University of Sarajevo - Mechanical Engineering Faculty
Technische Universität Bergakademie Freiberg
Lappeenranta-Lahti University of Technology LUT

Master's Thesis

THROUGHPUT TIME INCREASE APPLAYING DISCRET EVENT SIMULATION AND THEORY OF CONSTRAINTS

Haris Hodžić, BSc.

Sarajevo, Freiberg, Lappeenranta, May, 2022

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Master's thesis

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Subject and explanation of topic:

Discrete event simulations are widely recognized as powerful toll for investigating the performance and behaviour of manufacturing systems. In order to increase a system efficiency a current bottleneck should be recognized. To deal with a bottleneck theory of constraint could be applied.

In the theses a real manufacturing production of automotive parts or wood products will be modelled for one or more products and with a discrete event simulation software analyzed. Production performance like throughput, cycle time, work in process inventory and idle time of resources will be investigated. As a result of the simulation the bottleneck of the production system will be determined. Theory of constrained methodology will be applied in order to examine, analyze and suggest measures for a reduction of the spotted system constraint or eliminate it in order to increase the throughput time of the manufacturing system.

Mandatory literature:

[1] Rybicka, J.; Tiwari, A. & Enticott, S. (2016) Testing a Flexible Manufacturing System Facility Production Capacity through Discrete Event Simulation: Automotive Case Study. International Journal of Industrial and Manufacturing Engineering, Vol. 10, 719–723.

[2] Mourtzis, D.; Doukas, D. & Bernidaki, D. (2014) Simulation in Manufacturing: Review and Challenges. Elsevier, Procedia CIRP, 25, 213–229.

[3] Ikeziri, L.M. et al. (2019) Theory of constraints: review and bibliometric analysis. International Journal of Production Research, Vol. 57, 5068-5102.

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List of symbols and abbreviations

DES Discrete event simulation

TOC Theory of constraints

SD System Dynamics

Abstract

This master's thesis shows how simulation contributes to the research of bottlenecks and shows how it is possible to improve the production process through a technological solution. Prevent Goražde is a company that works in the automotive textile industry and provides a variety of vehicle seat covers. Britax Roemer baby car seat was used as the case for this thesis, with the goal of identifying a bottleneck in the manual work department and finding a solution to improve throughput and resource management. Theory of constraint (TOC) framework was used to analyse manual work department. The time required to prepare the cutout for labelling was identified as a bottleneck in the existing labelling process. The focus was also to describe simulation models, advantages and disadvantages of simulation models, as well as the analysis of simulations of discrete events in FlexSim.

The simulation has shown that the preparation time of cutouts for labelling can only be improved by using newer machines, which drastically reduce the time required to prepare them. By adding two new labelling machines into the labelling process, it is possible to replace five old machines currently in use and reduce human resources from five to two workers using technological solution. Companies in similar industries, such as the automobile industry, can benefit from the simulation performed in this paper.

Key words: simulation, discrete event simulation (DES), theory of constraints (TOC)

1 INTRODUCTION

The majority of real-world systems are too complicated for analytical evaluation of realistic models and must therefore be examined via simulation. A simulation is a process in which we use a computer to numerically analyze a model and collect data to estimate the model's desired true features. Computers and improvements in technology have resulted in the development of simulation methods. Using simulation approaches and technologies, many real-world processes can be modelled, simulated, and investigated.

A large range of simulation tools are now available, allowing for the comprehensive implementation of simulations of a wide range of production systems and processes. The simulation gives more realistic results and gives an insight into the necessary resources, capacities, time, efficiency, as well as many others.

The term simulation is based on the Latin "simulatio" which means "to pretend, deceive, or overdo," and its meaning is defined by the Latin word "simulacrum," which means "image, apparition, or apparition." Simulation modelling and simulation refers to a wide range of actions that involve creating a model of an actual system and simulating it, usually with the use of a computer. A simulation, as defined by the definition, is a projection of the real state of a process into a computer model of that process in order to generate answers to the following questions:

"What if?":

- What if the product's demand rises?
- What happens if a machine in the production facility breaks down?
- What if the production schedule is altered?
- What if the arrangement of the manufacturing equipment is changed?

Also, there are possible questions to consider when creating a simulation, and these include: what the simulation study is intended to achieve, what is being investigated, what conclusions are drawn from the simulation study solution, how to transfer the simulation study results to a real-world object, and so on. As a result, the simulation is distinguished by a widely applicable method in which a phenomenon is considered as a system that can be investigated further using a computer. As a result, the simulation is particularly beneficial when the observed system is extremely complex, i.e., when it contains a large number of subsystems and links, and some of the quantities are uncertain or unknown.

Simulation modelling has been used to solve problems at the strategic, tactical, and operational levels of management in a wide variety of industries. Simulations have found widespread usage in education and science, as well as in research and industry, where they are used to forecast and plan. Today, simulation is used in a variety of disciplines, including manufacturing, logistics, services, transportation, health, and military. Manufacturing is one of the most used areas, where simulations are used extensively. They are widely utilized in a variety of industries, including automotive, aircraft, specialized, machine production, and electronics. It enables the analysis of complex modern manufacturing processes, the elimination of production bottlenecks, the examination of the possibility of increasing the throughput of the manufacturing plant, the reduction of production inventories, the increase of machine utilization, and the reengineering of business processes.

To create computer simulation models, a variety of methods are available. This Master Thesis is focused only on discrete event simulation (DES). The DES technique is well suited to modelling difficulties such as operational emphasis, projected reductionism, quantitative character, discrete change, and narrow details. However, DES has some significant disadvantages, including its failure to capture the strategic/context of the modelled construction activity and its incapacity to resolve cause-effect feedback loops between project variables (Lee *et al.*, 2007).

To increase production system throughput, the Theory of Constrained (TOC) methodology was used to examine, analyse, and recommend strategies to minimize or remove observed constraints. Because there is always at least one constraint, the TOC uses the focusing process to identify it and restructure the entire organization around it. Everything that restricts the system from reaching its exact goal is considered as a constraint.

A manufacturing simulation in the company Prevent Goražde is presented in this study. The simulation was conducted with the aid of the FlexSim software. Software’s like FlexSim can be used to solve discrete issues as well as larger systems.

2 LITERATURE REVIEW

This chapter will include brief summaries of published articles on simulation, simulation modeling and applications of simulation modeling in manufacturing in order to better understand this topic.

One of the definitions of simulation states that it is a time-dependent imitation of an actual process or system. It enables the production of an artificial history for the observed system, as well as the study, observation, and conclusion-drawing based on historical facts that replicate the observed system's operations (Banks et al., 2005). The Figure 2.1 illustrates the historical overview of simulation in detail.

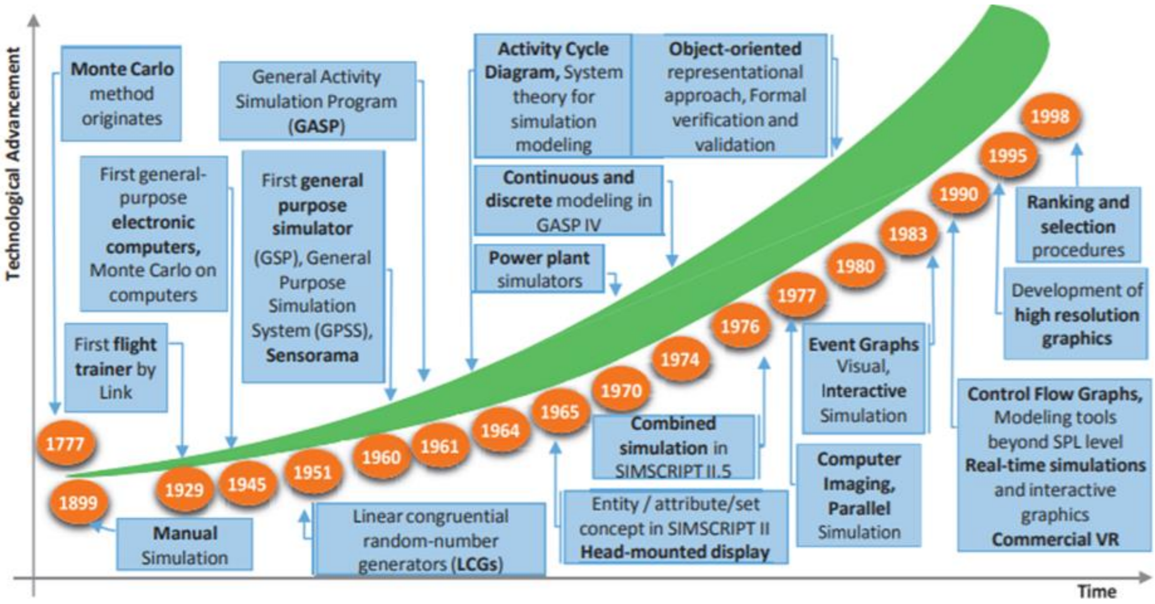


Figure 2.1 Historical Evolution of Simulation

History of simulations can be viewed through three phases or periods. where the first period begins in the time when there were no computers, in the early 1777s, and lasts until 1945, more precisely until the World War II. The second period is also called the formative period, which lasted from 1945 to 1970. And finally, the expansion period, which lasts until 1981, is period where a precise and clear definition of the simulation and the simulation process essentially appears. This is also the age of advances in computer technology that have made it easier to run a simulation. The most significant shift occurred during the formative period, with the development of the first general-purpose electronic computer, followed by Keith Douglas

Tocher's 1960 invention of the first general-purpose simulator as a tool for methodically building a simulation of an industrial plant composed of a collection of machines.

The importance of the use of simulation modeling, and the application of simulations in general, is considered in the work of Mourtzis, Doukas, Bernidaki (2014). The authors emphasize that simulation modeling and analysis are conducted in complex systems with the goal of developing and testing new operational concepts or systems that fit the requirements of modern manufacturing prior to their implementation. This is especially important since the manufacturing environment is evolving at a rapid speed these days as a result of globalization, technological advancements, and new trends. Figure 2.2 shows the basic concept of modeling and simulation in real world.

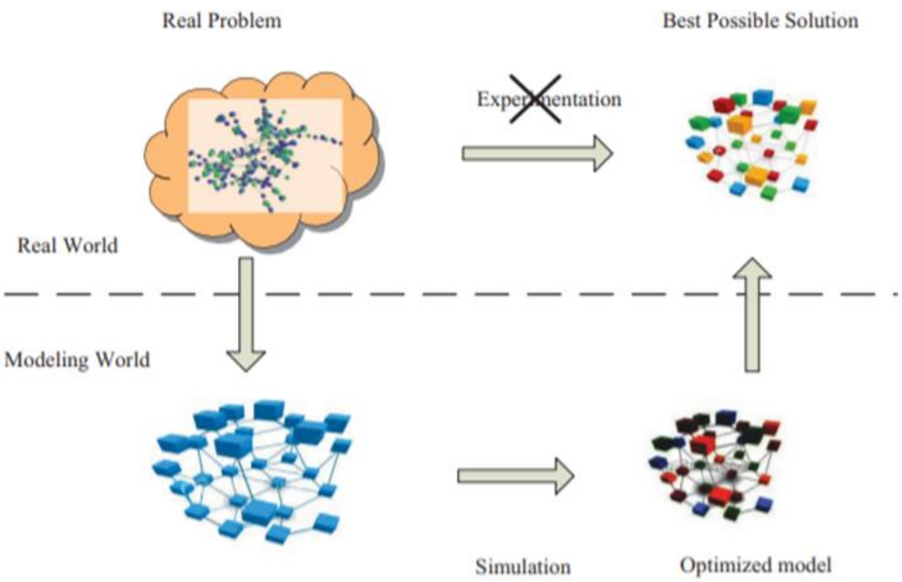


Figure 2.2 Modelling and simulation of real-world problem

Two of the most frequently used definitions of simulation modelling in the manufacturing context are discussed and utilized in their research. Although the definitions were presented a long time ago, all future research, including this, was based on the definitions that Chung (2004) stated in his work. Chung (2004) said that "Simulation modelling and analysis is the process of developing and experimenting with a computerized mathematical model of a physical system." Second definition by Banks, in a very similar way states that simulation is "replication of the behaviour of a real-world process or system over time. Simulation entails creating an artificial history of the system and observing that history in order to derive inferences about the operating characteristics of the real system that is represented” (Banks et al., 2005).

Banks, Carson, Nelson and Nicol (2005) in their book *“Discrete-event system simulation”* also point out that simulation is one of the most commonly used and accepted tools in operations research and system analysis, but there are cases when simulation is not an appropriate tool. As the authors point out, there are ten rules when simulations are not an appropriate tool, and these rules are: simulations should not be used when the problem can be solved by common sense, if the problem can be solved analytically, if it is easier to preform direct experiments, if the costs exceed the savings, if the resources or time are not available ,, if there is not enough time or if the personnel are not available, if managers have unreasonable expectations and if system behavior is too complex or cannot be defined.

Although there are several types of simulation (like continuous ones), their work focuses on discrete event simulation. Discrete event simulation is a technique for simulating systems where the state variable changes only at a discrete collection of time points (Banks et al., 2005). Their article covers theory and examples in order to demonstrate the scope of discrete event simulation's uses and benefits. There are numerous advantages to discrete event simulation. It is largely used to avoid real-world system interruption and to assess various system alternatives to solve an issue, as well as to make decisions on capacity planning, purchasing, strategic planning, training, and technology planning. It enables the analysis of various scenarios when developing new systems or upgrading current ones. The options can be simulated as scenarios, and system performance information from each scenario can be provided for comparison. They presented examples of performance data, like throughput, resource utilization, wait durations and lengths at work stations, required personnel levels, social or environmental performance, and the identification of bottlenecks.

Using simulation, it is possible to investigate the interactions between the variables in a system and their effects on various parameters. Bottleneck analysis can be used to detect where model entities are being delayed, as well as where resources are being overused or underused. Modern simulation software has animation tools that allow developers to visually explain the model to users, including the ability to speed up or slow down time to better perceive changes that occur frequently or infrequently (Banks *et al.*, 2005).

Rybicka, Tiwari and Enticott (2016) used simulations of discrete events for testing the production capacity of a flexible production system in their research. The research demonstrates how discrete event simulation may be used to manage complexity in a flexible manufacturing system and optimize production line performance in the automotive sector. As in the work of Banks and others, a concrete example is presented here through which all steps of the discrete simulation process were carried out, and it gave insight into understanding the impact of system constraints on its performance.

The notion of constraint is fundamental to understanding Theory of constraint (TOC) and its applications. The review and bibliometric analysis of Theory of constraints author's work of Ikeziri, Souza, Gupta and Fiotini (2019) shows and explains the basic concepts of constraints and the theory of constraint, and some of its applications. First of all, the authors referred to the already recognized definition of constraint which is presented by Cox et al., 2012 - TOCICO[1] dictionary defined as the factor that ultimately limits the performance of a system or organization. Every company encounters at least one constraint at any given time. Constraint theory is used to answer the following three questions, which are important for any strategy of continuous improvement: What can be improved?;To what are we changing?; How to cause the change? In the continuation of their work, based on all research and literature reviews, the authors concluded that TOC is in constant development with a rising trend, requiring further study.

[1] Theory of Constraints International Certification Organization - TOCICO

3 SIMULATIONS

3.1 Modelling and simulation

The model is a simplified version of a real system that is used to gain a better understanding of the system and/or to conduct further research and experimentation on it. Modelling is the process of developing (forming) a model. Simulation models are classified into three broad categories based on three fundamental characteristics:

1) change timing,
2) randomness,
3) data organization.

According to the degree of certainty/uncertainty associated with the outcomes, the models can be deterministic and stochastic. The simulation model can also be classified as static or dynamic depending on whether it is time-dependent or not. A static simulation is not time dependent, whereas a dynamic simulation is time dependent. Additionally, dynamic simulation model can be classified as continuous or discrete. Changes occur at discrete points in time in discrete simulations, whereas in continuous simulations, the time variable is continuous (Mourtzis *el al.,* 2014).

There are two types of variables in simulations:

1. Independent variables
2. Dependent variables

Independent variables are those whose values the user enters into the system, while dependent variables are those whose values are obtained as a result of the simulation. Examples of these variables are branch counters. The time between two consecutive arrivals of customers, the time of serving at the counter, the number of counters, the organization of waiting is an independent variable, and the length of the queue in front of the counters, waiting time in line, using the counter, system throughput are dependent variables. As can be seen from definitions, simulations attempt to transfer the true state of the system to the computer system and to make the computer system as close to the real system as feasible. Figure 3.1 shows the simulation procedure's algorithm.

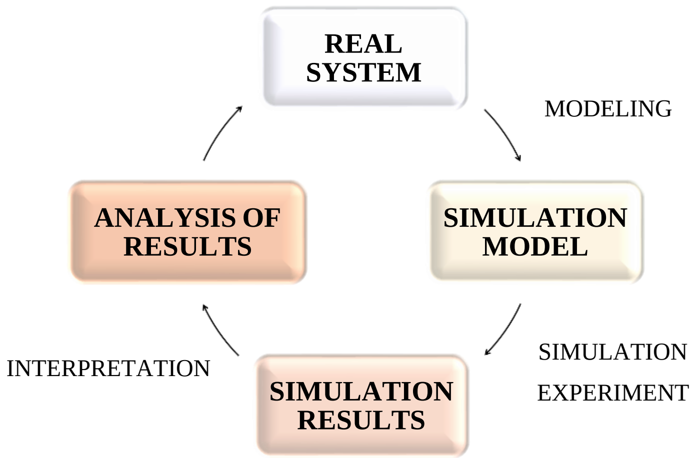


Figure 3.1 Simulation procedure

As illustrated in the Figure 3.1, simulation technique is divided into four stages:

- Original (real) system,
- Simulation model (computer program),
- Results of simulations,
- Analyses of results (meaning for real system)

3.2 Types of simulations

Simulations are divided into:

- Monte Carlo simulations
- Discrete simulations
- Continuous simulations
- Hybrid simulations

These simulations are distinct in their modelling approach, the nature of the problems they address, and the modelling and simulation methodologies they employ. All of the simulations mentioned above are dynamic in nature, with the exception of the Monte Carlo simulation, which is static in nature, but it is necessary to mention it in order to raise awareness of the distinction between this type of simulation. In this Master Thesis, Discrete event simulation was used.

3.2.1 Discrete event simulation

Discrete event simulation (DES) is the process of coding the behaviour of complex systems as a sequence of firmly defined events (Kiran, 2019).

Discrete event simulations are a type of stochastic simulation model, containing elements with random variables. If at least one of the variables in the model exhibits stochastic behaviour, the model becomes stochastic. A change in the state of a system can occur only at discrete points in time.

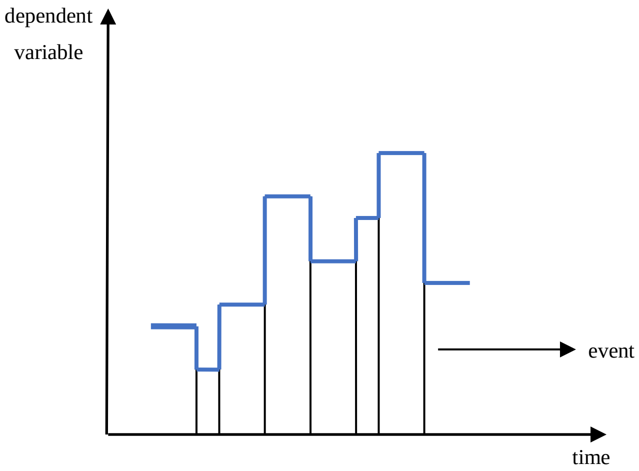


Figure 3.2 Discrete simulation

The term "event" refers to a distinct change in the state of a system at a particular point in time in "discrete event simulation." Discrete simulation, on the other hand, is used to explain state changes that occur at discrete time intervals. Conditional changes happen as a result of system-level interactions (if the machine performs processing on the material, the processing of the material is completed and its condition changes). A system's state can change only at distinct times in time (Kiran, 2019).

An event can occur for one of two reasons:

- the entry or exit of entities in the system (for example, if five additional customers come to the counter);
- the change in the value of an attribute (for example, if the speed of the employee at the counter changes)

Events can be classified as:

- Conditional - those that occur only if a certain condition is met
- Unconditional (planned) - those that occur after a specified length of time

These simulations are meant to help in the construction of detailed models of the system's structure and components, i.e. they mirror real-world systems and processes, as well as real-world items and their interactions.

Entities (objects) in discrete simulations are components of the system we are modelling. They can be:

- Permanent entities - remain in the model for the duration of the simulation
- Temporary entities - pass through the system.

Each entity can have multiple attributes, which describe the properties of the entity

System status is defined by:

- Entities contained in the model
- Attribute values

In a discrete simulation, time also changes discretely (i.e., discontinuously), which means that from the moment the last event occurred, time jumps to the moment the next event occurs, and so on. Also, a very important term in discrete simulations is the simulation clock that measures the elapsed simulation time.

In addition, it is very important to mention some of the terms that will be used during the average discrete simulation of events. An activity is an interaction of entities that lasts for some time, and during the course of the activity the state of the entity does not change. The beginning of the activity is related to some of the conditions for the beginning of the activity. Completion of an activity is related to the duration of that activity (after this time the activity ends). The process is a series of logically connected successive events that temporary entities go through (Kiran, 2019).

Discrete simulation is frequently used to model and analyse systems with tails waiting for resources (resources can include cash registers, buses, computers, and counters), where the primary description elements are as follows:

- The process's flow (usually shown by arrows that connect individual elements and decisions that determine the direction of the flow of the process)
- Resource capacities (describe the time in which a resource can be processed by an individual entity passing through the system, for example: 1 machine can process 1 semi-finished product in 3 minutes)
- Limitations (describe available resources, for example: 3 available machines or 4 employees, etc.)

At a minimum, an effective discrete event simulation process must exhibit the following characteristics:

- Predefined beginning and ending points, which can be discrete events or time instants.
- A way to keep track of how much time has passed since the process began.
- Since the process began, a list of discrete events has occurred.
- A list of discrete events that are pending or expected to occur until the process is expected to terminate (if such events are known).
- A graphical, statistical, or tabular representation of the current function of DES.

3.3 Advantages and disadvantages of simulation

The simulation is naturally appealing to the client since it represents how an actual system operates or how a system is regarded during the design stage. The output of the simulation should be identical to the outputs recorded from the actual system. Additionally, without making dubious assumptions, a simulation model system for theoretically solvable problems can be developed (such as the same statistical distribution for a random version). For these and other reasons, simulation is typically the technique of choice for problem solving.

3.3.1 Advantages

The following are some of the advantages of simulation which may explain for its widespread appeal (Law & Kelton, 1991):

- The majority of complex real-world systems with stochastic features cannot be effectively characterized by an analytically evaluable mathematical model. As a result, simulation is frequently the only sort of inquiry that is possible.

- Simulation enables the estimation of an existing system's performance under a hypothetical set of operational conditions.
- Using simulation, it is possible to compare alternative suggested system designs (or alternative operating rules for a single system) to determine which one best fits a specific criterion.
- We can exercise far greater control over experimental conditions in a simulation than we can in general when experimenting with the system itself.
- Simulation enables us to analyse a system with a large time horizon (for example, an economic system - in compressed time, or to investigate the detailed operation of a system in extended time.

3.3.2 Disadvantages

Several disadvantages include the following (Law & Kelton, 1991):

- Model creation requires specific skills. It is a skill that must be acquired through practice and time. Additionally, if two distinct competent individuals construct two distinct models, they may share some characteristics but are highly unlikely to be identical.
- Simulated results can be difficult to comprehend. Due to the fact that the bulk of simulation outputs are essentially random variables (since they are often based on random inputs), it can be difficult to discern whether an observation is the result of system interactions or randomness.
- Simulation modelling and analysis can be time consuming and costly. Reduced modelling and analysis resources may result in an insufficient simulation model or analysis for the task.
- Simulation is used in certain situations where an analytical solution is either not possible or desirable. This is particularly relevant when replicating certain sorts of waiting lines using closed-form queueing models.

4 SIMULATION ON COMPUTER

4.1 Simulation software tools and languages

Without the usage of simulation tools, simulations would be impossible. Modern simulation models, particularly those based on real systems with a huge quantity of input data and complex processes, are built on the back of simulation tools. It is possible to perform thousands of repeats of a procedure in a few seconds by using computers that accomplish a large number of operations per second.

There are several different approaches to creating simulations that lead to the same goal, but in different ways (Kreutzer, 1986). Thus, both general-purpose programming languages and procedure libraries can be used for simulations, but it is best to use simulation languages that are essentially created from these two, and that have a direct purpose.

Simulation languages are divided into (Ceric, 1993):

1. Simulation languages with command descriptions
2. Simulation languages for scenario building
3. Interactive simulation program generators
4. Generic data-driven simulation programs

4.1.1 General programming languages

A simulation program can be written in any general-purpose programming language. Numerous simulation programs have been written in FORTRAN and PASCAL, as well as in BASIC.

While it is possible to write it in these programs, there are certain disadvantages to this approach, including the necessity to redesign all of the fundamental processes that enable the description of the model and the execution of simulation tests. This greatly increases the development time of simulation programs, increases the likelihood of errors, and reduces the program's flexibility and efficiency.

General programming languages should be used only in the following circumstances:

1. Inability to obtain a better appropriate simulation tool.
2. As a result of the pressing demand for education.
3. Design and implementation of a novel simulation language.

Despite its disadvantages, the usage of general-purpose programming languages provides certain useful advantages, such as widespread distribution and portability. As a result of these advantages, software packages containing libraries of widely used and well-documented processes written in mainstream programming languages have been produced. Thus, ordinary programming languages become more valuable when used to create simulation programs.

4.1.2 Procedure libraries

To take advantage of the beneficiaries of universal programming languages, such as their widespread distribution, portability, wide variety of users, and relatively high efficiency, software packages containing libraries of processes written in general programming languages have been developed. These procedures are used to define the model's components, resolve time management issues, generate random numbers and variables, and so on. Developing simulation programs entails creating portions of the program in a generic programming language, often the main program and some methods that address the fundamental difficulties of discrete event simulation by invoking appropriate library procedures.

4.1.3 Simulation languages with command descriptions

These languages are designed specifically for the purpose of developing simulation applications and are geared toward tackling discrete simulation challenges. These programming languages often consist of a single fundamental component that may be used in the same way as a standard programming language, but is enhanced by commands and data structures that facilitate simulation modelling. This work requires a high level of programming experience.

4.1.4 Simulation languages for scenario building

The simplest method for naturally modelling a simulation situation is to use a module-based simulation language (blocks). The primary goal of this style of programming is to describe the blocks that transactions traverse throughout the model's existence. Examples of simulation languages of this type are ECSL, CAPS, DRAFT and DEMOS.

4.1.5 Interactive simulation program generators

These generators build appropriate simulation programs based on the model's features. Today's generators are built on the basis of activity cycle diagrams. They demonstrate the entities' life cycles by doing successive tasks and waiting for them to commence. Because these diagrams only depict the system's fundamental properties, the detailed qualities are described by modifying or extending the resulting program code. This category includes tools such as CAPS, DRAFT, and VS6 to name a few notable examples.

4.1.6 Generic data-driven simulation programs

These are programs to which users can give inputs and obtain output without having to understand the simulation program's mechanisms. This simplicity is achieved by restricting the system's description to a single class. Typically, these generic models are created using interactive tools that provide animated simulation execution. The better known packages of this type are FLEXSIM, SIMFACTORY, WITNESS and MAST.

4.2 Simulation modelling process

To ensure the success of the simulation study, a series of processes must be followed. Regardless of the type of problem or the study's purpose, the simulation procedure is constant. The following sections provide an overview of the simulation process's fundamental steps (Banks et al 2005).

4.2.1 Problem definition

The first stage is to define the study's objectives and to determine what problems need to be solved. The problem is defined further by objective observations of the procedure under study. Caution should be taken in determining if simulation is an appropriate tool for the research at hand.

4.2.2 Project planning

Creating a plan for a project is a difficult task. The project's tasks are separated into work packages, each with a designated responsible party. Milestones serve as a way to track development. This timeline is critical in determining if the project will be completed on time and with sufficient resources.

4.2.3 System Definition

System definition is a technical term that refers to the process of defining a system. Here, the system components to be modelled and the performance measures to be examined are identified, and then the modelling and analysis may begin. Most of the time, the system is extremely complicated, and so defining the system demands an experienced simulator who can discover the proper amount of detail while maintaining flexibility.

4.2.4 Model formulation

Understanding how the actual system acts, as well as establishing the fundamental requirements of the model, are required for the development of the appropriate modelling system. The creation of a flow chart depicting how the system runs aids in the understanding of the variables involved and how these variables interact with one another.

4.2.5 Input data gathering and analysis

Following the model's formulation, the type of data to be collected must be determined. In this phase, new data are collected, and the current ones are consolidated. Fitting data to theoretical distributions is performed. For instance, the rate at which a certain part arrives at the manufacturing plant may follow a normal distribution curve.

4.2.6 Model translation

Translation of the Model The model is translated into a programming language for use. General-purpose programming languages such as Fortran and simulation programs such as Arena are among the options.

4.2.7 Verification and validation

Verification and validation are two important aspects of any project. Verification is the process of confirming that a model behaves as predicted, which is typically achieved via debugging or animation approaches. Validation ensures that the model and the real system have no statistically significant differences and that the model accurately represents the real system. Statistical analysis can be used to verify results. Additionally, having an expert review and validate the model can help guarantee that it has face validity.

4.2.8 Experimentation and evaluation

Experimentation includes constructing alternative models, running simulations, and statistically comparing the performance of the alternative(s) system to that of the real system.

4.2.9 Documentation and implementation

The written report and/or presentation constitute the documentation. The study's findings and consequences are examined. The most advantageous course of action is determined, advocated, and justified.

4.3 FlexSim software

FlexSim is a sophisticated analytical tool for identifying problems and evaluating potential solutions throughout the design and operation of a system (Lavery, 2008). FlexSim is one of the most powerful modelling, analysing, and optimizing tools available for any real-time process. It is based on a three-dimensional representation of the system and enables the building of a model as well as its simulation and analysis. In Figure 4.1 Work window of FlexSim software is shown.

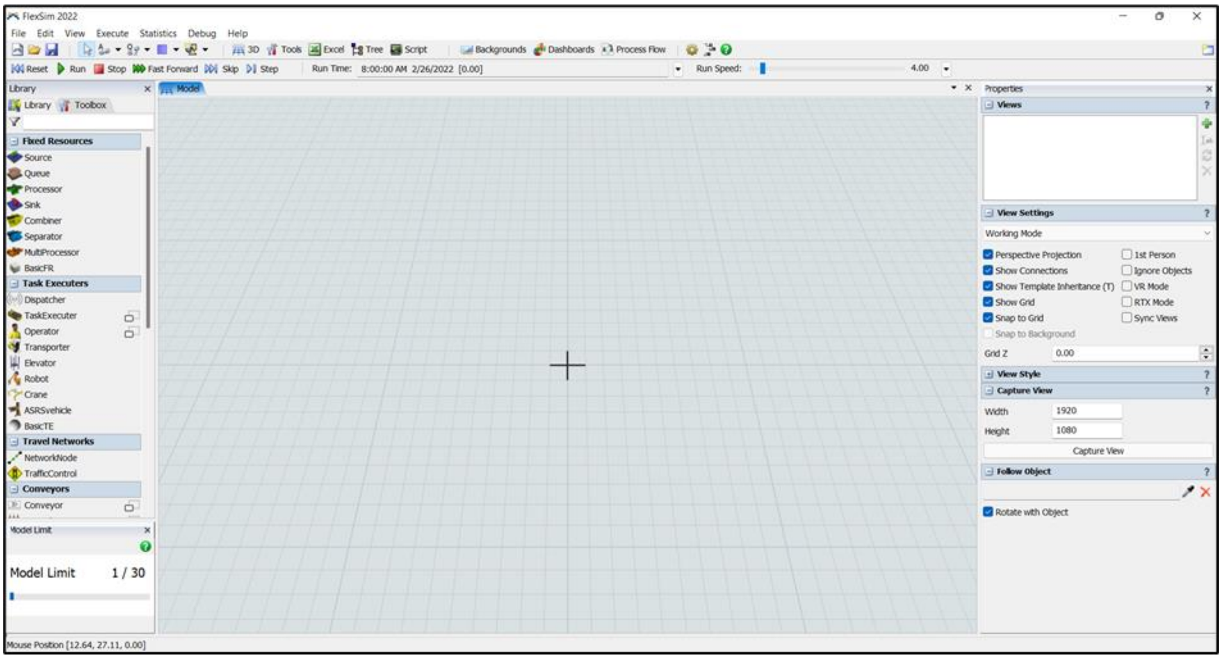


Figure 4.1 Work window of FlexSim software (2022)

FlexSim can be used to model and test systems and solutions before to their actual implementation in production, allowing for the avoidance of problems that may occur during the initial installation of a new system.

5 THEORY OF CONSTRAINTS

The theory of constraints (TOC) is a technique for determining what is restricting a project and improving it such that it is no longer a limitation. There is a high possibility that each production process has some constraints on the enterprise's output capacity, as the presence of a bottleneck is the primary element affecting the production line's and management's efficiency (Chiang et al., 2001).

According to one of the production-related definitions, a bottleneck is a part of a production process in which every resource that must be employed to maximize production is utilized to the fullest extent possible (Durlik, 1995). Numerous tools are specific to TOC. They give structure and consistency in problem identification and resolution, and help the organization stay focused on its mission. By Durlik (1995) the primary tools available are the following:

- The Five Focusing Steps
- The Thinking Processes
- Throughput Accounting

5.1 Five focusing steps

The theory of constraints has five focusing steps (Goldratt, E.M.,1990b):

1. Identify the constraint on the system. The weakest link in a system might be either physical or policy.
2. Determine the best strategy for exploiting the constraint. Goldratt advises the change agent to squeeze as much capacity out of a restricting component as possible without enduring costly changes or upgrades. One example is to minimize or eliminate downtime associated with bottleneck processes.
3. Make everything else a subordinate. The system's non-constraint components must be modified to a "setting" that enables the constraint to operate optimally. Following this, the entire system is reviewed to determine if the constraint has been moved to another component. When the constraint is removed, the change agent advances to step five.
4. Increase the constraint's elevation. "Elevating" the constraint refers to taking any step necessary to remove it. This step is only considered if the previous two have failed. This step considers significant changes to the existing system.

5. Retrace steps (return to step one), but be wary of "Inertia"

This is a continuous cycle that applies to all assets and constraints when businesses agree to implementing the theory of constraints as a strategy meeting.

An effective use of the theory of constraints will result in the following benefits (Goldratt, E.M.,1990b):

- Increased profit: this is the fundamental objective of TOC for the majority of businesses.
- Rapid Improvement: as a result of concentrating all attention on a single crucial area – the system constraint
- Increased Capacity: by optimizing the constraint, more products can be made
- Reduced Lead Times: by optimizing the constraint, product flow becomes smoother and faster

The techniques and strategies of the Theory of Constraints provide businesses with a framework for conducting a systematic and critical study of logistics with an emphasis on successful decision-making. The sooner restrictions are detected, the sooner corrective action can begin, allowing businesses to retain output and hence their competitive advantage.

6 SIMULATION OF MANUAL WORK DEPARTMENT IN COMPANY PREVENT GORAŽDE

6.1 Description of the plant for the production of car seats covers and baby seats

Currently, company Prevent Goražde makes car seat covers for Ford and BMW car brands, as well as Britax Roemer baby car seats. The products are made through several stages, which are:

1. Getting materials from the warehouse
2. Loading on the conveyor belt,
3. Tailoring
4. Intermediate phase
5. Manual work department
6. Sewing
7. Disposal
8. Packing

The cutting plant consists of 6 cutters. These cutters are used for tailoring all types of textiles for the complete production program. The tailoring process is dynamic, because all tailoring parameters depend on the type of cutting image, the number of cuts and the type of material. This means that there can be no standardized time for loading, tailoring and disposal. What further complicates the situation is that company Prevent Goražde works on several projects at once depending on customers demand, whereby the quantities to be produced are not fixed in a certain period of time. This complicates the simulation of the tailoring process and it is very difficult to optimize the process related to the preparation of the material before sewing. For these reasons, tailoring always goes one-two days before the sewing process. Due to the pause before sewing process, simulation of the entire process is not feasible because variations in separate processing stages prior to sewing have no impact on the further process. From company Prevent Goražde, it was clear that this is currently the best solution for them and, and it causes the least delays and problems, but as a result requires a large warehouse for disposal after the tailoring process.

Part of the warehouse where materials are disposed after tailoring is called intermediate phase. Some products, such as a baby car seats, require manual work that is done after the intermediate phase. This manual work is reflected in labelling stickers in precisely defined places as well as making openings that could not be made during tailoring. While monitoring the labelling process, it was realized that there was a problem with manual labour time. After looking for the process time data and number of workers, it was found that there is a bottleneck that can be analysed and improved. The labelling process is currently performed on older machines that are completely manual and require more workers and time. As a result, only a manual work department simulation was analysed.

6.2 Construction of a simulation model of manual work department

Before building a model, the problem to be solved through a simulation model must be first defined. Once the problem is defined, then the system data must be identified, and the necessary data collected. When the collection of all the necessary data to be used in the simulation is completed, the construction of the model can begin. The quality of the model itself will depend on the accuracy of the data collected in the field. It is desirable that the data needed for simulation is collected from multiple measurements to minimize error.

The construction of the model will be divided into three phases, which are:

1. Problem definition and system identification
2. Collect time of individual processes
3. Creating a 3D model in FlexSim software

6.2.1 Problem definition and system identification

During the tour of the manual work department and getting acquainted with the current situation, it was noticed that 5 workers work on the same machines that are used for labelling. Figure 6.1 shows a department of manual work, and Figure 6.2 shows a current layout.

Figure 6.1 Department of manual work for labelling

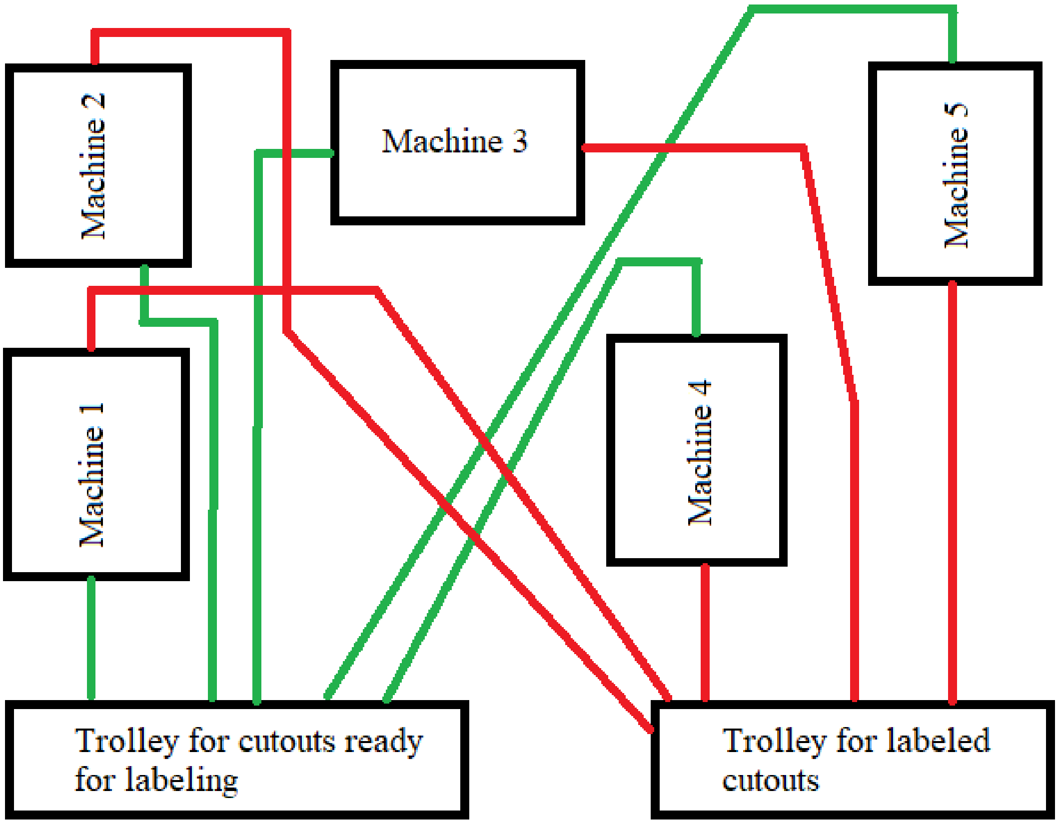


Figure 6.2 Layout of manual work department for labelling

In Figure 6.2 green represents path of cutouts before labelling, while red represents labelled cutouts that are finished. All 5 workers do the same job on same machines, where every worker is in charge of one machine. Manual work department is responsible only for labelling the stickers. Although it seems extremely simple, the labelling process takes a lot of time at the current stage. In order for the simulation to be constructed, the labelling process must first be identified, that is, all the steps that are done in the process itself, and those are:

1. Taking cutouts from the table
2. Putting the mold over the cutout
3. Putting the sticker in the mold
4. Machine operation
5. Disposing of the finished product on the table

The labelling process is shown in more detail in the scheme shown in Figure 6.3.

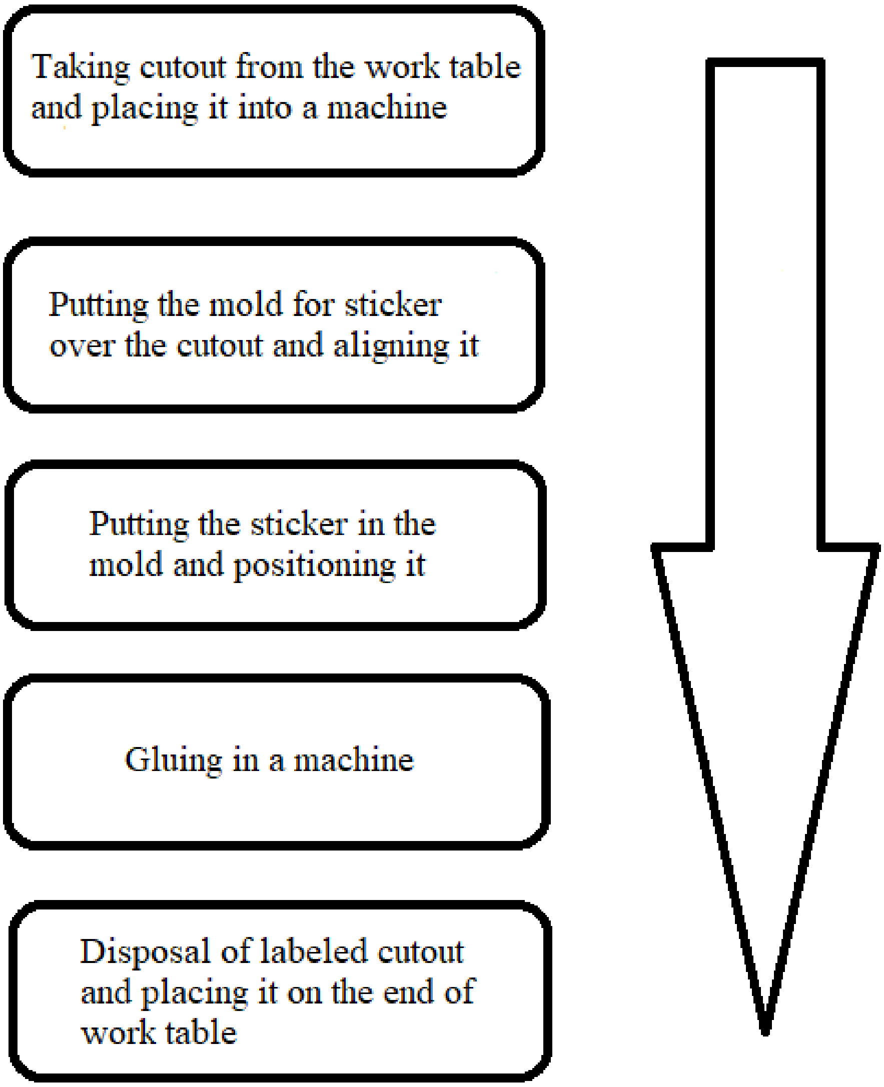


Figure 6.3 Scheme of the label gluing process

According to the data given by company Prevent Goražde, it was found that labelling one sticker on cutout takes thirty-three seconds, which is their prescribed norm. Most of that time was spent preparing the cutout and positioning the sticker, which takes twenty-five seconds according to the prescribed norm. The rest of the time is machine operation.

In addition to the above mentioned operations for labelling, an additional worker who is not part of the manual work department brings the cutouts ready for libelling on the trolley. A picture of a trolley with cutouts ready for libelling is shown in Figure 6.4

Figure 6.4 Trolley with cutouts ready for libelling

Additional worker is solely responsible for the transportation of semi-finished and finished items. Based on the company information, it was determined that there is no exactly prescribed norm for the amount he brings to workers. It depends on several factors, and most of all on the tailoring plan that is the process before, as well as the size of the series that is being made. It was also emphasized that regardless of the size of the series being done, the work is continuous and is done evenly throughout the working hours. Additional worker was not included in the simulation, because he is not part of manual work department and has no influence over the process.

Before the first step in libelling, it is necessary to take the cutouts from the trolley and put them on the individual work tables where the machines are located. Every worker does this work for herself. An individual work table that is the same for all five workers is shown in Figure 6.5 where cutouts ready for libelling are placed on the left side of the machine, while cutouts which are labelled are put on the right side of the machine.

Figure 6.5 Individual work table with libelling machine in the centre

In short, the libelling machine on individual tables is a hot press, in which stickers are labelled according to specific conditions of time, temperature and pressure combined.

When the workers finish a certain series, an additional worker comes and brings new cutouts for labelling. Also, he packs the labelled cutouts on trolley and transports them for sewing. Figure 6.6 shows a common work table, where all 5 workers leave the labelled cutouts before the additional worker puts them on a trolley and takes them for sewing process.

Figure 6.6 Common work table with labelled cutouts before packing on a trolley

Currently, the most demanding part of the whole process is putting the paper mold and stickers in the right place. It is the part of the job that requires the most attention, but also time. This process itself consists of several actions and those are:

1. Taking the cutout and placing it in the labelling machine
2. Attaching a paper mold on top of cutout and aligning the edges
3. Putting the sticker in the mold
4. Aligning a sticker in a mold

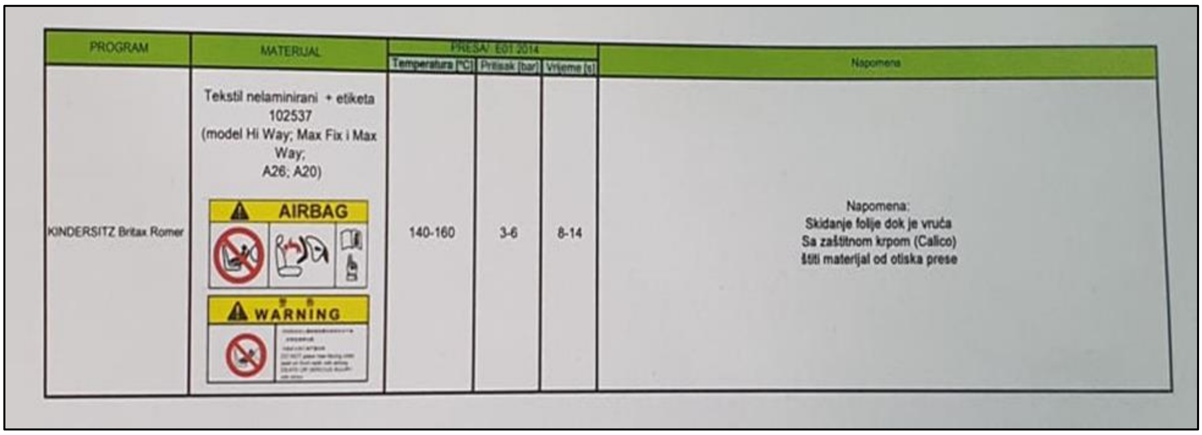
In Figure 6.7 a cutout with a paper mold and a positioned sticker can be seen.

Figure 6.7 Cutout with paper mold and positioned sticker before labelling

After these actions, the cutout is ready for labelling. Then the worker presses the pedal with her foot and the hot press of machine lowers and the labelling process according to a defined specification begins. After labelling is done, worker releases pedal, and machine lifts after which she disposes labelled cutout.

6.2.2 Time measurement of individual processes

The labelling process consists of two actions. The first is the preparation of the cutout for labelling the sticker, while the second is the process of labelling the sticker in the machine. The labelling conditions in the machine are met by the client in order for the stickers to adhere without issue, and there to be no returns of products due to peeling after use. Temperature, pressure, and process time are the three conditions. The client's prescribed labelling needs are shown in Figure 6.8.



PROGRAM	MATERIJAL	PRESA/ E01 2014			Napomena
		Temperatura [°C]	Pritisak [bar]	Vrijeme [s]	
KINDERSITZ Britax Romer	Tekstil nelaminirani + etiketa 102537 (model Hi Way; Max Fix i Max Way; A26; A20) AIRBAG WARNING	140-160	3-6	8-14	Napomena: Skidanje folije dok je vruća Sa zaštitnom krpom (Calico) štiti materijal od otiska prese

Figure 6.8 Temperature, pressure and time during labelling in the machine

In Figure 6.8 it is possible to see that labelling in the machine requires a temperature between 140-160 °C degrees, as well as a pressure between 3-6 bar. After extensive testing by company Prevent Goražde, it was discovered that 8 seconds is required for labelling in the machine at a temperature of 160 °C degrees and a pressure of 4 bar. Time of 8 seconds in the machine is fixed, and cannot be changed.

One of the most crucial steps of creating a simulation is measuring the time of individual processes, because if erroneous data is used, a simulation based on that data will be inaccurate. The time of preparation of the cutout for labelling could not be measured separately, and based on the real process, the total labelling time of one cutout was measured. This time represents the preparation of the cutout for labelling and labelling in the machine which was described earlier. The time study method was used to take ten measurements of the samples. Through the use of a stopwatch, the acquired measurement data can be seen in Figure 6.9. In this Figure 6.9 h represents accuracy level desired in percent of the job element, expressed as a decimal (5% = 0,05). Z is number of standard deviations required for desired level of confidence. S is standard deviation of the initial sample. $\bar{x}$ is mean of the initial sample, while n is required sample size (Heizer & Render, 2014). Equation (6.1) is used for calculation of standard deviation, while (6.2) is used for calculation of required sample size.

Observation	$\bar{x}_i$	$\bar{x}$	$x_i - \bar{x}$	$(x_i - \bar{x})^2$
1	33	33,2	-0,2	0,04
2	33	33,2	-0,2	0,04
3	35	33,2	1,8	3,24
4	32	33,2	-1,2	1,44
5	34	33,2	0,8	0,64
6	33	33,2	-0,2	0,04
7	34	33,2	0,8	0,64
8	32	33,2	-1,2	1,44
9	34	33,2	0,8	0,64
10	32	33,2	-1,2	1,44
$\bar{x}$ =	**33,2**		**$\sum (x_i - \bar{x})^2$**	**9,6**

Desired Confidence Level (%)	Z Value
90,11	1,65
95	1,96
95,45	2
99,11	**2,58**
99,73	3

3% within the true value	**0,03**

$$s = \sqrt{\frac{\sum(\text{each sample observation} - \bar{x})^2}{\text{number in sample} - 1}} \tag{6.1}$$

$\bar{x}$ =	**33,2**
s =	**1,032796**
z =	**2,58**
h =	**0,03**

Number of observations n ->

$$n = \left(\frac{zs}{h\bar{x}}\right)^2 \tag{6.2}$$

n =	**7,157304**	**7**

Figure 6.9 Observed and calculated time data for labelling

Figure 6.9 shows that measured average time $\overline{x}$ for labelling one cutout is 33,2 seconds with standard deviation of 1.03 second. Now, from the time of the total labelling process of one cutout, the time of preparation of the cutout for labelling can be obtained by subtracting the labelling time in the machine, which is fixed and amounts to 8 seconds. Based on this data, it can be concluded that the time of preparation of a cutout for labelling is 25.2 seconds with a standard deviation of 1.03 seconds.

Sample size n was confirmed as sufficient for this simulation, because based on the collected times, the desired reliability of 99,11%, accuracy within 3% and standard deviation of 1,03 second, the result is obtained that the required number of time measurements for individual process of preparing cutouts for labelling is n=7.

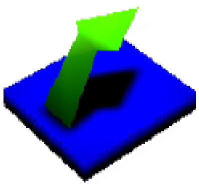
After defining all the steps, as well as the process times, it is time to create a 3D model in FlexSim software.

6.2.3 Building a 3D model in FlexSim with Library Objects

The objects in the FlexSim library are the fundamental building blocks upon which 3D models are constructed. Each item contains embedded logic that is frequently utilized in a wide variety of simulation models. Additionally, we can quickly alter the attributes and logic of these objects to adapt them to the unique requirements of a simulation project. Although the FlexSim library retains many objects, this section lists only those that are relevant to the simulation of this master thesis.

The objects that will be used in the construction of the manual work department simulation are:

- Source

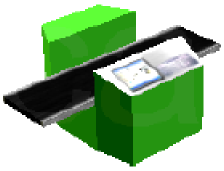


The task of this object will be to create flow items that will be sent to the workers on the machines. As mentioned earlier, there is an additional worker whose task is to bring the cutouts to the manual work department.

- Queue

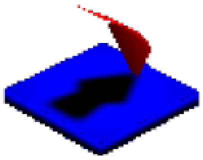
The number of queues depend on the number of workers working on labelling machines. In the actual world, a queue represents a table on the machine's left side, where the ready to label cutouts are placed.

- Processor



The processor is essentially a labelling machine. In the processor itself, it is possible to set the time of preparation for work, as well as the time of execution of work. Also, it is given that the operator, in our case the worker, participates in the preparation of the cutout for labelling.

- Sink



Sink represents the place of disposal of all cutouts after the labelling process. Just as the source gives us data on the number of inputs, so the sink gives us data on the output, i.e. the number of cutouts that have been completed.

- Operator

In our case, the operator is a worker working on the machine. In FlexSim we will connect it to the processor and include its work in the preparation of the cutouts for labelling.

6.3 Manual work department simulation in FlexSim

The simulation that will be presented in FlexSim will include three cases of manual work department in labelling process. The first case of labelling will simulate the already existing condition on old machines. Other two cases will involve the purchase of new semi-automated machines that are significantly faster. In these two new cases, the correlation between old and new machines will be presented. This simulation will attempt to demonstrate how multiple new machines may be utilized to produce same or better results, and replace the five machines currently in use. Following the presentation of the cases, the data gathered from the simulation will be compared and analysed.

6.3.1 Case 1: Simulation of current state

As already mentioned, five workers are currently working on five old machines, with the time of 33,2 seconds for labelling one cutout. The preparation of the cutout for labelling takes 25,2 seconds with standard deviation of 1,03 second, where the worker must take the cutout, put the paper mold, position the sticker, and then press the pedal for the machine that performs the labelling process for 8 seconds. Before the simulation, it is necessary to model current layout in manual work department. In Figure 6.10 it is possible to see the current layout.

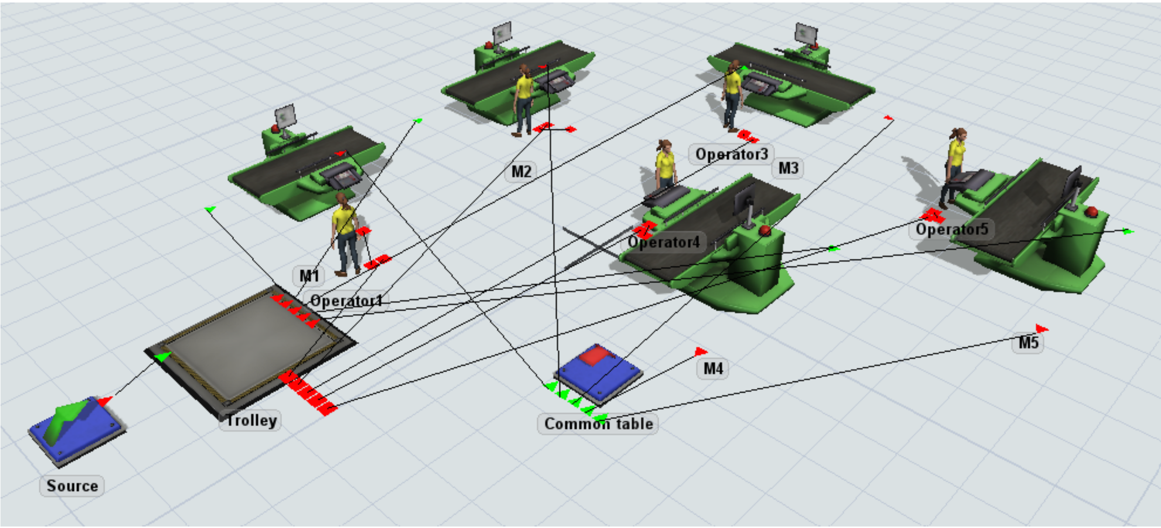


Figure 6.10 Current layout in the labelling process

In order to obtain data on the throughput in one day, it is necessary to enter the input data on the time of labelling one cutout, as well as the working time. Daily work shift of workers lasts 8 hours, or 28,800 seconds. The simulation was set up so that at the start of the work shift, the complete daily supply of cutouts is available for labelling and on the trolley. Depending on the size of the series they are labelling, the workers get a new series of cutouts few times per day. Figure 6.11 shows how Source was set in FlexSim.

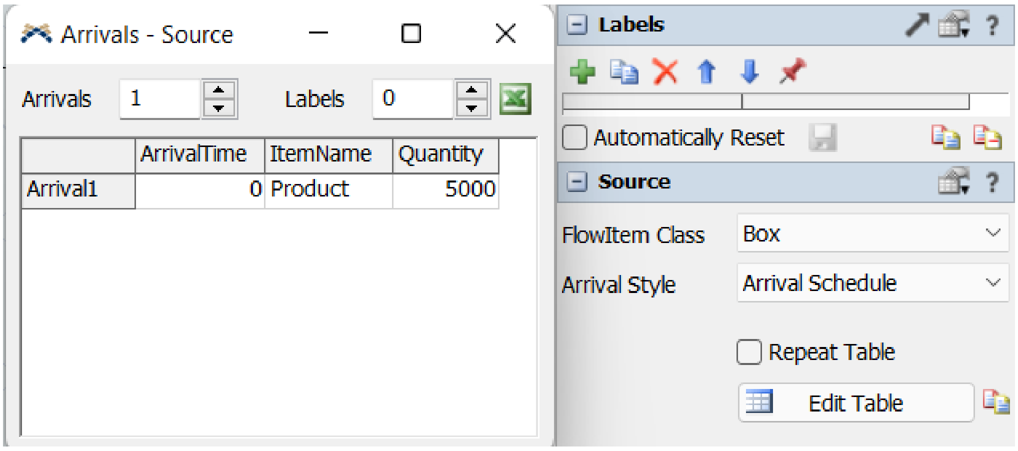


Figure 6.11 Source selection for one working day

Figure 6.12 shows entered time data for the current state in the preparation of cutouts for labelling.

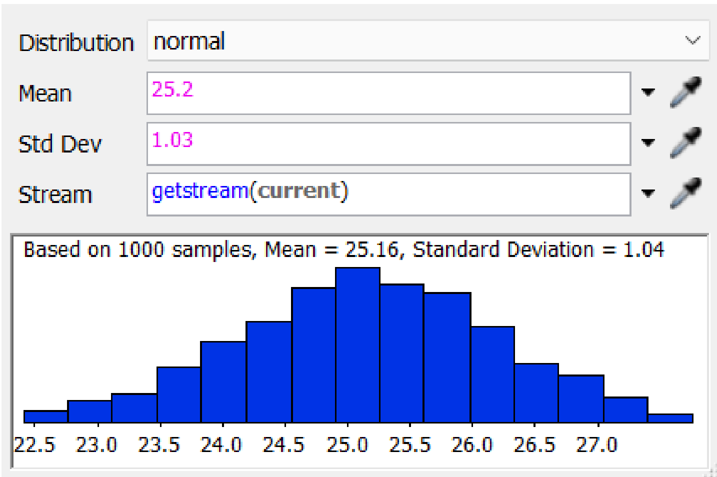


Figure 6.12 Time data for the preparation of cutouts

Figure 6.13 shows both preparation time of cutouts for labelling and machine process time, which is 8 seconds fixed.

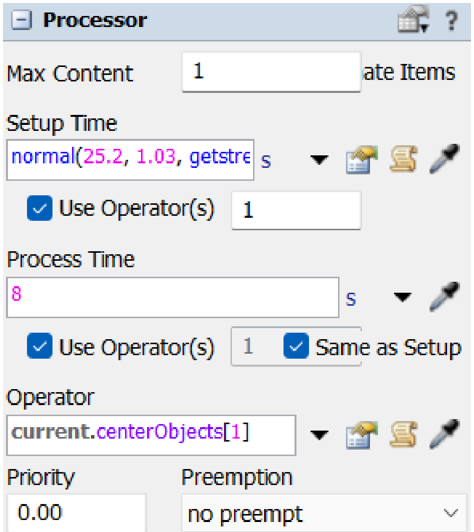


Figure 6.13 Time of preparation cutouts for labelling and process time

After entering all the data in FlexSim model, the simulation was released, and the following results were obtained. Figure 6.14 shows the throughput in the simulation during the working day, which confirms that workers label on average 866 cutouts per day. The total throughput of one working day in current state is 4328 cutouts.

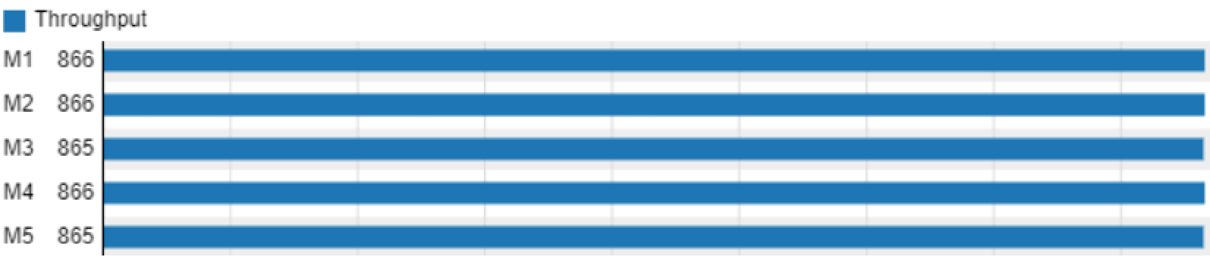


Figure 6.14 Throughput of each machine

Figure 6.15 shows the proportion of preparation and process time in one working day.

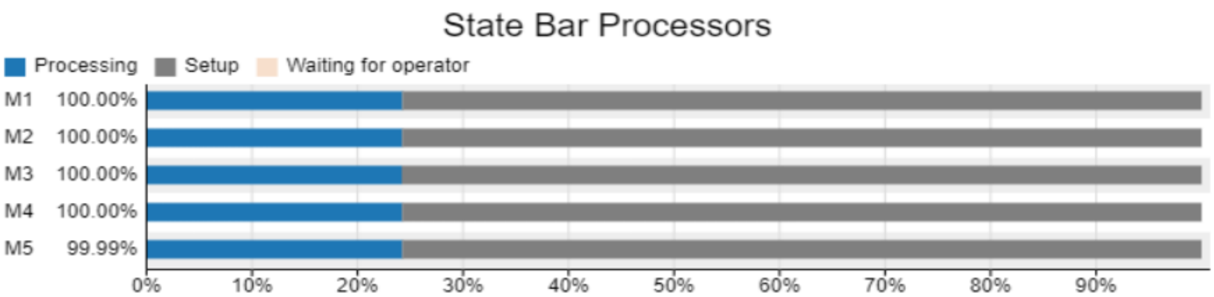


Figure 6.15 Proportion of preparation and process time during one working day

As can be seen from the Figure 6.15, and the same information was obtained from the company Prevent Goražde, the time of preparation of a cutout for labelling takes a long time. It takes up almost 75% of the time during the working day, and is currently the biggest problem in the whole labelling process. The process of preparation for labelling is not a real bottleneck because it is a process that takes up the same resource that performs labelling after positioning. However, all the principles of TOC can be applied to this case as well. To call this problem a bottleneck, the overall labelling process should be divided into two processes, as it is now one process which is done on same machine. In Figure 6.16 it is possible to see the Gantt graph, which represents a visual insight into the state of activity over time.

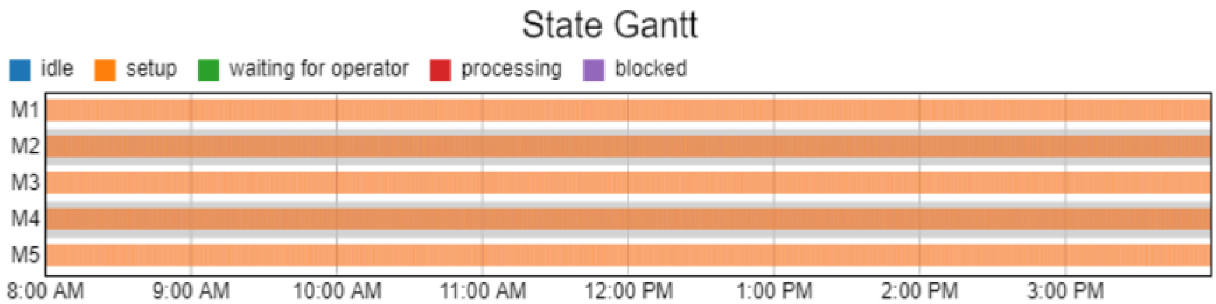


Figure 6.16 The state in the whole process during one working day

With these Graphs, it was immediately confirmed that there is a bottleneck in the current way of preparing stickers for labelling. It can be seen that there are no blocked and idle time during the whole working hours. Preparation for labelling is seen to be the biggest problem, and in its current state represents a blockade for higher output with the same resources. The current time of preparation of a cutouts cannot be improved because it has already reached its limits with these machines.

It was desired to find a solution that would significantly speed up the process of preparing the cutouts and with that to reduce the number of workers needed in the manual work department, while still achieving the same results. The rest of the workers would be transferred to other departments. The solution to this bottleneck was to approach with a technological solution, i.e. to replace five old machines with new semi-automatic machines shown in Figure 6.17.

Figure 6.17 Semi-automated labelling machine

What is new about this machine is that there is a bottom plate on which the cutout mold is fixed. This means that workers no longer have to place the mold on the cutout and align it. Also, advantage is that the stickers are mounted on a strip that rotates constantly, and it is not necessary to put and align them additionally. Result is an extremely high speed of preparing cutouts for labelling, whereby the new time of preparation is 5 seconds instead of 25,2 seconds, according to the data from machine supplier. The process time of the machine remained the same, at 8 seconds, as with the old machine. All this combined means that, now the worker only has to put the cutout in a precisely defined contour of the mold on a table and press the pedal for start of process of labelling.

In the next case, a new simulation will be made in which old and new machine will work in parallel, and based on the simulation, the differences in the results of these machines will be seen. In Case 1, the simulation did not show the scattering of data between individual processes on the working machine, because the only difference was in the layout, i.e. the different path that the workers walked to take the cutouts for labelling and return the cutouts after labelling. Also, because there is no variability between processes on particular machines, the last case could have been done without simulation.

6.3.2 Case 2: Simulation of old and new machine

In this case, the machines are placed parallel to each other. Figure 6.18 shows a layout of this case.

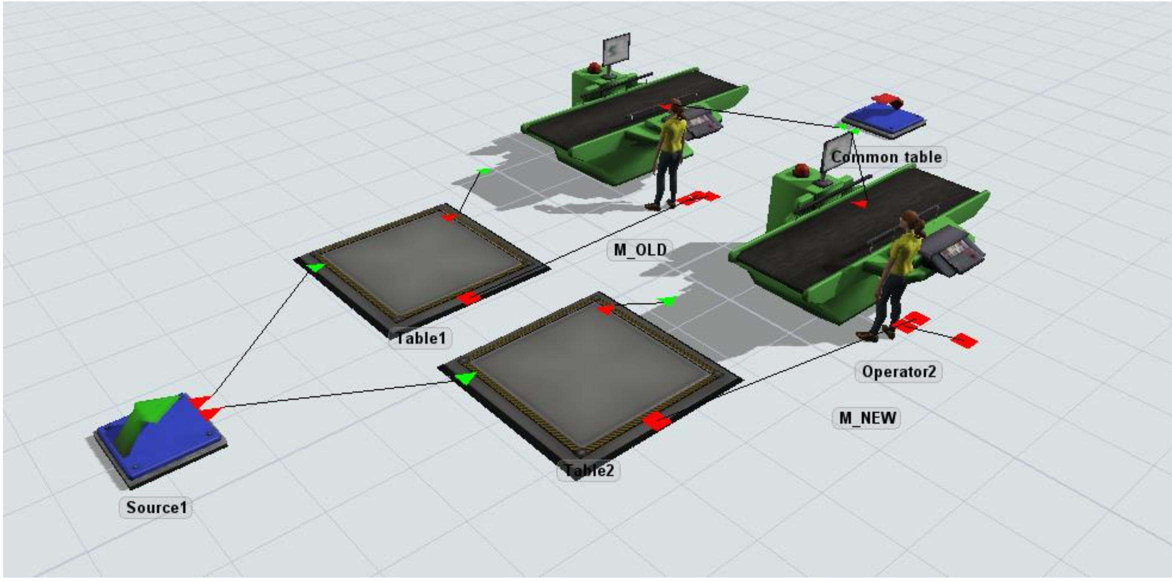


Figure 6.18 Layout with old and new machine

In this simulation, the old and the new machine were compared, with the machines placed side by side with separate tables with same quantity of cutouts. In this way results in performance can be more clearly compared. It is set that both workers do 866 pieces in a working day, which is the average number of cutouts that a worker can make on the current old machine. The preparation time on the new machine has been prescribed to 5 seconds in a normal distribution with a standard deviation of 1 second. Figure 6.19 shows preparation time for new machine.

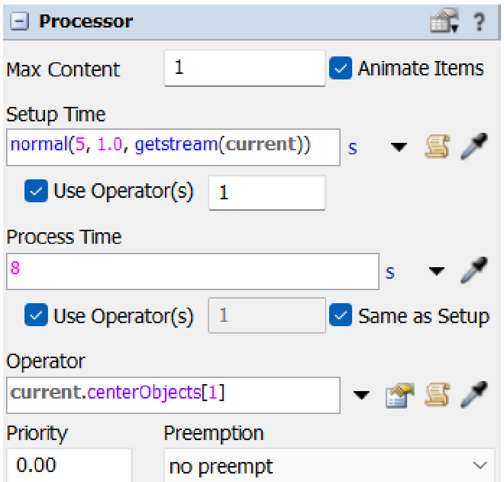


Figure 6.19 Time of preparation and process time for new machine

Based on the entered data, the results of simulation are shown in Figure 6.20 and Figure 6.21.

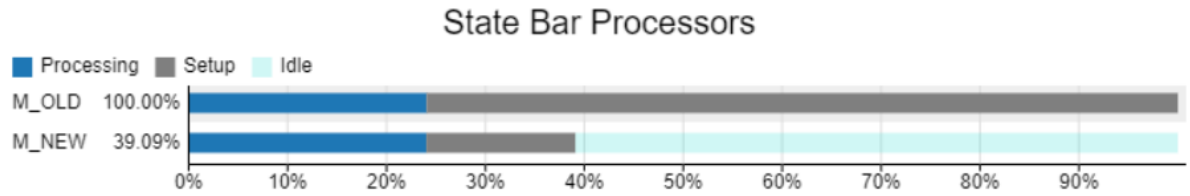


Figure 6.20 Proportion of preparation and process time between old and new machine in one working day

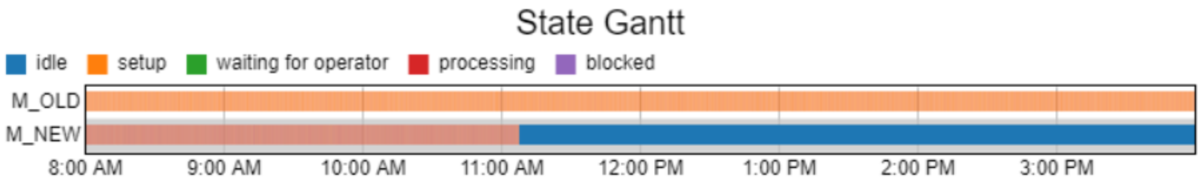


Figure 6.21 The state of old and new machine during one working day

As can be seen from the Figure 6.20, there is a huge difference with preparation time. In this way, the worker on the new machine would meet her daily prescribed norm at 11:08 a.m., while the worker on an old machine would do that norm throughout the whole working day. Because the time it takes to prepare a cutout for labelling is now shorter than the time of labelling process in the machine, a worker can prepare a new cutout for positioning in the mold while the labelling process is in progress.

To determine how many new machines could replace the 5 old ones currently in use, the throughput of the old and new machine was compared. Figure 6.22 shows the throughput of old and new machines during one working day.

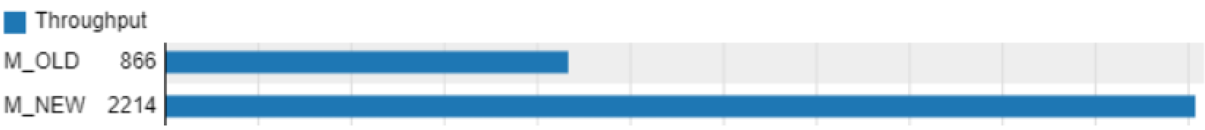


Figure 6.22 Throughput of old and new machine

Based on this simulation it can be seen that 2 new machines have very similar performance as 5 old machines. That case will be presented next.

6.3.3 Case 3: Simulation with two new machines

As seen from the previous simulation, the differences in machines performances are huge, so it raises the question of whether 2 new machines could meet the current prescribed norm, and thus replace the current 5 machines in use. Figure 6.23 shows the layout of the 3rd case with 2 new machines.

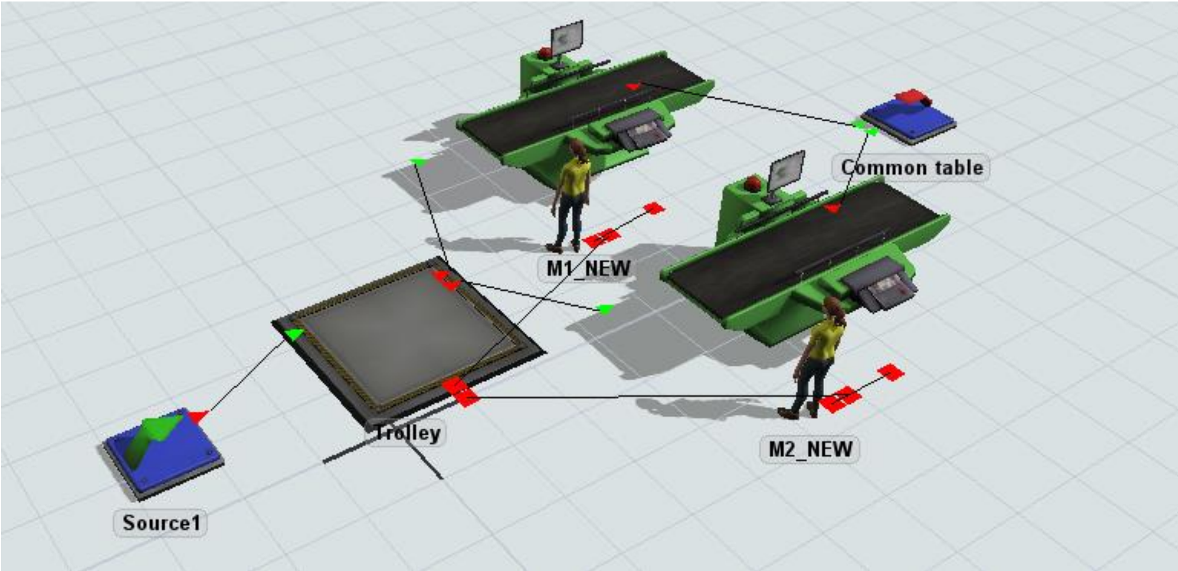


Figure 6.23 Layout with 2 new machines

In this simulation, it was assumed that 2 new machines can perform the entire prescribed norm currently worked by 5 machines. This, in essence, means that the norm of 4328 cutouts per day will be divided in half towards the new machines. The time of preparation of a cutout for labelling and process time in the machine is same as in previous case. Based on the entered data, the results are shown in Figure 6.24, Figure 6.25 and Figure 6.26.

Figure 6.24 represents new throughput with 2 new machines. Figure 6.25 is the state of machines during working day, while Figure 6.26 shows the Gantt chart showing the state of activity during time.

Figure 6.24 Throughput of 2 new machines

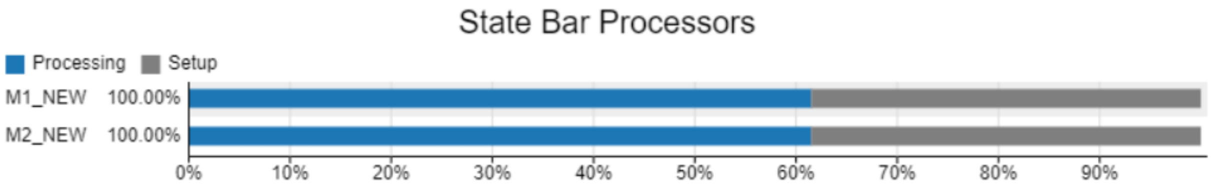


Figure 6.25 Proportion of preparation and process time during one working day

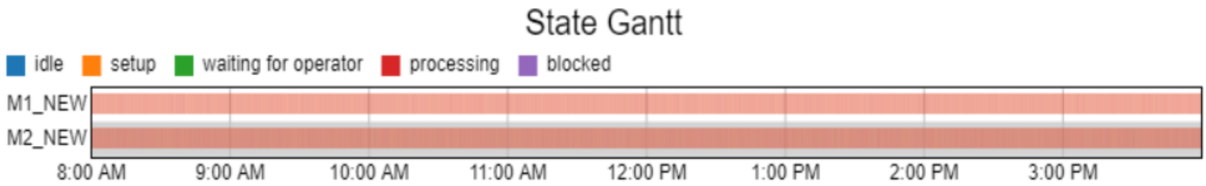


Figure 6.26 The state of new machines during one working day

Figure 6.25 shows that there was no idle time of machines, which indicates that the workers worked all the time during working hours. An inspection of the sink found that the norm was met, and the throughput in the simulation was 4427 cutouts per day, which can be seen on Figure 6.24 when M1 and M2 are combined. That means that with 2 new machines throughput is better by 99 cutouts than on 5 old machines. Figure 6.26 also confirms that the work was done continuously throughout the whole day, and that there were no blockages. This simulation showed that this case is possible in real world, and that 2 new machines could replace 5 old currently in use. New machines have better total output with less workers and resources.

It is important to emphasize that the company's main goal was not to increase total output of labelled cutouts, but to maintain same output with more efficient production and fewer resources. The bottleneck in this case was preparation time for labelling with the old machines, which was solved with technological solution by replacing old machines with new ones. Following the simulations, the next chapter provides a quick review of the financial side of the investment, i.e. its profitability.

7 INVESTMENT ANALYSIS

After the simulation of the baby car seat program, it was determined in case 3 that there is a justification for replacing old machines with new ones in the manner of maintaining the same output of labelled cutouts, while lowering number of workers to achieve the same results. Despite the fact that the new results look fine in the simulation, company Prevent Goražde must determine whether it is cost-effective to invest in new machines.

The next section includes a brief investment analysis, in which the key costs are considered, including the cost of operating the machine, the cost of human resources, and the cost of the machines.

The cost of old machine: 2500 €

The cost of new machine: 19275 €

The cost of human resources: 6000 € year/worker

Operating costs of an old machine: 14,8 €/monthly per machine

Operating costs of a new machine: 15,1 €/monthly per machine

7.1 Investment in 2 new machines

In this case in which five old machines were replaced with the new two machines, the results were as follows: The number of workers is reduced by 3. This results in savings of 3 x 6000 € = 18000 € / per year. Based on the company's information, old machines could be sold for 800 € per machine, which means that in this situation, a sale of old machines brings 5 x 800 € = 4000 €. Operating costs are also reduced in case with the 2 new machines, as the old machines have an annual cost of 12 months x 14.8 €/monthly per machine x 5 machines = 888 € / year, while with 2 new machines this cost is 12 months x 15.1 €/monthly per machine x 2 machines = 362.4 € / year. The investment for the purchase of 2 new machines is 2 x 19275 € = 38550 €.

According to equation (7.1) the return on investment will be:

$$R = \frac{38550\ € - 4000\ €}{18000 \frac{€}{year} + 362.4 \frac{€}{year}} = 1.88\ year \tag{7.1}$$

Meaning that, if all of the data presented in this study is achieved, the result is a return on investment in less than two years.

8 CONCLUSION

The Master Thesis shows that by applying simulation software we are able to improve and enhance all production processes that take place in a company. Using simulation, program can significantly reduce the production risk, as any changes that would be attempted to be made in the real world can be made in the simulated environment, and adequate changes can be made based on the simulation recommendations. The result of the thesis shows that FlexSim Simulation software can be used to analyse simple production process. The application of a computer simulation tool allows for the estimation of production line operations. The correct creation of the model and conduction of a simulation case are necessary for using a computer simulation to solve production problems.

This study explains why it's important to recognize the bottleneck in a production process where the idea of bottleneck exists, such as a flow from semi-finished to finished product. Once the bottleneck has been identified, detailed study can uncover areas where simple changes or new solutions can improve the process. The objective is to recognize how important the bottleneck is to the manufacturing system's total throughput.

In the specific case of manual work department in company Prevent Goražde, simulation was done in 3 cases to see if it is profitable to make changes in the manual work department and invest in the new machines in order to increase productivity and reduce costs. As the main goal was not to increase the quantity of labelled cutouts, it was necessary to find a solution that would produce the same results as now, but more efficient and with lower costs.

The biggest bottleneck has been shown to be the old machines used by the company, which are obsolete and which make the method of preparation for labelling slow. By purchasing new semi-automatic machines, this time of preparation for labelling would be significantly reduced, and productivity would increase at lower cost. After completing the simulation with the new machines and comparing it with the current way of labelling cutouts, great savings were obtained, and the return on investment is possible in less than two years. In addition, the company could move the surplus workers from the manual work department to another department. It is necessary to simulate the entire range of processes from start to end in order to fully optimize the production process and reduce process delays.

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