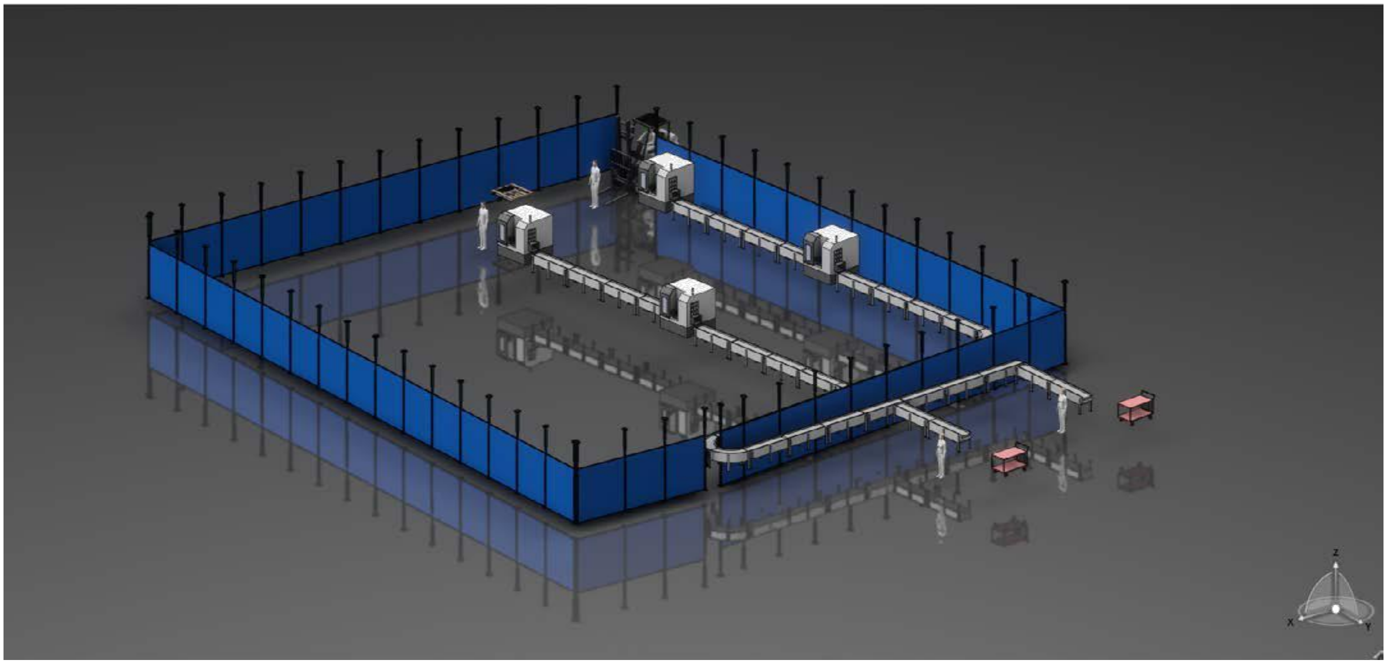
CHALMERS
UNIVERSITY OF TECHNOLOGY



Productivity improvement of an industrial production system using 3D discrete event simulation

Master's thesis in Production and product development

Kalogiannidis Georgios

Alexander Glacian

Department of Industrial and Material Science

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2017

ACKNOWLEDGEMENTS:

We would like to express our gratitude to our supervisor Henrik Kihlman. His constant efforts to review and keep track of the progress of the work, made him capable of providing us with constructive feedback which led to the very practical results that came up out of the project.

Also, we are exceptionally grateful to our examiner Johan Stahre, who kept track of the development of the text of the report and in the same time provided essential help for the completion of the literature part of the thesis project.

Furthermore, we would like to thank Prodtex Ltd, which gave us access to the software tool of Delmia 3D Experience, as well as access to their databases for using the necessary libraries with the 3D objects we needed.

Finally and more importantly, we would like to express our infinite gratitude and love to our families, who supported us all the way through this thesis project, in every possible way.

Productivity improvement of an industrial production system using 3D discrete event simulation

Using 3D simulation to improve Industrial Production Systems

Georgios Kalogiannidis / Glacian Alexander

Department of Industrial and Material Science

Chalmers University of Technology

ABSTRACT:

During the last decades the industrial world has made an irreversible turn towards the digital technologies in order to find optimal, robust, and trustworthy and in the same time more secure solutions for building modern production systems with respect to national and global regulation and with respect to social and environmental sustainability principles too. The new and modern software tools that were provided to the industry, nowadays have much more extensive capabilities more than just building a robust production system. They are capable of presenting accurate statistics about the performance of the system and provides multiple graphic tools to analyze it with the help of many different KPIs. These capabilities are used to make improvements of the current systems with respect to multiple different aspects. An important task that the modern simulation software tools are capable of achieving, is to provide solutions for the improvement of productivity of the existing production systems. So, in this current thesis project, a new simulation software tool developed by Dassault Systems, namely DELMIA 3D Experience is going to be used for implementing a 3D representation and simulation of a production system and then use the software tool to make a productivity improvement suggestions for the system.

Keywords: 3D Simulation, Productivity, Industrial Production Sustems.

TABLE OF CONTENTS

GLOSSARY

MPPEN = Master Program in Production Engineering.
FMS = Flexible Manufacturing System.
MIP = Mixed Integer Programming.
ACO = Ant Colony Optimization.
NSTLBO = Non Dominated Teaching Learning Based Optimization.
PMS = Production Monitoring System.
OEE = Overall Equipment Efficiency.
DES = Discrete Event Simulation.
OTE = Overall Throughput Effectiveness.
OLE = Overall Line Effectiveness.
TQM = Total Quality Management.
TEEP = Total Effective Equipment Productivity.
DBR = Drum Buffer Rope.
TOC = Theory Of Constraints.
MTBF = Main Time Before Failure.
TPS = Toyota Production System.
SMED = Single-Minute Exchange of Die.
IEN = Industrial Engineering Role in Delmia 3D Experience.
MID = Manufactured Item Definition App in Delmia 3D Experience.
PLD = Plan Layout Design App in Delmia 3D Experience.
ED = Equipment Design App in Delmia 3D Experience.
FFS = Factory Flow Simulation.
DMU = Digital Mockup Unit.
PP = Process Planning App in Delmia 3D Experience.
MTTF = Mean Time To Failure.
MTTR = Mean Time To Repair.

1. INTRODUCTION

1.1 BACKGROUND

In the modern economy of 21st century, the evolution of the digital manufacturing solutions along with evolution of the computational capabilities of the CPUs of modern computers, has created a new demand for modern methods for improving the productivity of the shop floor of industrial plants. These new solutions are expected to be more efficient, accurate and in the same time being capable of reducing the risk of the investment in production equipment as much as possible. Therefore the trend of using computer simulation tools for building digital models of real industrial production systems and test their performance offline, tend to become a dominant method for increasing the productivity of an industrial plant.

1.2 PROBLEM FORMULATION

The 3D discrete event simulation is a brand new method which has been recently introduced in the industrial sector, and this thesis project intends to dive as deep as possible in the capabilities of this new tool and investigate what a user can achieve by using this new tool.
As one of the major purposes of using the 3D Discrete Event Simulation is to improve the productivity of production systems, it is important to investigate what are the alternative methods that are proposed by the academia for the task of improvement of production systems. After an extensive research in the scientific literature databases, it was found that there is a lack of a scientific work, which summarizes all the different methods that are being proposed by academia (or have already been applied to industry).
Also since the purpose of every scientific work is to identify the repercussion of the productivity improvement to the society, it is very interesting to investigate how the productivity improvements in industrial plants affects the social sustainability and vice versa.

1.3 PURPOSE

The purpose of this thesis is to investigate and test the capabilities of the 3D simulation software namely Delmia 3D Experience. In the current work it is made an effort to derive with a methodology of how to use the different functionalities of the software for the purpose of building a digital 3D mock up of an industrial production system based on the requirements of the tool (assigning, assembly, inserting prerequisites etc). Moreover, it is part of the current work to apply the new and improved capabilities of the software to increase the productivity of an industrial production system.

Additionally, it was decided that it is important to incorporate a theoretical part in this thesis work in which an overview of the different methods for productivity improvement proposed from academia are going to be summarized. This research work can be used as a benchmark, for future thesis project that wish to investigate the possibility of productivity improvements, by using an alternative method apart from discrete event simulation. Moreover, as an extension it was decided to investigated the connection between the increase of productivity improvement of a production system and the welfare of the entire society in general. This connection in the current thesis work is defined by investigating the outcomes of increment of industrial output in social sustainability. Since the term of social sustainability is way too broad, in the following paragraph is clearly defined which aspects of social sustainability are being investigating in the current thesis.

1.4 OBJECTIVES

The main objectives of the thesis project is to present how a user can exploit the capabilities of the 3D discrete simulation for improving the efficiency of industrial plants, based on the guidelines provided by the relevant scientific literature. Furthermore, it is made an effort to come up with a methodology of how to use the 3D simulation for building a digital system.

1.5 DELIMITATIONS

As it is quite obvious, the scientific literature research part of this thesis, concerning the increase of productivity of industrial systems, is extremely broad, therefore it is necessary to set several limitations to the type of production systems, which are investigated for productivity improvements. Consequently, in the current thesis work, they were investigated only production systems with constant flow. Types of such production systems are continuous line flows (such as oil production or milk production, or ingot cast production) or industrial assembly lines, such as those that are currently used in the automotive and heavy truck industry. A common characteristic of all those production systems, is that they can easily be automated. Types of production systems which concern craft production or fixed position production systems (such as aircraft part production) will not be reviewed in the current thesis work.

As for the aspect of social sustainability, the literature search will be focused primarily on findings concerning the employment aspects and the beneficial effects of the increase of productivity to the entire economy of the society.

2. LITERATURE STUDY

For the purpose of investigating all the different methods which are either proposed by academia or have already been applied successfully in the real industrial world, a thorough investigation of the scientific literature was mandatory to be executed. In order to execute the literature study, several scientific literature search engines were used.

2.1 METHODOLOGY

As it was mentioned in the previous paragraph, the relevant research papers that were found and used for the completion of the research part of the thesis work, were tracked and collected by implementing an extensive search to the engines of Science Direct, Scopus, Elsevier and Google Scholar, as well as to the Chalmers Library's official website.
By using each search engine separately, a number of different combination of keywords was used for the identification of the proper literature from the vast availability of research work that exists on the web.
The keyword list that was used for searching proposed methods for productivity improvements in industry is the following:

- "Productivity" AND "Increase" AND "Methods" AND "Production Systems"
- "Production Systems" AND "Productivity" AND "Methods"
- "Productivity Increase" AND "Industry"
- "Production Systems" AND "Productivity Improvement"
- "Industry" AND "Simulation" AND "Productivity Improvement"
- "Production Systems" AND "Simulation" AND "Productivity Improvement"

As for the research literature search results for the influence of increase of productivity in social sustainability, were identified by using the keyword list:

- "Productivity Increase" AND "Employment" AND "Industry"
- "Productivity Increase" AND "Employment Prospects" AND "Industry"
- "Production Increase" AND "Industrial Sector" AND "Jobs"
- "Productivity Increase" AND "Employment Satisfaction" AND "Industry"
- "Simulation" AND "Prospects of Employment"

For the proper and efficient management of the scientific literature, the software tool of Mendeley was used for building the database with the relevant papers that were found and also to implement the citations of the research work for the final report of the thesis.

2.2 LITERATURE STUDY FOR PRODUCTIVITY IMPROVEMENT METHODS

In the published academic articles, there was found a number of different suggestions for the increase of productivity for the industrial sector.

In a research work it is proposed as a valid method for increasing the productivity of a certain industrial plant in Serbia, the collection of production data [1]. More specifically, the monitoring of the production times of parts was implemented and the data from the relevant times were registered in a database. The purpose of collection of these data was to find whether several changes in the design of production system or in the methods and the technological equipment, will have a positive influence to the reduction of the cycle times of the products, or the family products that the industrial plant was producing. The ultimate goal was to determine which structures of the production system were the most influential inside the system, therefore the changes of the system will be focused in these area exclusively. The changes that were made inside the system were concerning the modification of the working methods (more specifically the set up times) and the change of the number of operations for the manufacturing process. The final results after two years of data sampling from the industrial plant showed that the total production or manufacturing time was reduced considerably by applying these changes.

A second proposal from academia is a simulation methodology for improving the FMS of a steel production facility [2]. More specifically, the transportation system of the materials inside the system was found deficient and was in need of optimization in order to increase the overall availability of the system. The transportation of raw materials inside the system was executed by using trailers. In the simulation model, they were tested different alternative paths in order to minimize the waiting time of materials along with the number of pieces in the queue. In the current paper it was highlighted that the use of simulation has become available due to the evolution and the availability of strong processors with very large RAM capacity which are able to support the execution of several number of different alternatives for the design of the system. Before the execution of a simulation method, it is important several conditions to be met. These conditions are the followings:

1. Understanding of the system.
2. Determine the level of the simulation.
3. Gather the necessary data for the execution of the simulation.
4. Construction of the base model.
5. Appropriate method for analyzing the results.

In the conclusion of the current research work, it was clearly mentioned that the use of the simulation method as a tool for improvement of production systems, has been proved beneficial for providing very efficient solutions in a relatively small amount of time.

An additional proposal is the use of MIP as a solution to the problem of appearance of unwanted and unpredictable deviations in the production delivery times due to changes of several variables inside the production process [3]. These deviations create instability inside the system which are defined as nervousness and they are coming from several minor changes inside the production system. In the current research the scope was to determine whether or not the minimization of these instabilities have a certain influence to the cost of the production and to the productivity of the system in overall. Moreover, it was feasible to examine whether or not the decision making was able to become more flexible. The outcome of the research was that the minimization of the nervousness of the system did not have a major effect in the system cost and the decision making can become even more flexible in terms of scheduling of the production.

Furthermore, an alternative suggestion is the use of discrete event simulation software tools to investigate the effects of lean production concepts [4]. The goal of the research work was to investigate which were the benefits in terms of productivity increase inside the production system. Moreover, with the discrete event simulation tool in hand, it was manageable to investigate the effects of automation insertion and expose which were the benefits in the overall productivity inside the system.

Moreover, in another research paper the authors were investigating the effects of a two sided parallel type assembly line in the overall productivity [5]. For determining the exact number of workstations, a certain evolutionary algorithm was used, known as Ant Colony Optimization algorithm. The objective of the current research application was double. It was made an effort to minimize the number of work stations and in the same time tried to minimize the cycle time of each station respectively. With this effort, a managerial solution which was capable of increasing the productivity and in the same time decreased the cost of the line construction was tried to be produced. This optimal trade-off was strived to be achieved by using the ACO.

By diving even deeper to the literature, it was found another research work which provided a theoretical concept of how can the productivity be improved through the change of the standardized method of work [6]. The proposal of the current research was to use the concepts of the ideal state which needs to be set as goal to every production line and then by having a full understanding of the current state, the working standard is modified accordingly so it would lead to the ideal state. As a model, the authors presented the use of the concepts by the Toyota company. Unfortunately, the authors mentioned in the conclusion that there is still a large gap between the practical applications and the theoretical conceptual model that it was proposed.

Another suggestion was, the use of an algorithm namely NSTLBO to solve a multi-objective optimization scheduling problem for three different machining processes as an alternative for productivity increase, product quality and reduction of production cost [7]. The driving force for the industrial environment to apply this method was primarily the strict governmental regulations which have forced the industrial world to reduce the environmental footprint and specifically the energy consumption of the plants. The objective of the current research work was to investigate if this solution leads to maximum utilization of the production equipment that it is available. One major problem that it was exposed in the paper was the difficulty to determine which production parameters are the most important for translating them into objectives for the optimization problem. In the conclusion it was mentioned that the current optimization algorithm has notable better performance in the optimization of the parameters in comparison to those algorithms that they were used and also tested in the past. Examples of the other algorithms that were tested are GA, NSGA-II, PSO and MOTLBO.

Additionally, another research paper proposed a method for improving the productivity of a system the detection of the bottlenecks - productivity constraints with the use of an algorithm [8]. The current algorithm was developed in order to detect the bottlenecks inside a real production system. The scope of this research is to provide a tool in order to facilitate the decision making in maintenance and production decisions based on real time data. In the conclusion section of the research work it was mentioned that the main advantage of the current method in comparison with the simulation solutions, was that it was not required any special skills for building a digital simulation model in order to see what will happen and make an efficient decision making for maintenance and production issues.

Another approach derived from the literature to increase the productivity of manufacturing systems was through production monitoring systems according to Shiva et al. (2017). In the article the authors have used a problem-solving time production monitoring system (PMS) i.e. real time PMS at a pen manufacturing company to control the consumption of raw materials for the purpose of avoiding overconsumption phenomena inside the system. More precisely, it was mentioned that the consumption of the material inside the system was dependent from five particular parameters. These parameters were the processing temperature of the ink, the injection speed, the injection pressure, the injection time and finally the cooling time. It is declared inside the current scientific work that the proper setting of the parameters can lead to considerable reduction of overconsumption and thus improving also the productivity of the overall system. One application of the before mentioned method of PMS was capable of reducing the cost of consumption by 58% which in turn led to productivity improvement for the entire process. In conclusion, the article states that the application of the PMS in a production system, will positively contribute to the enhancement of the overall productivity [9].

2.3 LITERATURE STUDY FOR EFFECTS IN SOCIAL SUSTAINABILITY

An integral part of the literature study was the investigation of the effects of increasing productivity (or efficiency) in industry to the economy of the entire society. After an extensive and thorough investigation of the available scientific literature, it was found a research paper which tried to provide an answer to the important research question of whether or not the increase of employment in industry is positively correlated with the increase in the levels of productivity [10]. This question is of paramount importance for the scope of this thesis and for the society in general, as it exposes a major reason why the society needs to constantly try to increase the levels of productivity by using all the means that they are available. After an extensive research to the data acquired from multiple sectors of the economy including agricultural, mining, industrial and fishing sector, for the period of 1880 until 1930, it was found that there is a positive correlation in the increase of employment during these years. It is important also to mention that at that time, several other professions that are complementary to the industrial production such as transportation, clerical occupation and professional accounting services had increased their level of employment by six or even seven times more comparing with the initial one they had. Also the public sector had been grown due to the increased levels of productivity in industry. Also from the increased production output and efficiency of the equipment in agriculture, it was observed the trend of shifting manpower from agriculture to production shop floor where the manpower was doubled.
Another recent published research work provides results which support the previous study's results. More precisely, the scope of this research study was to present whether or not the results of incorporation of environmental and social sustainability aspects in the corporate strategy, improves the financial performance of the organization both in short and in long term [11]. In the conclusion of the research work it is stated that the improvement of social sustainability of the working environment brings beneficial results to the increase of productivity inside the organization.
Moreover, in the literature it was found an additional research work from the field of ergonomics. In this work, a number of ergonomic improvements have been applied to industrial production systems and they have been proved to bring a notable and in the same time positive impact in the increase of productivity of the systems in which they were applied to. In the conclusion, it is exposed a positive affiliation of the productivity improvement through the ergonomic improvements inside those systems with the economic survival and expansion of the organization in overall [12].
Quite similar results were found to an article which was dedicated to the results of changes in the industrial world. More specifically, the article uses as example the changes of BMW company. The car manufacturer applied several major ergonomic improvements to the working environment of the shop floor by investing a considerable amount of money to the respective changes. This investment finally paid back in terms of improvement in productivity and lower rate of absenteeism. It is very interesting to highlight that the relatively high average age of the employees combined with the poor engineering design of the tasks have led to extremely heavy physical load of the employees which probably was the reason of the high levels of absenteeism. The current project was implemented by the contribution of team leaders supported by their respective managers and technical experts and managed to achieve considerable results in

productivity improvement. In total number 70 changes were able to bring improvement of productivity by 7% [13].

By stretching even further the literature search in the current field, an academic article was found. This article contains a research work in which an investigation reveals a correlation between the productivity changes in the industrial sector and its macro - economic effects. The research that was made in the article focuses on the changes in employment rate regarding with changes in productivity growth in the industrial sector for a certain period of time. The quantitative results which were needed for the completion of the research work were collected by using a sampling from industrial plants located in several developing countries. The results have indicated that the industrial production performance is directly related with the overall welfare of the society. More specifically, productivity improvements in industrial plants have led to beneficial results to the economy in overall and vice versa [14].

2.4 DISCUSSION OF THE RESULTS FROM LITERATURE STUDY

2.4.1 OVERVIEW OF THE METHODS FOR PRODUCTIVITY IMPROVEMENTS

As it is clear from the results of the literature study, the dominant methodologies that are proposed by the academia for improving the productivity of industrial shop floors are the use of algorithmic methodologies along with simulation methods. Less popular appears to be the use of analytical mathematical methods derived from operational research, probably due to the fact that these methods are extremely complicated and computational demanding. Moreover, the theoretical concepts of improving the productivity of the plant by applying lean theoretical concepts, doesn’t seem to have much success to the industrial world yet.

2.4.2 HOW DISCRETE EVENT SIMULATION HAS BEEN APPLIED

The simulation methodologies that were found in the literature were proved as extremely useful and efficient tools for detecting the most important parameters that need to be changed inside the production shop floor for increasing the productivity of the plant. This was made possible due to the capability of the software tool to run alternative scenarios with different values of several parameters and compute easily and effectively the results in productivity. The most important barrier for the use of simulation methods in practice is to find individuals with specialized knowledge of how the simulation methods are being applied. Also it is important for these individuals to possess the necessary skills for applying this knowledge for building the digital models of the systems and extract the information which are used to monitor the changes inside the system.

2.4.3 INCREASE OF PRODUCTIVITY AND SOCIAL SUSTAINABILITY

As it is also mentioned in the results of the literature study, the increase of productivity of the industrial plants is of paramount importance for the economy of a nation in overall. Apart from the obvious gains of organizations who owns the production equipment and facilities, the society in overall benefits from the increase of productivity as it has proved to have a positive correlation with the increase of employment.

This fact explains also the current trend of the industry to use digital simulation solutions as a mean to increase the productivity in the production facilities. Also, it clarifies why big industrial organizations investigate large amounts of money to obtain licenses for these software tools and there is a demand for people with knowledge and skills to use these new tools.

3. PRODUCTION SYSTEMS

3.1 PRODUCTION SYSTEM CONCEPT

At this point, since the major part of the work of the thesis is related to the creation and development of production systems, a definition of the concept of production system would be extremely useful from the reader's point of view.

According to the definition of a production system, given by (Bellgran & Safsten, 2010) a production system can be defined as "a process of creating goods and/or services through a combination of material, work, and capital. Production can be anything from production of consumer goods, service production in a consultancy company, music or energy production"[12]. Inside the current literature it is also mentioned that the production system in most of the times is considered the same as the manufacturing system.

Another definition from the scientific literature for the production systems defines the production system as "a process that transforms resources into useful products or services".

More definitions which were found in the same literature for production system was considered as a transformation system where input (raw materials) are converted to output (product) through processes [12]. An example of transforming raw material to end products is machining and assembly processes in a production. Bellgran et al. (2010) mentions in the book that output from particular system may also be input to another system within the same production system. Production systems can be classified into systems perspective in order to realize the complexity for development of production systems. A production system typically consists of personnel, equipment and method where these components in combinations forms processes and resources to create product and services [12]. The three-different perspective of a production system given by the same literature are:

- Functional Perspective: System is transformation of processes, where input is converted to output.
- Structural Perspective: System where relation between different elements are defined
- Hierarchical Perspective: System is considered to be sub system of larger system [12].

The structure of production system has passed through several evolution stages throughout the years. The first form of a production system was constituted by only materials which were passing through several process (mostly crafts) in order to take the final form of a consumer product. The second form of production systems was the organization of resources, personnel and machines in a certain manner to carry out efficient production of consumer goods [12].

With the first industrial revolution which dates to 18th century it first began the organization of production in factories. During this period the production systems were consisted by simple machines that were using steam/water as the main power source to run the machines for the production process. The notable inventions that have been made towards the development of production system to the current form, were the steam engines, the use of machine tools and the development of equipment's in textile industry [12].

By the second industrial revolutions which took place during the period of 1900 – 1950 the consumer behavior changed radically. In order to satisfy the new customer needs, industries developed production systems in the form of being able to produce consumer goods in large quantities. Electricity was the main source which used to operate the production's system equipment in manufacturing plants. A characteristic example of such a production system was none other than Henry Ford's car manufacturer. This system's characteristics were the efficiency and accuracy of production in terms of electric power generation [12].

The 3rd industrial revolution during which dated from 1950 – 2000 was characterized by the integration of electronic systems to the function of production system. This shift can be explained due to a change in consumer behavior where the demand has transformed in mass customization of products. The form of a modern production system of this era is the one which utilizes computer management system for the maintenance of production system.

During the last decades, production systems are continuing to be developed and change form. This change in form is primarily based in technological trends. The most notable example is Germany's effort to increase the manufacturing capacity with the advanced development of production system which is defined as the 4th industrial revolution or alternatively is widely known as "Industrie 4.0". Internet of things (IoT) has made significant impact in the development of production system [15].

3.2 PRODUCTIVITY OF A PRODUCTION SYSTEM

At this point it is very meaningful to set a definition as it is existed in the literature of what exactly the productivity is. In the research work of (Bellgran & Safsten, 2010), the productivity is defined as "an absolute measure, stating the relation between what is achieved in production and the efforts required in achieving this" [12]. In the same literature a mathematical formula that defines productivity is the following:

Productivity = (Output) /(Input)[12].

In many cases inside the literature the definition of productivity tends to coincide with the efficiency of a production system.

As it is mentioned inside the scientific literature (Bellgran & Safsten, 2010), the productivity improvement of a production system, is the second major step for the development of a production system[12].

A more thorough definition of productivity was also found in scientific literature of production systems. In this research publication the author proposes an alternative definition of productivity other than as output over input. The companies measuring productivity will define the output and input based on the type of application that must be measured. In the article the author suggests that at all levels productivity can be improved through better methods, increased performance and utilization, which he expresses in the form of equation below:

$$\text{Productivity} = \text{Method (M)} \times \text{Performance (P)} \times \text{Utilization (U)}$$

The term method refers to the intended productivity rate, the term of performance refers to the speed through which operations can be carried out in relation to ideal cycle time and the term of utilization refers to the actual time spent in relation to the total planned time. By having accurately defined these three factors, one can measure the current productivity derived from the existing operations and by improving the same factors an increased productivity can be reached for operations in production system. [16]

Another more simplified definition of productivity that has found in the literature is the following. Productivity is usually defined as output over input[13].

At national level, the productivity can be defined as the gross domestic product per working hour[13].

As an extension to this part, it was considered useful to proceed a little further to the metrics of productivity of a production system. A research work in the current field highlights the need for creating advanced productivity metrics that are able to measure various parameters in production, and to help companies improve and optimize the productivity in order to stay competitive in the market. In this research a dynamic performance of a manufacturing system was analyzed using simulation analysis. At this point it is stated that simulation analysis is the most reliable method which is able to produce accurate and reliable results for such a study. The authors of the article have developed effective metrics that helps to calculate and analyze, the equipment and system's productivity for complex manufacturing system. These developed metrics are: the overall equipment effectiveness (OEE) and the overall throughput effectiveness (OTE) for meticulous quantitative measure of the equipment and system's productivity. These measurements have application in complex manufacturing systems. Those KPIs were integrated to a simulation software called ProModel as built-in functions in the software to facilitate the study of equipment and system productivity for analyzing the productivity improvement opportunities. The same software tool was also utilized for the analysis of the real-world case study where simulation analysis was carried out. Concluding, these KPIs are capable of providing an effective tool to industrial organizations for improving their manufacturing effectiveness in the respective production activities. Significantly this research study has given out virtual approach to represent the factory level productivity and look for productivity improvement opportunities [17].

Another tool for the measurement of the productivity was found in the research literature. The method of overall line effectiveness (OLE) in a continuous production process manufacturing system will help companies find potential productivity improvement areas. Nachiappan et al. (2005) developed a framework to model a manufacturing systems where 'n' number machines in series are present. A research study was carried out and it was based on a computer simulation analysis to evaluate the OLE for a production line manufacturing systems. A method like the one that was used can help companies to detect the bottleneck machines and to identify as accurate as possible the potential productivity improvement areas. The combined use of OLE with computer simulation analysis is more useful for a world class manufacturing companies to study their production processes. With these tools they identify inefficiencies in their processes and in the same time they obtain useful insights of their processes improvement capabilities and therefore to increase the productivity in their respective manufacturing system [18].

3.3 PROPOSED METHODS FOR INCREASING PRODUCTIVITY

In the existing literature for the production systems, was identified many strategies for increasing the productivity of an industrial production system.

One proposed method is the elimination of the disturbances inside the system as a valid strategy for improving the productivity of a plant [19]. As disturbances inside the system can be perceived any unpredictable interruption during the execution of the production process. One major disturbance is the failure of the production equipment such as failure of CNC machines, Robotic equipment etc.

Another proposed strategy for the improvement of efficiency of the industrial units is the elimination of the defects of the products from the design phase [19]. As defects, it is reasonable to define any property of the product that it is not align with the product specifications as they were defined by the customer demand.

As a feasible proposal from academic research work for the increase of productivity is also the increase of automation level inside the production units [20] [21]. With this way, it was recorded a productivity increase by ten times, in comparison with the method which utilizes manual work. Furthermore, an additional strategy for the improvement of productivity is the detection of the bottleneck part of the production flow [20]. The reduction of the scrap rate and the reduction of the rejection rate from the customer are several other strategies that can be used to increase considerably the productivity rate of an industrial plant [20].

Moreover, from another aspect, the productivity inside a production plant is also affected greatly by the psychosocial environment of the shop floor, as they have a large impact on the motivation and engagement of the employee with his/her task [20]. Therefore, another proposed strategy for the increase of productivity is the improvement of the ergonomics [20] of the workplace and the balancing of the workload between the operators in the workplace. Additionally, the improvement of the working standard itself, for utilizing better the capacity of the technological equipment that it is available [20].

From the psychological perspective of the employees, a research proposes as a strategy for the increase of productivity, the increase of motivation of the employees with awards [22].

Alternatively, another strategical proposal for the increase of productivity from the scientific literature focuses on the existing capacity of the industrial plants and more precisely on the utilization of the existing machinery and staff[16]. In the same research study the focus is shifted to the indoor of the industrial shop floor of an organization and more precisely to the staff and machinery. It is stated that a tremendous increase to the levels of productivity are feasible to be achieved only by improving the skill of the existing staff in order to follow the standard of work more accurately. The previous can be translated as faster pace of work of the labour and accurate conformity to the standard.

From the same study, the second area of focus for the productivity improvement strategy is the utilization of the machinery [23]. By increasing the capacity of the machinery, meaning to make the equipment capable of handling larger parts of the production, the productivity can also be raised dramatically. This second option has one major drawback and this is the fact, the production process is made vulnerable to disturbances.

In the literature it was also found as a viable strategy for the increase of productivity, the composition of a team of production engineers inside the production system, whose responsibilities will be improvements in the system and securing the production flow as well [24].

The implementation of lean strategies like 5S inside the industrial manufacturing cells, has been found as another strategy for the improvement of productivity of production systems [25].

More suggestions from the scientific literature for applied strategies of productivity improvement in manufacturing systems are the detection of shifting bottleneck machine [26].

Several theoretical strategies proposed by academia for productivity improvement have been identified in the literature such as TQM [27]. More information about this kind of strategies, are available to the reader from the respective literature.

By diving even deeper in the scientific literature it was found an article that presents several practical strategies for increasing the capacity and thus improving the productivity of the production systems of industrial organizations. The authors have developed 25 practical strategies for industrial companies to apply and improve the capacity of the industrial systems with the end goal of increasing the overall productivity of the system. The set of strategies were developed by using well established methodologies such as Theory of Constraints, Lean Manufacturing and Total Predictive Maintenance. When these strategies are applied they lead to increase of capacity and to productivity improvements as well, by condition the constraints are existed within the factory's boundaries. In the article it is also suggested that these particular strategies can be utilized by industrial companies which produce manufacturing products independently of the order in which they are produced. Those strategies can be used also independently or in combination. Briefly the 25 strategies that are proposed by the current literature are presented below [28]:

1. Strategy 1: Eliminate all periods of time lost in the bottleneck. This means that an hour lost on bottleneck is an hour lost in the whole system and being bottleneck should operate 24 hours a day.

2. Strategy 2: Improved processing times per unit. Perform continuous improvement actions in the working methods and the optimum use of the potential of the equipment.

3. Strategy 3: Deliver improvements in the power system engineer. The goal should be to synchronize the timing of food resources with the speed of processing of the resource itself, seeking continuous system flow.

4. Strategy 4: Improve the quality control system. The initiatives should ensure that there is no defective part is processed in the bottleneck, which can be obtained by adopting a 100% inspection immediately before the bottleneck.

5. Strategy 5: Making the contracting out or outsourcing of work from the bottleneck. In other words, implies subcontract or outsource part of production that was previously done by its bottleneck resource in order to purchase additional capacity.

6. Strategy 6: Buy additional capacity. You can obtain the following ways: buying new machine, hiring new workers to the bottleneck, using overtime for workers in the bottleneck or adding shifts to production.

7. Strategy 7: Relocation of the operations previously performed in the neck for other non-bottleneck machines that are operating with a surplus of capacity. The goal at this point is to divide the operation of the bottleneck in smaller sub-operations and redistribute them.

8. Strategy 8: Make improvements in the maintenance of machine bottleneck and critical system resources. The objective of improving the maintenance of machine bottleneck is to increase the coefficient of utilization (TEEP) and the availability of the critical resources in manufacturing.

9. Strategy 9: Conduct analysis and layout changes. At this point, it is suggested to apply the concepts of lean thinking mobile layout and simulate scenarios proposed using the technique of computer simulation to aid in decision making, apart from the results of the simulation.

10. Strategy 10: Implement the algorithm Drum-Buffer-Rope (DBR) system. The use of the DBR aims to operate on the factory floor to the five steps of process improvement of TOC, synchronizes the system from the bottleneck and protects the capacity of the bottleneck using the buffer immediately prior to the drum.

11. Strategy 11: Raise the TEEP of the resource bottleneck. His discussion is central to the capacity calculation because it determines the theoretical and not practical capacity of the equipment.

12. Strategy 12: Increase the availability (A) of the resource bottleneck. This strategy can be implemented as follows: MTBF raising and reducing the MTTR of the equipment.

13. Strategy 13: Oriented approach to product development. The concept here is to develop new products or components that would not overload of the factory but instead, aiming to exploit the gaps in the capacity of non-bottleneck resources.

14. Strategy 14: Modify existing products or components in order to reduce the processing time on bottleneck resource factory. Joint action between the area of Process Engineering and Product Engineering Company seeking to modify the concept of products focusing on the bottleneck; tend to generate good which alter.

15. Strategy 15: Conduct analysis and improvement of the bottleneck applying the subsystems and techniques of TPS. These suggestions, which are extremely popular in the scientific literature of production systems denote: Zero Defects, Standard Operation, SMED (Single-Minute Exchange of Die), Flow Synchronization and Continuous Improvement are good improvement strategies. The goal is to extend the TOC, the benefits that Lean approaches provide.

16. Strategy 16: Conduct analysis of restriction from seven losses in the TPS. The combination of the elimination of seven losses in the operation can generate earnings capacity in the bottleneck. It is recommended that this analysis is made by a multidisciplinary group involving the operators of the processes analyzed.

17. Strategy 17: Conduct analysis of improvement in the ergonomic point of view of the operation. Time and motion study, derived from scientific management are recommended.

18. Strategy 18: Make improvements in the production system in overall. In this case indicates the application of the principles of synchronous manufacturing, based on the five focusing steps of TOC.

19. Strategy 19: Evaluate the application of first principle of TOC that says to not focus in the balancing of the capacities instead change focus to the synchronization of the flow.

20. Strategy 20: Evaluate the application of second principle TOC that says, the Value of the marginal time in the bottleneck resource is equal to the rate of profit of the products processed for the bottleneck. That is, one hour earns in the bottleneck represents one hour earns all in the system.

21. Strategy 21: Apply the third principle TOC that says the marginal value of time in a resource bottleneck is not negligible. So, the focus of improvement actions must be directed towards the restrictions of the system.

22. Strategy 22: To consider the fourth principle of TOC which states that the level of use of a resource is not controlled by the restriction of the system. In principle, the idea is that the decision on the use of non-bottleneck must be made by analyzing the resource bottleneck.

23. Strategy 23: Apply the fifth principle of TOC which states that the resources must be used and not only activated. The use concept mentions the activation of resources that contribute positively to the performance of the company that is generating profits for the Company.

24. Strategy 24: Apply the sixth principle of TPS which states that the transferences of products inside the system do not need to be, and many times must not be, equal to the total processes. The fewer transferences of the products in the manufacturing system present considerable advantages in production process such as: it helps to keep the synchronization of the production, it reduces the total amount of time of crossing of the products and also it helps to identify more quickly the defects of product quality or intermediate parts.

25. Strategy 25: Apply the seventh principle that says the process batch should be variable. The process batch should be variable along with the route of the manufacturing activities over time. It is reasonable to assume that the number of processes can vary throughout the route of manufacturing activities due to the impact of the statistical fluctuations of the system and the different capacities of the resources.

At this point, the reader can observe easily that these methods have been more or less been proposed by other scientific literature concerning the field of productivity improvements.

4. DISCRETE EVENT SIMULATION OF INDUSTRIAL SYSTEM

The current software is a powerful 3D simulation tool but at the same time it is also a completely new software tool which was released by Delmia in 2015. As the tool was not provided in the curriculum of the MPPEN, the students was mandatory to invest a considerable amount of time in training with the new tool, so they are able to build the necessary competences to execute the appropriate tasks, that were proposed by the supervisor. The main sources of training were documentation in the form of powerpoint slides and online documentation material that was provided by Dassault from the company's official website. Additionally, a seminar offered by Dassault in Paris was attended by the participants, so more training material was gathered for the Plant Simulation App that existed inside the software's application toolkit and it was going to be used for the completion of the thesis project. For the purpose of completing this thesis project this is the most important App and in the same time the one with the least existing documentation for the users.

4.1 DELIMITATIONS OF THE DES APPLICATION

The current simulation model that is primarily used as a benchmark for the implementation of the improvement actions for the increase of productivity inside the system, includes several limitations.

During the execution of the simulation of the digital system, it is assumed that the product is being produced by fulfilling the specification of the customer and it does not present any quality issues.

4.2 3D EXPERIENCE APPS

The 3D Experience software functions by using a number of different Apps which are referred to different aspects of the production systems designing. In the current project were used primarily the Apps from the IEN role. More precisely, were used the Apps of Plant Layout Design and the Factory Flow Simulation. Additionally, the Apps of Manufacturing Item Definition and Process Planning from the Process Planner role along with the Equipment Design App which was part of the Shop Floor Equipment Engineer role were used for the completion of the task.

4.2.1 MANUFACTURED ITEM DEFINITION APP

The current App of the 3D Experience software is used for the definition of the product that is going to be produced inside the designed production system. The App is designed for the definition of sophisticated products which in many cases are complex assemblies constituted by other subassemblies.

The definition of each product inside the App is executed by using the option of "Scope Definition". The Manufactured Item Definition (MID), uses a structure of product flows, in the form of predecessor nodes, in order to sort the source of each product component in the design.

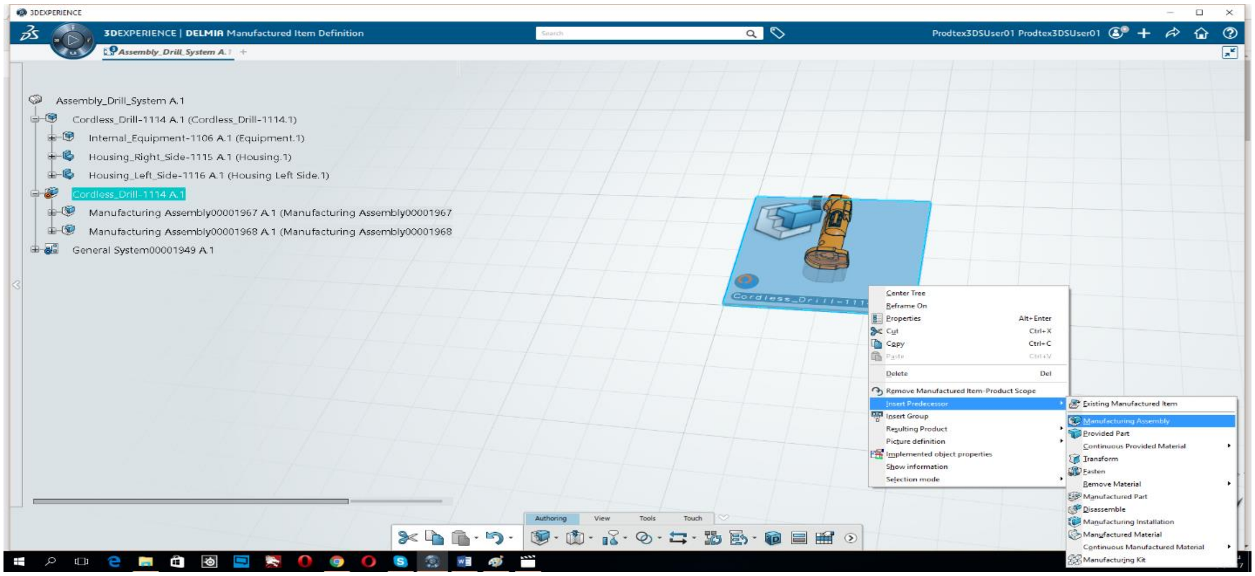


Figure 1: Definition of the type of Predecessor in MID App.

Then by using the Assembly Management functionality, the software makes the user capable of determining which parts of the subassembly are going to be included in the current Predecessor. The same procedure is being followed until the product is being defined to its basic components.

4.2.2 PROCESS PLANNING APP

The Process Planning (PP) App, helps the user to create a manufacturing plan for the production of a complex product. This product is usually the result of a sophisticated assembly. This PP app, is created to design the stages, in which the final product is going to be produced.

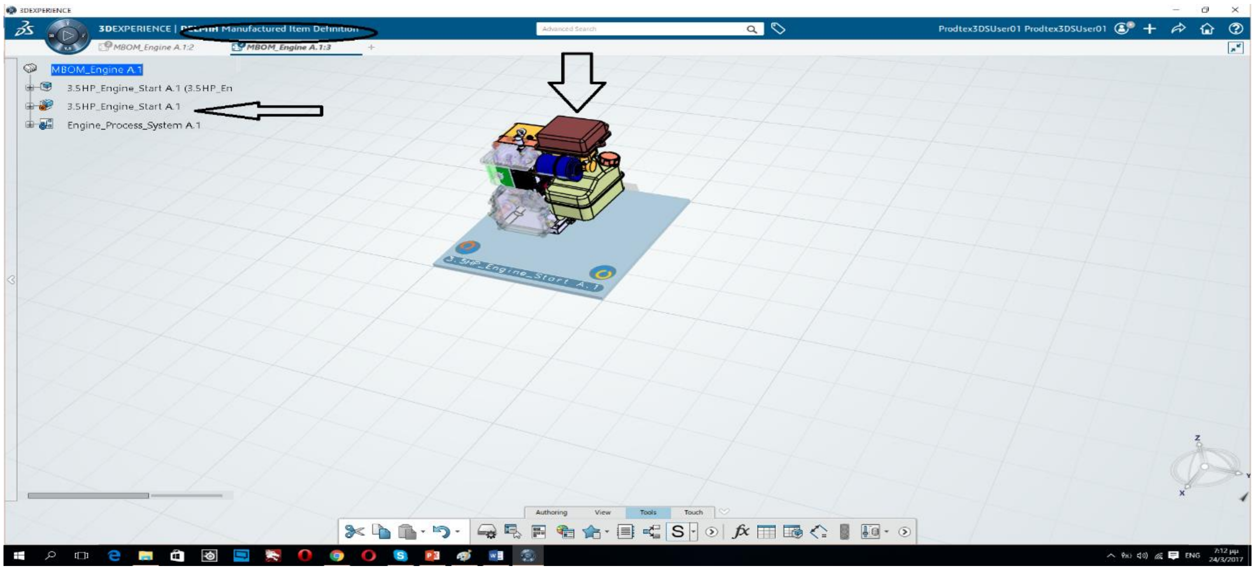


Figure 2 Definition of a complex product in PP

In the PP, it is possible to manage the work sequence that are needed for the product to be created in the form of a Gantt Chart.

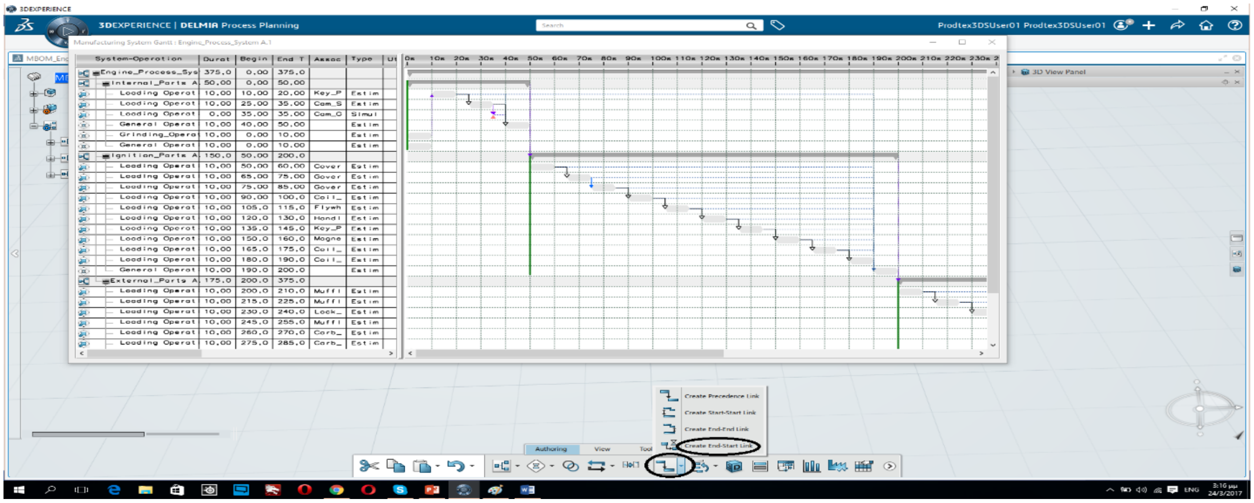


Figure 3 Managing Work Sequence in Gannt Chart in PP

Moreover, the user has the capability of balancing the workload inside the system.

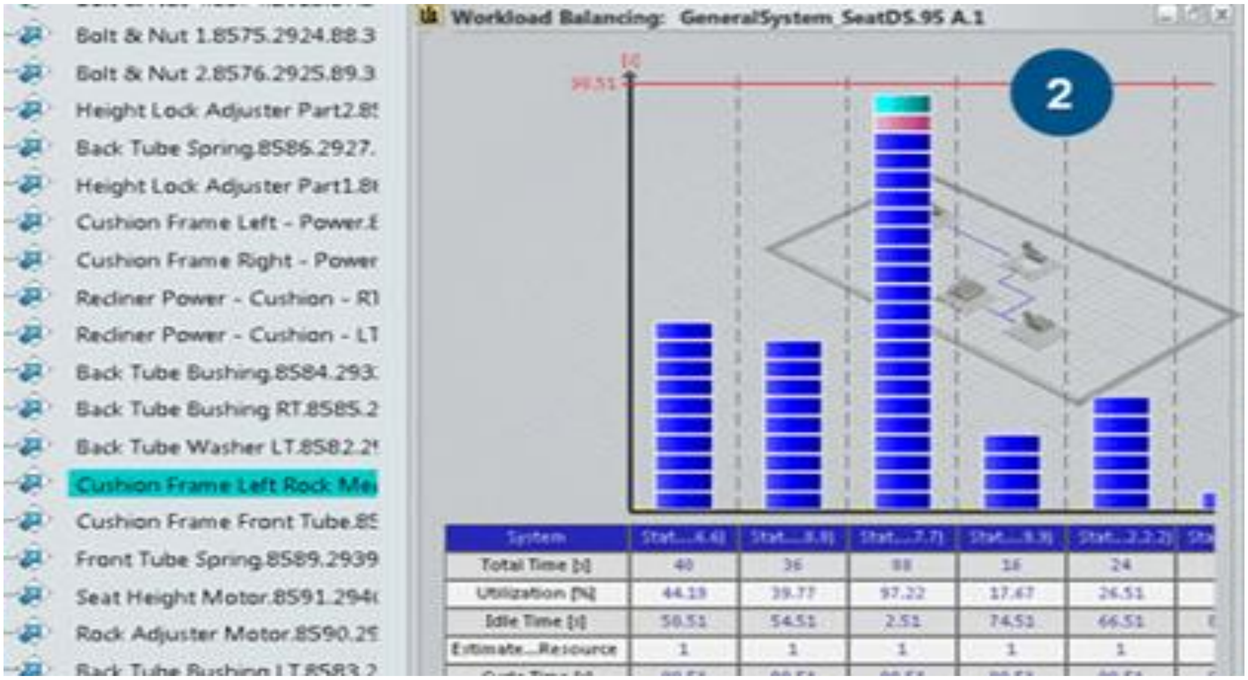


Figure 4 Work balancing in PP

4.2.3 PLANT LAYOUT DESIGN APP

The Plant Layout Design (PLD) App, provides the user with the capability of building a precise and accurate 3D representation of the actual production system, which is going to be used in the next step of the simulation process. The PLD provides a large database in the form of a catalog which exists online and it is equipped with 3D parts of different types of conveyors, CNC machines, Industrial Robots, Product Parts, Fences etc. The user is capable of selecting any of these 3D items to build the digital representation of the production facility inside the software.

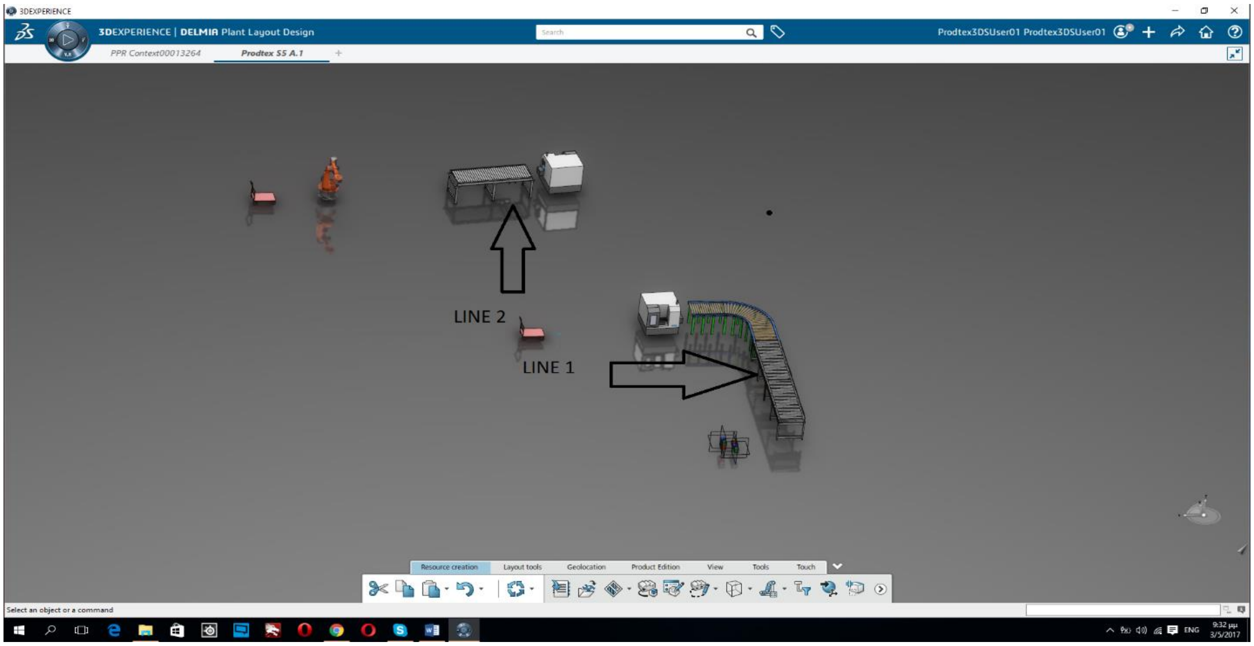


Figure 5: Production System in Plant Layout Design

The insertion of each type of equipment inside the model is being done, by accessing the correct catalog or by searching the desired item by using the search function.

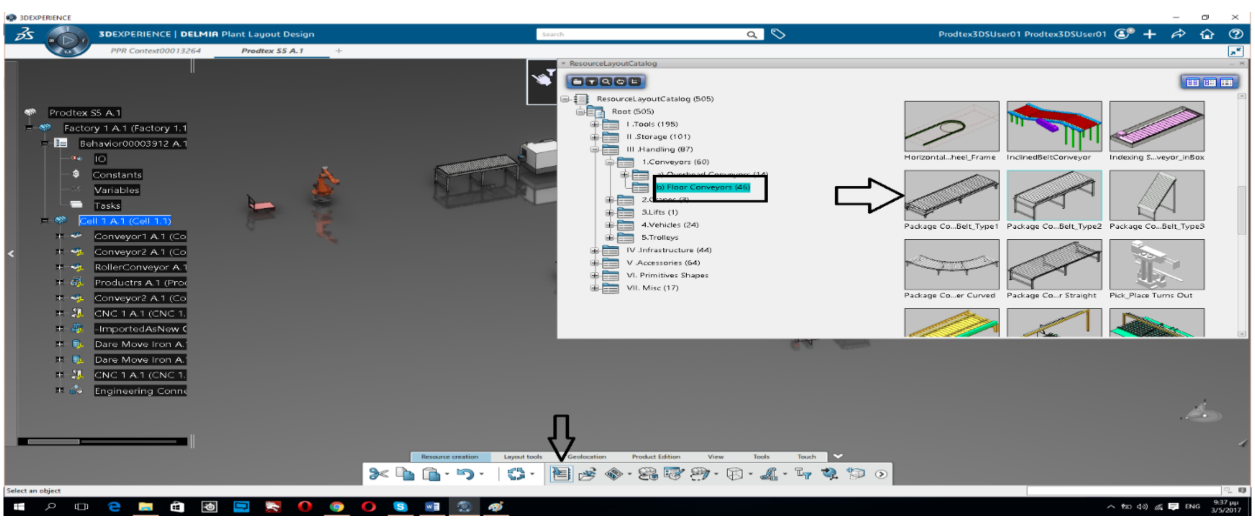


Figure 6: Selection of 3D Item for the System

The plan layout design App, also provides the user with the capability of inserting a certain 2D layout in the form of a drawing, and use this as a base for placing fences, machines, conveyors and buffers in the desirable locations inside the layout.

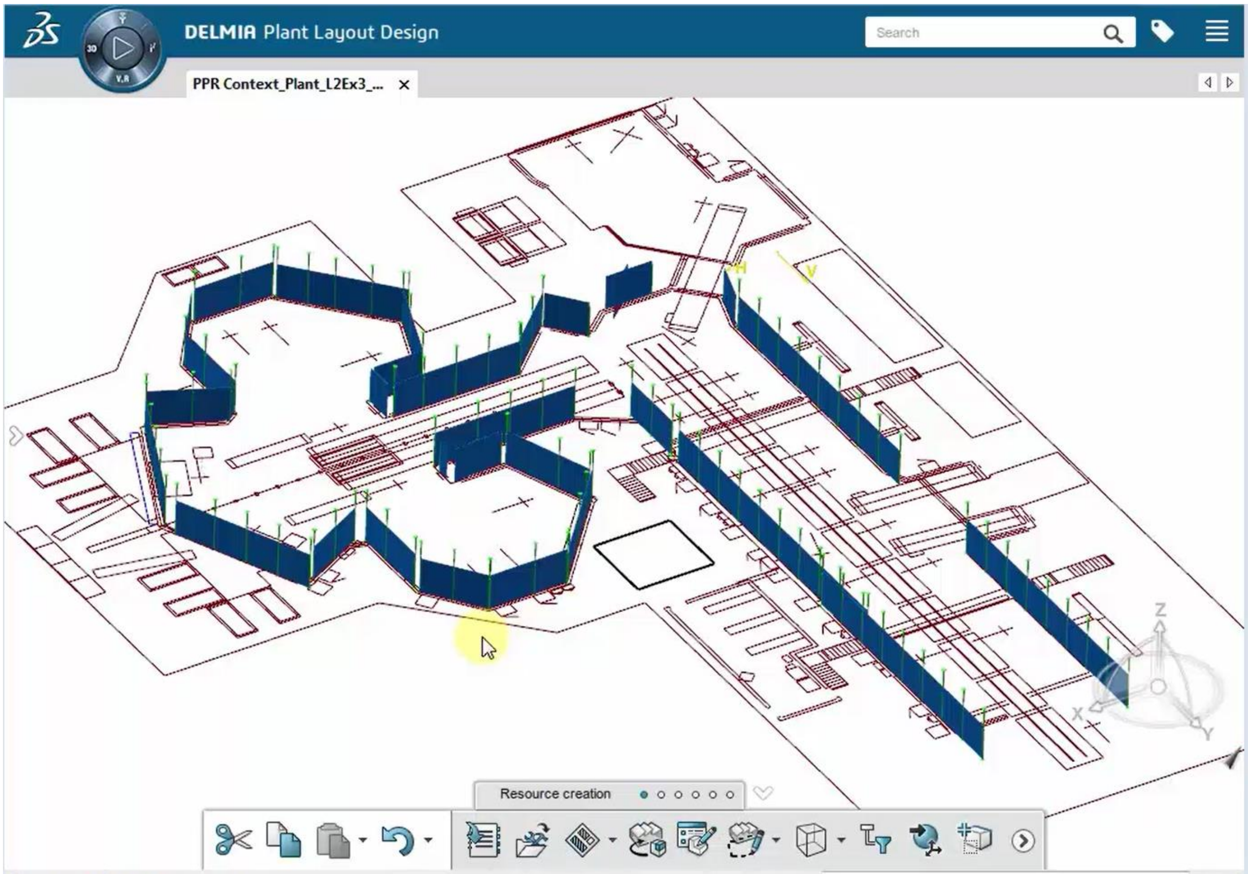


Figure 7: Fence Construction For Production System

4.2.4 EQUIPMENT DESIGN APP

The Equipment Design (ED) App is utilized in the software for defining the route of the products inside the system. It is an integral tool which is required for the definition of the flow direction of the products on the conveyors. Another important functionality of this App is that you can assign the form of different sections in the case the user want to insert a more complex type of conveyor in the system. Example of this type of conveyor is the curved conveyor type.

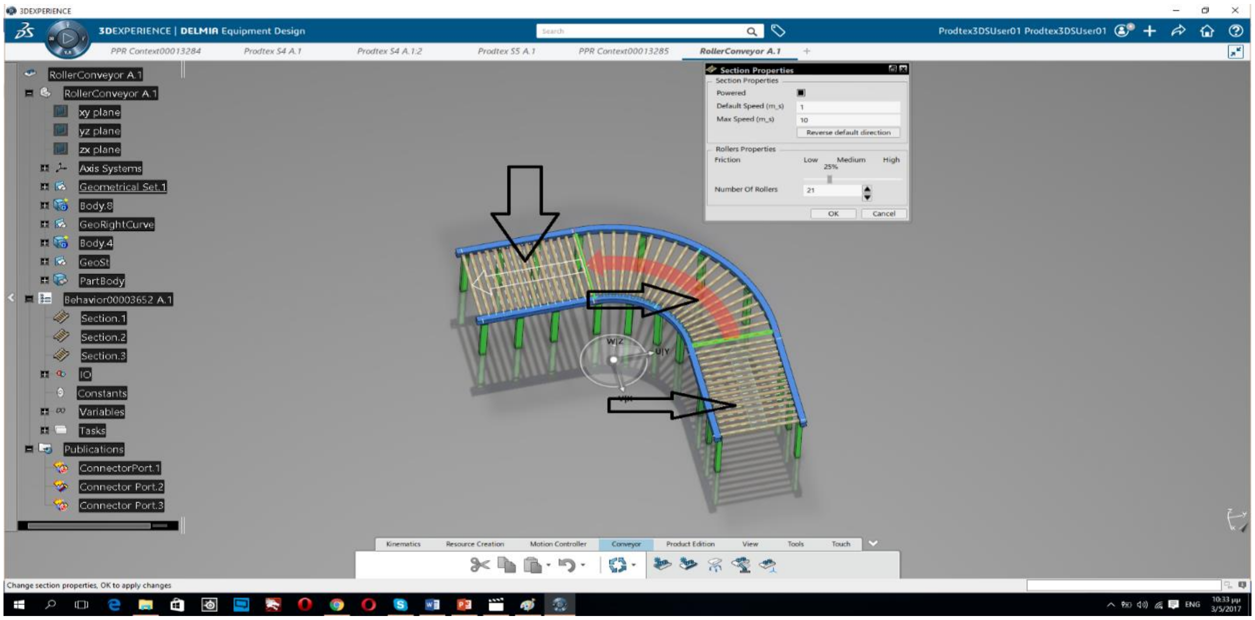


Figure 8: Definition of Different Sections of Curved Conveyor in ED App

Additionally, in this certain App, the definition of the multiple connector ports of the conveyors is executed. These ports are used later in the PLD App for quick connection of the conveyor with the rest of the network.

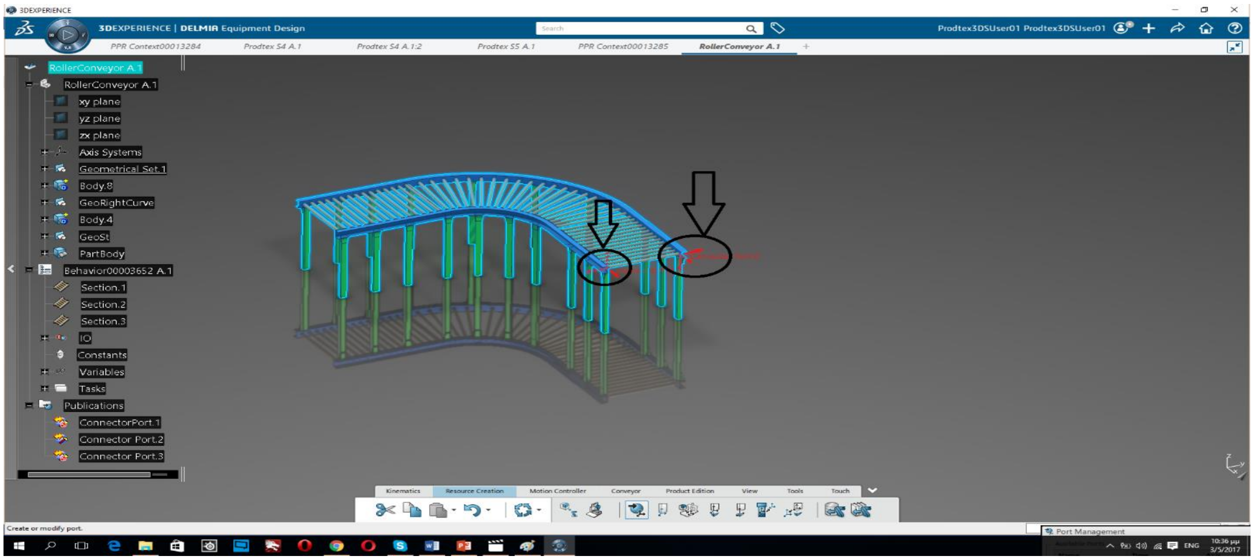


Figure 9: Connector Port Definition

4.2.5 FACTORY FLOW SIMULATION APP

In the Factory Flow Simulation (FFS) App, the user is able to perform a 3D simulation of the Digital Mock Up (DMU) of the production system that was created in the PLD. For the complete simulation to be fully initiated a sequence of tasks is mandatory to be performed. The sequence of these tasks includes the insertion of the type of the product that is going to be produced inside the system.

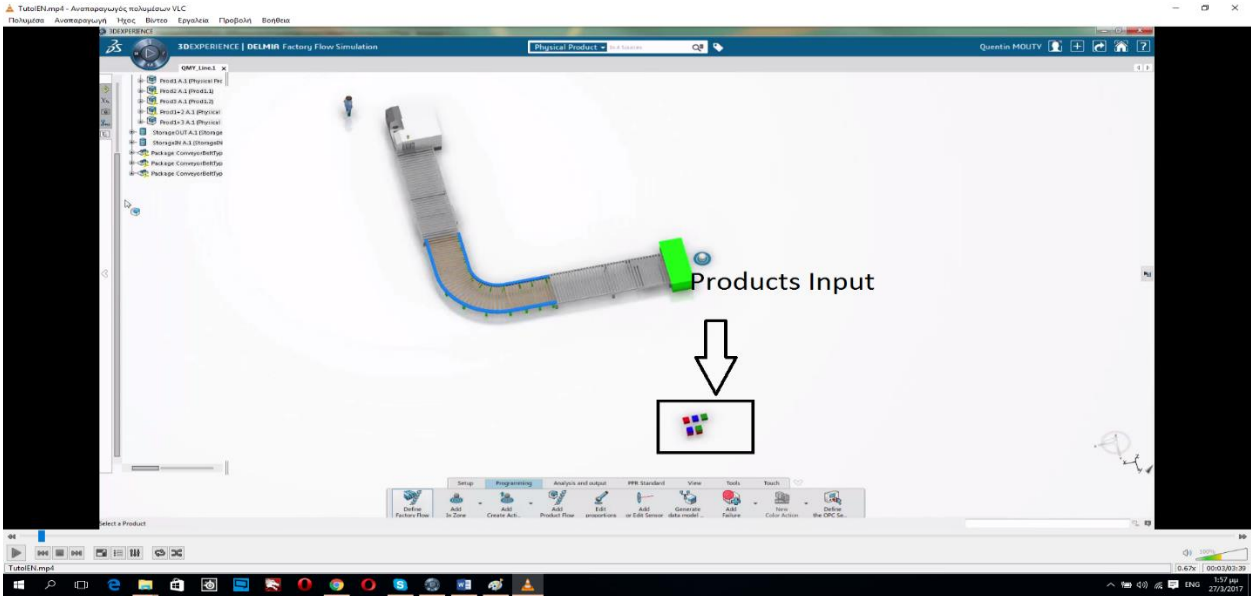


Figure 10 Product input in FFS

Then the direction of the product flow in the conveyors must be also defined before the execution of the simulation as it was mentioned in the previous paragraph of ED App.

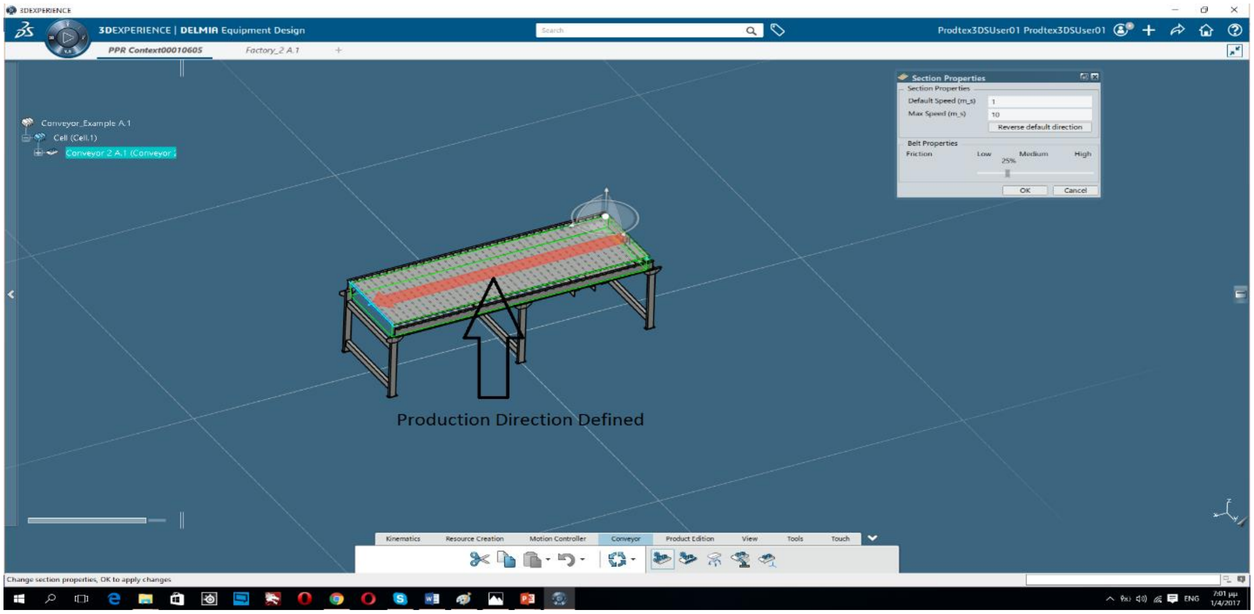


Figure 11 Definition of the Flow Direction in the conveyors.

After, the insertion of the workers in the layout follows and the definition of the proper positions of grabbing and placing the products between the buffers and machines.

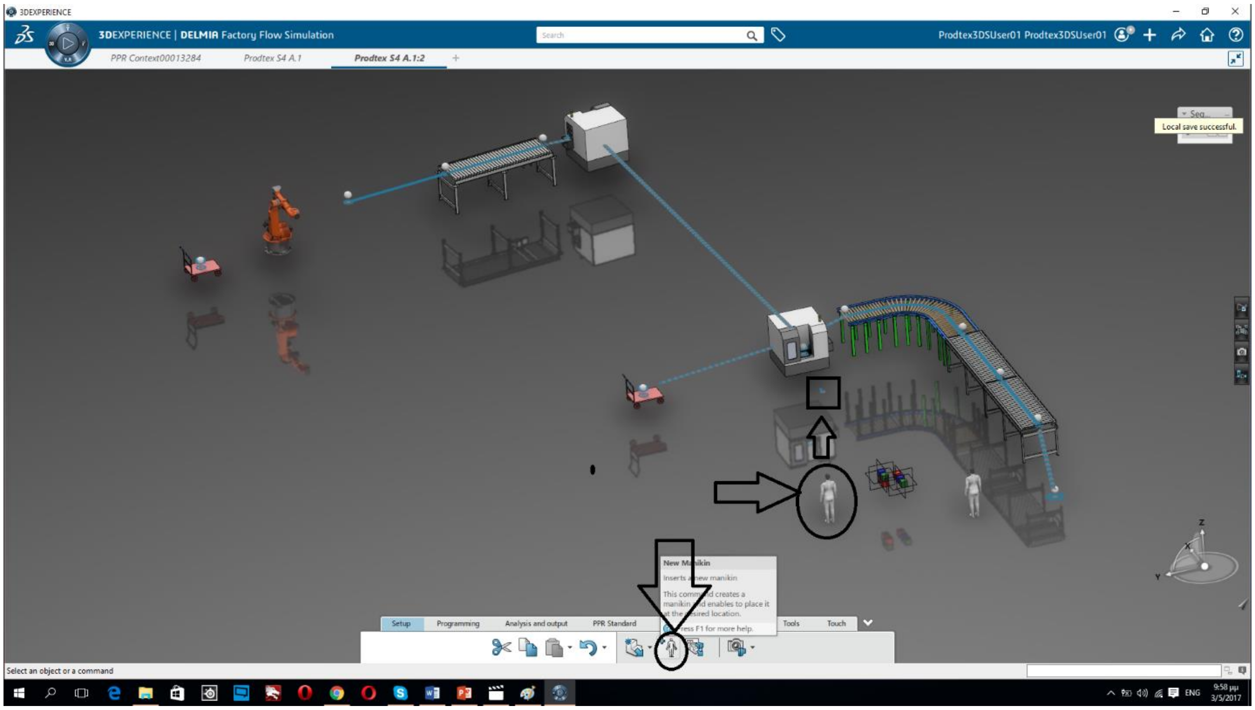


Figure 12: Insert Worker and Assign Product Pick Up Position

Then it is mandatory to define the production flow inside the system along with the relevant product transformations that are executed inside the system.

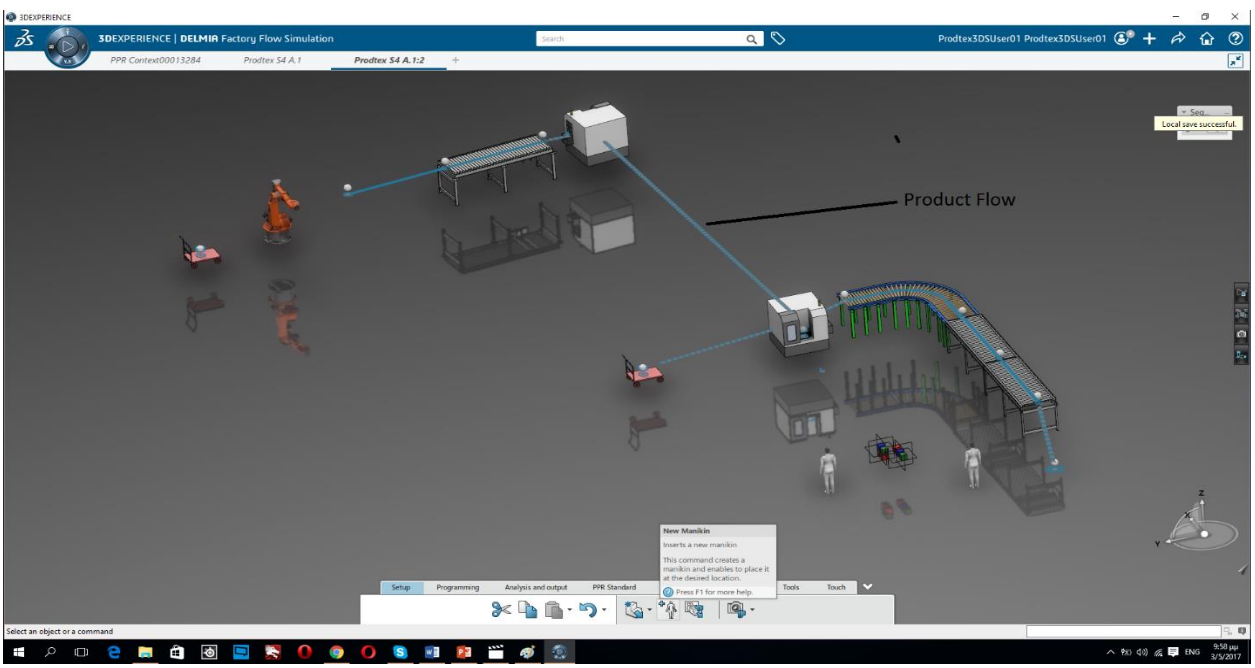


Figure 13: Defined Product Flow

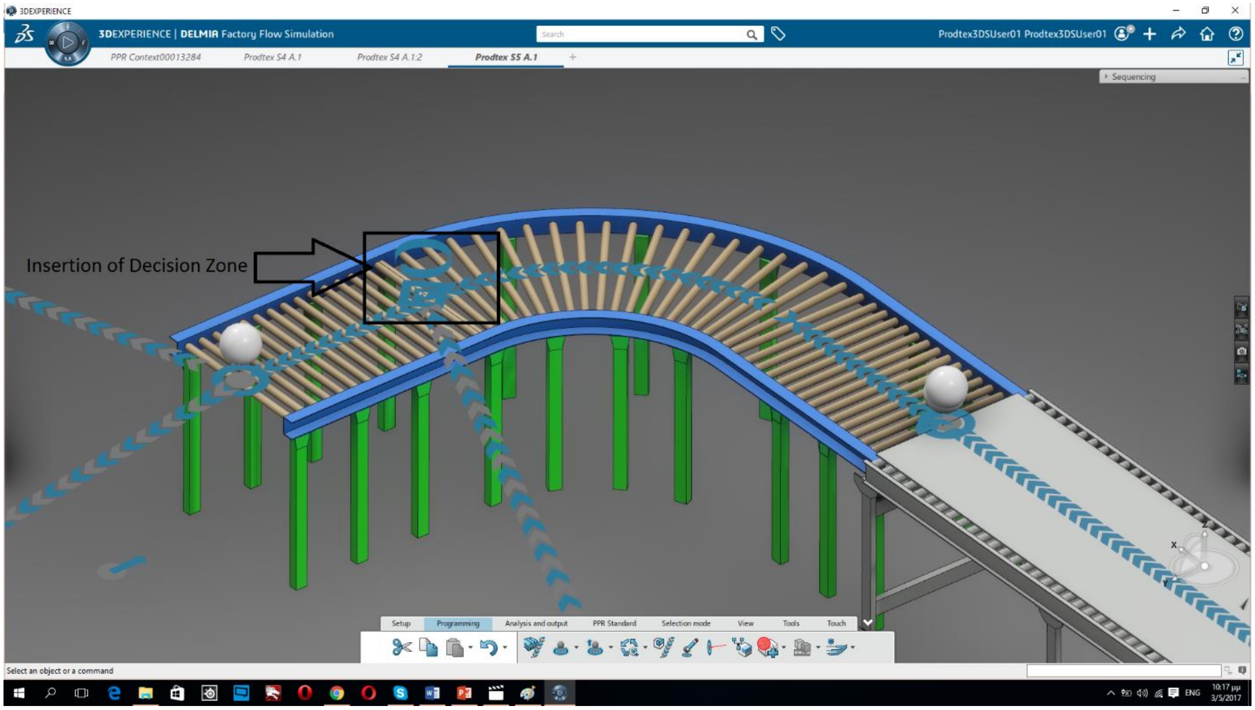


Figure 14: Insertion of Decision Zone

Afterwards, the simulation of the 3D production flow can be executed in three different forms. A discrete event simulation, a dynamic simulation type 1 and dynamic simulation type 2. These three different simulation types are explained in the master thesis project of Bernerus and Karlsson (Bernerus & Karlsson, 2016) [29].

4.2.6 METHODOLOGY OF BUILDING THE SIMULATION SYSTEM TO THE SOFTWARE

As it has become quite clear, how the software uses different Apps to build the system, it is not very clear at this point how these Apps are combined together, in order to finally build the desired model of the production system.

The first stage in the process of building the system, is to use the MID App. As it have already been explained in detail in the previous paragraph, the current App produces a map of the final shape of the product and all the sub parts which are going to be used for the creation of the current product.

Next in sequence comes the use of PP App. The difference of this App with the MID, is that it is used to create a classification of the process that are going to be executed in order to produce the product.

Once the plan of how the production is going to be structured is completed, then it is time to start building the 3D digital mock up with the PLD App. The 3D objects of the equipment, storages and employees, are inserted from respective libraries, labelled as “Catalogs”. The current App is used combined with the ED App. The late App, is used for the definition of several parts inside the system such as the conveyors.

Finally, for the execution of the simulation model and for the purpose of obtaining the results that are requested by the experiments, the FFS App is used. In the current App, the details about the functionality of the system are defined. Example of such details are failure and repair rates of the machines as well as task assignments to the employees inside the system.

The entire sequence of the respective Apps that are used inside the software is presented in the following flow diagram:

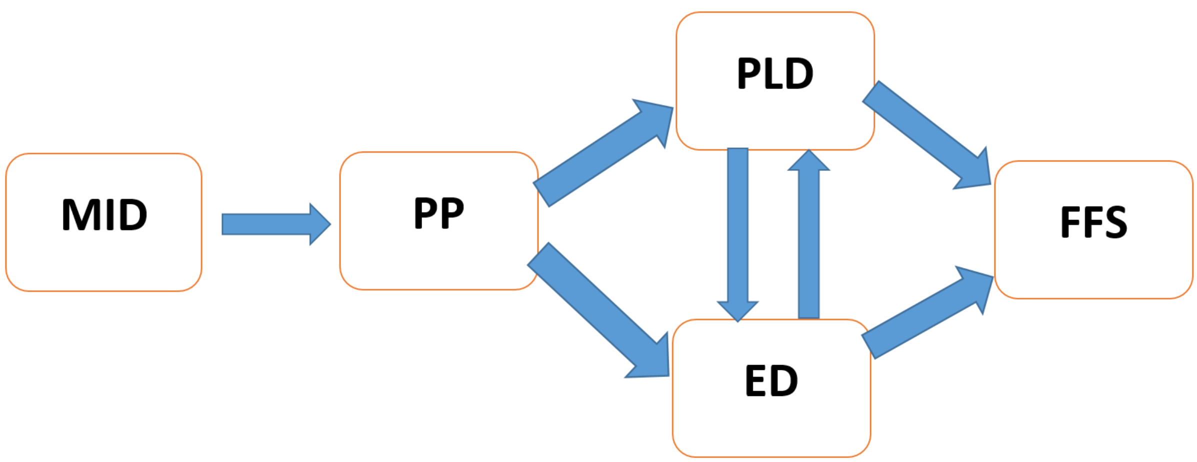


Figure 15: Flow Diagram of the Apps of the 3D Experience.

4.3 3D SIMULATION TASK

As it was mentioned earlier the practical part of this thesis project, is the demonstration of the capabilities of the current software, by applying it on an industrial production system. As a suitable industrial system, it was selected a coffee factory. This current industrial system, uses its equipment, to fill cups with coffee and then package the cups that were produced in the previous stage in a larger plastic pack of five pieces in total. The current system, was built from scratch inside the DELMIA software by using the available 3D Equipment that exist in the online server's database. For the 3D representation of the system, the user tried to attach the 3D objects together, as accurately as possible so the final simulation will be closer to the real system.

4.3.1 THE INDUSTRIAL PRODUCTION SYSTEM

The current coffee factory system, produces two different types of coffee products. These two different types refers to coffee products of different flavors. The two different products are denoted inside the system as products (cups or packages) with different colors (orange for the first type and purple for the second type). The same color coding is being applied to the plastic packaging as also for distinguishing the two separate products. Therefore, the implemented production system, is a parallel system with two independent lines. Inside the system there are two main machines which they are used for the filling and the packaging of the coffee cups. In every line, there are two machines in sequence. The first machine executes the task of filling the cups and the second executes the task of making the plastic packaging of the five cups. The transportation of the products inside the production system is being implemented by using a conveyor line. The two parallel lines are connected together to a single line, where the product is being transferred in two different terminals. In the end of each terminal, one employee takes the packaging and put it on a table.

The products are moving inside the system with the use of conveyor lines. There is only one type of conveyor inside the system and every product of the system is being moved with the same conveyor type.

In the current system, 4 employees are currently working and the task requirement is to transfer the products from each terminal to a final buffer. The main task of two of the employees is to transfer the product from the pallet to each respective machine and the other is to repair the failures whenever those occur in the machines of the system. One employee is responsible for repairing the failures of one line and the other is responsible for repairing the failures from the parallel line. The rest two employees, have been placed in the end of each respective terminal and they are responsible for transferring the end products to the sink buffers (in the form of two carriers). The gender of the employees has no effect in the execution's efficiency of the task. For the purpose of the execution of the simulation task, 4 human manikins belonging to the 75 percentile were selected. Those manikin models are aligned with the anthropometric characteristic of the average European citizen.

The 3D product types are existed inside the system upon a pallet. One employee takes the product from the respective pallet and then place it inside the respective machine (as it was mentioned earlier in the previous paragraph).

The flow of the production goes as follows. In the first parallel line of the system, the coffee cup with the orange color, is being inserted inside the first machine. In the first machine, the task of filling the cup is being simulated by assigning a certain cycle time in the specification of the equipment. Then the filled cup is being transferred to the second machine, where it waits for 4 more cups to be produced from the previous machine, (until 5 in total are collected to the second machine). It is important to mention that the coffee cups are transported from one machine to the other with the help of the conveyor lines. With the same method as before, the packs of 5 cups are being produced and they are forwarded to the terminal for each respective coffee product. The exact same process is followed by, also in the second parallel line of the system. In the next part of the conveyor system, the packs of each coffee type are mixed together and they are separated later when they reach their respective terminal.

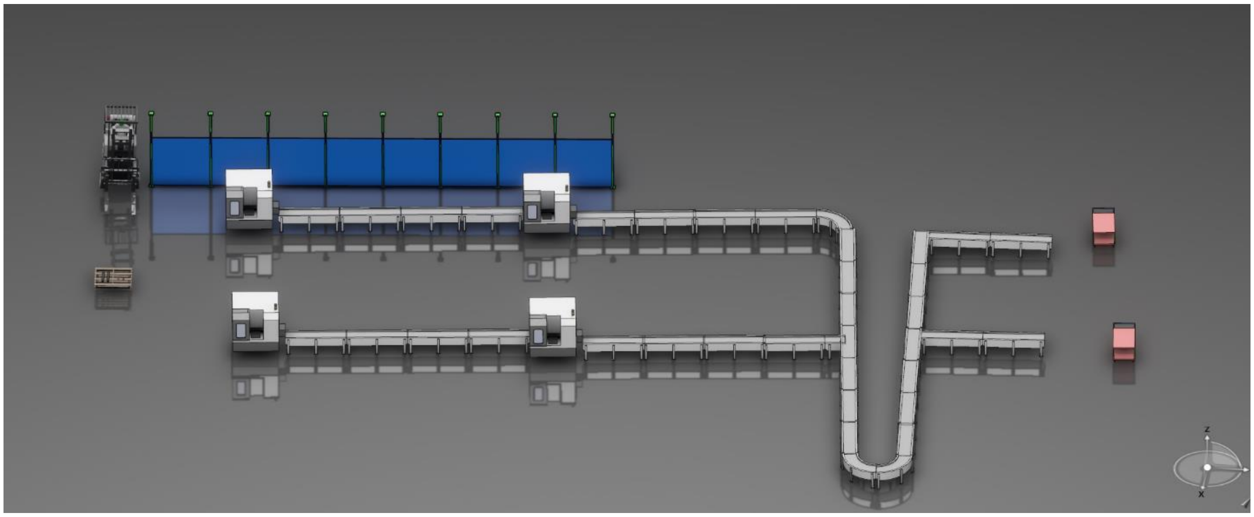


Figure 16:Production System Without the Flow Definition.

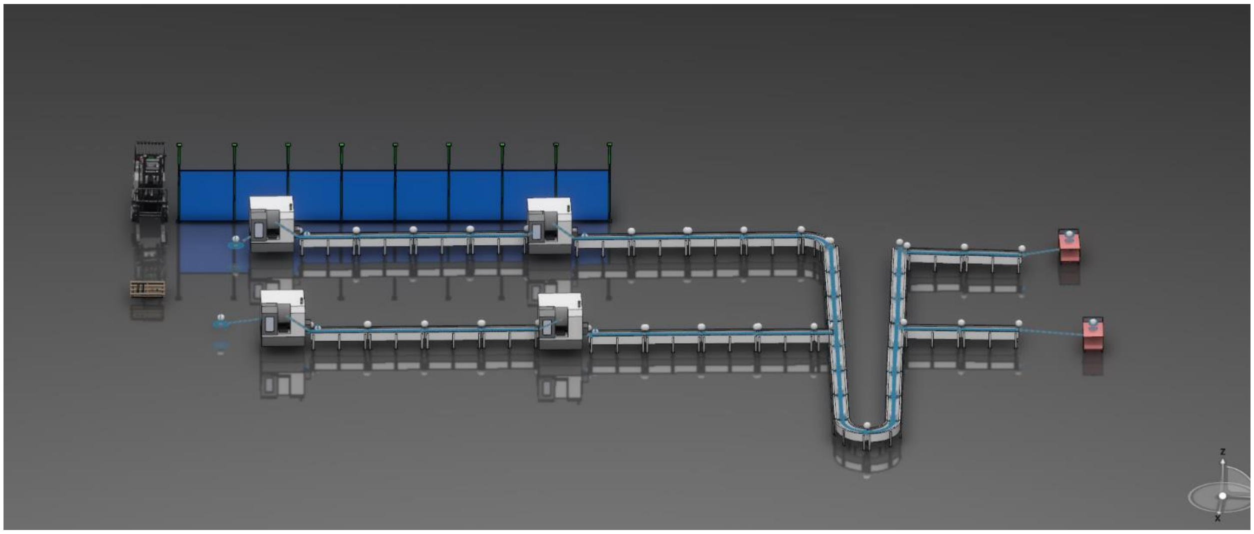


Figure 17:Production System with the Flow Definition

Moreover, in the equipment of the system, there is also very common the occurrence of failures of the machines.

4.3.2 INUSTRIAL SYSTEM'S SPECIFICATIONS

For the simulation of the production system, it is necessary to determine several relevant data relatively to the function of the equipment. The specifications of the system are the following:

Cycle time for the first machine in each line: 3s

Cycle time for the second machine in each line: 5s

MTTF: 100s

Time Distribution for failure occurrence time: Normal Distribution

Mean Time: 10s

Deviation: 5s

MTTR: 10s

Time Distribution for repair time: Normal Distribution

Mean Time: 1s

Deviation: 1s

Number of Available Products in the system: Practically Unlimited

Cart Capacity (Final Buffer): Practically Unlimited

Total Simulation Time: 8 h (1 Shift).

4.3.3 ASSUMPTIONS OF THE MODEL

As it is obvious from the system, the user have made several major assumptions for the execution of the simulation. The first major assumption is that CNC machines execute the tasks of filling the cups with coffee and producing the packs of coffee cups. This simplification has been made obviously, because there is a lack of a precise 3D model of the machinery which executes the before mentioned tasks. The easiest way for the current software to represent a machinery equipment of this kind, is by using the 3D model of a CNC machine. The second major assumption in the current model is that the cycle times for each product are constant and deterministic. Furthermore, another assumption that has been made is that the products are moved from one conveyor to another intact and without any losses. In other words that means there is no stuck occurrence of a product in any of the parts of the conveyor line. Additionally, it is assumed that the distributions of repair times and failure times are constant and invariable by the passing of the simulation time. Moreover, it is assumed that the separation of the coffee packs is perfectly executed without any mistakes, and that the workers are executing their tasks perfectly without the occurrence of any flaw. Also, it is assumed that the performance of the employees remains stable and constant, during the entire simulation period. Of course, as it was mentioned in the previous paragraph, the capacity of the source (pallet) and the sink (cart buffer), is unlimited. In addition, a set of important assumptions that have been made is that the equipment of the production system function independently to one another, the failures are dependent only to the overall production time (which means that when the machine is not operative, it does not affect the overall efficiency of the equipment at all) and that each machine has the same failure and repair rates. It is important to clarify also, that when a failure occurs in one of the machines inside the system and the machine is already processing one product, after the repair of the failure the product is not sent to the scrap, on contrary it is sent to the next stage of the production process. Phenomena of blockage and starvation in the equipment do not exist in the current simulation model.

4.3.4 LIMITATIONS OF THE SIMULATION PROCESS

One important limitation of the current thesis work, is the absence of any software skill, concerning the initialization, programming and use of any robot equipment, inside the software. Since the automation of the modern production systems, is closely related to the use of robotic equipment, then that means, inside the system was not able to simulate effectively 3D application of automated robotic equipment.

4.3.5 APPLICATION OF DIFFERENT SCENARIOS FOR PRODUCTIVITY IMPROVEMENT

In the paragraph of 3.3 there is a summary of 10 different strategies that can be applied inside an industrial system for improving its productivity. At this point the purpose is to try to incorporate these different strategies in the software by trying to translate them into quantitative conditions and insert them into the 3D Experience FFS Application. For benchmarking, a simulation of the initial model with the specifications which were already mentioned in paragraph 4.4.2 was executed. The results of the system's simulation have been registered and saved in the form of an excel file. Relevant data statistics concerning the total production output, the availability of the equipment, the frequency of the failures, the WIP, the availability of the workers and many other KPIs were recorded for comparing them with the respective KPIs came from future modifications of the initial system.

The results of the simulation process of the initial production system were presented in the excel spreadsheet (see Appendix).

As it is shown in the report, the total amount of products that have been produced inside the system is 2057 coffee packages. An important observation based on the above data is that the level of the production is very balanced between the two lines.

This fact also can be verified by the independent reports of the machines of the two lines. More precisely, they are presented the reports of the second machines for each line (see Appendix).

As the reader can observe from the above reports for the two machines, the output of each respective machine is slightly higher than the actual number of products that have been registered inside the buffers by the end of each terminal. This difference can be explained by the fact that by the end of the simulation, there were a several number of products in the conveyors that have not been transferred to the buffers. More precisely by the end of the simulation process, the number of products that exist on the conveyors is 2 products from the first line (orange coffee packages) and another 2 from the second line (purple coffee packages).

The different modification scenarios that were applied to the initial system according to the strategies which were described in the paragraph 3.3, are the following:

- **Try to reduce the disturbances inside the system:**

In this case the user tried to reduce the disturbances by reducing the failure rate inside the system. This case corresponds to the scenario of replacing the equipment with a new equipment which is more robust and reliable. Moreover, the case of decrease of the failure rate can end up by making substantial improvements in the maintenance strategy of the system. Example of this kind of maintenance strategy can be more frequent maintenance sessions or improve the way the current maintenance sessions is being implemented (standard of maintenance application).

In this case, several different scenarios were conducted as experiments and their results were recorded. In the first scenario the failure rate of first machines was reduced 30%. Meaning that the new MTTF of the first line of machines will increase and will became 130s instead of 100s. The results in the productivity of the system are available in the respective report in the Appendix part.

The productivity output can also be seen in the respective output reports for the two last machines from each respective line (see Appendix).

The next modification that was made, was the decrease of the failure rate of the second line of machines by 30%. So, in this case the new MTTF of the second row of the machines became 130s instead of 100s that initially was. The results from this modification scenario are shown in the Appendix part as well.

Same as in the previous scenarios, the productivity output for each line can be depicted in the reports of the second machines for each respective line. The reports of the desired equipment, can be found in the Appendix part for the current simulation scenario.

A third modification scenario was also tested at this point. In this scenario, the failure rate of all the machinery inside the factory, was reduced by 30%. The result of the combined reduction of the failure rate of the equipment is available on the respective report in the Appendix part.

The respective outputs of the two last machines of each respective line were shown in the respective reports (see Appendix).

Same as in the previous case the number of product outputs for each system was different than the one that was registered in the buffers of each terminal. The explanation of this phenomenon is the same as in the previous cases.

- **Introduction of automation inside the production system:**

In this scenario, it is made a comparison between the case in which the coffee products are inserted in the system automatically, without the intervention of the workers and the case in which the workers are going, receive and finally place the coffee cups in the first machines of each respective line. In the first case scenario, it is considered that there is an automation mechanism (such as a robotic arm) that it places the product in the machines almost automatically. The results for this particular scenario are coincided with the results of the initial system, as the assumption for the initial model was that the products were inserted in the respective machines automatically.
(See figures 17, 18, 19). So for the purpose of comparison of this current model with the model of manual transportation of products from the source inside the machines, a model with intermediate buffers in the beginning of the system containing the assignment of transportation task to the workers whom also perform the repair operations was created. A simulation of this production system was implemented inside the 3D Experience software for a shift of 8 hours and the results of the simulation are presented in the respective spreadsheet report in the Appendix.

Alternatively, another scenario for automation application, is the replacement of the workers of the final terminals. Instead of bringing manually the products to the respective carts (final buffers) the user initiates the transportation of the products automatically, from the end of the terminal to the buffer. This simplification can represent a simplistic approach of an ideal robotic equipment which is able to make, with the use of image processing, the recognition of the appropriate color of the product from the line and finally place it to the respective buffer. Likewise, the results from the simulation of this particular scenario are presented in the Appendix part of the project.

- **Improving the working standard, training the employees and increasing their motivation:**

By improving the working standard, and in the same time training the employees and stimulate them by providing rewards for their extra efforts, the availability of the employees can be increased inside the system. Since the simulation of the model is being implemented only for a single shift (8 hours), it is not possible to model the absenteeism. Instead, it is possible to measure the availability of the employees in the system. Unfortunately in this current software version it is not possible to model the availability of the employees. But it is possible to increase the speed of executing the respective task. In the first scenario, the speed of receiving the products by the employees and place them in the correct terminal was increased by 20%. The change of the speed was implemented only to the employees of the final terminals as they were the only employees that were executing the transportation task inside the system. The results which were derived from the simulation model are presented in the Appendix part.

The respective productivity outcomes from each machine can be found in the same Appendix part as well.

Moreover, an alternative scenario which reflects better the improvement of the skills of the employees derived from their training, is the decrease of the repair time of the machines. Same as in the previous scenarios, it is tested the assumption of decreasing the repair time of the machines by 30 %. The effects of this reduction to the productivity improvements inside the system are available in the respective report in the Appendix part.
The outputs from the last machines of each respective lines are available in the Appendix part.

- **Bottleneck detection inside the production system:**

In this particular scenario, an effort to identify the bottleneck part inside the system (if one was existing) was made. It is important to clarify at this point that as bottleneck, could be defined any resource inside the system, whether it is machine, worker, buffer or conveyor.
For identifying the bottleneck, the simulation software provide an additional functionality, which was able to identify graphically the bottleneck equipment inside the system. The graph depict the total amount of time which each resource is operative inside the system in the form of a bar graph. As it was already mentioned in the previous paragraphs, the bottleneck equipment, is defined as the equipment which is operative for the largest amount of time during the work.

The results from the bottleneck detection inside the system are the followings:

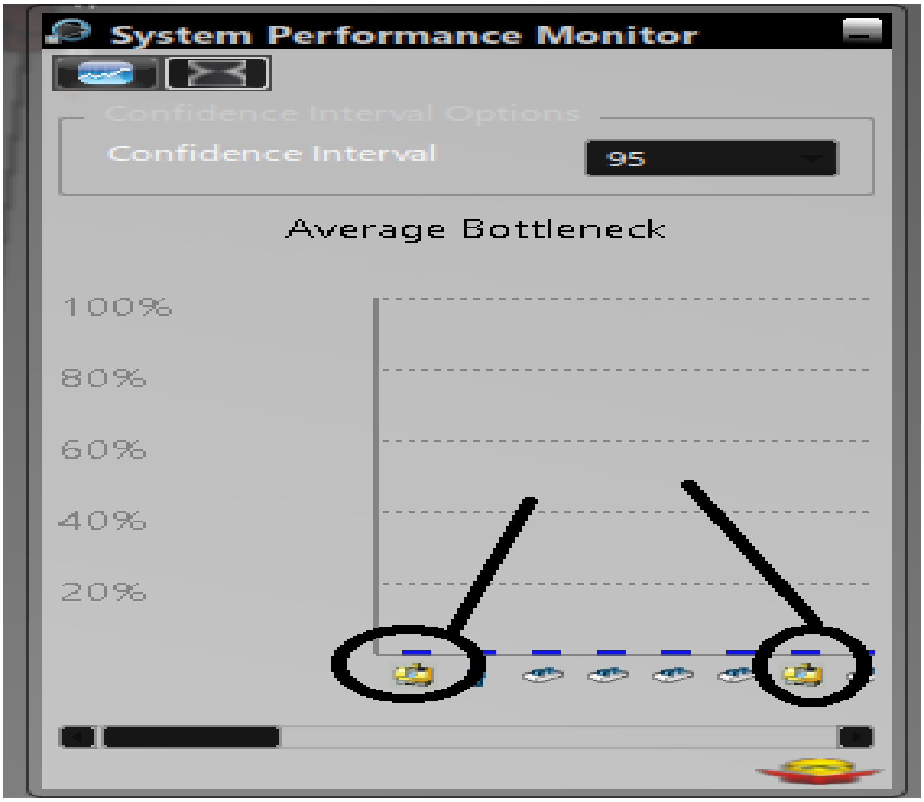


Figure 18: Graph of the bottleneck detection Function from 3D Experience.

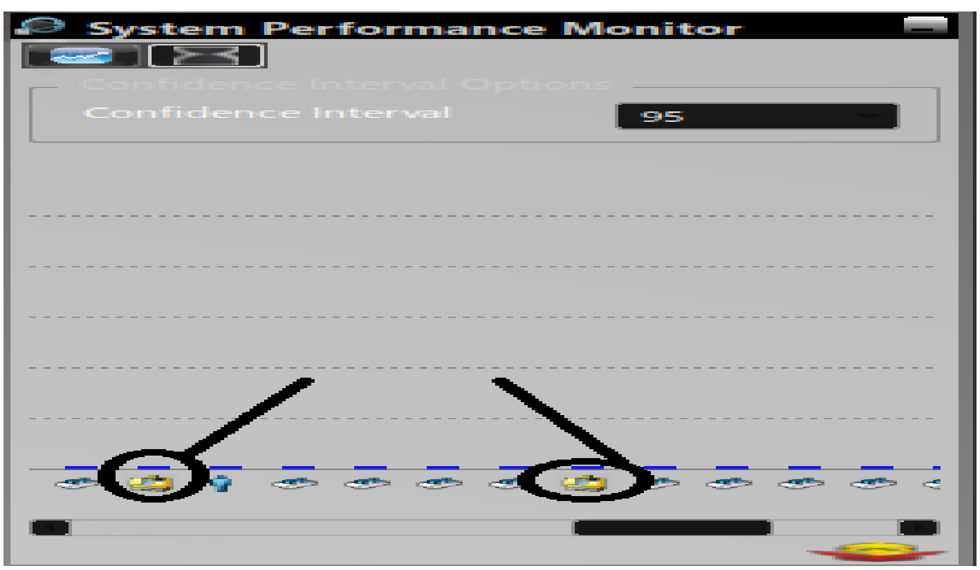


Figure 19: Graph of the bottleneck detection from 3D Experience.

As it is obvious from the graphs above, there is no bottleneck resource inside the system. So as it is easily conceivable, there was no meaning to continue with any simulation of the system with this particular method.

It is very important to comment, that the bottleneck detection method is very helpful to be executed preferably at the beginning of the analysis, as it has the ability to indicate which part of the production system does not operate effectively and to direct the efforts of improving the system towards the improvement of this current part. For example if an operator is not sufficiently perform to his/ her tasks, then the improvement efforts can be directed to which extent his/her skills improvement leads to considerable improvement of the production output of the system.

With the same logic, if a machine inside the system has been detected as the bottleneck of the system, then the simulation tasks can be directed to what effects will have on productivity an alternative balancing of the workload between the rest of the equipment in the system.

- **Increasing the capacity of the machinery inside the system:**

In this particular scenario, it is possible to investigate the effects of a possible equipment change, with another one of larger capacity. In the current digital model, this scenario can be tested by increasing the number of products that can be used as input (and naturally also as output) to each machine of the first line respectively, by producing at the same cycle time. The results of this scenario are shown in the respective report in the Appendix.

An alternative scenario of capacity increase of the existing equipment is the combined increase capacity of both of the machines inside the system. More precisely in addition to the increase capacity of the first machine of each line, a simulation run will be executed in order to investigate which are the results in productivity output of the entire system, if the output capacity of the second machines for each line is doubled. This scenario represents the realistic alternative of substituting the existing machines with new which have a second nozzle and they are able at the same time to fill two times the number of cups they were filling during the cycle time for the first machines of each line. Same concept applies also to the second machines, as they can be thought as a replacement with a new equipment which has a second package workbench besides the existing one, and in the same cycle time can produce double the amount of the packages that it was capable of producing previously. The results of this scenario in terms of production output can be seen in the respective section in the Appendix.

The respective reports which include information for the productivity output of the 2nd machines for each respective lines, are available in the Appendix Part.

4.3.6 RESULTS OF THE SIMULATION EXPERIMENTS

As it was obvious from the results of the output reports came from the paragraph 4.4.5, not all the recommendation from the academia produced the expected results in productivity improvement that the reader was expecting. An overview of the productivity increase that came from each particular scenario is shown in the bar graph below.

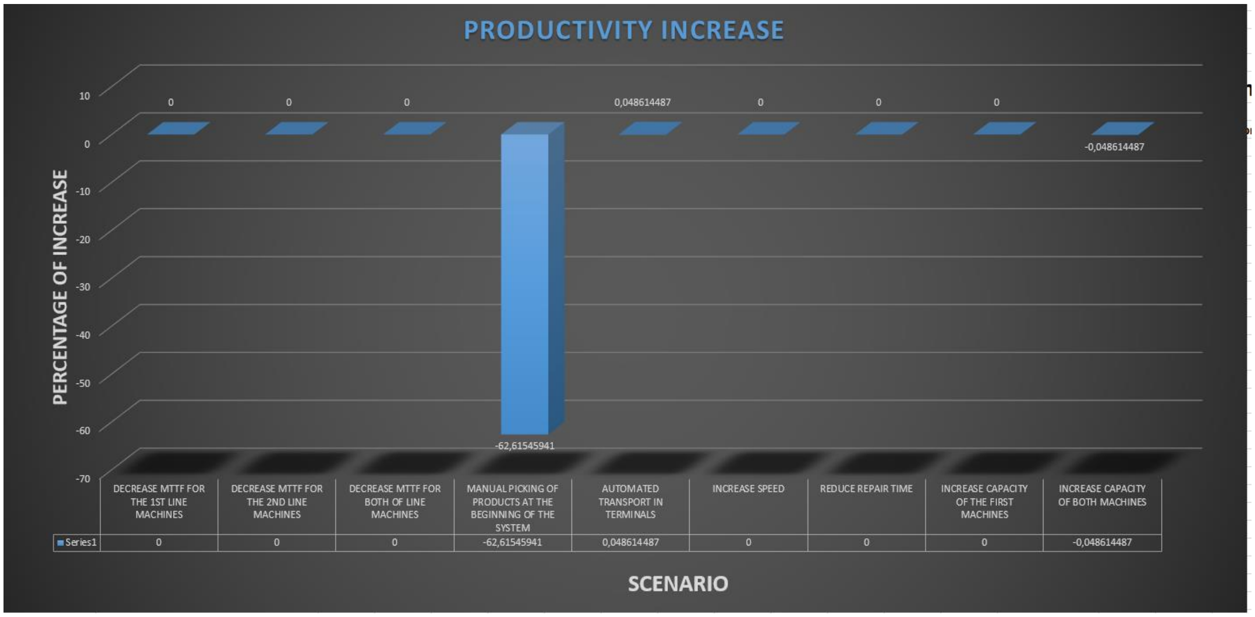


Figure 20: Productivity Increase Overview For the total Production Level for each particular scenario.

The above results were derived by using the initial system's simulation results as benchmark. The productivity change was calculated by using the following formula and it is expressed in % percentage.

% *__Productivity Change__* = {[(Total Production Output from the current scenario) – (Total Production Output from the Initial System)]/ (Total Production Output from the initial system)]} *100. (1)

As it is become obvious from the bar chart above, most of the scenarios for the productivity improvement led to either zero or negligible change in productivity levels for the industrial plant. More precisely the scenarios of decreasing the MTTF by 30% for the 1st machines of each line, or the second machines of each line, or for all the machines of the system, lead to absolutely 0 improvement in productivity output. Same conclusions were derived from the simulation scenarios of increasing the speed of transferring of the final products (coffee cup packages) by the employees in the respective final terminals of the system. Similar behavior was observed in the system for the reduction of the failure rates of the machines by 30% for each machine simulation scenario. As terminal inside the current report is defined the end position of each production branch before the final buffers. For clarification purposes the terminal positions for this production system are shown in the picture below.

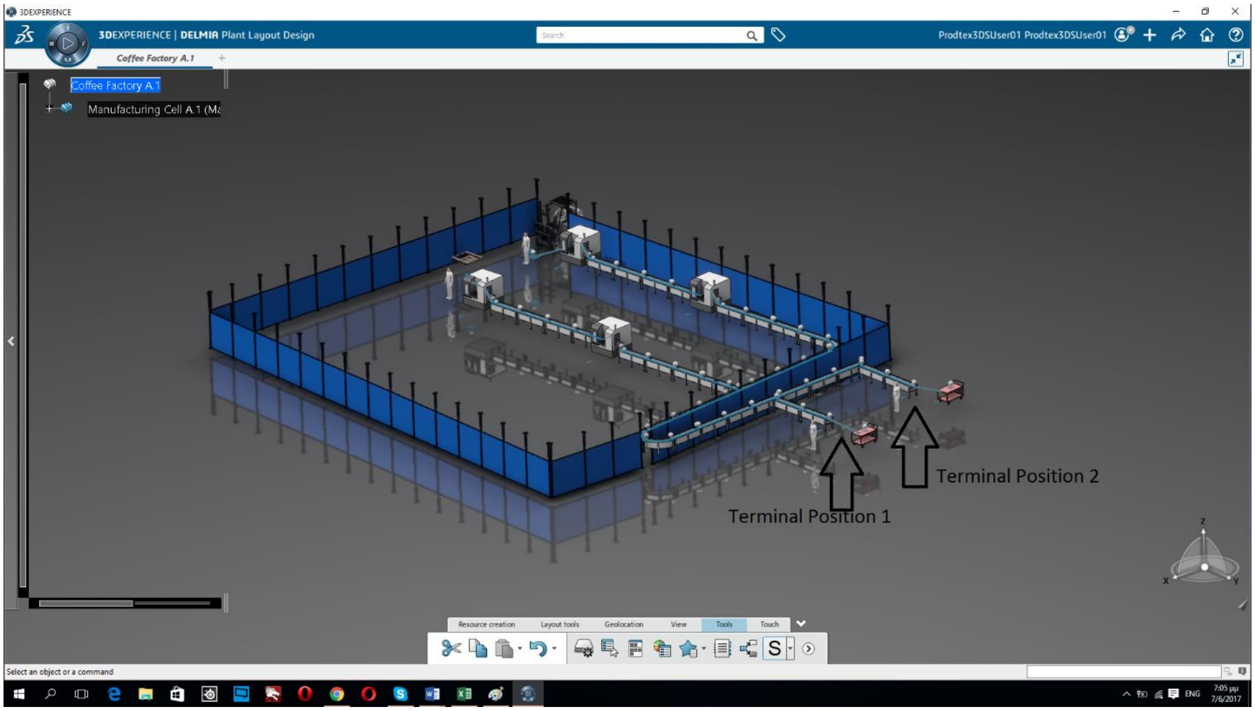


Figure 21: Positions of the Terminals inside the system.

Unexpectedly zero change in terms of productivity output was given the scenario of capacity increase of the 1st machines of the production lines. The logical thinking of an individual that a possible increase of the capacity of the equipment of the production system would definitely lead to substantial or at least considerable increase in the production output of the system, does not seem to be applicable in this particular production system. The expected and obvious result of substantial productivity increase of the system, was not confirmed by the scenario of capacity increase of all the machines of the production system. The double capacity of the 2nd machine of each production line, was not only able to increase the production output of the entire system, on the contrary, it led to reduction of the production level by 0,048 % (Figure 47). At this point it is made crystal clear why the industry is investing so heavily in simulation applications. In this particular example, with the use of simulation results the organization is able to avoid two mistaken investments that could lead to the financial demise of the company.

The only scenario which led to beneficial results in terms of productivity improvements, was the increase of automation of the process. The use of an automated process to feed the products in to the system, in comparison to the alternative option of feeding the products manually (by the employees) to the machines, has led to the substantial increase of productivity by 62,61% in overall. This particular scenario was simulated contained the manual carry of the products to the respective machines. This scenario led to a very low total productivity level of 769 products in the respective terminals. It is important to remind that the initial system's specification contains the implicit assumption that the products are carried immediately from the source to the machines without the interventions of the workers. So the total production output (as it was stated in the paragraph 4.3.5) was 2057 products. By using the formula (1) for the calculation of the production output variance, it is made clear that the subtrahend of the numerator is far greater than the subtracter. This explains the negative value (- 62,61%) in the bar chart can for this particular scenario. This difference in the definitions of the scenarios, has led to this great negative value of the productivity increase percentage.

The introduction of automation to the final terminals of the system, has not led to a considerable increase of productivity in overall. The result of this automation was only able to increase the total production output by 0,048 %.

Furthermore, as it was mentioned also in the previous paragraph, the introduction of the method of bottleneck detection in the initial's system simulation, was not able to lead to any meaningful results. At this point it is made also apparent that the bottleneck of the production system was the manual transferring tasks of the products to the machines in the beginning of the system. It is safe to make this assumption cause the scenario of automatic transportation of the products to the machines, lead to substantial increase of production output of the entire system.

For purpose of completion, the graphs which depicts the overall productivity improvements (or losses) in each terminal of the production system, for every scenario are the followings:

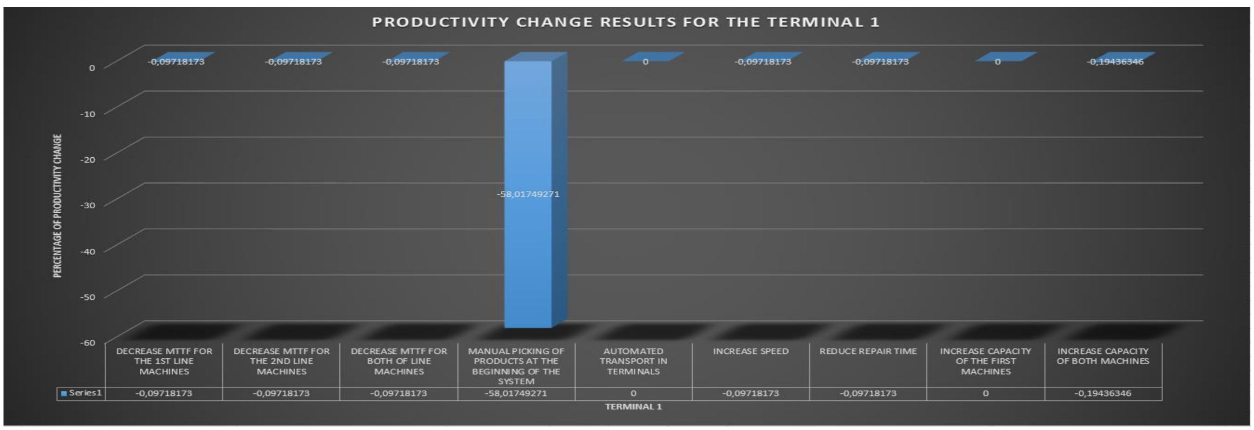


Figure 22: Productivity Improvements (losses) from the application of different scenarios in the 1st terminal.

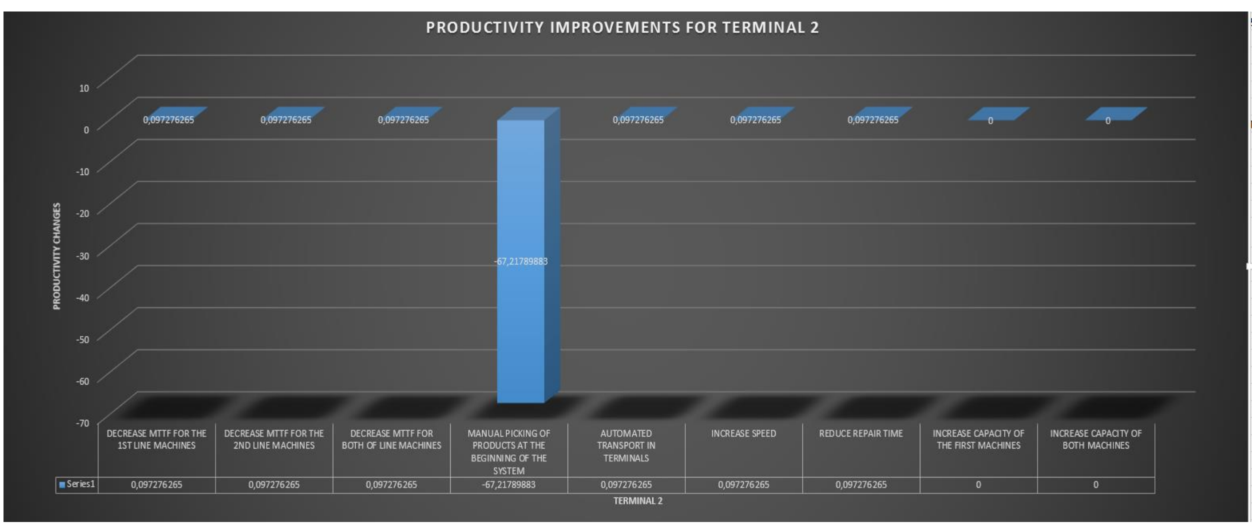


Figure 23: Productivity Improvements (losses) from the application of different scenarios in the 2nd terminal of the production system.

5. DISCUSSION

By completing the design of experiments for the current thesis project and obtained the results from the respective tests, which support these experiments, from the simulation software of 3D Experience, several very important findings were discovered. The first important outcome of the current thesis was that the scientific methods that are proposed by the academia and are available in the respective scientific literature, are indeed able to produce beneficial results, in terms of productivity improvements, for the production systems in which they are applied. Although, it was proved from the results of the simulation experiments, that a certain limitation exists and fractures the potentiality of beneficial results of these methods. The most important observation from this application was the fact that not all of them, are able to produce considerable beneficial results, in the productivity increase for the same production system. It was made obvious that the intrinsic nature of the production system, have a major influence to the result which each method can produce. Even more interesting but at the same time extremely dangerous (in terms of financial investment), was the fact that several methods can even produce negative results instead of the beneficial ones, which they were expected to produce. This concealed danger can be proved lethal, especially in the occasion when an investor decides to blindly base his investing decisions in the scientific literature proposals, without prior have tested them. So, the only reliable way for someone to identify these dangers and predict the results of his/her actions, is to use the simulation process.

Additionally, it is important to be understood that even the simulation methods have limitations to the precision of the result that they are able to produce. The simulation techniques are not able to predict changes in the external environment of the system, such as changes in law regulations, potential changes in the manpower of the organization or possible equipment degradation, due to insufficient maintenance strategy etc. So, the results of the simulation scenarios must be treated with extreme caution and become clear the short “life expectancy” of these results.

Also the accuracy of the results of the simulation process is greatly affected by the capability of the model to represent the reality as accurate as possible. This is one of the main reasons why this certain thesis project decided to base its activities on a new 3D simulation software. Probably the importance of precise representation of the reality by the software was not so obvious in the current flow simulation model, as it would be in production systems, in which the use of advanced automation equipment (such as industrial robotic arms) is needed for their function. In these kind of production environments such as aircraft wing assembly stations, the exact and precise way of how the equipment implements a task and how much time is needed for every single activity, is of paramount importance for the precise calculation of the production output and the quality of the work, and it can play an important role in the reduction of investment risk to these technologies.

As it was made quite obvious, even though individual and independent application of each proposed method for productivity improvements does not necessarily lead to beneficial results for the increase of productivity, there is no evidence of what the methods are able to produce in cases when they are used combined. So potential research capabilities that have been exposed by the current thesis work, are the application of the scientific methods (which are already proposed in the previous chapters of the thesis work) combined in pairs, by three or even combined all of them together at the same time. The goal is the exploration of the possibilities of improvements of the system’s productivity by simulating the current or an alternative production system.

Additionally, from the paragraph 4.2 it was stated that one major limitation of the current thesis project was the application of automated equipment such as industrial robotic arm or PLC devices. Application of these technologies unfortunately were not performed in this project. The limitations of time for the end of the current project combined with the lack of technical support, were barriers to the capability of the students to obtain the skill of using this equipment inside the software for an advanced technology application. So,

another alternative proposal for a future thesis work, was to test the capabilities of the current simulation software to production systems which contain application of high tech equipment.
Furthermore, from the training and the extensive use of the tool for the completion of the necessary tasks that were assigned to the thesis workers from the academic staff, it was discovered that the tool is extremely powerful on providing many useful information about the production output of the system. Considering also the capabilities of 3D Experience to provide dynamic monitoring information of the production process, combined with graphical tools that are measuring the KPIs such as WIP, availability of the equipment, amount of time a worker spends on repairing failures etc, the current software tool consists a very attractive simulation solution for the industry. Unfortunately, the current software tool presents limitations to the statistical information that it provides. One example of this omission is the calculation of the energy consumption of the equipment. In this way the user is not able to provide a holistic solution about the overall impact of the current proposed solution considering the environmental impacts. Consequently, the environmental impact is pretty much ignored in the current production solutions that are proposed by this software solution.
Additionally, from the economic aspect, the current software does not provide the user with the capability of making calculation of cost (in terms of investment cost) of the relevant equipment or functional cost of the production process. These data are extremely useful, to support decision making activities for actual investments in production equipment.

6. CONCLUSION

From the overall work of the current master thesis, many extremely useful, practical and in the same time interesting results were derived. From the literature search which was devoted the first part of this thesis project, it was made a detailed overview of the methods which are proposed and are currently used from the industry for the increase of productivity of the shop floors. As it was observed, the simulation methods were one of the most frequently proposed solution for this endeavor. In parallel, an effort was made to investigate which are the true motives for an entire society and for the industrial organizations to increase the productivity at the shop floor level. As it was explained in paragraph 2.4, the increase of productivity benefits both the society, as it leads to higher employment rates and opportunities for the citizens and the organizations as it leads to higher profits. The literature part of this thesis is concluded with a review of several of the most important theoretical proposals from academia, for the increase of productivity for manufacturing shop floors. These proposals were used as benchmark in the simulation experiments, whose purpose were to test whether these proposals were able to produce practical results in the productivity improvement of the industrial plants.

The second part of this thesis work, which was devoted to the use of a 3D Simulation software, produced extremely important results as well. The execution of the simulation experiments, that were designed by using the proposals found by the theoretical part, revealed that not all the productivity improvement strategies, are able to produce beneficial results, in terms of productivity improvements, for an industrial plant. Additionally, it was proved that several apparent logical scenarios, that are expected to lead to productivity improvement, are producing the exact opposite results from the expected ones. A very characteristic example of such a case can be found in paragraph 4.4.5 and more specifically, in the simulation scenario of increase the capacity of the machines, inside the production system.

7. BIBLIOGRAPHY

[1] V. Spasojevic - Brkic, et al., "Production cycle time reduction in low and medium low tech companies: a case study for Serbia," Aug 2016.

[2] M. Mohammadi, et al., "Optimizing Flexible Manufacturing System: A Developed Computer Simulation Model," IJE TRANSACTIONS B: Applications, vol. vol. 29, no. 8, pp. 1112 - 1119, Aug. 2016.

[3] C. Herrera et al., "A reactive decision making approach to reduce instability in a master production schedule," International Journal of Production Research, vol. 54, no. 8, pp. 2394 - 2404, 2016.

[4] M. Afifi, et al., "Discrete and Continuous Simulation Approach to Optimize the Productivity of a Modular Construction Element," in ISARC, 2016.

[5] David Z. Zhang,. I. Kucukkoc, "Type -E parallel two sided assembly line balancing problem: Mathematical model and ant colony optimization cased approach with ptimized parameters,"

Computer and Industrial Engineering, vol. 84, pp. 56 - 69 , 2015.

[6] P. Kuhlag, et al., "Improving productivity by deriving and defining, Target conditions in the value stream of packing," TRANSACTIONS OF FAMENA, 2015.

[7] J. Balic, et al., "Multi objective optimisation of machining and micro machining processes using non dominated sorting teaching learning based optimisation algorithm," J Intell Manuf, 2016.

[8] A. Skoogh et al., "REAL TIME DATA DRIVEN AVERAGE ACTIVE PERIOD METHOD FOR BOTTLENECK DETECTION," Int. J. of Design & Nature and Ecodynamics, vol. Vol. 11, no. No.3, pp. 428 - 437, 2016.

[9] S. Prasad et al., "Productivity Enhancement Through Production Monitoring System," IJABER, vol. 14, pp. 339-351, 2016.

[10] M. EZEKIEL, "Population and Unemployement," *Annals of the American Academy of Political and Social Sciences ,* 1939.

[11] R. Cagliano, A. Longoni, "Environmental and Social Sustainability Priorities Their Integration in Operation Strategies," International Journal Of Operations and Production Management, vol. 35 , no. 2, pp. 216-245, 2014.

[12] D. C. Alexander, "The Economics Of Ergonomics," in *PROCEEDINGS of the HUMAN FACTORS AND ERGONOMICS SOCIETY 38th ANNUAL MEETING* , Alabama, 1994.

[13] C. Loch et al., "How BMW is defusing the demographic time bomb," *The GLOBE,* pp. 1-5, 2010.

[14] U. Pieper, "Deindustrialisation and the social and economic sustainability nexus in developing countries: Cross country evidence on productivity and employment," *The Journal of development studies,* vol. 36, no. 4, pp. 66-99, 2000.

[15] J. stahre, "PPU-180 Production systems," Production (chalmers Area of Advance), 2015.

[16] P. Almstrom, "Productivity measurement and improvement:A theoretical model and applications from the manufacturing industry," pp. 24-26, 2012.

[17] Samuel H. Huang et al., "Manufacturing productivity improvement using effectiveness metrics and simulation analysis," *International Journal of Production Research ,* vol. 41, no. 3, pp. 513-527, 2003.

[18] R.M. Nachiappan, N. Anantharaman, "Evaluation of overall line effectiveness (OLE) in a continuous product line manufacturing system", Journal of Manufacturing Technology Management, vol. 17, no. 7, pp. 987-1008, 2006.

[19] K. Saftsten, M. Bellgran, "Production Efficiency," in *Production Development: Design and Operation of Production Systems*, Springer London Dordrecht Heidelberg New York, 2010, pp. 282 -285.

[20] A. Kinnander, P. Almstrom, "Productivity Potential Assessment Method: Assessing and Benchmarking the improvements potential in manufacturing systemsat shop floor level," *Internationla Journal of Oprations and Production Management,* vol. Vol. 60, no. 7, pp. 758 - 770, 2011.

[21] A. Kinnander, P. Almstrom, "Productivity Potential Assessment of 30 Suppliers to the Automotive Industry," in *The Third Swedish Production Symposium*, Gothenburg, Dec. 2009.

[22] L. Nicoleta et al., "Employee suggestion system (Kaizen Teian) the bottom up approach for productivity improvement," in *International Conference on Economic Engineering and Manufacturing Systems*, Brasov, Nov. 2009.

[23] P. Almstrom et al., "How to improve productivity 160%," in *Swedish Production Symposium*, Gothenburg, 2014.

[24] A. Kinnander, P. Almstrom, "Results and conclusions from the productivity potential assessment studies," in *The second Swedish Production Symposium*, Stockholm, Nov. 2008.

[25] P. A. Gunasekaran, "Implementation of Productivity Improvement Strategies in a Small Company," *Technovation ,* vol. Vol.18, no. 5, 1998.

[26] C. Roser et al., "Shifting Bottleneck Detection," in *Proceedings of the 2002 Winter Simulation Conference*, Japan, 2002.

[27] T. Grundberg, "A review of improvement methods in manufacturing operations," *Work Study,* vol. Vol. 52, no. 2, pp. 89-93, 2003.

[28] I. Pergher et al., "STRATEGIES FOR INCREASING PRODUCTIVITY IN PRODUCTION," INDEPENDENT JOURNAL OF MANAGEMENT & PRODUCTION (IJM&P), vol. Volume 5, no. n. 2, pp. 344 - 359, 2014..

[29] M. Karlsson, E. Berneluk, "Simulation with 3D Experience, Evaluation of the software for production flow simulation in manufacturing industry," Chalmers University of Technology, Gothenburg, 2016.

[30] D. Pacheco et al., "Strategies for Increasing Productivity In Production System," *Independent Journal of Management & Production,* vol. 5.2, pp. 344-359, 2014.

[31] A. Delmas, S. Pekovic, "Environmental standards and labor productivity: Understanding the mechanisms that sustain sustainability," *Journal of Organizational Behavior,* vol. 34, pp. 230-252, 2013.

8. APPENDIX

DATA FROM THE SIMULATION SCENARIOS:

- INITIAL SYSTEM:

Overall System Report:

Arrival & Dispatch										
System	Products Arrived									
In Zone.1	5160									
In Zone.2	5160									
Production										
System	Products					State Times			Average Processing Time	Average Requirement Time
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed		
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000	5159	5158	5158	5158	0	15474,816	2972,209	7352,975	2,557	0,44
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000	5155	1030	5150	1030	0	5154,183	15568,083	5077,734	3,712	10,14
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000	5158	5157	5157	5157	0	15471,587	2878,343	7450,07	2,553	0,4
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000	5155	1031	5155	1031	0	5155	15279,526	5365,474	3,671	9,78
Storage										
System	Products		Content		Waiting Time			State Times		Utilization (%)
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
Table Cart_1.2	1028	0	1028	512,471	0	0	0	99,09	25700,91	99,61
Table Cart_1.1	1029	0	1029	512,871	0	0	0	75,984	25724,016	99,70
Worker										
Worker Name	Products Transferred	State Times			Distance Travelled	Utilization (%)				
		Idle	Processing	Travelling						
Human00001124.1	0	15095,071	2234,024	8470,905	9,32E+06	41,492				
Human00001125.1	0	14826,094	2210,194	8763,712	9,64E+06	42,535				
Human00001126.1	1028	22215,209	0	3584,791	2,62E+06	13,895				
Human00001127.1	1029	20176,045	0	5623,955	4,11E+06	21,798				
Conveyor										
Conveyor Name	Products Transferred	State Times			Utilization (%)					
		Wait for Input	Wait to Output	Travelling						
COnveyor2.2	5157	15485,184	0	10314,816	39,98					
COnveyor2.4	5156	15486,184	0	10313,816	39,976					
COnveyor2.6	5156	15488	0	10312	39,969					

Figure 24:Productivity Level of Initial System.

Machines For Each Line:

1	Simulation Time 25800		Time in Second									
2	Warmup Time 0		Length in Millimeter									
3	Run 1											
4												
5												
6	Production											
7												
8	Run	Products					State Times			Average Processing Time	Average Requirement Time	Utilization (%)
9		Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed			
10	1	5155	1030	5150	1030	0	5154,183	15568,083	5077,734	3,712	10,142	19,977
11												
12	Products											
13												
14	Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output		
15		Min	Max	Avg								
16	prd-Interfix to be defined 45904986-00003300.1	5	65,407	17,97	0	5155	5150	0	0	0		
17	prd-Interfix to be defined 45904986-00004992.1	0	0	0	0	0	0	1030	0	1030		
18												
19	Operations											
20												
21	Operation	Count	Processing Time			Requirement Time						
22			Min	Max	Avg	Min	Max	Avg				
23	Transform.2	1030	5	5	5	0,288	36	15,1				
24												
25	Failures											
26												
27	Repairs	Count	Repair Time			Requirement Time						
28			Min	Max	Avg	Min	Max	Avg				
29	Repair.1	504	0,037	3,882	1,08	0	0	0				
30												
31	Product Inventory											
32												
33	Raw Material			Work In Process			Finished Product					
34	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg			
35	1	5	3,59	0	1	0	0	0	0			
36												
37	Cycle Time											
38												
39	Count	Cycle Time										

Figure 25: Second Machine of First Line.

1	Simulation Time 25800		Time in Second									
2	Warmup Time 0		Length in Millimeter									
3	Run 1											
4												
5												
6	Production											
7												
8	Run	Products					State Times			Average Processing Time	Average Requirement Time	Utilization (%)
9		Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed			
10	1	5155	1031	5155	1031	0	5155	15279,526	5365,474	3,671	9,786	19,981
11												
12	Products											
13												
14	Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output		
15		Min	Max	Avg								
16	prd-Interfix to be defined 45904986-00003302.1	5	92,875	18,144	0	5155	5155	0	0	0		
17	prd-Interfix to be defined 45904986-00004990.1	0	0	0	0	0	0	1031	0	1031		
18												
19	Operations											
20												
21	Operation	Count	Processing Time			Requirement Time						
22			Min	Max	Avg	Min	Max	Avg				
23	Transform.4	1031	5	5	5	0,288	36	14,816				
24												
25	Failures											
26												
27	Repairs	Count	Repair Time			Requirement Time						
28			Min	Max	Avg	Min	Max	Avg				
29	Repair.1	530	0,37	5,032	1,086	0	0	0				
30												
31	Product Inventory											
32												
33	Raw Material			Work In Process			Finished Product					
34	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg			
35	0	5	3,625	0	1	0	0	0	0			
36												
37	Cycle Time											
38												
39	Count	Cycle Time										

Figure 26: Second Machine of Second Line.

- <u>INCREASE THE MTTF OF THE FIRST MACHINES OF EACH LINE BY 30%:</u>

Overall Report:

19	System	Products					State Times			Average Processing Time	Average Requirement Time
20		Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed		
21	Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5160	5159	5159	5159	0	15477	2790,439	7532,561	2,555	0,41
22	Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5155	1030	5150	1030	0	5152,836	15378,855	5268,309	3,685	9,95
23	Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5160	5159	5159	5159	0	15477	3230,673	7092,327	2,555	0,48
24	Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5155	1030	5150	1030	0	5154,982	15511,341	5133,678	3,681	10,01
25											
26	Storage										
27											
28	System	Products		Content		Waiting Time			State Times		Utilization (%)
29		Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
30	Table Cart_1.1	1028	0	1028	512,548	0	0	0	95,141	25704,859	99,63
31	Table Cart_1.2	1029	0	1029	512,721	0	0	0	81,476	25718,524	99,68
32											
33	Worker										
34											
35	Worker Name	Products Transferred	State Times			Distance Travelled	Utilization (%)				
36			Idle	Processing	Travelling						
37	Human00001124.1	0	14868,942	2303,301	8627,757	9,49E+06	42,368				
38	Human00001149.1	0	15285,081	2114,832	8400,087	9,24E+06	40,755				
39	Human00001127.1	1028	18675,11	0	7124,89	5,20E+06	27,616				
40	Human00001148.1	1029	21398,537	0	4401,463	3,21E+06	17,06				
41											
42	Conveyor										
43											
44	Conveyor Name	Products Transferred	State Times			Utilization (%)					
45			Wait for Input	Wait to Output	Travelling						
46	COnveyor2.2	5159	15482	0	10318	39,992					
47	COnveyor2.4	5158	15484	0	10316	39,984					
48	COnveyor2.6	5158	15484	0	10316	39,984					
49	COnveyor2.8	5155	11479,836	4085,825	10234,338	39,668					
50	COnveyor2.13	1030	23740	0	2060	7,984					
51	COnveyor2.14	1030	23740	0	2060	7,984					
52	COnveyor2.15	1030	23740	0	2060	7,984					
53	COnveyor2.16	1030	23740	0	2060	7,984					
54	Conveyor_Curved.1	1030	24327,955	0	1472,045	5,706					
55	-ImportedAsNewCoffeeQJ9 Conveyor_Base_Straigth.1	1030	23740	0	2060	7,984					
56	Conveyor_Vert.1	1030	23740	0	2060	7,984					
57	Conveyor_Vert.2	1030	23734,753	5,247	2060	7,984					

Figure 27: Overall System Production Output for decreasing the failure rate of the first machines.

Machines:

	A	B	C	D	E	F	G	H	I	J	K	L
1	Simulation Time 25800		Time in Second									
2	Warmup Time 0		Length in Millimeter									
3	Run 1											
4												
5												
6	Production											
7												
8	Run	Products					State Times			Average Processing Time	Average Requirement Time	Utilization (%)
9		Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed			
10	1	5155	1030	5150	1030	0	5152,836	15378,855	5268,309	3,685	9,954	19,972
11												
12	Products											
13												
14	Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output		
15		Min	Max	Avg								
16	prd-Interfix to be defined 45904986-00003302.1	5	62,201	18,167	0	5155	5150	0	0	0		
17	prd-Interfix to be defined 45904986-00004990.1	0	0	0	0	0	0	1030	0	1030		
18												
19	Operations											
20												
21	Operation	Count	Processing Time			Requirement Time						
22			Min	Max	Avg	Min	Max	Avg				
23	Transform.2	1030	5	5	5	0,288	36	14,916				
24												
25	Failures											
26												
27	Repairs	Count	Repair Time			Requirement Time						
28			Min	Max	Avg	Min	Max	Avg				
29	Repair.1	514	1,199	3,898	1,051	0	0	0				
30												
31	Product Inventory											
32												
33	Raw Material			Work In Process			Finished Product					
34	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg			
35	1	5	3,63	0	1	0	0	0	0			
36												
37	Cycle Time											
38												
39	Count	Cycle Time										

Figure 28: Productivity output report for the 2nd machine of the 1st Line.

Simulation Time 25800		Time in Second									
Warmup Time 0		Length in Millimeter									
Run 1											
Production											
Run	Products					State Times			Average Processing Time	Average Requirement Time	Utilization (%)
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed			
1	5155	1030	5150	1030	0	5154,982	15511,341	5133,678	3,681	10,014	19,981
Products											
Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output		
	Min	Max	Avg								
prd-Interfix to be defined 45904986-00003300.1	5	64,386	18,169	0	5155	5150	0	0	0		
prd-Interfix to be defined 45904986-00004992.1	0	0	0	0	0	0	1030	0	1030		
Operations											
Operation	Count	Processing Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Transform.4	1030	5	5	5	0,288	36,751	15,045				
Failures											
Repairs	Count	Repair Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Repair.1	518	0	3,92	1,059	0	0	0				
Product Inventory											
Raw Material			Work In Process			Finished Product					
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg			
1	5	3,631	0	1	0	0	0	0			
Cycle Time											
Count	Cycle Time										

Figure 29: Production Output for the 2nd Machine of the 2nd Production Line.

Workers Reports:

Simulation Time 25800		Time in Second				
Warmup Time 0		Length in Millimeter				
Run 1						
Worker						
Run	Products Transferred	State Times			Distance Travelled	Utilization (%)
		Idle	Processing	Travelling		
1	0	14868,942	2303,301	8627,757	9,49E+06	42,368

Figure 30: Repairman 1 – Line 1

A	B	C	D	E	F	G
Simulation Time 25800		Time in Second				
Warmup Time 0		Length in Millimeter				
Run 1						
Worker						
Run	Products Transferred	State Times			Distance Travelled	Utilization (%)
		Idle	Processing	Travelling		
1	0	15285,081	2114,832	8400,087	9,24E+06	40,755

Figure 31: Repairman 2 – Line 2

	A	B	C	D	E	F	G
1	Simulation Time 25800		Time in Second				
2	Warmup Time 0		Length in Millimeter				
3	Run 1						
4							
5							
6	Worker						
7							
8	Run	Products Transferred	State Times		Distance Travelled	Utilization (%)	
9			Idle	Travelling			
10	1	1028	18675,11	7124,89	5,20E+06	27,616	
11							
12	Products						
13							
14	Product	Waiting Time			Initial	Input	Output
15		Min	Max	Avg			
16	prd-Interfix to be defined 45904986-00004990.1	4,167	4,167	4,167	0	1028	1028

Figure 32: Terminal Employee 1

Simulation Time 25800		Time in Second				
Warmup Time 0		Length in Millimeter				
Run 1						
Worker						
Run	Products Transferred	State Times		Distance Travelled	Utilization (%)	
		Idle	Travelling			
1	1029	21398,537	4401,463	3,21E+06	17,06	
Products						
Product	Waiting Time			Initial	Input	Output
	Min	Max	Avg			
prd-Interfix to be defined 45904986-00004992.1	2,572	2,572	2,572	0	1029	1029

Figure 33: Terminal Employee 2

Buffers Reports:

Simulation Time 25800		Time in Second								
Warmup Time 0		Length in Millimeter								
Run 1										
Storage										
Run	Products		Content		Waiting Time			State Times		Utilization (%)
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
1	1028	0	1028	512,548	0	0	0	95,141	25704,859	99,631
Products										
Product	Waiting Time			Initial	Input	Output				
	Min	Max	Avg							
prd-Interfix to be defined 45904986-00004990.1	0	0	0	0	1028	0				
Product Inventory										
Raw Material			Work In Process			Finished Product				
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg		
0	0	0	1	1028	512,548	0	0	0		

Figure 34: Buffer 1 – Terminal 1

Simulation Time 25800		Time in Second								
Warmup Time 0		Length in Millimeter								
Run 1										
Storage										
Run	Products		Content		Waiting Time			State Times		Utilization (%)
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
1	1029	0	1029	512,721	0	0	0	81,476	25718,524	99,684
Products										
Product	Waiting Time			Initial	Input	Output				
	Min	Max	Avg							
prd-Interfix to be defined 45904986-00004992.1	0	0	0	0	1029	0				
Product Inventory										
Raw Material			Work In Process			Finished Product				
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg		
0	0	0	1	1029	512,721	0	0	0		

Figure 35: Buffer 2 – Terminal 2

- <u>INCREASE THE MTTF OF THE SECOND MACHINES OF EACH LINE BY 30%:</u>

Overall:

System	Products					State Times			Average Processing Time	Average Requirement Tim
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed		
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5160	5159	5159	5159	0	15477	2790,439	7532,561	2,555	0,4
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5155	1030	5150	1030	0	5152,836	15378,855	5268,309	3,685	9,9
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5160	5159	5159	5159	0	15477	3230,673	7092,327	2,555	0,4
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5155	1030	5150	1030	0	5154,982	15511,341	5133,678	3,681	10,0
Storage										
System	Products		Content		Waiting Time			State Times		Utilization (%)
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
Table Cart_1.1	1028	0	1028	512,548	0	0	0	95,141	25704,859	99,6
Table Cart_1.2	1029	0	1029	512,721	0	0	0	81,476	25718,524	99,6
Worker										
Worker Name	Products Transferred	State Times			Distance Travelled	Utilization (%)				
		Idle	Processing	Travelling						
Human00001124.1	0	14868,942	2303,301	8627,757	9,49E+06	42,368				
Human00001149.1	0	15285,081	2114,832	8400,087	9,24E+06	40,755				
Human00001127.1	1028	18675,11	0	7124,89	5,20E+06	27,616				
Human00001148.1	1029	21398,537	0	4401,463	3,21E+06	17,06				
Conveyor										
Conveyor Name	Products Transferred	State Times			Utilization (%)					
		Wait for Input	Wait to Output	Travelling						
COnveyor2.2	5159	15482	0	10318	39,992					
COnveyor2.4	5158	15484	0	10316	39,984					
COnveyor2.6	5158	15484	0	10316	39,984					
COnveyor2.8	5155	11479,836	4085,825	10234,338	39,668					
COnveyor2.13	1030	23740	0	2060	7,984					
COnveyor2.14	1030	23740	0	2060	7,984					
COnveyor2.15	1030	23740	0	2060	7,984					
COnveyor2.16	1030	23740	0	2060	7,984					
Conveyor_Curved.1	1030	24327,955	0	1472,045	5,706					
-ImportedAsNewCoffeeQJ9 Conveyor_Base_Straigth.1	1030	23740	0	2060	7,984					
Conveyor_Vert.1	1030	23740	0	2060	7,984					
Conveyor_Vert.2	1030	23734,753	5,247	2060	7,984					

Figure 36: Production Output for the scenario of decrease failure rate in the 2nd machines for each line.

Machines:

Simulation Time 25800		Time in Second									
Warmup Time 0		Length in Millimeter									
Run 1											
Production											
Run	Products					State Times			Average Processing Time	Average Requirement Time	Utilization (%)
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed			
1	5155	1030	5150	1030	0	5152,836	15378,855	5268,309	3,685	9,954	19,972
Products											
Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output		
	Min	Max	Avg								
prd-Interfix to be defined 45904986-00003302.1	5	62,201	18,167	0	5155	5150	0	0	0		
prd-Interfix to be defined 45904986-00004990.1	0	0	0	0	0	0	1030	0	1030		
Operations											
Operation	Count	Processing Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Transform.2	1030	5	5	5	0,288	36	14,916				
Failures											
Repairs	Count	Repair Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Repair.1	514	1,199	3,898	1,051	0	0	0				
Product Inventory											
Raw Material			Work In Process			Finished Product					
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg			
1	5	3,63	0	1	0	0	0	0			
Cycle Time											
Count	Cycle Time										

Figure 37: Output Report for the 2nd Machine of the 1st line of the system.

Simulation Time 25800		Time in Second									
Warmup Time 0		Length in Millimeter									
Run 1											
Production											
Run	Products					State Times			Average Processing Time	Average Requirement Time	Utilization (%)
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed			
1	5155	1030	5150	1030	0	5154,982	15511,341	5133,678	3,681	10,014	19,981
Products											
Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output		
	Min	Max	Avg								
prd-Interfix to be defined 45904986-00003300.1	5	64,386	18,169	0	5155	5150	0	0	0		
prd-Interfix to be defined 45904986-00004992.1	0	0	0	0	0	0	1030	0	1030		
Operations											
Operation	Count	Processing Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Transform.4	1030	5	5	5	0,288	36,751	15,045				
Failures											
Repairs	Count	Repair Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Repair.1	518	0	3,92	1,059	0	0	0				
Product Inventory											
Raw Material			Work In Process			Finished Product					
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg			
1	5	3,631	0	1	0	0	0	0			
Cycle Time											
Count	Cycle Time										

Figure 38: Output Report for the 2nd Machine of the 2nd line of the system.

- <u>INCREASE THE MTTF OF ALL THE MACHINES BOTH OF THE LINES BY 30%:</u>

Overall:

Production										
System	Products					State Times			Average Processing Time	Average Requirement Time
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed		
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000	5154	5153	5153	5153	0	15459,505	2962,358	7378,137	2,561	0,4
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000	5152	1030	5150	1030	0	5150	15305,855	5344,145	3,675	9,8
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000	5160	5159	5159	5159	0	15477	3351,052	6971,948	2,553	0
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000	5157	1031	5155	1031	0	5155	15674,774	4970,226	3,735	10,2
Storage										
System	Products		Content		Waiting Time			State Times		Utilization (%)
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
Table Cart_1.1	1028	0	1028	512,564	0	0	0	95,141	25704,859	99,6
Table Cart_1.2	1029	0	1029	512,754	0	0	0	81,451	25718,549	99,6
Worker										
Worker Name	Products Transferred	State Times			Distance Travelled	Utilization (%)				
		Idle	Processing	Travelling						
Human00001124.1	0	14876,149	2267,42	8656,431	9,52E+06	42,341				
Human00001149.1	0	15422,61	2172,851	8204,539	9,03E+06	40,222				
Human00001127.1	1028	18675,11	0	7124,89	5,20E+06	27,616				
Human00001148.1	1029	21398,562	0	4401,438	3,21E+06	17,06				
Conveyor										
Conveyor Name	Products Transferred	State Times			Utilization (%)					
		Wait for Input	Wait to Output	Travelling						
COnveyor2.2	5152	15495,495	0	10304,505	39,94					
COnveyor2.4	5152	15496	0	10304	39,938					
COnveyor2.6	5152	15496	0	10304	39,938					
COnveyor2.8	5152	11508,716	4066,64	10224,644	39,63					
COnveyor2.13	1030	23740	0	2060	7,984					
COnveyor2.14	1030	23740	0	2060	7,984					
COnveyor2.15	1029	23740,067	0	2059,933	7,984					
COnveyor2.16	1029	23742	0	2058	7,977					
Conveyor_Curved.1	1029	24329,385	0	1470,615	5,7					

Figure 39: Production Output of the System

Machines:

Simulation Time 25800		Time in Second									
Warmup Time 0		Length in Millimeter									
Run 1											
Production											
Run	Products					State Times			Average Processing Time	Average Requirement Time	Utilization (%)
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed			
1	5152	1030	5150	1030	0	5150	15305,855	5344,145	3,675	9,82	19,961
Products											
Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output		
	Min	Max	Avg								
prd-Interfix to be defined 45904986-00003302.1	5	63,369	18,194	0	5152	5150	0	0	0		
prd-Interfix to be defined 45904986-00004990.1	0	0	0	0	0	0	1030	0	1030		
Operations											
Operation	Count	Processing Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Transform.2	1030	5	5	5	0,288	36	14,854				
Failures											
Repairs	Count	Repair Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Repair.1	528	0,511	4,649	1,09	0	0	0				
Product Inventory											
Raw Material			Work In Process			Finished Product					
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg			
1	5	3,632	0	1	0	0	0	0			
Cycle Time											
Count	Cycle Time										

Figure 40: Output for 2nd machine line.

1	Simulation Time 25800		Time in Second									
2	Warmup Time 0		Length in Millimeter									
3	Run 1											
4												
5												
6	Production											
7												
8	Run	Products					State Times			Average Processing Time	Average Requirement Time	Utilization (%)
9		Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed			
10	1	5157	1031	5155	1031	0	5155	15674,774	4970,226	3,735	10,248	19,981
11												
12	Products											
13												
14	Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output		
15		Min	Max	Avg								
16	prd-Interfix to be defined 45904986-00003300.1	5	65,287	18,045	0	5157	5155	0	0	0		
17	prd-Interfix to be defined 45904986-00004992.1	0	0	0	0	0	0	1031	0	1031		
18												
19	Operations											
20												
21	Operation	Count	Processing Time			Requirement Time						
22			Min	Max	Avg	Min	Max	Avg				
23	Transform.4	1031	5	5	5	0,288	36	15,198				
24												
25	Failures											
26												
27	Repairs	Count	Repair Time			Requirement Time						
28			Min	Max	Avg	Min	Max	Avg				
29	Repair.1	498	0,111	3,702	1,115	0	0	0				
30												
31	Product Inventory											
32												
33	Raw Material			Work In Process			Finished Product					
34	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg			
35	1	5	3,606	0	1	0	0	0	0			
36												
37	Cycle Time											
38												
39	Count	Cycle Time										

Figure 41: Output for 2nd Machine Line 2.

- <u>MANUAL TRANSFERRING OF THE PRODUCTS IN THE BEGINNING OF THE SYSTEM:</u>

Overall:

System	Products Arrived									
In Zone.1	5160									
In Zone.2	5160									
Production										
System	Products					State Times			Average Processing Time	Average Requirement Time
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed		
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000	2170	2169	2169	2169	0	6507,639	17910,871	1381,491	2,56	6,34
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000	2168	433	2165	433	0	2165	20415,697	3219,303	3,641	30,82
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000	1690	1689	1689	1689	0	5067,697	19582,801	1149,501	2,553	8,84
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000	1689	337	1685	337	0	1685	21944,049	2170,951	3,689	42,58
Storage										
System	Products		Content		Waiting Time			State Times		
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	Full / No Reorder
Dare Move Iron.1	2171	2170	5	3,193	1,412	99,909	37,939	8,588	21,412	257
Table Cart_1.1	432	0	432	215,408	0	0	0	122,527	25677,473	
Dare Move Iron.2	1691	1690	5	3,21	0,984	114,772	48,96	9,016	20,984	257
Table Cart_1.2	337	0	337	167,724	0	0	0	121,84	25678,16	
Worker										
Worker Name	Products Transferred	State Times			Distance Travelled	Utilization (%)				
		Idle	Processing	Travelling						
Human00001124.1	2170	6051,569	955,928	18792,503	1,37E+07	76,544				
Human00001149.1	1690	4700,039	792,027	20307,934	1,48E+07	81,783				
Human00001127.1	432	23410,561	0	2389,439	1,74E+06	9,261				
Human00001148.1	337	24236,546	0	1563,454	1,14E+06	6,06				
Conveyor										
Conveyor Name	Products Transferred	State Times			Utilization (%)					
		Wait for Input	Wait to Output	Travelling						
COnveyor2.2	2169	21462	0	4338	16,814					
COnveyor2.4	2169	21462	0	4338	16,814					
COnveyor2.6	2169	21462	0	4338	16,814					
COnveyor2.8	2168	19499,836	1963,213	4336,951	16,81					

Figure 42: Manual Transferring From Source Output Report.

Machines:

Production											
Run	Products					State Times			Average Processing Time	Average Requirement Time	Utilization (%)
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed			
1	1689	337	1685	337	0	1685	21944,049	2170,951	3,689	42,581	6,531
Products											
Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output		
	Min	Max	Avg								
prd-Interfix to be defined 45904986-00003300.1	5	127,8	39,644	0	1689	1685	0	0	0		
prd-Interfix to be defined 45904986-00004992.1	0	0	0	0	0	0	337	0	337		
Operations											
Operation	Count	Processing Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Transform.4	337	5	5	5	41,854	75,969	64,945				
Failures											
Repairs	Count	Repair Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Repair.1	177	1,182	4,234	1,192	0	0	0				
Product Inventory											
Raw Material			Work In Process			Finished Product					
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg			
1	5	2,593	0	1	0	0	0	0			
Cycle Time											
Count	Cycle Time										
	Min	Max	Avg								
337	56,476	136,012	76,387								

Figure 43: Second Machine Second Line Output.

Workers Reports:

Simulation Time 25800		Time in Second				
Warmup Time 0		Length in Millimeter				
Run 1						
Worker						
Run	Products Transferred	State Times			Distance Travelled	Utilization (%)
		Idle	Processing	Travelling		
1	2170	6051,569	955,928	18792,503	1,37E+07	76,544
Products						
Product	Waiting Time			Initial	Input	Output
	Min	Max	Avg			
prd-Interfix to be defined 45904986-00003302.1	4,097	4,097	4,097	0	2170	2170

Figure 44: Worker 1 First Line

Simulation Time 25800		Time in Second				
Warmup Time 0		Length in Millimeter				
Run 1						
Worker						
Run	Products Transferred	State Times			Distance Travelled	Utilization (%)
		Idle	Processing	Travelling		
1	1690	4700,039	792,027	20307,934	1,48E+07	81,783
Products						
Product	Waiting Time			Initial	Input	Output
	Min	Max	Avg			
prd-Interfix to be defined 45904986-00003300.1	6,138	6,138	6,138	0	1690	1690

Figure 45: Worker 2 Second Line

Simulation Time 25800		Time in Second					
Warmup Time 0		Length in Millimeter					
Run 1							
Worker							
Run	Products Transferred	State Times		Distance Travelled	Utilization (%)		
		Idle	Travelling				
1	432	23410,561	2389,439	1,74E+06	9,261		
Products							
Product	Waiting Time			Initial	Input	Output	
	Min	Max	Avg				
prd-Interfix to be defined 45904986-00004990.1	3,322	3,322	3,322	0	433	432	

Figure 46: Worker 1 Terminal 1

Simulation Time 25800		Time in Second					
Warmup Time 0		Length in Millimeter					
Run 1							
Worker							
Run	Products Transferred	State Times		Distance Travelled	Utilization (%)		
		Idle	Travelling				
1	337	24236,546	1563,454	1,14E+06	6,06		
Products							
Product	Waiting Time			Initial	Input	Output	
	Min	Max	Avg				
prd-Interfix to be defined 45904986-00004992.1	2,791	2,791	2,791	0	337	337	

Figure 47: Worker 2 Terminal 2

Buffer Reports:

Simulation Time 25800		Time in Second								
Warmup Time 0		Length in Millimeter								
Run 1										
Storage										
Run	Products		Content		Waiting Time			State Times		Utilization (%)
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
1	432	0	432	215,408	0	0	0	122,527	25677,473	99,525
Products										
Product	Waiting Time			Initial	Input	Output				
	Min	Max	Avg							
prd-Interfix to be defined 45904986-00004990.1	0	0	0	0	432	0				
Product Inventory										
Raw Material			Work In Process			Finished Product				
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg		
0	0	0	1	432	215,408	0	0	0		

Figure 48: Buffer 1 - Terminal 1

Simulation Time 25800		Time in Second								
Warmup Time 0		Length in Millimeter								
Run 1										
Storage										
Run	Products		Content		Waiting Time			State Times		Utilization (%)
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
1	337	0	337	167,724	0	0	0	121,84	25678,16	99,528
Products										
Product	Waiting Time			Initial	Input	Output				
	Min	Max	Avg							
prd-Interfix to be defined 45904986-00004992.1	0	0	0	0	337	0				
Product Inventory										
Raw Material			Work In Process			Finished Product				
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg		
0	0	0	1	337	167,724	0	0	0		

Figure 49: Buffer 2 - Terminal 2

- <u>AUTOMATIC TRANSFERRING OF PRODUCTS TO THE TERMINAL BUFFERS:</u>

Overall:

Production

System	Products					State Times			Average Processing Time	Average Requirement Tim
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed		
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5158	5157	5157	5157	0	15471,675	2917,928	7410,397	2,556	0,4
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5155	1030	5150	1030	0	5151,017	15313,902	5335,081	3,699	9,9
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5157	5156	5156	5156	0	15469,012	3201,6	7129,388	2,558	0,4
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5155	1031	5155	1031	0	5155	15531,864	5113,136	3,696	10,

Storage

System	Products		Content		Waiting Time			State Times		Utilization (%)
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
Table Cart_1.1	1029	0	1029	512,807	0	0	0	88,011	25711,989	99,6
Table Cart_1.2	1029	0	1029	512,894	0	0	0	78,508	25721,492	99,6

Worker

Worker Name	Products Transferred	State Times			Distance Travelled	Utilization (%)
		Idle	Processing	Travelling		
Human00001124.1	0	14955,419	2216,12	8628,461	9,49E+06	42,033
Human00001149.1	0	15279,879	2176,403	8343,718	9,18E+06	40,776

Conveyor

Conveyor Name	Products Transferred	State Times			Utilization (%)
		Wait for Input	Wait to Output	Travelling	
COnveyor2.2	5157	15486	0	10314	39,977
COnveyor2.4	5156	15486,745	0	10313,255	39,974
COnveyor2.6	5156	15488	0	10312	39,969
COnveyor2.8	5155	11528,884	4040,346	10230,77	39,654
COnveyor2.13	1030	23740	0	2060	7,984
COnveyor2.14	1030	23740	0	2060	7,984
COnveyor2.15	1030	23740	0	2060	7,984
COnveyor2.16	1030	23740	0	2060	7,984
Conveyor_Curved.1	1030	24327,955	0	1472,045	5,706
-ImportedAsNewCoffeeQJ9 Conveyor_Base_Straigth.1	1030	23740	0	2060	7,984
Conveyor_Vert.1	1029	23740,104	0	2059,896	7,984

Figure 50: Output of automatic transferring from terminals to the buffers.

Workers Reports:

Simulation Time 25800		Time in Second				
Warmup Time 0		Length in Millimeter				
Run 1						
Worker						
Run	Products Transferred	State Times			Distance Travelled	Utilization (%)
		Idle	Processing	Travelling		
1	0	14955,419	2216,12	8628,461	9,49E+06	42,033

Figure 51: Repairman line 1

Simulation Time 25800		Time in Second				
Warmup Time 0		Length in Millimeter				
Run 1						
Worker						
Run	Products Transferred	State Times			Distance Travelled	Utilization (%)
		Idle	Processing	Travelling		
1	0	15279,879	2176,403	8343,718	9,18E+06	40,776

Figure 52: Repairman 2 - Line 2

Machines:

Production											
Run	Products					State Times			Average Processing Time	Average Requirement Time	Utilization (%)
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed			
1	2168	433	2165	433	0	2165	20415,697	3219,303	3,641	30,823	8,391
Products											
Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output		
	Min	Max	Avg								
prd-Interfix to be defined 45904986-00003302.1	5	110,988	34,167	0	2168	2165	0	0	0		
prd-Interfix to be defined 45904986-00004990.1	0	0	0	0	0	0	433	0	433		
Operations											
Operation	Count	Processing Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Transform.2	433	5	5	5	29,654	60,775	47,053				
Failures											
Repairs	Count	Repair Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Repair.1	228	0	3,399	1,061	0	0	0				
Product Inventory											
Raw Material			Work In Process			Finished Product					
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg			
1	5	2,87	0	1	0	0	0	0			
Cycle Time											
Count	Cycle Time										
	Min	Max	Avg								
433	34,654	115,804	59,487								

Production											
Run	Products					State Times			Average Processing Time	Average Requirement Time	Utilization (%)
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed			
1	5155	1030	5150	1030	0	5151,017	15313,902	5335,081	3,699	9,905	19,965
Products											
Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output		
	Min	Max	Avg								
prd-Interfix to be defined 45904986-00003302.1	5	67,006	18,334	0	5155	5150	0	0	0		
prd-Interfix to be defined 45904986-00004990.1	0	0	0	0	0	0	1030	0	1030		
Operations											
Operation	Count	Processing Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Transform.2	1030	5	5	5	0,288	36	14,853				
Failures											
Repairs	Count	Repair Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Repair.1	515	0,245	4,649	1,097	0	0	0				
Product Inventory											
Raw Material			Work In Process			Finished Product					
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg			
1	5	3,662	0	1	0	0	0	0			
Cycle Time											
Count	Cycle Time										
	Min	Max	Avg								
1030	5,288	67,006	25,036								

Figure 53: Production of Second Machine from Line 1.

Production											
Run	Products					State Times			Average Processing Time	Average Requirement Time	Utilization (%)
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed			
1	5155	1031	5155	1031	0	5155	15531,864	5113,136	3,696	10,057	19,981
Products											
Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output		
	Min	Max	Avg								
prd-Interfix to be defined 45904986-00003300.1	5	59,961	18,157	0	5155	5155	0	0	0		
prd-Interfix to be defined 45904986-00004992.1	0	0	0	0	0	0	1031	0	1031		
Operations											
Operation	Count	Processing Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Transform.4	1031	5	5	5	0,288	36	15,061				
Failures											
Repairs	Count	Repair Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Repair.1	513	0,015	3,76	1,076	0	0	0				
Product Inventory											
Raw Material			Work In Process			Finished Product					
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg			
0	5	3,628	0	1	0	0	0	0			
Cycle Time											
Count	Cycle Time										
	Min	Max	Avg								
1031	5,288	59,961	25,02								

Figure 54: Production of Second Machine from Line 2.

Buffers Reports:

Simulation Time 25800		Time in Second								
Warmup Time 0		Length in Millimeter								
Run 1										
Storage										
Run	Products		Content		Waiting Time			State Times		Utilization (%)
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
1	1029	0	1029	512,807	0	0	0	88,011	25711,989	99,659
Products										
Product	Waiting Time			Initial	Input	Output				
	Min	Max	Avg							
prd-Interfix to be defined 45904986-00004990.1	0	0	0	0	1029	0				
Product Inventory										
Raw Material			Work In Process			Finished Product				
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg		
0	0	0	1	1029	512,807	0	0	0		

Figure 55: Buffer 1 - Automatic Transportation of Products to Terminals

Simulation Time 25800		Time in Second								
Warmup Time 0		Length in Millimeter								
Run 1										
Storage										
Run	Products		Content		Waiting Time			State Times		Utilization (%)
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
1	1029	0	1029	512,894	0	0	0	78,508	25721,492	99,696
Products										
Product	Waiting Time			Initial	Input	Output				
	Min	Max	Avg							
prd-Interfix to be defined 45904986-00004992.1	0	0	0	0	1029	0				
Product Inventory										
Raw Material			Work In Process			Finished Product				
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg		
0	0	0	1	1029	512,894	0	0	0		

Figure 56: Buffer 2- Automatic Transportation of Products to Terminals

- <u>INCREASE OF TRANSPORTATION SPEED OF THE EMPLOYEES IN THE TERMINALS:</u>

Overall:

System	Products Arrived									
In Zone.1	5160									
In Zone.2	5160									
Production										
System	Products					State Times			Average Processing Time	Average Requirement Tim
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed		
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5160	5159	5159	5159	0	15477	2790,439	7532,561	2,555	0,4
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5155	1030	5150	1030	0	5152,836	15378,855	5268,309	3,685	9,9
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5160	5159	5159	5159	0	15477	3230,654	7092,346	2,555	0,4
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5155	1030	5150	1030	0	5154,982	15511,341	5133,678	3,681	10,0
Storage										
System	Products		Content		Waiting Time			State Times		Utilization (%)
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
Table Cart_1.1	1028	0	1028	512,567	0	0	0	95,078	25704,922	99,6
Table Cart_1.2	1029	0	1029	512,732	0	0	0	81,433	25718,567	99,6
Worker										
Worker Name	Products Transferred	State Times			Distance Travelled	Utilization (%)				
		Idle	Processing	Travelling						
Human00001124.1	0	14868,942	2303,301	8627,757	9,49E+06	42,368				
Human00001149.1	0	15285,061	2114,832	8400,107	9,24E+06	40,756				
Human00001127.1	1028	19148,565	0	6651,435	4,86E+06	25,781				
Human00001148.1	1029	21691,012	0	4108,988	3,00E+06	15,926				
Conveyor										
Conveyor Name	Products Transferred	State Times			Utilization (%)					
		Wait for Input	Wait to Output	Travelling						
COnveyor2.2	5159	15482	0	10318	39,992					
COnveyor2.4	5158	15484	0	10316	39,984					
COnveyor2.6	5158	15484	0	10316	39,984					
COnveyor2.8	5155	11479,836	4085,825	10234,338	39,668					
COnveyor2.13	1030	23740	0	2060	7,984					
COnveyor2.14	1030	23740	0	2060	7,984					

Figure 57: Productivity Output for the System

Machines:

Simulation Time 25800		Time in Second									
Warmup Time 0		Length in Millimeter									
Run 1											
Production											
Run	Products					State Times			Average Processing Time	Average Requirement Time	Utilization (%)
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed			
1	5155	1030	5150	1030	0	5152,836	15378,855	5268,309	3,685	9,954	19,972
Products											
Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output		
	Min	Max	Avg								
prd-Interfix to be defined 45904986-00003302.1	5	62,201	18,167	0	5155	5150	0	0	0		
prd-Interfix to be defined 45904986-00004990.1	0	0	0	0	0	0	1030	0	1030		
Operations											
Operation	Count	Processing Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Transform.2	1030	5	5	5	0,288	36	14,916				
Failures											
Repairs	Count	Repair Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Repair.1	514	1,199	3,898	1,051	0	0	0				
Product Inventory											
Raw Material			Work In Process			Finished Product					
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg			
1	5	3,63	0	1	0	0	0	0			
Cycle Time											
Count	Cycle Time										

Figure 58: Productivity Output for the 2nd machine of the 1st line.

Simulation Time 25800		Time in Second									
Warmup Time 0		Length in Millimeter									
Run 1											
Production											
Run	Products					State Times			Average Processing Time	Average Requirement Time	Utilization (%)
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed			
1	5155	1030	5150	1030	0	5154,982	15511,341	5133,678	3,681	10,014	19,981
Products											
Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output		
	Min	Max	Avg								
prd-Interfix to be defined 45904986-00003300.1	5	64,386	18,169	0	5155	5150	0	0	0		
prd-Interfix to be defined 45904986-00004992.1	0	0	0	0	0	0	1030	0	1030		
Operations											
Operation	Count	Processing Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Transform.4	1030	5	5	5	0,288	36,751	15,045				
Failures											
Repairs	Count	Repair Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Repair.1	518	0	3,92	1,059	0	0	0				
Product Inventory											
Raw Material			Work In Process			Finished Product					
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg			
1	5	3,631	0	1	0	0	0	0			
Cycle Time											
Count	Cycle Time										

Figure 59: Productivity Outcome of the 2nd machine from Line 2.

Workers Reports:

Simulation Time 25800		Time in Second				
Warmup Time 0		Length in Millimeter				
Run 1						
Worker						
Run	Products Transferred	State Times			Distance Travelled	Utilization (%)
		Idle	Processing	Travelling		
1	0	14868,942	2303,301	8627,757	9,49E+06	42,368

Figure 60: Repairman 1 - line 1

Simulation Time 25800		Time in Second				
Warmup Time 0		Length in Millimeter				
Run 1						
Worker						
Run	Products Transferred	State Times			Distance Travelled	Utilization (%)
		Idle	Processing	Travelling		
1	0	15285,061	2114,832	8400,107	9,24E+06	40,756

Figure 61: Repairman 2 - line 2

Simulation Time 25800		Time in Second				
Warmup Time 0		Length in Millimeter				
Run 1						
Worker						
Run	Products Transferred	State Times		Distance Travelled	Utilization (%)	
		Idle	Travelling			
1	1028	19148,565	6651,435	4,86E+06	25,781	
Products						
Product	Waiting Time			Initial	Input	Output
	Min	Max	Avg			
prd-Interfix to be defined 45904986-00004990.1	4,167	4,167	4,167	0	1028	1028

Figure 62: Terminal Employee 1

Simulation Time 25800		Time in Second				
Warmup Time 0		Length in Millimeter				
Run 1						
Worker						
Run	Products Transferred	State Times		Distance Travelled	Utilization (%)	
		Idle	Travelling			
1	1029	21691,012	4108,988	3,00E+06	15,926	
Products						
Product	Waiting Time			Initial	Input	Output
	Min	Max	Avg			
prd-Interfix to be defined 45904986-00004992.1	2,572	2,572	2,572	0	1029	1029

Figure 63: Terminal Employee 2

Buffers Reports:

Simulation Time 25800		Time in Second								
Warmup Time 0		Length in Millimeter								
Run 1										
Storage										
Run	Products		Content		Waiting Time			State Times		Utilization (%)
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
1	1028	0	1028	512,567	0	0	0	95,078	25704,922	99,631
Products										
Product	Waiting Time			Initial	Input	Output				
	Min	Max	Avg							
prd-Interfix to be defined 45904986-00004990.1	0	0	0	0	1028	0				
Product Inventory										
Raw Material			Work In Process			Finished Product				
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg		
0	0	0	1	1028	512,567	0	0	0		

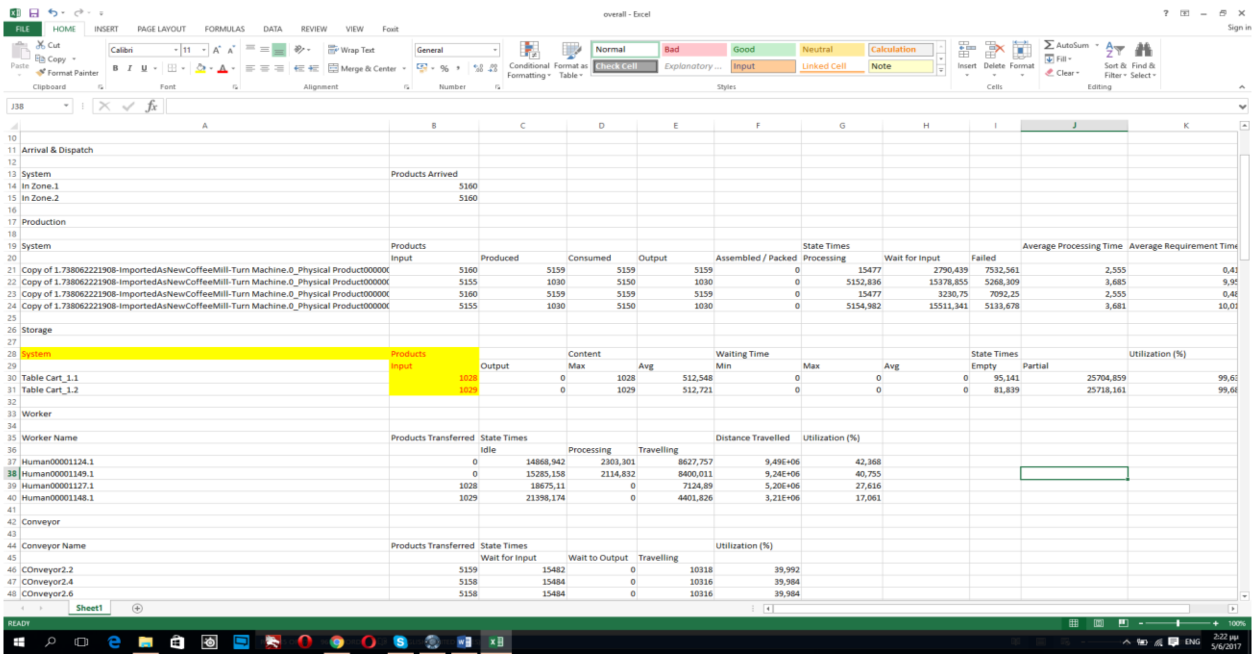
Figure 64: Buffer 1 – Terminal 1

Simulation Time 25800		Time in Second								
Warmup Time 0		Length in Millimeter								
Run 1										
Storage										
Run	Products		Content		Waiting Time			State Times		Utilization (%)
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
1	1029	0	1029	512,732	0	0	0	81,433	25718,567	99,684
Products										
Product	Waiting Time			Initial	Input	Output				
	Min	Max	Avg							
prd-Interfix to be defined 45904986-00004992.1	0	0	0	0	1029	0				
Product Inventory										
Raw Material			Work In Process			Finished Product				
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg		
0	0	0	1	1029	512,732	0	0	0		

Figure 65: Buffer 2 - Terminal 2

- <u>DECREASE THE REPAIR TIME OF THE EQUIPMENT:</u>

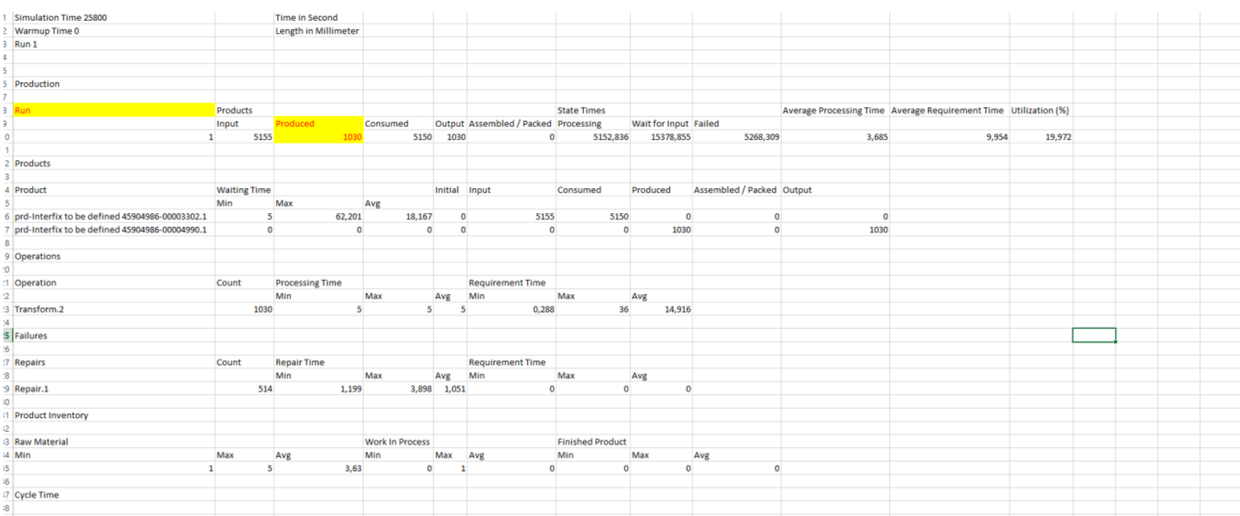
Overall:



Arrival & Dispatch										
System	Products Arrived									
In Zone.1	5160									
In Zone.2	5160									
Production										
System	Products					State Times			Average Processing Time	Average Requirement Time
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed		
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000	5160	5159	5159	5159	0	15477	2790,439	7532,561	2,555	0,41
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000	5155	1030	5150	1030	0	5152,836	15378,855	5268,309	3,685	9,95
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000	5160	5159	5159	5159	0	15477	3230,75	7092,25	2,555	0,48
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000	5155	1030	5150	1030	0	5154,982	15511,341	5133,678	3,681	10,01
Storage										
System	Products		Content		Waiting Time			State Times		Utilization (%)
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
Table Cart_1.1	1028	0	1028	512,548	0	0	0	95,141	25704,859	99,63
Table Cart_1.2	1029	0	1029	512,721	0	0	0	81,839	25718,161	99,68
Worker										
Worker Name	Products Transferred	State Times			Distance Travelled	Utilization (%)				
		Idle	Processing	Travelling						
Human00001124.1	0	14868,942	2303,301	8627,757	9,49E+06	42,368				
Human00001149.1	0	15285,158	2114,832	8400,011	9,24E+06	40,755				
Human00001127.1	1028	18675,11	0	7124,89	5,20E+06	27,616				
Human00001148.1	1029	21398,174	0	4401,826	3,21E+06	17,061				
Conveyor										
Conveyor Name	Products Transferred	State Times			Utilization (%)					
		Wait for Input	Wait to Output	Travelling						
COnveyor2.2	5159	15482	0	10318	39,992					
COnveyor2.4	5158	15484	0	10316	39,984					
COnveyor2.6	5158	15484	0	10316	39,984					

Figure 66: Productivity Output for the System

Machines:



Simulation Time 25800		Time in Second									
Warmup Time 0		Length in Millimeter									
Run 1											
Production											
Run	Products					State Times			Average Processing Time	Average Requirement Time	Utilization (%)
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed			
1	5155	1030	5150	1030	0	5152,836	15378,855	5268,309	3,685	9,954	19,972
Products											
Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output		
	Min	Max	Avg								
prd-Interfix to be defined 45904986-00003302.1	5	62,201	18,167	0	5155	5150	0	0	0		
prd-Interfix to be defined 45904986-00004990.1	0	0	0	0	0	0	1030	0	1030		
Operations											
Operation	Count	Processing Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Transform.2	1030	5	5	5	0,288	36	14,916				
Failures											
Repairs	Count	Repair Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Repair.1	514	1,199	3,898	1,051	0	0	0				
Product Inventory											
Raw Material			Work In Process			Finished Product					
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg			
1	5	3,63	0	1	0	0	0	0			
Cycle Time											
Count	Cycle Time										

Figure 67: Productivity output for the 2nd machine of the 1st line.

Simulation Time 25800		Time in Second									
Warmup Time 0		Length in Millimeter									
Run 1											
Production											
Run	Products					State Times			Average Processing Time	Average Requirement Time	Utilization (%)
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Failed			
1	5155	1030	5150	1030	0	5154,982	15511,341	5133,678	3,681	10,014	19,981
Products											
Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output		
	Min	Max	Avg								
prd-Interfix to be defined 45904986-00003300.1	5	64,386	18,169	0	5155	5150	0	0	0		
prd-Interfix to be defined 45904986-00004992.1	0	0	0	0	0	0	1030	0	1030		
Operations											
Operation	Count	Processing Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Transform.4	1030	5	5	5	0,288	36,751	15,045				
Failures											
Repairs	Count	Repair Time			Requirement Time						
		Min	Max	Avg	Min	Max	Avg				
Repair.1	518	0	3,92	1,059	0	0	0				
Product Inventory											
Raw Material			Work In Process			Finished Product					
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg			
1	5	3,631	0	1	0	0	0	0			
Cycle Time											
Count	Cycle Time										

Figure 68: Productivity Output for the 2nd machine of the 2nd line

Workers Reports:

A	B	C	D	E	F	G
Simulation Time 25800		Time in Second				
Warmup Time 0		Length in Millimeter				
Run 1						
Worker						
Run	Products Transferred	State Times			Distance Travelled	Utilization (%)
		Idle	Processing	Travelling		
1	0	14868,942	2303,301	8627,757	9,49E+06	42,368

Figure 69: Repairman 1 - Line 1

Simulation Time 25800		Time in Second				
Warmup Time 0		Length in Millimeter				
Run 1						
Worker						
Run	Products Transferred	State Times			Distance Travelled	Utilization (%)
		Idle	Processing	Travelling		
1	0	15285,158	2114,832	8400,011	9,24E+06	40,755

Figure 70: Repairman 2 - Line 2

Simulation Time 25800		Time in Second				
Warmup Time 0		Length in Millimeter				
Run 1						
Worker						
Run	Products Transferred	State Times		Distance Travelled	Utilization (%)	
		Idle	Travelling			
1	1028	18675,11	7124,89	5,20E+06	27,616	
Products						
Product	Waiting Time			Initial	Input	Output
	Min	Max	Avg			
prd-Interfix to be defined 45904986-00004990.1	4,167	4,167	4,167	0	1028	1028

Figure 71: Terminal Worker 1

Simulation Time 25800		Time in Second				
Warmup Time 0		Length in Millimeter				
Run 1						
Worker						
Run	Products Transferred	State Times		Distance Travelled	Utilization (%)	
		Idle	Travelling			
1	1029	21398,174	4401,826	3,21E+06	17,061	
Products						
Product	Waiting Time			Initial	Input	Output
	Min	Max	Avg			
prd-Interfix to be defined 45904986-00004992.1	2,572	2,572	2,572	0	1029	1029

Figure 72: Terminal Worker 2

Buffers Reports:

Simulation Time 25800		Time in Second								
Warmup Time 0		Length in Millimeter								
Run 1										
Storage										
Run	Products		Content		Waiting Time			State Times		Utilization (%)
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
1	1028	0	1028	512,548	0	0	0	95,141	25704,859	99,631
Products										
Product	Waiting Time			Initial	Input	Output				
	Min	Max	Avg							
prd-Interfix to be defined 45904986-00004990.1	0	0	0	0	1028	0				
Product Inventory										
Raw Material			Work In Process			Finished Product				
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg		
0	0	0	1	1028	512,548	0	0	0		

Figure 73: Buffer 1 - Terminal 1

	A	B	C	D	E	F	G	H	I	J	K
1	Simulation Time 25800		Time in Second								
2	Warmup Time 0		Length in Millimeter								
3	Run 1										
4											
5											
6	Storage										
7											
8	Run	Products		Content		Waiting Time			State Times		Utilization (%)
9		Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
10	1	1029	0	1029	512,721	0	0	0	81,839	25718,161	99,683
11											
12	Products										
13											
14	Product	Waiting Time			Initial	Input	Output				
15		Min	Max	Avg							
16	prd-Interfix to be defined 45904986-00004992.1	0	0	0	0	1029	0				
17											
18	Product Inventory										
19											
20	Raw Material			Work In Process			Finished Product				
21	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg		
22	0	0	0	1	1029	512,721	0	0	0		

Figure 74: Buffer 2 - Terminal 2

- <u>CAPACITY EXPAND OF THE FIRST MACHINES OF EACH LINE:</u>

Overall:

Arrival & Dispatch

System	Products Arrived
In Zone.1	5160
In Zone.2	5160

Production

System	Products					State Times				Average Processing Time	Average Rec
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Wait to Output	Failed		
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5160	5155	5155	5155	0	3093	19532,93	296,845	2877,225	2,548	
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5155	1030	5150	1030	0	5153,734	17648,734	0	2997,531	3,696	
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5160	5155	5155	5155	0	3093	19684,527	296,845	2725,627	2,544	
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5155	1031	5155	1031	0	5155	17760,704	0	2884,296	3,714	

Storage

System	Products		Content		Waiting Time			State Times		Utilization (%)
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial	
Table Cart_1.1	1029	0	1029	512,809	0	0	0	97,028	25702,972	99,624
Table Cart_1.2	1028	0	1028	512,961	0	0	0	81,494	25718,506	99,684

Worker

Worker Name	Products Transferred	State Times			Distance Travelled	Utilization (%)
		Idle	Processing	Travelling		
Human00001124.1	0	20062,358	945,65	4791,992	5,27E+06	22,239
Human00001149.1	0	20289,589	895,872	4614,539	5,08E+06	21,358
Human00001127.1	1029	18668,177	0	7131,823	5,21E+06	27,643
Human00001148.1	1028	21400,925	0	4399,075	3,21E+06	17,051

Conveyor

Conveyor Name	Products Transferred	State Times			Utilization (%)
		Wait for Input	Wait to Output	Travelling	
COnveyor2.2	5155	23441,155	0	2358,845	9,143
COnveyor2.4	5155	23441,155	0	2358,845	9,143
COnveyor2.6	5155	23441,155	0	2358,845	9,143

Figure 75: System's output for the capacity increase scenario of the 1st Machines for each line.

- <u>CAPACITY EXPAND OF THE FIRST MACHINES OF EACH LINE:</u>

Overall:

Production											
System	Products					State Times				Average Processing Time	Average Rec
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Wait to Output	Failed		
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5160	5155	5155	5155	0	3093	20357,93	296,845	2052,224	2,559	
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5155	1030	5150	1030	0	2575	20923,263	288,4	2013,337	3,729	
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5160	5155	5155	5155	0	3093	20301,131	296,845	2109,023	2,565	
Copy of 1.738062221908-ImportedAsNewCoffeeMill-Turn Machine.0_Physical Product00000(	5155	1030	5150	1030	0	2575	20885,885	288,4	2050,715	3,657	
Storage											
System	Products		Content		Waiting Time			State Times		Utilization (%)	
	Input	Output	Max	Avg	Min	Max	Avg	Empty	Partial		
Table Cart_1.1	1027	0	1027	519,263	0	0	0	102,339	25697,661	99,603	
Table Cart_1.2	1029	0	1029	505,318	0	0	0	126,454	25673,546	99,51	
Worker											
Worker Name	Products Transferred	State Times			Distance Travelled	Utilization (%)					
		Idle	Processing	Travelling							
Human00001124.1	0	21757,907	584,727	3457,366	3,80E+06	15,667					
Human00001149.1	0	21665,34	636,97	3497,69	3,85E+06	16,026					
Human00001127.1	1027	18682,043	0	7117,957	5,20E+06	27,589					
Human00001148.1	1029	21398,537	0	4401,463	3,21E+06	17,06					
Conveyor											
Conveyor Name	Products Transferred	State Times			Utilization (%)						
		Wait for Input	Wait to Output	Travelling							
COnveyor2.2	5155	23441,155	0	2358,845	9,143						
COnveyor2.4	5155	23441,155	0	2358,845	9,143						
COnveyor2.6	5155	23441,155	0	2358,845	9,143						
COnveyor2.8	5155	23422,175	18,979	2358,845	9,143						
COnveyor2.13	1030	24481,6	0	1318,4	5,11						
COnveyor2.14	1030	24481,6	0	1318,4	5,11						
COnveyor2.15	1030	24481,6	0	1318,4	5,11						
COnveyor2.16	1030	24481,6	0	1318,4	5,11						
Conveyor_Curved.1	1030	24775,578	0	1024,422	3,971						

Figure 76: Productivity Output for the scenario of increasing the output of both machines for each line in the system.

Machines:

Simulation Time 25800		Time in Second										
Warmup Time 0		Length in Millimeter										
Run 1												
Production												
Run	Products					State Times				Average Processing Time	Average Requirement Time	Utilization (%)
	Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Wait to Output	Failed			
1	5155	1030	5150	1030	0	2575	20923,263	288,4	2013,337	3,729	27,343	9,981
Products												
Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output			
	Min	Max	Avg									
prd-Interfix to be defined 45904986-00003302.1	5	60,111	21,268	0	5155	5150	0	0	0			
prd-Interfix to be defined 45904986-00004990.1	0,56	0,56	0,28	0	0	0	1030	0	1030			
Operations												
Operation	Count	Processing Time			Requirement Time							
		Min	Max	Avg	Min	Max	Avg					
Transform.2	515	5	5	5	14,617	61,288	40,563					
Failures												
Repairs	Count	Repair Time			Requirement Time							
		Min	Max	Avg	Min	Max	Avg					
Repair.1	249	0,031	3,705	1,1	0	0	0					
Product Inventory												
Raw Material			Work In Process			Finished Product						
Min	Max	Avg	Min	Max	Avg	Min	Max	Avg				
1	10	4,248	0	2	0,011	0	0	0				
Cycle Time												
Count	Cycle Time											

Figure 77: Productivity Output for the 2nd Macine of the 1st line of the system.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Simulation Time 25800		Time in Second										
2	Warmup Time 0		Length in Millimeter										
3	Run 1												
4													
5													
6	Production												
7													
8	Run	Products					State Times				Average Processing Time	Average Requirement Time	Utilization (%)
9		Input	Produced	Consumed	Output	Assembled / Packed	Processing	Wait for Input	Wait to Output	Failed			
10	1	5155	1030	5150	1030	0	2575	20885,885	288,4	2050,715	3,657	26,577	9,981
11													
12	Products												
13													
14	Product	Waiting Time			Initial	Input	Consumed	Produced	Assembled / Packed	Output			
15		Min	Max	Avg									
16	prd-Interfix to be defined 45904986-00003300.1	5	52,974	21,647	0	5155	5150	0	0	0			
17	prd-Interfix to be defined 45904986-00004992.1	0,56	0,56	0,28	0	0	0	1030	0	1030			
18													
19	Operations												
20													
21	Operation	Count	Processing Time			Requirement Time							
22			Min	Max	Avg	Min	Max	Avg					
23	Transform.4	515	5	5	5	21,406	61,288	40,51					
24													
25	Failures												
26													
27	Repairs	Count	Repair Time			Requirement Time							
28			Min	Max	Avg	Min	Max	Avg					
29	Repair.1	270	0,158	4,108	1,095	0	0	0					
30													
31	Product Inventory												
32													
33	Raw Material			Work In Process			Finished Product						
34	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg				
35	1	10	4,324	0	2	0,011	0	0	0				
36													
37	Cycle Time												
38													
39	Count	Cycle Time											

Figure 78: Productivity Output for the 2nd Machine of the 2nd line of the system.