went down. Some of the operating times were reduced by almost one third, what is explained by a lower production rate compared to experiment 2.

3.4. Experiment 4

The model now should be simulated with the appropriate number of replications. This parameter consists of the number of times the entire simulation will be repeated in order to achieve a trustable result. To define the number of replications the model from the last experiment should have, it will be firstly run with 30 replications, and the throughput rate results shown in Fig. 10:
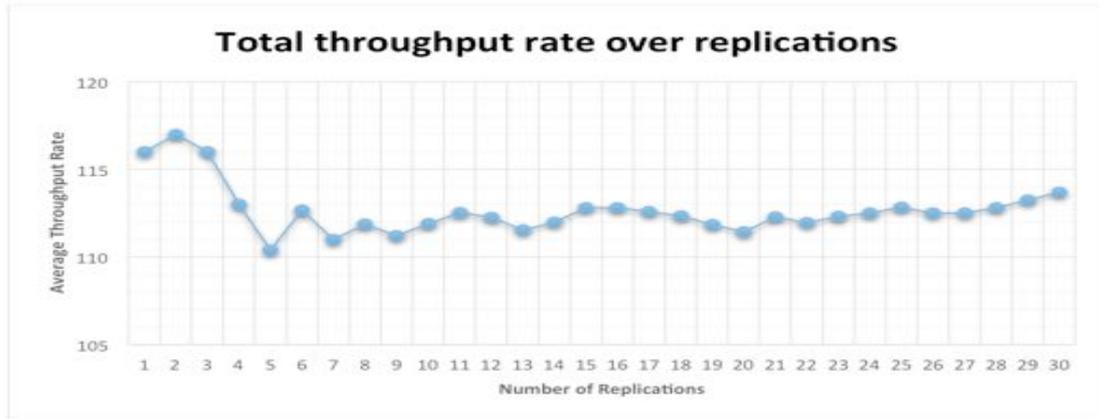
Figure 10. Experiment 4: Number of replications determination

After Fig. 10 analysis, it was concluded that a good throughput rate average stabilization happens after the number 11, since where all of the others remains almost the same (around 112 parts). The results are revealed by Tab. 4:

Table 4. Experiment 4 results

Name	Total Exits	Average Time In System (Min)
Type I	57.36	52.17
Type II covered	55.18	49.92
Rejected Type I	1.64	34.28
Rejected Type II	2.91	45.23

Comparing the results to the previous experiment, the throughput rate of Type2 parts decreased while Type1 parts increased, surpassing it. That is not what was expected, as the average time in system for Type1 parts is higher than Type2, but it can be concluded, facing the fact that this is a more reliable result, that this difference is so small, that other factors, such as transport logic, could be even more determinant than the operating time of the machines involved in each process. As this is relatively a small variation, and due to the mentioned fact, the results are clearly acceptable. The machines and stations utilization and resources utilization are shown in Fig. 12.
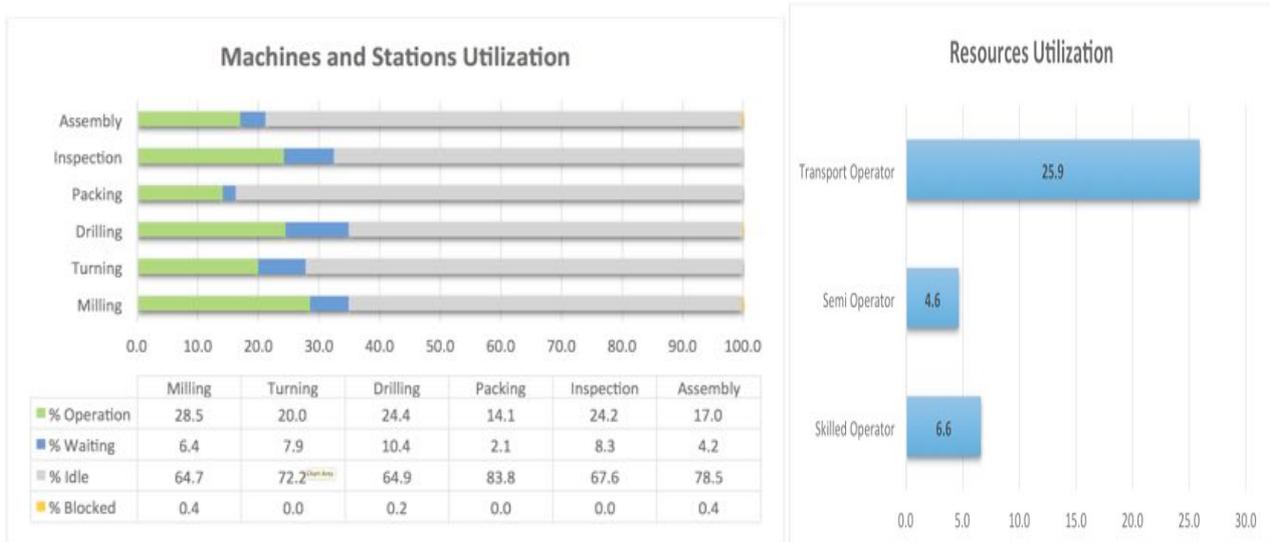

Figure 12. Experiment 4: Machines, Stations and Resources Utilization

The utilization of the machines and resources were really similar to experiment 3, showing just little variations. This shows that the warm-up period was able to bring a reliable data, and the replications, made it even closer to the real industry, but it did not affect the results after the warm-up a lot.

3.5. Experiment 5

Now, the product mix was changed: blank parts are 75% Type1 and 25% Type2. The results are shown by Tab. 5:

Table 5 – Experiment 5 results

Name	Total Exits	Average Time In System (Min)
Type I	82.27	55.51
Type II covered	27.82	49.47
Rejected Type I	3.00	44.19
Rejected Type II	1.45	42.47

As expected there was a huge rise in the type 1 throughput rate (43.4%) and Type2 manufactured parts was reduced by half. The machines and stations utilization and resources utilization are shown in Fig. 13. Also, Fig. 14 enables the comparison between experiments 4 and 5, highlight the resources utilization improvements.

Figure 13. Experiment 5: Machines, Stations and Resources Utilization
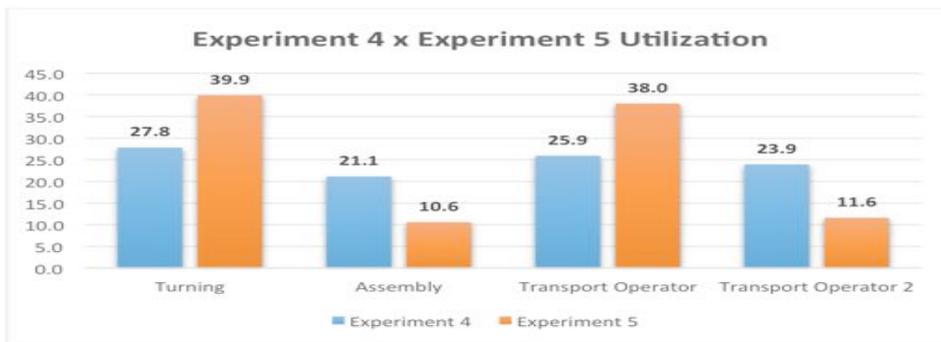

Figure 14. Experiment 5: Detailed bar chart comparison

As exposed by Fig. 16, the turning machine (exclusive for Type1) should have raised its utilization (raised 43.5%), given that Type1 production had a huge increase. Also the assembly (exclusive for Type2) should present a reduction of its utilization (decreased by half), given that Type2 parts production was cut by half.

And because that each path network and transport operator is operated by a different resource, their utilization can also be compared. The same trend can be observed. The transport operator for Type1 parts had a 46.7% increase, while the Type2 parts transport operator utilization was cut by half.

3.6. Experiment 6

Utilizing the experiment 4 model, where blank parts were still 50% of each type, this experiment aims to find the system configuration that would double its manufacturing production if blank parts entering the system were twice the value set before. To double the number of blank parts in the system, its arrival time was changed from an exponential distribution of 20 minutes to 10 minutes, and the results are summarized by Tab. 6.

Table 6. Experiment 6 results

Name	Total Exits	Average Time In System (Min)
Type I	116.64	84.16
Type II covered	110.64	78.39
Rejected Type I	5.82	80.35
Rejected Type II	6.27	72.89

As a surprise, the system configuration was already able to provide an almost exactly doubled result, with no other change besides the arrival time rate of blank parts. The machines and stations utilization and resources utilization are shown in Fig. 17.

Analyzing experiment 4 machines and resources utilization charts, it is concluded that the previous system was being sub utilized. Every machine had its utilization growth (doubled or raised more than twice compared to experiment 4), but none of them achieved overused status while the system was capable to guarantee the new throughput rate.

Figure 17. Experiment 6: Machines, Stations and Resources Utilization

4. CONCLUSION

The computer-based tool importance shows up as the complexity of the analysis of an industry plant increases. Simulation models take into account interdependence and the randomness, that actually happen in real life, to characterize the behavior of the model, what is not true for spreadsheets, that use only averages to represent important data such as resource availability and operating times. The variability present in real plants is not well represented by the other types of analysis. It provides reliable future prediction and much more important and detailed data to help decide whether an investment would be reasonably profitable or not. The user can quickly identify bottlenecks generated by system interdependencies, allowing implementing and improvements analysis.

Visual animation clarifies studied issues to achieve better results. It can also be a really crucial tool inside a company for presentation and as part of training. It is much easier to expose ideas using the facility layout animation, encouraging teamwork and process understanding. Deeper analysis could also prevent the company from unnecessary new hires, and the facility rearrangement and organization leads to productivity. In the other side of the coin, time and cost of a simulation model are taken into account. For certain situations, creating a complex model would represent too much effort for something that could be easily analyzed by a single spreadsheet. And even tougher than creating a model and simulating it, the most important thing is the ability to interpret the results. Due to high variability and system instability, sometimes it can be a hard task and involve a lot of time and work.

The present assignment was able to accomplish the purposed objectives, highlighting bottlenecks and machines and operators overuse, as a huge number of possibilities to improve the model productivity. After each experiment. the task became more challenging, in order to achieve maximum efficiency in a real plant that was facing many productivity problems at the beginning.

5. REFERENCES

Ekere, N. N. and Hannam, R.G. 1989. An Evaluation of Approaches to Modeling and Simulhating Manufacturing Systems. International Journal of Production Research, 27 (4): 599-611.

ProModel <https://www.promodel.com/pdf/Justifying%20Simulation.pdf>, accessed on 20/03/2014 at 19:35.

Verma, R.; Gupta, A. and Singh K. R.G. 2009. A Critical Evaluation and Comparison of Four Manufacturing Simulation Softwares. Kathmandu University Journal of Science, Engineering and Technology, Vol 5, pp 104-120.

Benson, D., 1997. Simulation Modeling and Optimization Using ProModel. Proceedings Winter Simulation Conference

Uzsoy, R.; Lee, C. Y.; Vega, L. A. M., 1992.A Review Of Production Planning And Scheduling Models In The Semiconductor Industry Part I: System Characteristics, Performance Evaluation And Production Planning. IIE Transactions Vol. 24 , Iss. 4.

Averill, M.; Law. A. M.; 2008. Simulation Modeling Theory and Ideal Construction Models. Proceedings of the 40th Conference on Winter Simulation.

Benita, M. B., 1998. Supply chain design and analysis: Models and methods. Int. J. Production Economics 55 (281—294). Department of Mechanical, Industrial, and Nuclear Engineering, University of Cincinnati.

6. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.