## Contents

ABSTRACT I
SAMMANFATTNING III
ACKNOWLEDGMENT V
CONTENTS VII

1 INTRODUCTION 1
Project Objective ....................................................................................................................... 1
Project directives .......................................................................................................................... 1
Problem statement ....................................................................................................................... 2
Project limitations ....................................................................................................................... 3

2 RESEARCH METHODOLOGY 5

3 THEORETICAL BACKGROUND 9
Simulation Fundamentals .............................................................................................................. 9
Definition in industrial context ..................................................................................................... 10
Simulation versus Emulation ....................................................................................................... 10
Simulation applications ............................................................................................................... 13
Simulation advantages and disadvantages .................................................................................. 14
Different Classification of simulation .......................................................................................... 14
Simulation and modeling Formalisms .......................................................................................... 15
Simulation methodologies ............................................................................................................ 17
Continuous ................................................................................................................................. 17
Discrete-Event ......................................................................................................................... 17
Discrete-Rate ............................................................................................................................. 18
Monte-Carlo ............................................................................................................................... 18
Selection of the right methodology ............................................................................................. 19
Application of different methodologies ....................................................................................... 20
Discrete Event Simulation basics .................................................................................................. 21
History of Discrete Event Simulation ........................................................................................... 21
The characteristics and structure of DES (Time-event-state) ....................................................... 22
Discrete Event Simulation application ........................................................................................... 24
Manufacturing application ......................................................................................................... 26
Construction Engineering .......................................................................................................... 27
Logistics, Transportation, and distribution .................................................................................. 27
Business process ........................................................................................................................ 27
Military applications ................................................................................................................... 27
Service industries ....................................................................................................................... 28
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 SIMULATION MODEL (CASE-STUDY)</td>
<td>29</td>
</tr>
<tr>
<td>Description of ASRS</td>
<td>29</td>
</tr>
<tr>
<td>ASRS operations procedure</td>
<td>31</td>
</tr>
<tr>
<td>Logic of the ASRS</td>
<td>34</td>
</tr>
<tr>
<td>ASRS Problem</td>
<td>35</td>
</tr>
<tr>
<td>Suggested Solution</td>
<td>38</td>
</tr>
<tr>
<td>Model Conceptualization</td>
<td>39</td>
</tr>
<tr>
<td>Data Collection</td>
<td>41</td>
</tr>
<tr>
<td>Statistical Distributions</td>
<td>42</td>
</tr>
<tr>
<td>Model Structure</td>
<td>44</td>
</tr>
<tr>
<td>Results of the simulation model</td>
<td>45</td>
</tr>
<tr>
<td>5 RESULTS</td>
<td>47</td>
</tr>
<tr>
<td>Simulation Challenges</td>
<td>47</td>
</tr>
<tr>
<td>The borders between paper and pen, spread sheets, and Simulation</td>
<td>48</td>
</tr>
<tr>
<td>An analogy: Production vs. Simulation</td>
<td>51</td>
</tr>
<tr>
<td>Lean Simulation Framework for simulation projects</td>
<td>52</td>
</tr>
<tr>
<td>Introducing a few Lean tools to improve Simulation Projects</td>
<td>58</td>
</tr>
<tr>
<td>6 CONCLUSIONS &amp; RECOMMENDATIONS</td>
<td>61</td>
</tr>
<tr>
<td>Skepticism when using simulation</td>
<td>61</td>
</tr>
<tr>
<td>The cost of simulation projects</td>
<td>61</td>
</tr>
<tr>
<td>The inherent randomness of results</td>
<td>61</td>
</tr>
<tr>
<td>The time spent on a simulation project</td>
<td>63</td>
</tr>
<tr>
<td>Complexity of model designed for the end user</td>
<td>63</td>
</tr>
<tr>
<td>Lack of enough information for translating the reality into the simulation environment</td>
<td>63</td>
</tr>
<tr>
<td>Clearing up skepticism when using simulation</td>
<td>64</td>
</tr>
<tr>
<td>The high cost of simulation projects</td>
<td>64</td>
</tr>
<tr>
<td>Inherent Randomness</td>
<td>64</td>
</tr>
<tr>
<td>Time spent</td>
<td>65</td>
</tr>
<tr>
<td>Complexity</td>
<td>65</td>
</tr>
<tr>
<td>Lack of enough information for translating the logic to the simulator</td>
<td>65</td>
</tr>
<tr>
<td>Formation of a DES team</td>
<td>66</td>
</tr>
<tr>
<td>Future use</td>
<td>69</td>
</tr>
<tr>
<td>7 REFERENCES</td>
<td>70</td>
</tr>
</tbody>
</table>
Introduction

Project Objective

The current study focuses on the application of Discrete Event Simulation (DES) by modeling of a real-life process. However, before that, there has been a study around simulation generally as well as defining the different categories of simulation. This way, the reader can realize the exact position of DES in the more general area of simulation.

However, this study is not meant to elaborate the discrete event simulation theory (although it will provide the reader with some introduction). Rather, it is aimed to briefly define simulation, then introducing discrete event simulation as a tool and later on provide some research around the application of discrete event simulation in the area of production. Then challenges of using discrete-event as a decision-making tool or problem solving tool, has been investigated. Also a practical case-study has been done which has been a valuable project for experiencing the real challenges of using simulation (DES in this project) in a real-life industrial environment.

In brief, this study is aimed for gaining multiple results, among them:

- Understanding of the simulation concept.
- Recognition of Discrete-event methodology, its nature and possible application
- Performing a real-world simulation project in an industrial environment
- Providing a framework for DES use plus suggestions for improvement of such projects.
- Discussion around challenges of using application and possible solutions.

Project directives

The presented project has been commissioned by Volvo Construction Equipment in Eskilstuna, Sweden and is cooperated among Volvo CE, Volvo IT and Mälardalen University. All the data, results and the framework provided in this study is the property of Volvo CE Corporation. Any use of the data (either total or partial) requires written permission of Volvo Construction Equipment, Sweden.

The project has been performed under thesis work for gaining Master Degree in Product, Production and Logistics area. The simulation software used in this project was ‘ExtendSim’ software by Imagine That ™ Corporation which is licensed by Mälardalen University.

Volvo Construction Equipment was the sponsor for the current project and the Volvo IT also was interested in the results of this project.
Problem statement

Volvo Construction Equipment is one of the world-class manufacturers of construction equipment that develops, manufactures and markets those kinds of products. The products include a wide range of construction equipment such as dump trucks, excavators, wheel loaders, graders etc. The company also provides soft products that are referred to after sales services plus innovative modern tools designed for customer.

The company’s long-term demand forecast indicates an increase in demand in a way that the company has to double the production rate in order to be able to produce the desired number of customer demand in the following years.

This good news, however, creates some challenges for the people involved in production planning as well. Reaching the roof demand and developing the production system to be able to produce the increased output is accompanied by lots of disputes and uncertainties. Therefore, there should be an extensive planning for making sure that all components and departments of the production system would adapt to the situation in near future.

The hardening department in Volvo CE is one of the most significant and sensitive parts of the operation in Volvo Construction Equipment as majority of the machined articles, mostly gears, ought to go through the hardening process to get hardened. As mentioned above, the company is facing an increase in demand that would result in the higher rate of production including different types of gears used in the axle and transmission. Consequently, the number of gears that need heat treatment process would considerably increase.

Today, the hardening department works smoothly in accordance with other production units and can fulfill the current demand of the assembly unit. However, due to the predicted high rate of production, the company has invested in another automated heat treatment furnace for working in parallel to the old one. On the other hand, these two furnaces that are supposed to work in parallel are coupled to a common ASRS which supplies and feeds both furnaces with parts.

ASRS stands for Automated Storage and Retrieval System and it is a set of computer-controlled equipments designed for handling high volume of articles being transported into and out of inventory. ASRS systems as the name reflect can store and retrieve articles in an automatic way without manpower interference.

The ASRS system installed in the hardening department of Volvo Construction Equipment has been purchased a few years ago when the long-term demand was not a significant matter. However, because of the demand increase it has to handle quite larger number of articles in comparison to what it is doing right now.

But this change brings uncertainties for the management staff at the Hardening Department as well as the planning engineers of the factory. They are not sure about the maximum capacity of the ASRS system that makes them worried about an undesirable situation i.e. a situation where
the ASRS system cannot keep up with the high rate of the input and output articles into and out of it.

One of the tools that can help when such problems arise in production is simulation. Simulation and the methodology of simulation which suits production environments is Discrete Event Simulation. Such a tool enables the production planners and engineers to simulate the desired system and make it work in a virtual environment to see how it would react to the upcoming changes. It also makes it possible to try different scenarios and implement sensitivity analysis by changing different variables and seeing the results.

Therefore in this study, the goal has been, with help of discrete event simulation assist decision making process for the mentioned problem. So, the system has been simulated using a discrete event simulation method and the behavior of the system under different situation has been analyzed. Apparently, this would not be possible without realizing the logic behind the ASRS system and how it handles the incoming and outgoing parts.

The idea has been to build a model that can help the process managers to predict the upcoming situation before the increase in demand causes serious problem and disturb the production activities.

However, discrete event simulation and its application in industries is both broad and interesting area of knowledge which has the potential of being more investigated and analyzed. Therefore, both Volvo CE and Volvo IT are interested the application of DES in future, besides simulating the AS/RS. By reflecting on the results and the experience gained from the mentioned simulation together with studying around simulation and specifically Discrete Event Simulation fundamentals there is an expectation to devise a framework which enables the company to use discrete-event simulation effectively. Thus after combining those parts (theoretical studies around DES plus the practical application of DES in an industrial project) this project aims to provide some guidelines for performing the simulation projects in production area. This concept has been described and elaborated more in details in the proposed framework for ‘Lean Simulation’ in the results chapter.

**Project limitations**

The current project has been constrained within Thesis Work for gaining a Master Degree in Production and Logistics area and it follows the rules and regulations regarding thesis work at Mälardalen University.

The data collected for building the model that has been gathered from different sources as: Equipment Log, Production Manager, Staff, and time record and study. Therefore it might be exposed to some human errors in some cases.
The results of the project that is related to guidelines for using DES in production would later be used in further projects. In addition, the constructed model would help the process experts in Volvo CE to have a better estimation of the capacity of the ASRS equipment.

In this project, the main focus would be on discrete-event simulation (DES) and its applications as one of the methodologies of simulation and other methodologies have not been regarded. So, this project does not cover other methodologies of simulation such as continuous simulation or discrete-rate simulation (although some basic definitions have been provided for making the report comprehensive plus narrowing down to the desired subject).
Research Methodology

As mentioned, one of the current project’s results is a framework for the application of DES within production. However, the basic methodology used in the model is Banks et al (2001) model shown in Figure 1. The proposed algorithm in results section is a developed version of this algorithm considering the practical issues and industrial aspects of a simulation project.

![Figure 1- Steps in a simulation study, Banks et al. 1999](image-url)
This research is a combination of literature study and a case study performed at Volvo Construction Equipment in Eskilstuna, Sweden. The goals of the research can be divided into two main parts:

- Developing a Discrete Event Simulation (DES) model that can respond to the question aroused regarding production challenges of an Automated Storage and Retrieval System (ASRS) in the hardening department at Volvo CE as a case study.
- Apart from building the model and analyzing the results, the valuable experiment of building a model for solving a practical issue in production plus literature study around the discrete event area have provided a holistic picture regarding the application of DES in production, its advantages and disadvantages. Thus, a framework for using DES within production in the most efficient way has been provided eventually.

So, from the application prospective, the current study can be regarded as an ‘applied study’ rather than a ‘pure research’. This is while considering the objective of the study it is both explanatory and exploratory. The literature study tries to explain the principals of Discrete Event as one of the main formalism of simulation area. The case study, on the other hand seeks existing and potential applications of DES in production and logistics field.

Figure 2 provides a concise chart showing different aspects of the study. As it could be inferred, there is a focus on transforming the data and theories into knowledge that can be used in future in the related areas.

The main components of the research conducted could be described as following. A literature study section reflects the principals of the simulation area. Then the case study is explained. This part includes explanation of the process under investigation to provide the reader with a picture of the activities done in the hardening department plus details of the ASRS equipment which is almost a significant part of the process in the research. The next part states the modeling process and the methodology chosen.
The data-collection methods used in the research are research plus field research. When it comes to library research, the most common method is analysis of historical records. Also, in field research area, both participant and non-participant observation have been implemented. The other methods of data-collection were personal interviews, questionnaires, and case study data. No mail or telephone survey has been done regarding the research.

For selection of the most suitable people regarding this project, it has been tried to interview with the people who are involved in the production planning, production system, plus the manager of the simulated process in this project. Also, the chief executive manager has been interviewed regarding any future application of simulation in the organization.

The research or literature study has been done in the beginning of the project and then modeling, running and analyzing the model has taken place. In the first steps of the project, it has been tried to study about the principals of simulation and specifically the Discrete Event Simulation features and its application in industries. This period gave an insight to the whole subject and ability to know exactly where Discrete Event Simulation stays in the simulation concept.

Later, the focus has shifted on the on the process, gathering the required data and performing the modeling procedure. It has been tried to base the data collection, process mapping and modeling on standard methodologies for getting reliable scientific results. Apart from the model and analyzing the results, another phase of the current research is to analyze the application of Discrete Event Simulation as a tool for decision making process in production which is based on the results and experience from the case-study done plus literature study around the subject. However, all the experience and challenges during the process has been logged continuously so
that they are considered in the proposed framework as one of the purposes of this study is to uncover the practical problems when it comes to performing a discrete-event simulation project and providing a solution which covers such challenges.

The project has been divided into two main sections where in once part, the simulation theory and discrete-event simulation application in industry has been investigated. On the second part of the project, the simulation modeling has been done.

Also, another project has been performed during summer for preparing a graphical user interface (GUI) for the model as the manager realized the need of a simple and understandable interface for the model.

In the data collection for modeling the process, it has been tried to gather sufficient number of data samples to increase the liability of the model and at the same time simplifying the validation of the model. This matter has been discussed in detail in the simulation model chapter plus the method of choosing the most suitable distribution in modeling process.

Finally, to make the modeling process cohesive and more understandable, some methods of how the model has been conceptualized has been mentioned in the simulation model chapter. Please refer there for more detailed information.
Theoretical background

In this chapter, it has been tried to cover the definitions, concepts and formalisms of simulation plus providing the basic knowledge needed for the reader to get acquainted with simulation and specifically discrete event simulation basics. By studying this chapter, the reader would be able to grasp the basic concepts of simulation science and would get to know how a simulation program and specifically Discrete Event Simulator works. In some parts some explanations are provided as clarifications for avoiding misunderstanding or confusion.

Simulation Fundamentals

The word ‘Simulation’ is defined quite differently in different sources which a few of these definitions are presented below.

Merriam-Webster Dictionary’s definition:
‘To have or produce a symptomatic resemblance to’

Merriam-Webster’s Online Dictionary:
“The imitative representation of the functioning of one system or process by the functioning of another”

Longman’s definition for simulation:
‘To make or produce something that is not real but has the appearance or feeling of being real’

Oxford also defines simulation as:
‘A situation in which a particular set of conditions is created artificially in order to study or experience something that could exist in reality’

Among these definitions, the one that fits most into the content of this study is the last one provided by Oxford Dictionary which explains simulation as a situation where a set of conditions is created in a not-real environment to enable the possibility of experiencing and studying of a real system. However, more precise and scientific definitions follow as well.
Definition in industrial context

When it comes to the simulation in industry, the definitions are mostly specialized around processes or systems due to the aim of using simulation in industry which later would be discussed in this chapter. A few definitions of simulation within industrial studies are presented in the following:

Page (1994) describes simulation as ‘the use of mathematical or logical model as an experimental vehicle to answer questions about a reference system’.

Simulation is the imitation of the operation of a real-world process or system over the time (Banks et al 2004).

According to Krajewski et al (2007), ‘the act of reproducing the behavior of a system using a model that describes the process of the system is called simulation’.

Johansson (2006) also brings a definition of simulation originally from Encarta\(^1\) that describes simulation as:

“The construction of a mathematical model to reproduce the characteristics of a phenomenon, system, or process, often using a computer, in order to infer information or solve problems”

Finally, considering the industrial context as the area of simulation in this research, a definition of the simulation is presented in the current study as following:

“Simulation is the science of creating a virtual version of a real-world process with a certain level of abstraction (depending on the purpose of the simulation), in order to study a process for either gaining insight or providing a solution regarding a problem aroused.”

In this definition it has been tried to provide a broad definition of simulation which at the same time focuses on industrial use of it that is the main focus of this study. Otherwise, simulation can include a much wider spectrum.

Simulation versus Emulation

Before going forward into more specific subjects around simulation, it is better to mention the difference between the terms ‘simulation’ and ‘Emulation’ which seems to be somehow ambiguous sometimes. The definition provided by Banks (1999), defines the simulation as an imitation of the operation of a real-world process over time. However, this should be remembered that when considering simulation as a professional expertise (as it is consumed at

---

\(^1\) A digital multimedia encyclopedia published by Microsoft Corporation from 1993 to 2009
least in this study), one must be aware of how the behavior is imitated which is a delicate point that distinguishes between simulation and emulation.

When considering simulation, the system behavior is generated by a set of interactions and logics designed by the modeler himself or herself according to the real system. Whereas in emulation, the modeler can embed the logic of the system in his/her model by either by purchasing or downloading it (normally from the system producer). In another words, if the modeler outsources the logic of the system in his/her system, then it is called ‘emulation’, rather than ‘simulation’.

Figure 3 shows this difference in a simple way for clarification. In the left picture, a model of a calculator is created by writing a program that imitates what the real calculator does in reality. The right picture, however, shows an emulation of the calculator where the modeler has gotten a dump of the calculator’s firmware and writes a program that loads it and the runs it.

Once the process is simulated and the model is ready to use, the user (that might be the modeler himself/herself, process experts, or analyst in general) would input the desired data according to the scenarios designed and then he/she would run the simulation and would analyze the results produced.

According to Krajewski (2007), ‘a simulation model cannot prescribe what should be done about a problem. Instead it can be used to study alternative solutions to the problem. The alternatives are systematically used in the model, and the relevant operating characteristics are recorded. After all the alternatives have been tried, the best one is selected’.

As it could be conceived from the definitions above, simulation could be supposed as creation of a fake or virtual version of reality that provides possibilities which would be accompanied by lots of constraints if real-world. Some of these constraints are:
• **Time:** This is probably one of the top reasons that urge process experts to think of simulation as a tool for creating their prospective systems. An example of this case could be prediction of population distribution in a country or continent. For this one has to be able to fast-forward in time by simulating of the target society. This feature of simulation that is called ‘Time Compression’ makes simulation a spectacular solution in long-term planning for complicated systems.

• **Cost:** Sometimes it is theoretically possible to build the desired system to be able to analyze it. However, it may become insanely expensive or even practically impossible to do that. Instead, a simulation of the desired situation could give leading results for making further decisions. For this factor, one can think of crash tests where the cost of a simulation can be a lot cheaper than performing a real accident. Or deciding about the required storage for an oil refinery complex.

• **Complexity:** The more interactions between the components of a system, the more complicated become its study. The ‘Airport Logistics’ is a good example of complexity factor. Although there is no formula or absolute condition for deciding when to use simulation, there are some guidelines which lead to know when to use simulation. This matter would be discussed in detailed later in the discussion chapter where an algorithm would be introduced for deciding when to implement simulation.

• **Gaming:** This issue is discussed by Krajewski (2007) where he explains the usefulness of simulation in practicing and analyzing managerial decisions. As stated by him ‘Simulation is useful in sharpening managerial decision-making skills through gaming. A descriptive model that relates managerial decisions to important operating characteristics (e.g. profits, market share, and the like) can be developed. From a set of starting conditions, the participants make periodic decisions with the intention of improving one or more operating characteristics. In such an exercise, a few hours’ “play” can simulate a year’s time. Gaming also enables managers to experiment with new ideas without disrupting normal operations’.
Simulation applications

One of the primary questions that could be asked recurrently when it comes to simulation is ‘why should we use simulation’. Diamond (2010) clarifies the reasons to use simulation as following:

- Predict the course and results of certain actions
- Gain insight and stimulate creative thinking
- Visualize your processes logically or in a virtual environment
- Identify problem areas before implementation
- Explore the potential effects of modifications
- Confirm that all variables are known
- Optimize your operations
- Evaluate ideas and identify inefficiencies
- Understand why observed events occur
- Communicate the integrity and feasibility of your plans

However, this answer triggers more discussions around ‘when to use simulation for the mentioned purposes’. It means that one may argue that it is possible for instance to optimize the process using conventional methods such as use of mathematics or spreadsheet computer software. For finding the best answer to this question, this matter is discussed under the title of ‘The borders between paper and pen, spread sheets, and Simulation’ in the ‘results’ section where it has been tried to provide clues for when to start thinking of simulation as a tool providing solution to a problem.

Some other examples of simulation which implies the wide application of simulation in different areas has been provided by different authors:

- Rapid prototyping (Aluru et al 2001), 3 D modeling (Fröhlich et al, 2000), cutter path simulation (Huang et al 2000), fluid flow simulation (Patnaik et al, 2000), robot program generation (Sivayoganathan & Al-Dabass 1999), computer vision (D'Sousa et al 1999), assembly (Sze & Lee 2001), inspection (Fröhlich et al 2000), traffic studies (Owen et al 2000), disease propagation (Newman and Watts 1999), and warehouse simulation (Forcinio, 2000). It can be seen that it is quite popular in academic and industrial circles.
Simulation advantages and disadvantages

According to Yücesan et al (2000), simulation has the following advantages:

- **Time compression:** A simulation model can predict years in a few seconds. This is something that cannot be achieved with similar results.
- **Component integration:** It is possible to integrate complex systems and investigate the relations among them.
- **Decreasing risk:** Using simulation decreases the potential risks (either physical or financial) to a certain degree. It can even release the risk totally.
- **Scaling:** Sometimes there is a need for studying a system in bigger scales. Simulation enables its users to have bigger scale of their systems and study the consequences with much less cost.
- **Repeatability:** Simulation let the process experts to repeat the system so many times without disturbing the real process.
- **Control:** Having a sophisticated model if the system lets the user to have full control on different components of the desired system.

Some disadvantages of using simulation however, include:

- **The high amount of expertise:** to build a sophisticated model that could be responsive to the defined problems, demands high expertise.
- **High cost and long time:** Normally simulation projects take a lot of time and require high amount of budget.
- **No perceivable result:** Sometimes the result of a simulation project is nor perceivable for the user and the results must be processed a lot for being understandable.

Different Classification of simulation

When it comes to how simulation is categorized, there are quite a few categorization made due to different application and area of the study. Law & Kelton (1991) and Banks et al (2001) introduce three main categories of classification for simulation:

- Static – Dynamic
- Deterministic – Stochastic
- Continuous – Discrete
When the system is analyzed in a certain point in the time, then the simulation done could be considered as static. Accordingly, when the system is analyzed over time and its characteristics (depending on the purpose and context) the simulation done is dynamic.

When it comes to deterministic- Stochastic classification, it could be supposed that the main factor that determines a simulation to be deterministic or stochastic is the existence of random numbers within the model. In another words, when the simulated model includes random generator(s), then it would not produce the same results every time it runs. This type of simulation project could be regarded as stochastic that means the system has random probability distribution in it.

The third classification which is discrete – continuous has been discussed in details as it would results into the introduction of Discrete-Event simulation which is the base of the current project and also is used in the modeling procedure. Also, in the following classification the discrete-continuous nature of simulation results into a more precise classification which divides the simulation into three different types, methods, or formalisms.

Therefore, in this study, as industrial application (and specifically production) is under the main focus, it has been tried to consider the one that leads the reader to the desired paradigm which is mostly used in production area i.e. discrete event simulation.

Simulation and modeling Formalisms

Zeigler et al (2000) in their book ‘Theory of Modeling and Simulation’ divide the simulation and modeling formalisms in three main classes. It was in the first edition of this book (1976) that the first formulation for simulation approaches has been presented. This formulation includes three main classes of simulation approach or formalisms:

- Differential Equation System Specification (DESS)
- Discrete Time System Specification (DTSS)
- Discrete Event System Specification (DEVS)

Both DESS and DTSS formalisms have mathematics controlling their computerized incarnation, whereas discrete event models are more affected by their simulation language and are based on system time-event status.

Figure 4 depicts the mentioned formalisms with some graphs reflecting the logic behind each plus how the mentioned formalisms change over time.
Differential Equation System Specification (DESS): The traditional differential equation systems, having continuous state and continuous time; in this formalism, the behavior of system is generated in a continuous way considering its use of differential equations as the base of algorithm. So, it produces unlimited number of system state over the desired simulation period which creates a continuous curve if transferred on a diagram.

Discrete Time System Specification (DTSS): Systems which operate on a discrete time base; This formalism also uses mathematics equation produce the system state over the time, but the difference is that this method does not produce unlimited number of system state. Rather, it quantifies the system state in limited number of time points that has a certain interval.

Discrete Event System Specification (DEV): Systems with different time intervals which change the state of the system; Discrete Event Simulation (DES) uses a quite different logic for producing the system behavior over the time. As the DTSS method, the DEV also produce quantified
(limited) number of system state. However the difference is that in DEVS the time intervals are not necessarily equal. And the main factor affecting the time intervals is the system state due to an event occurrence in the system.

Therefore the time jumps to the next event and at the same time the state of the system (system status) is measured and then the same cycle continues until the whole system’s behavior is produced (end of simulation).

**Simulation methodologies**

In the last few paragraph formalisms of simulation has been introduced which is originated by the simulation programming languages’ nature. A similar classification of simulation would be provided which classifies the methods and is more related to the software and tools and in which domain simulation is performed. This classification is useful when it comes to determining what type of tool to use for simulating a certain process. Diamond (2010) has provided a concrete classification for that which follows.

**Continuous**

In these types of systems, the time-step is fixed and time advances in equal increments. The value also changes as the time change continuously. So the system value could be extracted at any desired point in the time. Time advance is even. A spaceship’s velocity and fuel status could be an example of such system (Figure 5)

![Figure 5- Continuous time-line](image)

**Discrete-Event**

Discrete-events however have a totally different logic behind them. Despite continuous systems where time advances evenly and system status is logged continuously, in discrete-event systems time advances in respect to the occurrence of certain events. And in fact those events cause the state-change in the system. Normally the time-steps are not in equal increment. One can suppose an elevator as a system. Then, different levels of building would be the status. Most of the production activities that have discrete nature could be and sometimes should be simulated by this methodology to get the most useful results (Figure 6)

![Figure 6- Discrete-event timeline](image)
**Discrete-Rate**

This methodology could be supposed as a combination of both continuous and discrete-event methodologies. As continuous models, they consider the flow rather than items. However, system recalculate the status (value and rates) when events occur. A discrete production activity (e.g. assembly) which includes a continuous process (e.g. painting) could be a good example of such systems. (Figure 7)

**Monte-Carlo**

This method uses random numbers and a set of statistical methods for providing solutions for problems which includes a large amount of probabilities. In Monte-Carlo method a model is run many times and the results are analyzed (due to the existence of random numbers in a model). Therefore, one can say that Monte-Carlo could be incorporated in any model in a way.

The name Monte-Carlo is originated from the area of the Principality of Monaco in France, specifically the ward of Monte Carlo/Spélagues, where the Monte Carlo Casino is located- a world-famous gambling center.
Selection of the right methodology

After introducing these methodologies, the most probable question would be ‘what should be modeled with what type of methodology?’ The selection of methodology is directly related to the nature of the process which is being studied and the purpose of the simulation project. Basically it is the ‘the state change’ and ‘time steps’ that determines the methodology.

Table 1 demonstrates some information which elaborates this matter.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Continuous</th>
<th>Discrete Event</th>
<th>Discrete Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is modeled</td>
<td>Values that flow through the model</td>
<td>Discrete entities ‘items’ or ‘things’</td>
<td>Bulk flows of homogeneous stuff or flows of otherwise distinct entities where separation is not necessary</td>
</tr>
<tr>
<td>What causes a change in state</td>
<td>A time change</td>
<td>An event</td>
<td>An event</td>
</tr>
<tr>
<td>Time steps</td>
<td>Interval between time steps is constant. Model recalculation is sequential and time-dependant</td>
<td>Interval between events is dependant on when event occurs. Model only recalculates when events occur.</td>
<td>Interval between events is dependant on when event occurs. Model only recalculates when events occur.</td>
</tr>
<tr>
<td>Characteristics of what is modeled</td>
<td>Track characterization in a database or assume the flow is homogenous</td>
<td>Using attributes, items are assigned unique characteristics and can then be tracked throughout the model.</td>
<td>Track characteristics in a database or assume the flow is homogenous.</td>
</tr>
<tr>
<td>Ordering</td>
<td>FIFO</td>
<td>Items can move in FIFO, LIFO, Priority, time-delayed, or customized order</td>
<td>FIFO</td>
</tr>
<tr>
<td>Routing</td>
<td>Values need to be explicitly routed by being turned off at one branch and turned on at the other (values can go to multiple places at the same time.)</td>
<td>By default, items are automatically routed to the first available branch (items can only be in one place at a time.)</td>
<td>Flow is routed based on constraint rates and rules that are defined in the model (flow can be divided into multiple branches.)</td>
</tr>
<tr>
<td>Statistical detail</td>
<td>General statistics about the system: amount, efficiency, etc.</td>
<td>In addition to general statistics, each item can be individually tracked: count, utilization, cycle time.</td>
<td>In addition to general statistics, effective rates, cumulative amount.</td>
</tr>
<tr>
<td>Typical uses</td>
<td>Scientific (biology, chemistry, physics), engineering (electronics, control systems), finance and economics, System Dynamics.</td>
<td>Manufacturing, service industries, business operations, networks, systems engineering</td>
<td>Manufacturing of powders, fluids, and high speed, high volume processes. Chemical processes, ATM transactions. Supply chains.</td>
</tr>
</tbody>
</table>

Table 1- Differences between Discrete-Event, Discrete-Rate, and Continuous simulation
However, sometimes, one process could even be modeled with different methodologies depending on the purpose of the project or the taken strategy.

**Application of different methodologies**

Each simulation methodology has its own area of application as a result of its capabilities resulted by the structure of the programming. In another words, simulation software packages are designed according to the demand in different areas and applications. Consequently, a simulation tool which is designed for one area may be useless or extremely difficult to adapt in another area.

For example, even a powerful simulation tool designed for studying continuous chemical processes would be highly limited and inapplicable when it comes to simulating a simple discrete model of a hospital logistics. And that is the reason why commercial producers of simulation packages try to provide wide range of choices when it comes to simulation.

Diamond (2010) has provided brief information about the application of the different simulation methodologies. (Table 2)

<table>
<thead>
<tr>
<th>Modeling method</th>
<th>What is modeled</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Time</td>
<td>Processes</td>
<td>Processes, Chemical, Biological, Economic, Electronics</td>
</tr>
<tr>
<td>Discrete event</td>
<td>Individual items</td>
<td>Things: traffic, equipment, work product, people.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Information: data, message, and network protocols, at the packet level</td>
</tr>
<tr>
<td>Discrete rate</td>
<td>Flows or stuff</td>
<td>Rate-based flows of stuff: homogeneous products, high speed production, data feeds and streams, mining</td>
</tr>
</tbody>
</table>

Table 2- Application areas of simulation methodologies plus examples, Diamond (2010)

This should be determined in the very first steps of simulation projects where decisions about the simulation methodology have to be clearly defined to prevent further loss. This matter would be discussed in a more detailed way later when it comes to the proposed framework for a successful simulation project.
Discrete Event Simulation basics

As explained in this section before, discrete event simulation (DES) which is derived from the Discrete Event System Specification formalism (DEVS) is one of the main methodologies of simulation. In this section, it has been tried to provide the reader with a brief history of DES plus a step by step introduction to Discrete Event Simulation (DES) and the logic behind its structure along with examples for clarification. Also, application areas of DES plus some other useful information around it has been provided.

History of Discrete Event Simulation

Discrete event simulation has been used sporadically for a long time in industries as a decision making support tool. However, the complicated process of coding and programming even for fairly simple problems has always caused the process experts to lean toward other tools for analyzing and improving the processes. Thus, there has been always a tangible distance between process experts and Discrete Event Simulation as a supplementary tool for decision making.

When considering a simulation project, some negative factors have always been an indispensable cause for disregarding simulation as a main decision making support tool. Among those factors the following could be mentioned:

- High level of difficulty
- Time consuming process of modeling
- Diverse tools available in the market
- High cost of the software and experts

However, this situation has not lasted for a long time. A flashback to the history of the discrete event languages reveals the five important eras for its evolution (Nance 1993).

- The Period of Search (1955-1960)
- The Advent (1961-1965)
- The Formative Period (1966-1970)
- The Expansion Period (1971-1978)
- Consolidation and Regeneration (1979-1986)

As it could be perceived from the simulation programming languages history, the two last decades of the 20th century has been a critical period in which discrete event simulation began to spread itself to different fields of science, including manufacturing and production.

In contrary to the negative factors mentioned above, the following reasons have been the main motivation that drove the application of discrete event in manufacturing and production area:
The development of simulation languages: As described above, the more simulation programming languages improved, the more powerful the simulation tools became and their liability. This would also give the software developers to present their products with more confidence to the market.

Technology improvements: As the technology improved, the problems aroused in different areas of production became more and more specialized and complex. The high amount of calculation plus the importance factor of uncertainty involved in the problems has motivated the experts to consider IT-tools as a suitable solution for such problems.

The emergence of specialized simulation software packages: The competition among the simulation tool providers along with the increasing demand for purpose-oriented solutions naturally led to the emergence of diverse tools and categorized packages for each areas of application.

The mentioned factors imposed the usage of the discrete event simulation for solving complicated issues in production field. However there is still a gap between the existing DES tools and the practical application of them in reality. This gap is a result of a set of facts that cause resistance against the entire diffusion of discrete event in industry and production. This matter has been discussed thoroughly in the results section and some suggestions has be presented to overcome those challenges which prevent the industries to make use of DES in the most efficient way possible.

The characteristics and structure of DES (Time-event-state)

As described in previously, discrete-event simulation is based on events which cause the state change in the system. So, it goes without saying that unless an event has not happened, the system status would not change.

Table 3 reflects a simple example of the occurrence of a discrete process (elevator) and how the simulation model recalculates the system and updates system status over time.
Table 3 - An example of a discrete-event and system change

For more clarification, one can consider the 15th time step which can be seconds, minutes, and etc.

Time = 15
Event = Pressing the elevator button
System status = Queue at 1st floor=0, 2nd floor=0, 3rd floor=1, elevator =busy

The mentioned hypothetical example shows how system status changes over time. An important characteristic which makes DES a flexible tool is that it is basically possible to define the most significant system states that are critical in the system analysis. Figure 8 demonstrates a simple structure of discrete-event system simulation adapted from Kreutzer (1986).

![Figure 8- DES structure, Kreutzer (1986)](image)

As described before, discrete-event simulation is one of the methodologies in the simulation area. When the system has the discrete behavior and the events during time causes the system
to change its state, discrete event is the most suitable solution for simulating the system behavior.

Figure 9 illustrates a simple comparison among three main methodologies of simulation.

As it could be seen in this figure, discrete event is more dependent on the events that trigger the system state to change. The logic and procedure behind discrete-event tools are useful to study and it makes the modeler aware of the logic and the function of discrete-event.

**Discrete Event Simulation application**

For gaining knowledge around discrete-event simulation and its applications some studies has been done in the current project. Here, it has been tried to study the most relevant material from reliable academic resources which could lead to gaining a proper insight to the application of DES in production. Some valuable works has been done around either discrete event simulation or its impact and function in production and manufacturing area. Among those which have been used in this study:

Holst (2004) in his doctoral dissertation under the title of ‘Discrete-Event Simulation, Operation Analysis, and Manufacturing System Development’ first introduce manufacturing systems and then after writing about the principles of DES, continues with his proposed method for
integration of DES in manufacturing. He also mentions a few cases where DES has been implemented in Swedish and Japanese industry.

Johansson (2005) also has developed a proposal for a Modular Discrete Event simulation methodology in his PHD dissertation under the title of ‘On Virtual Development of Manufacturing Systems’. He has done a wide study around DES plus modular manufacturing systems where he discusses them to be more adaptable to DES implementation. Johansson’s proposed model considers the ability to create 3-D simulation of the desire manufacturing system which is not favorable in the current study.

Table 4 includes some statistics about the studies conducted on the use of DES in industry that follows:

<table>
<thead>
<tr>
<th>Usage Measured</th>
<th>Replies</th>
<th>Response rate</th>
<th>Main country Studied</th>
<th>conducted year</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>9%</td>
<td>431</td>
<td>NA</td>
<td>UK</td>
<td>1991</td>
<td>SSG (1991)</td>
</tr>
<tr>
<td>4%</td>
<td>95</td>
<td>42%</td>
<td>Sweden</td>
<td>1992-93</td>
<td>Saven (1994)</td>
</tr>
<tr>
<td>7%</td>
<td>140</td>
<td>20%</td>
<td>Sweden</td>
<td>1999</td>
<td>Ericsson (2005)</td>
</tr>
</tbody>
</table>

Table 4- Studies on the use of Discrete-event simulation in industries (Johansson, 2006)

Ericsson, U. (2005) has also tried to investigate the application of Discrete-Event by performing a study around the diffusion of discrete event in Swedish industries. He has investigated the application of DES tool in a few Swedish companies to provide an estimation of its application in a typical industrialized country.

Earlier in this study, some areas of application for different methodologies of simulation have been introduced. The next step is to focus on the applications of Discrete Event Simulation, as the main subject of this study research.

The following table provides brief information about the most common disciplines, fields and eventually applications of Discrete Event Simulation. Diamond (2010) has provided some of the most common disciplines and applications of DES provided in Table 5.
Discrete event simulation is a broad area in the simulation and it can be used for modeling any process which includes events that occur in certain points in the time. Also, depending on the level of expertise and innovative skills, it can provide solutions or decision-making guidelines for processes with discrete nature.

Some of the areas of application of discrete event simulation provided by Banks (1996) categorize follows.

**Manufacturing application**

Manufacturing and production are among the most important and frequent areas of application of DES due to discrete nature of the manufacturing activities. Johansson (2005) classifies some of these applications as:

- Analysis of assembly operations
- Optimization of cycle time and utilization
- Investigation of the dynamics in supply chain

Also, using DES as a decision-making support tool could be another example of the application of DES in manufacturing and production.
Construction Engineering

Discrete event simulation allows the construction managers to have a better look at the dynamic interactions of the facilities and operations. This possibility, along with the static analysis, makes them able to have a full control on the process and a good estimation of the upcoming activities.

Johansson (2005) takes some examples for this case:

- Construction of a dam embankment
- Investigation of the structural steel erection process
- Special-purpose template for utility tunnel construction

Logistics, Transportation, and distribution

Making use of discrete event simulation in such areas as logistics, transportation and distribution networks would be useful for better planning and controlling the different elements of the network.

Some of the examples of the application of DES in logistics are:

- Airport management
- Train network solutions
- Analysis of capacity managements in terminals

Business process

Application of discrete event simulation in business processes such as banks, hotels, etc. would let the business experts to have better estimation of the market situation, customer demand which helps them to plan better in aspect of time, personnel, and production scheduling to lower costs.

Military applications

As mentioned earlier one of the potential areas of using simulation is scenario planning. Using discrete event simulation in military context would let the commanders to test their scenarios with different layouts and make sure about the decisions.

Also, DES could be of great help when it comes to logistics planning when the budget and the facilities are limited and need to be precisely used.
Service industries

The service industry sector has recently benefited a lot from using discrete event simulation for improving their process and see if their resources comply with the customer requirements. The service sector can also make use of DES to analyze their logistics and apply lean concepts as Six Sigma.
Simulation Model (case-study)

As mentioned before, the current study is a combination of theoretical study plus a world-life example of discrete-event simulation project. Both aspects of the project have been performed in an attempt to provide a smooth framework (structure) that could be used when simulation projects are meant to be done in organizations.

In this chapter, the simulation model done at Volvo Construction Equipment has been elaborated and the model has been explained. Then in the results chapter, the desired framework has been demonstrated and explained.

There are two types of competence required for simulating a system:

- System Knowledge
- Simulation Knowledge

In this chapter, first the system (AS/RS) has been explained to provide some knowledge about the system and later the simulation process is provided.

Description of ASRS

ASRS stands for Automated Storage and Retrieval System and it is a set of computer-controlled equipment designed for handling high volume of articles being transported into and out of inventory. ASRS systems are widely used in the manufacturing; warehousing and distribution points and provide flexibility for the inventory systems and apparently the whole production system.

This system has numerous advantages such as:

- Providing control and tracking over the articles
- Making the production more flexible that leads to flexible planning
- Decreasing labor cost together with quick operation

These systems are normally composed of aisle racks in which a machine moves the parts in horizontal/vertical directions to store or retrieve articles to/from the racks. Figure 10 shows the picture of such system used in Volvo Construction Equipment in Eskilstuna, Sweden.
The ASRS system coupled to the Heat Treatment Process facilities plays an important role in the material flow of the factory. Therefore the functionality and availability of this system has a direct effect on Hardening Department’s capacity and consequently total output of the factory.

The ASRS used in the heat treatment process plays an important role in the hardening process as any single delay or error in it would lead to delays in the assembly process and eventually factory output. It is simply an automated storage between Machining Department and Hardening Process. This ASRS system performs four activities:

1. Store the raw parts (either through Direct Charging or input conveyors).
2. Feeds the furnace with raw articles according to the defined priorities.
3. Receives the hardened parts from the furnace and storing them.
4. Delivering ready parts as output for next processes (further machining or assembly).

The system has different input/output scattered around it and contains two types of items:

a. Fixtures: These fixtures hold the parts in specific numbers during the heat treatment process. Normally parts are taken to the ports and then empty fixtures are purchased from the ASRS and are loaded with parts and sent back into the ASRS system. Then they are sent to the heat treatment process according to the priority and then conveyed back to ASRS system. After that the fixture including ready parts is purchased through ASRS computer and parts are transformed on palettes, and the empty fixtures are returned to the ASRS system.
b. Articles (gears): The articles that get into the ASRS are gears used in the axle or transmission units of construction equipment. There are different types of gears entering the ASRS and heat treatment that requires different fixtures. Figure 11 shows an example of parts (gears) on the related fixture.

**Figure 11- Typical products on trays**

**ASRS operations procedure**

The ASRS system is consisted of single-aisle (two banks, each in one side of the stacker crane) rack system including 18 bays and 6 levels. A 3-d schematic view of such system is shown in Figure 12. Storage and retrievals can be performed to/from the racks only on the internal sides of the aisle. The storage system is connected to the rest of the process by a few conveyors (which have different attributes when it comes to being an input, output, or both). There are different pick and drop stations around the ASRS system and as mentioned earlier they are pick, drop, or both pick/drop stations.

The stacker crane works between two racks and has both horizontal and vertical movements at the same time. It moves toward receive/delivery point (called port here) and once it reaches the desired position, the shuttles extend to pick/drop a tray and then the shuttle moves back.

Every incoming tray is placed on one of the input points on the incoming conveyors and sent to the ASRS after registration in the computer. Then the stacker crane takes the tray and puts it on a free cell in the racks. This tray would be called according to the priority defined and would be sent to the furnace for the heat treatment process. After spending about 18 hours in different phases of heat treatment process the parts are ready and hardened. The ready parts are sent to the ASRS again. Afterwards, they are called using the computers beside the ASRS and then they are sent to the next operation that can be either hard machining or assembly.

As described before, the ASRS performs four different tasks i.e. storing, feeding, receiving and delivery. When considering the logistic aspects of these tasks, all transportations done by the ASRS could be categorized into two main types: incoming and outgoing. Here is the definition of these two expressions to avoid further possible misunderstanding:
- Incoming: articles or fixtures getting into the ASRS through a port.
- Outgoing: articles getting out of the ASRS through a port.

All these parts get into and come out of the input/output points in different points that are called ‘Ports’ in this report. Each port is designed for a specific purpose and hence definite group of articles are fed and purchased through each port. Figure 12 shows these different ports and their location around the inventory.

![Figure 12- Different input/output points (Ports) and their numbers](image)

Table 6 includes the names of those ports and what they are used for. It includes all nine ports that have different attributes when it comes to the rate and frequency of parts that enter or exits.

<table>
<thead>
<tr>
<th>Port no.</th>
<th>Port title</th>
<th>Type</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Utmatning</td>
<td>output</td>
<td>Exit parts (auto-charge)</td>
</tr>
<tr>
<td>2</td>
<td>Inmatning</td>
<td>input</td>
<td>Feeding in parts (auto-charge)</td>
</tr>
<tr>
<td>3</td>
<td>I-Bana</td>
<td>input/output</td>
<td>Purchase the articles which need blasting, Sending in blasted ones</td>
</tr>
<tr>
<td>4</td>
<td>U-Bana,1</td>
<td>output</td>
<td>Purchase empty fixtures</td>
</tr>
<tr>
<td>5</td>
<td>U-bana,2</td>
<td>input</td>
<td>Send in filled fixtures</td>
</tr>
</tbody>
</table>
Table 6- Different ports’ information

For being able to study the behavior of the ASRS system, some information about the specification of the system plus the logic that the system is working based on that has been gathered that is reflected in the following (Table 7).

<table>
<thead>
<tr>
<th>Items</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Racks</td>
<td></td>
</tr>
<tr>
<td>Number of places in the storage</td>
<td>~ 850 cells</td>
</tr>
<tr>
<td><strong>Stacker Cranes</strong></td>
<td></td>
</tr>
<tr>
<td>Number of stacker cranes</td>
<td>1 Unit</td>
</tr>
<tr>
<td>Horizontal DirectionVelocity</td>
<td>~ 1 (m. /sec.)</td>
</tr>
<tr>
<td>Vertical DirectionVelocity</td>
<td>~ 0.7 (m. /sec.)</td>
</tr>
<tr>
<td>Loading/unloading time</td>
<td>10 (sec.) / sum: 20 (sec.)</td>
</tr>
<tr>
<td><strong>Incoming Conveyors</strong></td>
<td></td>
</tr>
<tr>
<td>Number of incoming conveyors</td>
<td>6</td>
</tr>
<tr>
<td><strong>Outgoing Conveyors</strong></td>
<td></td>
</tr>
<tr>
<td>Number of outgoing conveyors</td>
<td>6</td>
</tr>
<tr>
<td>Number of items’ types on each tray</td>
<td>variable</td>
</tr>
<tr>
<td>Number of trays on each rack</td>
<td>variable</td>
</tr>
</tbody>
</table>

Table 7- Specification of the system

---

2 The provided information has been gathered by experiment and may contain human error.
Logic of the ASRS

The ASRS system works under a defined logic that is set by the supplier company and is specialized into each situation that it is operating in. This logic has been entered into the PLC of the system by the system provider. However, it could be reprogrammed later by entering the new logic into the system PLC.

After studying the behavior of the ASRS system in the hardening department, a general logic of the system showing the principles of scheduling the tasks has been developed. This is shown in Figure 13 and some explanations for different sections have been provided.

![Figure 13- The algorithm of the logic of the ASRS system](image-url)
ASRS Problem

The problem with the ASRS system is a potential problem, yet an important one. The significance, as mentioned above, is because of the strategic effect of hardening process on the output of the whole factory. If hardening process, for any possible reason, stops working for a while and the limited buffers in the assembly get finished; the assembly line would face lack of components. On the other hand the limited storage before hardening process also would be fully loaded and machining department would be forced to stop manufacturing of gears. This mean the whole factory would stop functioning.

Therefore, there is a logical anxiety about an unanswered potential problem:

- Ability of ASRS system to keep up with the highest rates for all input/output articles (finding out the capacity of the ASRS would be of great help then).

It should be mentioned again that today, the ASRS system can cope with the current volume considering the current production rate and working in accordance to only one heat treatment furnace. However, the problem arises when considering the high demand of the products in the following years when both furnaces would be running in parallel at the same time with their highest Takt-time possible.

As mentioned earlier, the company has investigated in buying another automated Heat Treatment facility due to increased demand that is predicted in near future. So, the ASRS system would run in parallel with both furnaces that basically means the input/output rate for the port-7 (see Figure 12) would increase dramatically (rates and different scenarios would be elaborated later in this study). When considering the interactions in the system and the current rules for parts with different attributes, this increase would affect other ports (possibly one or a few of the ports no.1, 2, 3, 4, and 5 depending on the article type to be hardened) as well; meaning it will lead to more parts coming into and getting out of the ASRS in general.

The problem arises when realizing there is no clue about the functionality of the ASRS system under the future state. In another words, there is no guaranty if the ASRS could response to all of the ports with new higher rate of articles. In the worst scenario, the ASRS system would not be able to handle the incoming/outgoing parts in an efficient way and queues would start to form in front of ports. This means that the ASRS and consequently hardening department would turn into a bottleneck and would halt the production flow.

Thus, simply described any single delay or stop in the process of hardening would affect the whole factory output. Therefore, the addition of the new furnace and its effects on the high bay function should be precisely investigated to avoid any possible catastrophe. This problem has created uncertainty among the managers in consequence of the vague picture of forthcoming situation.

The top view of the ASRS system provides a clearer picture of the condition of the ports and their attributes. The green color stands for input attribute and red color shows the ports where parts can only exit the ASRS system (Figure 14).
All of the ports have special routines and attributes regarding the rate of incoming/outgoing parts, the type of parts and how regular the parts enter/exit these ports. In the following paragraphs, these routines are discussed and it has been tried to provide a clear picture of the system regulations plus different rates for each port. This information would be used later in the modeling process to construct a model that is as close as possible to the real situation.

**Port no.1- Feed out (Utmatning)**

This port together with port no.2 is used for the parts that charged automatically without transforming on the palettes. Normally, the machined parts are transformed into the palettes that are stored on the inventory by hardening department. Then they are taken into the hardening workshop and are transformed on to the fixtures and finally sent into the ASRS storage. However, some parts have another process of charging i.e. Auto-charging. This means the parts are transformed on to the fixtures right after the machining process and then transported to the hardening workshop. In the hardening workshop, they are sent into the ASRS storage directly. This would decrease the lead time of the auto-charged products as well as reducing cost by decreasing the tied-up capital in the storages.

**Port no.2- Feed in (Inmatning)**

This port is the input for the auto-charged parts. As mentioned, this port is used for feeding the ASRS by the parts that are loaded on fixtures directly after machined parts.

**Port no.3- Blasting port (I-Bana)**

This port is used for the parts that need to be blasted. After the hardening process is finished all the parts are stored in the ASRS storage. Then the ones that need blasting are purchased using ASRS computers. These parts are transformed on to the blasting fixtures and pass the blasting process. After that, they are transformed on to the palettes and sent to the next process i.e. hard machining or assembly.
Port no.4- Manual feeding-1 (U-Bana, 1)

As mentioned above, normally the parts are transported to the hardening workshop in palettes. For sending the parts into the ASRS, they need to be manually transformed onto hardening fixtures and then sent to the ASRS storage. This port is used for purchasing empty hardening fixtures for loading them with soft parts.

Port no.5- Manual feeding-2 (U-bana, 2)

When the parts are loaded on the hardening fixtures, they are sent into the ASRS through this port. So, this port can be considered as an input port for the manually loaded parts. Apparently, the input/output rates for this port and port no.4 are the same as all the hardening fixtures purchased that are sent into the ASRS after being loaded by parts in a manual way.

Port no.6- Furnace-1 (Ugn-1)

Parts get out of this port in a regular way. As each furnace can have three specific Takt-times depending on which group of articles are in the furnace (short takt-time, long takt-time or gear-rings).

Port no.7- Furnace-2 (Ugn-2)

Port no.6 and port no.7 are the connection between ASRS and the heat treatment furnaces and both furnaces work in the same way. Therefore, they have the same takt-time and consequently input/output rates.

Port no.8- Gear ring-1 (Robot-bana, 1)

Gear rings are loaded on empty 5-level fixtures, and then they are sent into the ASRS. After passing through the hardening process, they come out through port no.9 and transformed on to the conveyors for exit.

Port no.9- Gear ring-2 (Robot-bana, 2)

This port and port no. 8 are coupled with a robot which loads gear-rings on the fixtures and delivers the hardened parts. Similar to the port 4 and 5, these ports have a common rate as well. So, each time a fixture full of ready parts is delivered in port 9, the empty fixture is transported to port 8 and loaded with a new set of gear-rings and then sent into the ASRS.
Suggested Solution

As described before, one of the ultimate goals of the current project is to find out about the ability of the ASRS system to handle the higher rates of parts getting into/out of it. In another words, it has been tried to find out an estimation of the maximum capacity of the ASRS system considering the current working rules by using discrete-event simulation.

However, when it comes to model a complicated system, there are always limitations to produce the real behavior of such systems as existed in the real-world and also, sometimes it not even required to simulate the system with all its details in the lowest levels. Thus, a modeler must be able to find the best possible abstraction level\(^3\) which provides an acceptable solution for the problem. And depending on which levels of abstraction is chosen, the pre-assumptions and conditions of the modeling would change. So, it is of great importance to pay attention to this critical stage in the modeling.

Regarding the ASRS model, it must be mentioned that the ASRS system and the working rules around it form a complicated system which includes a lot of interactions among different components of the system (equipments, operators, dynamic planning, variable working shifts, variable outputs, etc.). And simulating such system with all the details in the low abstraction level would be a complicated process. Plus sometimes, the complexity of a certain level of abstraction in a model would push the modeler to lean toward using another methodology of simulation or even paradigm. For instance, a modeler which wants to simulate the behavior of a small society of people when a bomb explodes nearby has to consider agent-based modeling\(^4\) rather than conventional modeling paradigms.

So, for modeling the ASRS system some assumptions has been considered for the system to become modeled in the desired abstraction level. Among those assumptions:

- The operators’ working rules has been transformed into some distributions. Although not applicable in the real world, but this has to be done for the system to become modeled. So, the input rates are more regular than reality (as so many problems could disturb the regularity in reality such as sickness, mood, personal attitude, etc.)
- The articles (parts) are assumed to be the same due to the unimportance of the article types in this study.
- Because the planning data is varying throughout the time, so some waiting times and other factors have been defined by the most suitable distribution. This has been done by data-collection and using the software Stat::Fit\(^5\) by Geer Mountain Software Corporation.

---

\(^3\) The complexity level of the system supposed to do a simulation is called abstraction level. The higher the abstraction level, the simpler the system is assumed. Respectively, the lower the level of abstraction, the more detailed the model.

\(^4\) Agent-based modeling is a class of modeling and simulation where there is autonomous system components involved in the system and their reactions would affect on the system behavior. More details of such simulation methods are out of the boundary of the current study.
In the following, the model structure would be explained and later on, the results would be presented in the results section.

According to the algorithm provided by Banks et al (2001) after the problem is formulated and the objectives are set, the model concept and data collection must be done. First of all, conceptualization of the model has been explained and later some information regarding data collection has been provided.

**Model Conceptualization**

For simulating any system, one must be able to design a concept of the desired system that is translatable for the tool which is used for simulation. After studying the ASRS system and analyzing its behaviors a general path which most of the parts follow has been extracted. This process flow has been shown in the Figure 15.

![Figure 15- The general concept of the Model](image)

According to this flow, generally parts get into the process (with an attribute of assign which means part is being stored). Then they stay in a queue where they are sorted according to the pre-defined priority. These steps are shown in Figure 16.

![Figure 16- Part 1](image)

Then the part enters the ASRS system by the means of automatic crane. The parts stay in the ASRS system for a certain time and then they are sent to the furnace to be hardened. These steps are shown in Figure 17.

![Figure 17- ASRS Transport (store)](image)
Then the parts enter the furnace to get the hardening process. After the heat treatment, the attribute of parts are changed from ‘store’ to ‘retrieve’. That means the parts are not longer stored rather they need to be retrieved and get out of the process (Figure 18)

![Figure 18- Heat Treatment](image)

Later on, the parts are sent back into the ASRS and again after passing a certain amount of time, they are retrieved and get out of the process and then they exit. (See Figure 19)

![Figure 19- ASRS Transport (retrieve)](image)

Although not all of the items follow this routine, it is the main flow which forms the structure of the model. So, if we consider different inputs to the system, then we would have the following structure for the model concept shown in Figure 20.

![Figure 20- Main concept](image)

As mentioned previously, the layout of the hardening department has changes and another furnace has been added to the equipments. So, an alternative concept would be such as the one shown in Figure 21.
The next step is to determine the different process and transport times for different inputs. This has been explained thoroughly in the next part.

Data Collection

Each port around ASRS has different function and is used for different purposes. So, when collecting data, all ports has been considered and following tables contain some of the data which had to be collected\(^5\). The following data shows transport time from the moment that crane takes the part in a port until it places it on a cell in ASRS.

**Table 8- Transport time- Inmatning port**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transporttid (s)</strong></td>
<td>37</td>
<td>25</td>
<td>34</td>
<td>47</td>
<td>44</td>
<td>73</td>
<td>42</td>
<td>58</td>
<td>56</td>
<td>53</td>
</tr>
<tr>
<td><strong>Transporttid (s)</strong></td>
<td>42</td>
<td>52</td>
<td>50</td>
<td>30</td>
<td>33</td>
<td>38</td>
<td>47</td>
<td>46</td>
<td>57</td>
<td>62</td>
</tr>
</tbody>
</table>

**Table 9- Transport time- I-Bana port**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transporttid (s)</strong></td>
<td>62</td>
<td>48</td>
<td>57</td>
<td>45</td>
<td>46</td>
<td>68</td>
<td>56</td>
<td>55</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td><strong>Transporttid (s)</strong></td>
<td>48</td>
<td>49</td>
<td>50</td>
<td>59</td>
<td>58</td>
<td>35</td>
<td>50</td>
<td>55</td>
<td>35</td>
<td>27</td>
</tr>
</tbody>
</table>

**Table 10- Transport time- U-Bana port**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transporttid (s)</strong></td>
<td>75</td>
<td>79</td>
<td>42</td>
<td>69</td>
<td>45</td>
<td>31</td>
<td>30</td>
<td>52</td>
<td>48</td>
<td>56</td>
</tr>
<tr>
<td><strong>Transporttid (s)</strong></td>
<td>28</td>
<td>31</td>
<td>34</td>
<td>46</td>
<td>32</td>
<td>45</td>
<td>38</td>
<td>55</td>
<td>46</td>
<td>52</td>
</tr>
</tbody>
</table>

\(^5\) All data presented here has been collected manually by a human being and it may contain some errors.
The Application of DES in Production

The presented data contain the time that it takes for a typical transport for moving an article in the mentioned port. So for example the first number in the Table 8 means that it takes 37 seconds for an article to be taken by crane and be stored in the ASRS system.

All the other data has been collected during the project and some simplifications have been done regarding the data.

**Statistical Distributions**

For feeding the data into the software, the data must be analyzed and the closest distribution must be chosen. For that purpose, in this study one statistic software has been used due to its precision and practicality. Otherwise, there are some mathematical methods which generate the most suitable distribution.

Here an example has been which demonstrates the process of extracting the most suitable distribution to the gathered data for Inmatning port (Table- 8). The distribution generated is the closest distribution which fits the data collected.

First we have to input the data into the software which has been done manually. (Figure 22).

![Figure 22- input data to the software](image-url)
Then by using the option ‘auto-fit’ the software asks for the type of distribution needed (which naturally is ‘Discrete distribution’ for the current project). This is show in Figure 23.

![Figure 23-Selecting the type of desired distribution](image)

In the next step, the software proposes a few distributions which best fit the input data along with a ranking which helps the selection (see Figure 24).

![Figure 24- Results (distributions)](image)

The same process has been repeated for all the data so that the best distribution for all the data is determined. The software has also the capability of exporting the distribution to some software such as ExtendSim, GoldSim, FlexSim and so on which simplifies the data transfer between two environments and also prevents data loss or making mistake when entering the data.
Model Structure

The next step in modeling the process is to translate the concept to the blocks in the software. In this step some conflict might come up due to the lack or differentiation of the existing blocks to the assumed concept. This step which sometimes is called ‘model transition’ is undoubtedly one of the most crucial steps of the simulation and must be done carefully.

After the model conceptualization and when the data is collected, the structure of the model must be created. Although there is always possibility to adjust the model and re-edit it, it is important that the model core has a rational structure. This would prevent confusion and re-work later in the next steps. The model structure which is suggested for the ASRS system has been demonstrated in Figure 25.

![Figure 25- Model structure](image)

The main sets of blocks which represent different components and specifications of the real-world system shown in figure-25 are:

1- The blocks which define the attributes for the articles and also assign a distribution to them so they are processed with their specific distributions.
2- The process blocks including the transport process of items plus the waiting in the ASRS as well as the heat treatment the furnace.
3- Scenario planning block which enables to run the model by either one of the furnaces or both respectively.
Results of the simulation model

The model has been tested with some input data just to make sure that the input excel sheet is coupled correctly to the model and for validation purpose. The results of the primary runs plus some descriptions over the excel sheet which functions as a median between the model and the user as an input/output reflector are shown in Figure 26.
The results of the current simulation model has been discussed with the managers involved in the process and it has been analyzed for seeing if the output data could be used as a decision-making support for future planning.

The model would be archived and refined and re-used with different input data to provide decision making support for different hypothetical and potential scenarios.

It goes without saying that any simulation model includes some simplifications and assumptions which alters the level of reliability and confidence of its implementation. However, considering the use of distributions which are extracted from the real-life experience and also the validation and verification of the model, one can surely use it as a supplementary tool which helps managers in their decision making plus it enables them to get insight to their process.
Results

The results of this project could be divided into two main sections:

First of all, the results of the simulation model which were presented in the previous section. The reason for that is to keep the text cohesive so that the reader could follow the content easily.

The second part of result section includes the results and reflections gained through studies, discussion and articles around the simulation (DES specifically) subject plus the experience of a ‘real-world’ case i.e. simulation of the ASRS system. This part would mostly focus on the use of simulation as a tool in industry and how it could be used in the most efficient way possible.

Figure 27 shows a simple picture of the result chapter.

![Figure 27- Results of the current project](image)

Simulation Challenges

Two main challenges are usually aroused when a simulation project is desired to be done:

1. To decide whether to use simulation as a tool for decision making or not.
2. How to perform an agile simulation project so that it can help to solve the problem as much as possible in the shortest time possible.

First challenge necessitates clear criteria which could help the experts to distinguish between the problems that need simulation and the ones that could be handled without using it (this subject would be discussed later in this chapter).

The second challenge however, is affected by the complexity of the problems aroused plus considering the profitability or outcome of a simulation project. This is tremendously affected by project management plus simulation skills of the project team (a comprehensive model for applying Lean Simulation projects would also be introduced in this section for clarifying this subject).

Firstly, the borders between considering and not considering simulation as a solution for a problem would be discussed and later some guidelines and tools would be produced for performing simulation projects.
The borders between paper and pen, spread sheets, and Simulation

This is probably one of the most controversial and interesting discussions in simulation studies. As mentioned earlier in this study, simulation is a powerful tool that if implemented correctly and in the right context, could help for processing the data and transforming it into a sort of knowledge by processing the data and providing results out of raw data. Figure 28 shows an abstract picture of the process in which raw data will shift into knowledge through simulation and analysis.

In the first phase, the current data would be modeled and then in the second phase the model would run considering different scenarios possible. Then in the third (last) phase, the results of the simulation would be analyzed which makes it possible to select the right action.

But one of the most crucial questions before doing a simulation project with all the required budget and time, is that “what is the border between controversial solutions and simulation?” or “when simulation is the appropriate tool to consider?”

Naylor et al (1966) have provided some goals of using simulation in his book about ‘computer simulation techniques’ that follows:

- Simulation enables the study of complex systems and the internal interactions within them.
- Alterations in different systems can be simulated in order to evaluate the corresponding effect.
- Improvements to the system under study can be obtained through the knowledge gained during its modeling.
- The interaction and importance of the different variables of a system can be obtained through changing simulation inputs and assessing the corresponding outputs.
- Simulation serves as an educational tool.
- New designs can be tested with the use of simulation before implementation.

Banks et al (1996) also proposes the following uses for simulation that is somehow similar to what Naylor et al (1966) had suggested thirty years ago.

- Simulation enables the study of and experimentation with the internal interactions of a complex system, or of a subsystem within a complex system.
- Informational, organizational and environmental changes can be simulated and the effect of these alterations on the model’s behavior can be observed.
- The knowledge gained in designing a simulation model may be of great value toward suggesting improvements in the system under investigation.
- By changing simulation inputs and observing the resulting outputs, valuable insight may be obtained as to which variables are most important and how the variables interact.
- Simulation can be used as a pedagogical device to reinforce analytic solution methodologies.
- Simulation can be used to experiment with new designs or policies prior to implementation, so as to prepare for what may happen.
- Simulation can be used to verify analytic solutions.

These guidelines, even general, can provide clues for using the simulation at the right time and on the right problem. However, the experience shows that there is no clear border or criteria which can confirm or reject the absolute use of simulation for a problem. But still, there are some factors which can push the experts toward using simulation or preventing them to use it. Some of the factors can be listed as following:

- **Level of complexity** (interactions among system elements): The more complex a system is, the more it would demand a simulation model for studying different elements of it.
- **Level of uncertainty** (probability): The more probabilities are involved in a process, the more uncertainty would be aroused when trying to analyze the system. Accordingly, the usage of classical methods or even excel sheets would not be able to handle the problem. However, simulation has the possibility to contain possibilities and different level of uncertainty in it.
- **Recurrence of experiments**: If a system supposed to be investigated frequently, then it is best to model it once and observe the results of the many experiments only by re-adjusting the parameters and seeing the results. Although this may look an expensive investment in the beginning, it would save a significant amount of time and cost considering long term application.

- **The cost of simulation project**: This factor could also affect the choice between considering and not considering simulation for solving a problem indirectly. Sometimes the high cost of simulation urges the managers to compromise about the precision of the solution and go for the cost-efficient alternatives which are more probably less precise. In that case cost could be considered as a hinder factor for making use of simulation.

- **The time of the simulation project**: This factor sometimes becomes a serious drawback for choosing simulation as an alternative for problem solving. The project definition and the time plan could somehow determine if simulation is supposed to be considered or not.

- **Dynamic- static analysis**: When it comes to the dynamic systems, there are spreadsheets and simulation models which would be of preference and which one among those two to choose demands precise studies around the behavior of the system plus analyzing all the other mentioned factors as well.

Figure 29 shows a simple picture of the mentioned factor which pushes toward using or not using simulation for problem solving.

![Simulation consideration spectrum](image)

Figure 29- Simulation consideration spectrum

As illustrated in the figure- XX, there are several factors which regulate the decision makers mind toward using or not using simulation for a certain problem. The level of importance of each factor varies considerably due to the context and the purpose of the simulation project done.

Therefore, one can say that when choosing between different methods of solving a problem (including simulation as an alternative) there is no absolute rule of thumb which determines the best alternatives. That means that there is no clear-cut distinction between choosing methods and sometimes there are both advantages and disadvantages for three or a pair of alternatives which is a matter of trade-off or compromise in another word.
An analogy: Production vs. Simulation

A simulation project can be compared to a production operation in many ways. The Figure 30 shows some of these similarities and tries to provide an analogy between those two processes i.e. production and simulation. Although the analogy may seem irrelevant, it could be useful when considering the simulation project as a process which results in products and also can be modified and improved continuously.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Production</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operator</td>
<td>Modeler</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product</th>
<th>Part</th>
<th>Model</th>
</tr>
</thead>
</table>

| Quality | OK/Not OK | Verified + Validated |

Figure 30-An analogy between Production and Simulation

The purpose of this analogy is to prove the point that like production activities, simulation projects also can be aligned with “Lean” concepts to make them lean and as efficient as possible. As mentioned before, one of the purposes of this project is to provide a framework for simulation projects in productions by both studying literature and performing a real-world simulation project. Lean simulation framework concept has been proposed in the current study and it aims to provide clear, simple and thorough framework for simulation projects done in the production area which most certainly results in the desired results. This concept has been explained in the following section.
Lean Simulation Framework for simulation projects

Looking at the literature around simulation project methodologies, one can realize that there are adequate information and algorithms introduced about how to perform a project simulation (including discrete event). These algorithms help the modelers to run successful simulation projects by following the defined steps precisely. Among these methodologies, the following two algorithms has been introduced by Banks et al. (1999) and Law and Keltin (2000) that are presented in Figure 31 and Figure 32 respectively.
Figure 31- Steps in a simulation study, Banks et al. 1999
However, it has been normally seen that simulation projects become more complicated than what it seemed before their kick off. Some of the factors that can complicate simulation projects are:
- **Lack of enough input data**: Before investing on simulation projects and spending money and effort on them, the person or team responsible for simulation project must be sure that all the required information for building model according to the abstraction level needed would be available when needed. An example of this factor experienced in the current project was the lack of data about the AS/RS system specifications plus the logic behind the PLC programming of it. This may prolong the project time and might even possibly lead to modeling in a level of abstraction except than what has been supposed formerly.

- **The time needed for collecting data**: Sometimes finding out about a data (that could be for example the process time of one machine) may take much longer than what was expected. This could be as a result of different reasons that are normally neglected or not predicted in advance. Therefore, even the availability of a specific data needed for modeling would not be enough to perform a successful simulation project. The data should be rather available at the right time for the modeler to be able to keep up with the time plan.

- **The dynamic project objectives or condition**: This is a rare situation but still possible and important. In this case, the project goals can vary over time or they may vary because of some new information found or something happening during any phase of the simulation study. One example would be when the customer of the simulation project realizes that the process investigated is not a bottleneck anymore (due to a change or any other reason) and would prefer to shift the project on another part instead. This can sometimes lead to abort the current project or re-considering the whole procedure.

Therefore, one cannot achieve the desired results of a simulation project only by only following a theoretical framework and not considering different practical aspects of a simulation project and their effects on the project progress trend. So, it is extremely important for simulation projects to consider all the possible practical effects besides the chosen methodology. Otherwise, the whole project may be a waste of time or a project with results that are not even worth for keeping in the archive.

Considering the mentioned facts about simulation projects, there is a need for a sophisticated algorithm which is more adaptable to the real-world industrial projects and could consider the practical challenges of simulation projects in industrial environments along with the academic and methodological viewpoint.

Furthermore, a common experience in running simulation projects in industry is that they turn out to be a loss (both in time and cost) irrespective how much effort has been done. This is mostly because of rushing into the use of simulation without considering all aspects of the project. Therefore, there is a need for a process to determine and analyze different aspects of a simulation modeling before the project kick-off. A procedure has been suggested in the Figure 33.
This algorithm is devised to fill the gap between an “only theoretical” and a “practical” simulation project. One of the most important issues addressed in this algorithm is the primary plan which could be supposed as a preliminary contract for the project. This plan includes important information about the project which all must be discussed and agreed on before any step for modeling. Some of the most significant factors are:

- Simulation project time
- Simulation project cost
- Tool (software) and methodology used
- SIPOC (supplier, input, process, output, customer)

As mentioned earlier, today’s complex industrial problems cannot be solved by using conventional methods provided in the basic scientific books. They rather need modern agile methods that can handle the problem by putting extra emphasis on the practicality of the solution in a real-life situation. Therefore, there is a need for designing algorithms regarding how
to proceed in a simulation project so that the resulted model could turn out to be practical and even reusable for later use.

In this project, it has been tried to develop an algorithm for simulation projects which considers both theoretical plus the practicality of the project. This algorithm is presented in the Figure 34. This algorithm is mainly focused on modeling part of the project, although some parts of it are related to the previous algorithm which considers the practical issues around the project.

Figure 34- Lean Simulation procedure algorithm© (Volvo CE, Sweden)

Although similar to the previous methodologies, some of the advantages of such methodology (including both algorithms) are:
• **Preventing further conflicts:** Sometimes simulation projects turn out to be a failure due to lack of a thorough project definition in the beginning. This is prevented by the use of the mentioned method as it considers all aspects of the project especially the practical aspects that are discussed in the primary plan before project kick-off.

• **Practicality of the method:** This enables the commercialization of the discrete-event projects.

• **Traceability of deficiencies:** One of the advantages of such method is that the modeler or system analyzer would be able to trace the reasons of inefficiency for the model by following the algorithm and finding the exact cause part which causes it.

### Introducing a few Lean tools to improve Simulation Projects

One of the useful tools that could help simulation projects to become more efficient and purpose oriented is the use of SIPOC cycle that is normally used for process management or improvement activities. SIPOC refers to the words supplier, input, process, output, and customers. In every simulation project three main aspects must be clearly defined i.e. Input, Process and Output plus who is responsible for them (shown in Figure 35).

![Figure 35- 3 basic factors of a typical project](image)

However, SIPOC cycle provides a high-level understanding for the scope of the simulation project. It is a great tool for defining the boundaries of the project both for modeler and customer. It also brings up some of the potential barriers that may be neglected normally. So, before rushing off into the modeling phase, it is better to create a SIPOC for simulation projects so that the project outline is clearly defined for all stakeholders and all the potential problems appear and get discussed (Figure 36).
The SIPOC cycles make the different elements of the simulation project visible and clear. However, after defining the supplier, process and customer and determining the input/output of the simulation process it is the time to do the modeling process (the algorithm proposed has been provided before in this chapter). The next step is to focus on the process that here is the simulation process and trying to improving it as much as possible. For this purpose another tool could be suggested that helps to make the simulation project as lean as possible i.e. PDCA cycle.

The PDCA cycle that stands for Plan–Do–Check–Act or Plan–Do–Check–Adjust is an iterative method that enables the process or product improvement. It can be implemented either in different phases of the simulation process or it can be aligned to the whole simulation process. By using this tool and applying its concept to the whole simulation procedure or applying it partially to a part of the project (such as model transition), the all aspects of the project would become clear. Also, the method would be refined by further checking and would get better and better (Figure 37).
Conclusions & recommendations

In this section, some of the factors which cause pessimism about the use of simulation as either a problem-solving tool or decision-making tool are discussed. Thereafter, some suggestions for removing these barriers have been suggested.

Later on some discussions around the future use of simulation has been done to provide the reader with a perspective of how simulation would evolve in future and how significant it would become in the area of production and manufacturing.

Skepticism when using simulation

Today, there is no doubt that simulation (and specifically discrete event simulation) is a powerful tool that can provide solutions (in fact as described before it provides clues for achieving the best solution possible) for complicated problems where a mass of interactions, probabilities and data exist. However, there is always a dilemma when deciding whether to run a simulation project or not. Apart from the psychological causes that are resulted from the point that discrete event simulation is still an uncovered tool and has not been widely spread in industries, there are some other factors that cause discrete event not to be implemented as frequently as it deserves to be. Some of the factors are presented below:

The cost of simulation projects

The more complicated the problem, the more expertise is needed for modeling it and gaining the desired solution. This consequently makes the cost of the project higher because of high cost of skilled modelers. Also, the cost of the software would also increase accordingly as complex problems need more professional software to be handled.

The inherent randomness of results

Whether or not, every simulation tool has an inherent randomness in its nature. Although this feature of simulation programs makes them capable of handling uncertain situations where probabilities are engaged, it may create a sense of insecurity. Figure 38 shows an example of two different results by producing two random series of numbers between 0 and 1 including 10 values. These numbers are generated using the formula=RAND () only for providing an example.
In the next 2 tests, the same two series are regenerated recurrently so other sets of values are produced and three reps have been chosen. These tests have been shown in the Figure 39.
Even if this test would be run so many times, there would not be any regulation that can justify the numbers. So, this, although proving the correctness of the random characteristic of generated numbers, may lead to some doubt as well. For instance, suppose an example of simulation where these 10 numbers would represent the time of a process that normally takes values among 1 – 100 seconds and if by any chance all the produced numbers turn out to be around 10 second, then the results of this study would not be so reliable.

**The time spent on a simulation project**

Suppose a situation where the company “A” needs to decide for the production rate for a specific product that is ordered suddenly by one of the key customers at a very profitable price that should be delivered in 5 months from the date which the contract is signed. But the company “A” has a hard time for planning this order among current production. So the manager decides to define a simulation project where they can virtually measure analyze the required parameters. Therefore, they contact company “B” (a consult company that runs simulation projects) and the company “B” accepts all the terms proposed unless they declare the needed time for project has been estimated about 3 months!

This may push the manager in company “A” to reconsider the use of simulation and start thinking of other solutions even if he/she is forced to compromise in a way (cost, precision, etc.).

**Complexity of model designed for the end user**

This may be a rare situation, but is a possible factor that may ban the use of simulation as a tool for helping decision-making process in industry. Sometimes, the model built for solving a problem is not only one-time used model rather it may be used several times by reconfiguration and updating it. Therefore, a complex model that is only understandable for the modeler or simulation experts would not be of any favor for the customer.

**Lack of enough information for translating the reality into the simulation environment**

This is another factor that could limit the usage of simulation. A model should be as much flexible as possible to provide a reliable solution to different problems aroused from different perspectives. As discussed before in chapter, for achieving such model there should be a few enablers available such as:

- System Expertise
- Simulation Expertise
However, along with these two factors, there is another significant factor that plays an important role in the project success i.e. required information according to the level of model. Apparently, in an industrial-based simulation, there are several factors involved such as human beings, machines, material flow and rate, etc. Any lack of critical information in one of these would disturb the simulation process.

**Clearing up skepticism when using simulation**

*The high cost of simulation projects*

Undoubtedly, the cost of simulation projects is high even for world-class companies, let alone medium and small-sized companies. However, the more the software providers of simulation enter the market and the more the competition among them, the more efficient and cheaper tool would be available.

But, still there is a limitation for this matter and considering all of these matters, simulation is regarded as an expensive tool. Therefore, it should be tried to confine the use of simulation to the projects that has no other solution except simulation. It means that simulation should be considered as the last choice for solving the problem after checking all the possible solutions available and analyzing all them thoroughly. (This matter has been discussed under the title of ‘the borders between paper and pen excel sheets and simulation).

*Inherent Randomness*

For this problem to be solved, first of all it is of extreme importance before kick-off of the project to determine if the problem does really need considering random number generators or not. This could be sometimes avoided by using tables extracted from machine log or at least preparing tables that resemble the real-world data to a good approximation level. Next step for reducing the negative effect of randomness in simulation is learning how to choose the distribution that fits best into the data available. This will help the simulation to be as close as possible to the reality as the distribution would create numbers that are reliable when it comes to decision making according to simulation results.
**Time spent**

Apparently, the time of the simulation project must be diminished in order to prevent this obstacle. This could be gained by the following methods:

- Automating the process of simulation.
- Using software that possibly has built-in modules and ready blocks
- Using modern methods of project management for decreasing the time needed for performing the project such as agile project management. (This matter is out of the framework of this study).

**Complexity**

Making the model as simple as possible considering the main purpose of the model, could help for decreasing the complexity of it. Also, preparing user-friendly graphical user interface for it which includes guides for different sections of the model would be a good solution. In case if the model includes different levels for different users, a user manual could be provided for different user-levels so that each user can use it according to his position, level of expertise and most important his/her need.

**Lack of enough information for translating the logic to the simulator**

For overcoming this problem, it is better to decide about the critical information needed for the project and make sure that they are either available or would be available when they are needed. This would avoid any disturbance in the project later after project kick-off.

This subject is of great importance when it comes to run a success simulation project and it is considered in the proposed framework in the results section.
Formation of a DES team

The use of discrete-event simulation in an organization could help a lot when it comes to decision making around complex problems involving lots of calculations along with probability and uncertainty. Nevertheless, simulation projects are normally complicated and if not applied to the right context may not result in the desired way plus wasting considerable amount of time and budget. This would provide two choices for companies; either outsourcing simulation projects or forming their own internal simulation organization. For those organizations which need the use of simulation continuously, it is necessary to form a DES team to prevent high cost of outsourcing and at the same time increasing the reliability of the results by keeping the relations short.

Therefore, in this study it has been tried to propose a team structure for DES project and also a standardized work method so that the projects could be performed in a standardized way and produce similar results.

A discrete-event simulation in production is the resultant of three major competences i.e. production, simulation, and management. Any lack of competence in each of these areas would lead to misunderstanding of the problem and consequently to the inefficiency of the simulated model. Therefore, a DES team should consist of three sections each contributing to a specific aspect of the project. Figure 40 shows a simple reflection of the DES-team and the different types of imperfect cooperation.

- **Production:** This part of the team is responsible to manage all the issues about the production and provide the needed information and technical support for modeling. Some crucial information about the process such as process time, Takt-time, material flow, and so on would be provided by production experts. Also, this part of the team has a significant role when it comes to the verification and validation of the model.

- **Simulation:** The simulation part of the DES team is responsible for all the issues around simulation and modeling of the process. This section has to be able to simulate the process in the most suitable level possible to provide solutions to the problem. Also,
preparing a proper GUI so that the model would be understandable for the user is another responsibility of this section.

- **Management:** The managerial knowledge is always required in simulation projects as the purpose of the projects is defined by the managers involved. The management division of the DES team has somehow a critical responsibility as it has to prepare the project plan and see if the project is progressing in the right direction. Also, it is the management team which decides about which scenarios have to be planned in the model. Furthermore, the output of the model is majorly used by the management team for decision making purposes.

In different simulation projects, there might be situations where conflicts are aroused among the DES team divisions. These conflicts are natural due to the different perspective of different divisions and those conflicts have to be solved by providing scientific solutions and discussion around the problem. The combination of the competence in the DES team would make it possible to handle different projects within production. The existence of multi-skilled experts in the DES team would be a valuable asset as it decreases the project time and eases the problem-solving process.

The amount of the contribution of each of these competence areas (DES team divisions) would be variable in different projects depending on the type of project. However, it is normally the management part which plays an important role in the defining goals and strategies based on the model results.

When the DES team is formed, then it is crucial to define a standardized method for confronting different problems which need simulation as a decision making tool. The algorithm provided in this research could be the base of the discrete-event simulation projects in organizations so that the projects are done in a common standardized way all the time. Figure 41 shows a standardized work procedure for the DES team which helps the simulation projects to be as error-proof as possible.
Figure 41- Standardized work for DES team© (Volvo CE, Sweden)
Future use

Holst (2004) in his broad study around Discrete Event Simulation and its integration to the manufacturing system development has mentioned about the future of modeling and simulation originally from the Next-Generation Manufacturing (NGM) project done in the United States of America:

... modeling and simulation (M&S) will reflect a new way of doing business rather than supporting technology. It will make virtual production a reality. All production decisions will be made on the basis of modeling and simulation methods, rather than on build-and-test methods. M&S tools will move from being the domain of the technologist, to being a tool for all involved in the product realization, production and business process.

Considering these facts and despite all of the hindering factors mentioned before, the simulation trend is moving forward with a fast pace. Sooner or later companies that want to stay competitive in the tight markets today would find the use of inevitable and necessary for survival. Among all of the factors driving the use of the simulation, the complexity of the calculations plus the uncertainty involved in complex broad systems, are the main ‘pushing’ factors toward the use of simulation (discrete-event simulation included).

This demands a newer ‘viewpoint’ toward discrete-event simulation in future organizations. Being pessimistic about the integration of simulation into the production systems, not only solves no problems, but also would deprive the company from the future advantages, potentials and possibilities of simulation integration into their activities.

In conclusion, companies are better to have strategic attitude toward integration of simulation into their system. As mentioned in the conclusions and recommendations creating an internal department inside the organization (DES team) is a good idea to start forming the simulation capability. Although it may take a while (depending on the conditions) for an organization or company to integrate simulation and make use of it in and efficient way, but it would definitely pay off in long term as the company could benefit from using simulation as a decision-making tool for any complex upcoming situation plus having full control on their process considering the future changes and possibilities in the market. Consequently those companies can make use of simulation as a key competence for becoming successful.