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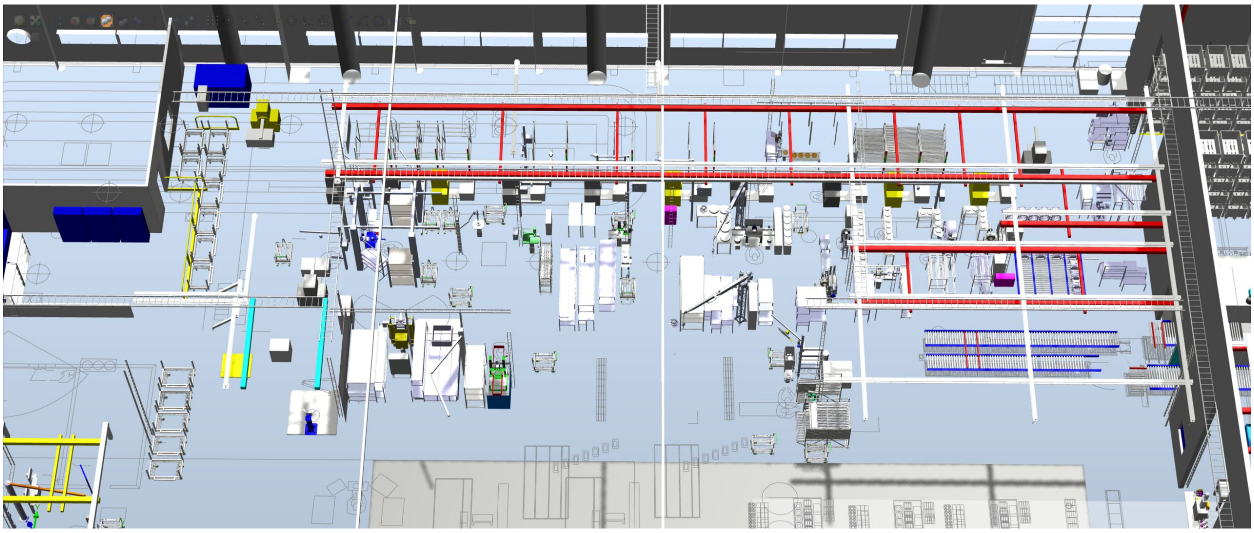

Internal Logistics Simulation for a New Production Line under a Risk Assessment Approach

A Simulation study at Company X focusing on Failure Mode and Effect Analysis

Master's thesis in Production Engineering

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Master's thesis 2020

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Cover: Image of Company X production Line.

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Abstract

With many industries adhered to the Industrie 4.0, the competitiveness in different domains are prevailing. The technologies are advanced for numerous advantages, trying to benefit in all possible ways. With mass-customization leading to an increase in product variety, urges companies to deliver the products on time, in which, the internal logistics in the production units plays a vital role. Simulating this internal logistic flows helps the companies to predict the flow of materials, material requirement & identify the bottlenecks in the flow. Simulation greatly reduces the cost and time required for bringing a logistic flow into function. Simulation projects are crucial and care should be taken such that a minimum of risk should be faced while conducting these projects.

The project team (students conducting the thesis work) develops a framework on how to perform a risk analysis study in a simulation project in theory and application. The thesis starts with building a simulation model for the logistic flow of materials required for the assembly of components at Company X expecting to satisfy their customers with effective delivery. The model is built using the Banks Methodology. This thesis deals with the different kind of risks that might be faced while conducting a simulation project, how to identify, evaluate and mitigate the risk using Failure Mode and Effect Analysis (FMEA) tool. The simulation project at the company is used as a base to conduct FMEA.

By the end of the report, the readers can find the results obtained from the simulation study. The model and the results will help the company to evaluate their logistic flow. Also, the FMEA methodology will facilitate the company to identify future risks and serves as a guideline on how to perform a risk assessment. This FMEA methodology can be followed for any simulation projects. The thesis team also provides improvement suggestions for the company.

Keywords: internal logistics, discrete event simulation, material handling, failure mode and effect analysis, risk analysis

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Kushal Jalige Ravikumar
Tarun Manjunath
Göteborg, August 2020

Glossary

FMEA Failure Mode and Effect Analysis
RPN Risk Priority Number
BOM Bill-of-material
JIT Just-in-time
DES Discrete Event Simulation
WBS Work Breakdown Structure
CAD Computer Aided Design

.

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1
Introduction

This chapter describes about material handling in an automotive industry and how they are related to our company case. The rest of the chapter explains the objective, purpose and focus of the thesis. Also, there rises a research question and delimitation of the thesis.

1.1 Background

Material handling is very important for manufacturing industries because it involves the movement, storage and control of material from one place to another. The material handling process is functioned manually, semi-automatically and complete automatically to reduce inventory, satisfy customers and reduce overall handling cost of manufacturing, distribution and transportation [1].

Internal logistics are vital for different industries such as manufacturing, healthcare, food and beverages etc. They are necessary and critical, also time consuming. For manufacturing industry, 80% of the lead time for the material handling account for internal logistics [2]. Around 30-40% is the processing cost of the internal logistics at producing industries [3]. The main reason of this impact on the industries is that, it involves high degree of material handling and high degree of labour usage, affecting the overall cost of the operation. Since, internal logistics is of high importance in industries, it is wise to simulate the material flow to see the risks it could possible generate. Simulation is used in such cases, to generate an artificial history of the system to understand the behavior and performance of the logistic flow before being brought down to the real world.

Risks may occur at any phase of the simulation project, which could hinder the desired results. This project helps to identify, tackle, and be aware and prepared for the risks using FMEA. For which in this project knowing that risks may prevail, FMEA tool is used to determine the risks and uncertainties. This tool represents the practical framework for mitigating risks. FMEA finds the root cause of the failures and makes the user to come up with optimal solution/solutions instantly. These FMEA methodology could be used for the future project as well. Knowing the importance of material handling, internal logistics, and simulation and risks in simulation, the relation between these terms and the company are detailed in the following.

1.2 Case Company

Before we start with the case company the project team would like to mention that because of high confidentiality with the data, the name of the case company is not being mentioned in the report and some of the sensitive data has been removed or blurred. The name of the company and the locations are mentioned as company-X and location A, B in the future chapters. Also, the name of the components have been removed and have been addressed as just components or parts.

Among the internal logistics material handling, one of the modes is the milk run, in which the parts are supplied to the assembly line by the transporter and returns back to the storage, while on the way back, transporter picks up the empty boxes/pallets for refilling [5]. To verify and check the functionality of the material flow in a manufacturing industry, simulation is used, which shows the virtual flow of materials to avoid risks and identify bottlenecks. Many automotive industries, use simulation to foresee the risks in the assembly line and take precautions accordingly. Company-X has decided to move the production line for component-A, from Company-Y in location-B to Company-X in Location-A and is focused to move the assembly process during summer 2020. The new line has a production mix of different variants using numerous parts in the pre-assembly and assembly stations. Even though the production is being shifted from an existing line, the space available in the material storage area, buffers and line-feeds racks has considerably reduced.

With a change in demand and available space, the production of these components has made it essential for the project team to be more precise and definite in its material and production planning. For this, a suitable tool which is DES is used, which helps to analyze and predict the variations in the production flow. It is a challenging task to fit the new production line in the currently available workspace. New products will compete for storage, material flow and bottleneck and this requires more precise production planning and layout design. The limited space and time creates more constraints in the logistic flows and escalates the need to have a new and improved transport set-up.

Also, while developing the model, it is better to analyze risks possessed, to overcome the barriers that hinder the tasks as well as it could be documented, for the future reference for the company. This comprehends the purpose of the thesis, which will be on simulation and risk assessment analysis. Along with this, the company expects improvising recommendations, to further improve their assembly line.

1.3 Purpose

Simulation is a powerful tool, but it can also be costly if not done properly. Therefore, to minimize the risk of project failure, the project team enforces risk management analysis. The aim of the thesis is to build a simulation model for the logistic flow, perform a risk analysis study to reduce risks while conducting such simulation projects in industries and steps to define on how to structure a simulation project. The main purpose is to mitigate the risks occurring at different phases of a simulation project, to overcome the barriers while developing a simulation model and at the same time, obligate improvements, such as the determination of bottlenecks, material requirements and storage capacity. Overall, the purpose is to improve the internal logistic flow and suggest better use of FMEA methods for more competitive production.

The risk analysis is supported by a versatile tool known as ‘Failure mode and effect analysis‘ (FMEA), used to analyse the degree of risks associated at each stage of the simulation process. To assess the FMEA tool, the project team decides to simulate the material flow of the internal logistics at the company and determine the degree of risks in the process.

1.4 Objectives

The main objective of the thesis work is to analyze the risks associated with the simulation process, executing it on the material flow of the internal logistics for the new production line of components using FMEA tool. Also, it is supplemented with the Siemens Tecnomatix Simulation software for the project team to perform the simulation process, from which the risks are analyzed and effort is made to mitigate it. With the help of this simulation model, design a futuristic logistical setup, evaluate logistical solutions to fulfil the assembly line needs and to provide improvement suggestions.

The objective of the project can be further dealt with detail in each phase as follows:

- Simulation model- Modelling the production line according to the previous state (in Location-B) and if it would fit the new production layout.
- Data collection- proper data collection needs to be done to ensure that the model can be trustworthy and that it can be used for further analysis.
- Validation- To validate the model, the created simulation model has to be compared and verified with the existing data (no of parts required/variant/day, buffers, takt, material handling time etc.)
- Analysis-Simulation runs, factors affecting smooth flow, experimental design, bottleneck analysis, improvement suggestions, future state are some of the important results for the stakeholders.

Certain risks are faced in each of these simulation phases. These risks are analysed based on the critical points obtained from the RPN vs. risk factor graph.

The project team supports the ongoing project at the company with simulation, identify problems in the current production flow comparing it to the new layout and propose suitable solutions for the same. The focus will be to simulate the flow of materials from the Prep area (kitting area)/Drop-zone up to packing. This is the main area of focus because the assembly and pre-assembly area are considered to be the heart of material movement and utilisation. Since it is a new product flow in the plant it is also important to see if there are any problems in the proposed production line, are there any bottlenecks (other than the ones identified before) or if the material supply routes are efficient or not. A CAD design of the new proposed layout and critical areas of material movement can be found in appendix A.1

1.5 Research Question

Knowing the objectives of the thesis, the project team comes up with a research question, which is:
" *How can failure mode and effect analysis be used in a discrete event simulation project ?*"

1.6 Delimitation

- The thesis work will focus on developing only the production flow of one component and not the rest of the plant or the new generation of the products.
- The data used in the simulation model will be historic data collected previously and the thesis will not include any data collection from the machines.
- As there are numerous tools to support the risk analysis, the project team decides to use FMEA, for it is easy to understand the method and apply it on the simulation project. The RPN ranking are solely based on the experience and knowledge of the project members.
- Due to the COVID-19 situation, several visits to the previous production site , supervisions and interviews with the concerned people working on the production development process had to be cancelled. Several actual data were not collected because of this reason and has been suitably assumed and mentioned whenever used in this report.
- The simulation analysis will cover only the flow of material from kitting/drop-zone area to pre-assembly and assembly station (a total of 18 pre-assembly and 10 main assembly stations). This is due to the complexity of building the model and doing several analyses with high quality within the deadline of the project.

2

Theoretical Framework

In this chapter, it illustrates the concept of internal logistics, simulation and why the integration of simulation and logistics is required in this demanding world. This chapter explains the advantages and disadvantages of simulation, and chalks out different types of simulation modelling. Out of which, DES is chosen for logistic integration. While performing simulation, risk analysis is conducted, therefore a brief introduction on risk management and assessment is illustrated in this chapter. Also, to perform risk assessment, the tool FMEA is required and it‘s importance are elaborated in this chapter

2.1 Internal Logistics

Logistic is very important for business world, supporting strategic planning; involving distribution and transportation of the materials in an industry. The definition of internal logistics is the movement of materials and it‘s support for the operations within a company, which comprises of several processes that involves, warehousing, stock control and storage systems, material handling, equipment and information technology [6]. Since, internal logistics contribute largely and have immense effect on industries, there are several advantages that helps industries to prevail. The advantages of internal logistics are [7]:

- Better inventory management, lower inventory levels, reduced carrying costs
- Improved on-time deliveries
- Less handling and damage, efficient receiving
- Proactive notification of disruption
- Administrative efficiency
- Increased customer satisfaction

There are drawbacks as well, which need to be taken care off by industries. There might be possibilities of [8]:

- Losing control over the flow of materials
- Poor worker quality
- Poor service levels
- Misleading feedbacks
- Co-ordination problems among workers
- Environmental responsibilities

With increasing customer demand in today‘s world, the change of pace is extremely high, and the companies has to oblige to the changes, as the customers are the main driving forces. The main concern for industries is the satisfaction of their customers, as they demand high quality, quality services and increasing value for the same. As the expectations are high, the companies has to improve their logistics systems into a fully integrated system, which is simulation. The integrated system helps the logistic to function as one, thereby, creating awareness of the total functionality. For logistics and simulation to integrate, there are certain inputs required from the senior management, industrial engineering, information technology, operations and system supplier to run the simulation model [9]. With simulation tool in hand, and with increasing changes in the market, a person has to learn the tool, and must be able to design, develop and implement the changes in the product or processes. Overall, the material handling is becoming more integrated and complex, for which, simulation is highly required to meet the customer demands.

2.2 Simulation

Simulation is the imitation of a real-world process or system over time. Simulation involves the generation of an artificial history of the system and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system being represented [10]. For more sophisticated simulations, a DES is used with an advantage to simulate dynamics in the production system. A production system is very much dynamic depending on variations in manufacturing processes, assembly times, machine set-ups, breaks, breakdowns and small stoppages [11]. Simulation changes the development process and is illustrated in 2.1. Any development without simulation is time consuming and not economically feasible. Whereas in a virtual world, the time and resource to be invested in testing of these processes are minimal and more results can be obtained precisely.

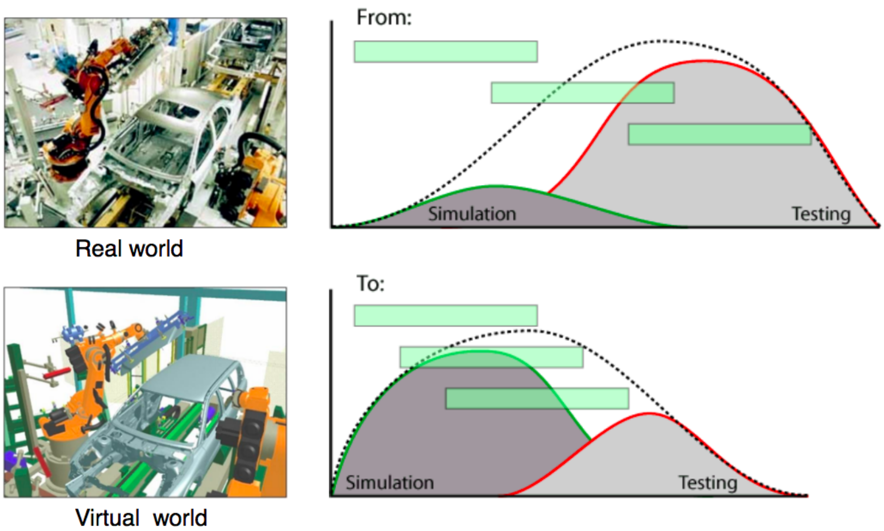

Figure 2.1: Change in development process [12]

2.2.1 History

Simulation hypothesis was first introduced by Rene Descartes and followed by Hans Moravec who experimented with transforming a real world into simulation. Simulation has brought an enlightenment to the industry engineers, where it is undoubtedly one of the multifaceted and important topics to any organisation [13]. Simulation was introduced to bring a huge impact on productivity capacity and an immense evolution in the visualization and graphics over the past years. The main reason for this, is the fact that quality, safety and productivity are manipulated with the help of the simulation regardless of its occurrence - could be in the office, in a manufacturing area or in a warehouse.

2.2.2 Types of Simulation Models

This section explains the different kind of models that can be used for simulation. Several models are combined together to form simulation platform according to the requirements. Some of the different types of models are as follows

2.2.2.1 Deterministic and Stochastic Models

Determinism is a philosophical proposition that every event, including human cognition and behavior, decision and action, is causally determined by a chain of prior occurrences. Determinism may also be defined as the thesis that there is at any instant exactly one physically possible future. [14].
A phenomenon is defined as stochastic when it's course of events is impossible to exactly predict. A state does not fully determine its next state. The randomness makes that different courses of events happens with more or less probability [15]

2.2.2.2 Dynamic and Static Models

A dynamic system is one where it's variables can change without any external influence. The system is influenced by it's own history and time plays a crucial role in the output results. Whereas, a static model is a system with direct instantaneous connections between it's variables. Two events are entirely related in such models.

2.2.2.3 Discrete and Continuous Models

A discrete model are time-based jumping between events, when a new event has occurred a new state for the system is calculated. In a time continuous model, the system state is represented by dependent variables that change continuously over time, as defined by differential equations.

2.3 Discrete Event Simulation (DES)

DES concerns the changes of a system's state on different points in time [16]. It is a collection of techniques that, when applied, generates sample paths (sequences) which characterize the behavior of a DES dynamical system [17]. A DES is a stochastic, dynamic, discrete and event oriented model. DES models share a common structure and components, which supports coding,debugging and future changing of the model, even though different software packages may be used [18]. This is a unique advantage of using a DES as it has the ability to imitate the dynamics of the real world system, this can be used to understand, analyse and evaluate various strategies to build an efficient real system with the minimum amount of resources.

DES has applications in various fields and industries, from health care to service systems, and from smaller production units to more complex production systems, military applications, airports, service sectors etc.

2.3.1 Business Motivation

Use of computer simulations has gained popularity over the last few decades, and some of the main reasons are the reduction in cost of computers and simulation software, emergence of more user-friendly and powerful simulation tools, increase in the speed of model building and delivery [19]. Some of the other reasons for the increased popularity of the simulation software are as follows

- **Increase in global competition-** The pressure on the businesses to increase their competitiveness has intensified, as almost every sector can provide products and services globally. These new systems are generally complex and costly and have less room for errors. Hence, the companies have to rely more on simulation for a more efficient system [19].
- **Cost Reduction Efforts-** One of the main focus of lean and agile systems is cost reduction. Companies are strained to increase their productivity while decreasing their investments. In such conditions a simulation models becomes a essential tool to increase the robustness of the system[19].
- **Improved Decision Making-** As changes in the variables are not under direct control of the management, changes in the production system are not optimal. Simulation is effective for the management to validate the effects of any variable and therefore improve the decisions in areas of product mix, policy changes, addition and deletion of resources and maintenance etc.. [19].
- **Effective Problem Diagnosis-** The management faces challenges in solving problems in areas like throughput reduction, large setup times, imbalance in resource utilization, large inventories and waiting times. One can analyse the current situation of the system, find out the root causes of any problems and also suggest new changes for the improved system [19].
- **Prediction and Explanation Capabilities-** Simulation provides both prediction and explanation capabilities of a system. One can analyse how the system responds to certain variation in the input and also explain why the system acted like that and predict how the system acts when the variables are changed. This facilitates the user to experiment on new things and analyse how the system reacts to new changes. Deeper understanding of the cause and effect relation of the system helps the management to greatly understand the system and to improve them.

2.3.2 Advantages and Disadvantages of Simulation

The benefit of using a simulation tool is beyond just providing an overview of the future, some of the advantages are as follows [10],

- Making correct choices before committing resources, since corrections are expensive and time consuming.
- Simulation helps in clear analysis of a particular event,for example, production analysis for a whole year can be done in few minutes, or even examine a minute production for several hours.
- Usually the management would not be aware on why and how few phenomena occurs in a system. simulation helps the user to determine the answers by reconstructing the system and conducting detailed examinations.
- An advantage of exploring different possibilities without investing much time and resources. it gives a wider possibility of exploring new things.
- Because of the complex structure of the systems it is difficult to consider all the interactions taking place in a given moment. Simulation helps to diagnose these problems and allows to better understand the interactions in the system.
- It helps to easily identify the constraints in the system. By using bottleneck analysis, one can identify the cause of delays.
- Simulation helps to design a system based on analysis and on how it should operate, rather than someones thoughts and ideas.
- One can visualise their plan beyond a CAD drawing using the animation features in many simulation software. Animation helps to detect design flaws in a system.
- The cost of a simulation study is substantially less than one percent of the total amount being used for the implementation of a design or redesign.

On the other hand the disadvantages of simulation can include [10],

- Model building is a difficult process, it requires special training and is learned over time and through experience.
- Since most of the simulation outputs are random variables, it is difficult to interpret results.
- Modelling and analysis is a time consuming process.
- Simulation can be used in cases where analytical solutions are possible. it might be used inappropriately.

2.4 Risk management

Oscar Wilde stated , "Only the past is certain; the future is at best only probable."Nowhere is this more evident than in the ever-changing world of business [21]. Risk is the possibility of loss or injury. Project risk is an uncertain event or condition that, if it occurs, has an effect on at least one project objective [24]. Risk management focuses on identifying and assessing the risks to the project and managing those risks to minimize the impact on the project. None of the projects are risk-free, as there are several events that can have a negative impact on the development of the project.

The process of risk management is about eliminating or avoid risks but, to accomplish it, it requires parameters such as identification, assessment and management of risks. The objectives of project risk management are to increase the impact and likelihood of positive events and to decrease the impact of negative events in a project. In an industry level, projects are complicated and unique, and involves a wide investment of resources, people, finance and facilities. The future path would be unclear and confusing making the organisations to find new solutions. One way of controlling and managing this uncertainty is through project risk management.

2.4.1 Existing Approach to Risk Management

It is to be understood that the definition of risk includes not only threats or downsides but also has a lot of opportunities and upsides. The traditional Standard dictionary defines the word risk as a synonym of threat. In the current situation, many professional risk management standards consider risk as a wholly negative effect while few adopt a neutral definition stating both upside and downside impacts. Few groups consider a broader approach explicitly including opportunity as a part of risk. Here are some of the examples of how risk is defined in few standards and guidelines.
Negative definition- Event or situation that may adversely affect the direction of the program, delivery of its output or achievements of its benefits [28].
Neutral definition- combination of the probability of an event occurring and its consequences for project objectives [29].
Broad definition- Uncertainty of outcomes, whether positive opportunity or negative threats [30].

There are several definitions for word risk and it is difficult to choose one while performing a project. Hence management professionals tend to choose one or more standards that support the requirement in their work. Sub-sequentially over the course of time, the definition of risk has been shifted from a negative perspective to a more neutral and broader perspective [21].

2.5 Risk Management Process

A typical risk management project is conducted in five steps. The risk management process is as visualised in 2.2. The risk management process starts with the definition phase. Its an important phase to establish a context and the objectives of the project are being understood and agreed upon. The result of this phase is a definition document with the purpose to record the decision of the scope and details of the risk process often called the risk management plan [21].

The second phase is the risk identification phase and it determines what might happen to the objectives of the project and how the effect would be. There are different ways of identifying the risks and few commonly used techniques are by conducting risk workshops, interviews and brainstorming sessions [21].

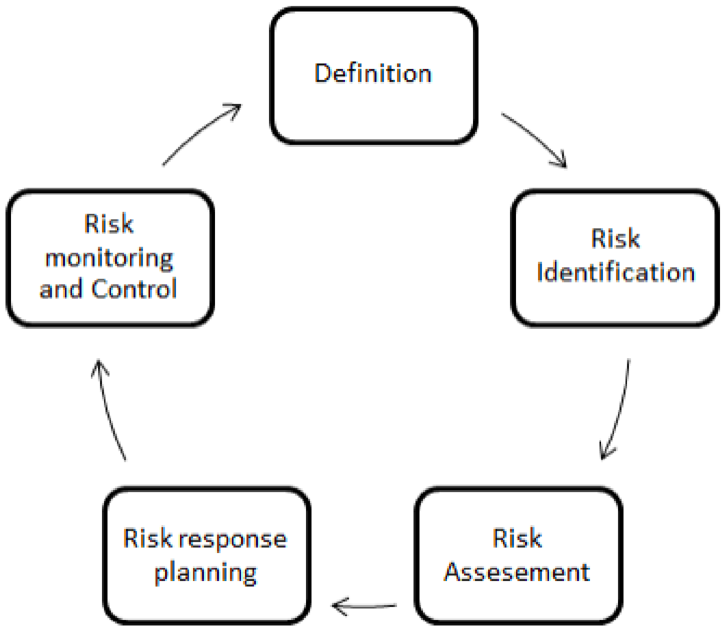

Figure 2.2: Risk management process

The third phase is the risk assessment phase. The risk assessment aims to establish the overall level of risk exposure of the project and prioritize identified risks in order of importance. Risk assessment can be done both qualitatively and quantitatively [21]. The output from the risk assessment will allow the project team to see which activities and risks require the most attention [21].

The fourth step in the risk management process is risk response planning. It is important to decide on how to respond to the identified risks. Unless actions are taken in the risk response phase, the risk identification and assessment process is of no use. It is also important to formulate response strategies in order to tackle these risks [21].

The final phase is the risk monitoring and control phase and is to ensure that the agreed risk and response are implemented effectively to communicate risk status to project stakeholder, and to maintain a current assessment of risk exposure. The purpose of the final phase is to monitor and review the risks [21].

2.5.1 Identification and Classification of Project Risks

The main objective of risk identification is to expose and capture as many risk as possible. Though it is impossible to identify all risks that a particular project might face. The challenge is to identify the risk with sufficient time to spare to enable them to be managed effectively. Risks are identified several times throughout the project and should not be limited to one persons perspective and rather should involve a wide group of project stakeholders so that different perspectives are taken into consideration [22].

Risk identification uses several techniques that are not just limited to exposing threats, but also equally used for revealing opportunities. It is difficult to adopt a particular technique to identify risks. Humans are creatures of habit and they tend to follow a particular pattern of behavior which is hard to resist. So when project team members are encouraged to use a familiar Risk Identification technique in an unfamiliar way, there is a natural tendency to revert to how things were done previously, even if mental assent is given to the new way [22]. Some of the most frequently used techniques are explained below.

Brainstorming is a commonly used form of risk identification, since it is a group creativity technique. It has several other benefits along with the primary aim of identifying risks. It is a platform for people to express their concerns openly without the fear of being criticised or blamed. Brainstorming for risk identification follows the same approach but instead of problem solving, the task to identify risks to the project [22].

A risk identification checklist is a powerful mean to ensure learning from previous experience, since it has the data of the number of risks that have been identified in the previous project. The approach is done with simple closed questions allowing only a few specified answers. An answer of "No" or "unknown" indicates a possible risk to the project. The list of questions in the risk identification checklist can be structured using WBS. It is good to include potential responses to the risk that have been found effective in the previous projects [22].

One of the most famous and effective form of identifying risk is by talking to people, conducting interviews. Interviews can be done in simple ways, an example is just by sitting with the project stakeholders and asking them what they perceive as risks to the project [21]. The interview should be conducted in a confidential environment, where the interviewee can be encouraged to express concerns honestly without fear of reprisal or blame. Some of the key qualities that an interviewee should possess can be described using the ACTIVE mnemonic: Attention, Concern, Time, Involvement, Vocalization, Empathy [22].

2.5.2 Risk Assessment

Once the risks are identified, it is now important to evaluate these risks and focus should be made on prioritising the risks based on their impact on the project. In projects where resources are limited, prioritisation helps in effective planning of further activities. It is difficult to understand which risks are most important to be solved. Different stages of the project can be ranked by relative riskiness and the level of risk exposure.

There are two fundamentally different approaches to assess the important risks in a project. Risk assessment can be done both qualitatively and quantitatively. Qualitative Risk Assessment aims to describe each risk using words and phrases, with the aim of enabling the risk to be understood in sufficient details to allow development of appropriate responses [23]. Quantitative Risk Analysis, is about using numbers to represent the dimensions of each risk, then performing some statistical or numerical analysis to determine the overall effect of risks acting together on project objectives [23].

Each risk has two dimensions, probability and impact, and can be classified as high, medium and low. The risks are segregated or assessed based on few standard set of criteria. The labelled probability defines how severe a risk is and helps in identifying both negative (threats) and positive impacts (opportunities) [23]. Qualitative assessment identifies the risks and lists them in priority order for further actions. In any project, risks occur in random collections. A risk of Qualitative risk assessment is that it addresses the risks one at a time and puts them into similar groups.

An approach that deals with the combined effect of risk occurring randomly and includes consideration of inter risk effect is required and here is the purpose of using quantitative risk analysis. Quantitative risk assessment helps to build a model representing various identified risks that can be incorporated. This provides a detailed view of the overall effect of risk on the project (both threats and opportunities) [23]. Several techniques are used for building such models and some of them are Monte Carlo models, decision trees, influence diagrams and FMEA.

2.5.3 Risk Response Planning

Once the risk has been identified and assessed according to both qualitative and quantitative approach, the next step is to formulate a plan to tackle the identified risk. The response plan must be realistic, effective, appropriate, affordable and achievable taking each risk into consideration. Once the different possible risks are assessed, the response planning must be such that the important and urgent ones must be addressed first and the lesser important ones can be treated with less urgency [25]. Risks must be selected depending on its nature, severity and manageability. The response planning phase includes avoidance or elimination, transfer, mitigation or reduction, and acceptance.

Elimination is to remove a risk or prevent it from affecting a project. It would not be feasible to completely eliminate the risk but it must be the first priority to consider for each risk. Transferring the risk is to find another party who must take the responsibility to handle the risk. The aim here is to ensure that the risk is handled by the party which is best able to deal with it effectively. Mitigation and reduction aim to reduce the size and effect of the risk by identifying the probability of occurrence and its severity of impact. Preventive steps can be taken to reduce the likelihood of a risk occurring. For accepting a risk, active plans and actions should be taken if the risk occurs in the future. These type of risk must be actively monitored such that their severity does not cause more risk or problems to the project. Once the risks are accepted proper monitoring must be done and clear vigilance must be made to implement required actions when these risks occur [25].

2.5.4 Monitoring and Control

The final phase of the risk management process is risk monitoring, control and reviewing. The main purpose of this step is to ensure that the implemented risk responses are working efficiently, to check the status of the risk and communicate the same to different stake holders, These risks should be reported and monitored continuously. Regular analysis of the risk should be made during the lifetime of the project to check the status of the risk, determine if new responses are required and to identify new risks [26].

2.5.5 Failure Modes and Effects Analysis (FMEA)

One should know what FMEA is, before performing the analysing process. The definition of FMEA is, "the systematic, proactive method for evaluating a process to identify where and how it might fail and to access the relative impact to different failures, in order to identify the parts of the process that are most in need of change" [31]. By understanding the philosophy of FMEA, the project team performs the process, by first recognising the processes involved in the project, analysing what could go wrong, why does failure occur and finally it‘s consequences.

The team performs this to prevent the risks from multiplying or from happening again. The FMEA process highlights the level of risk, by scoring the risk factors. The project team assess the risk based on the score and try to mitigate as much as possible. It should be known, any failures occurring in the project will violate the project‘s result. However, FMEA is performed to stabilize the working process and not affect the result.

3

Methodology

This chapter illustrates the practical framework performed for the simulation. The Banks Methodology explains the detailed steps followed in each phase of simulation. Also, the importance of risk assessment tool FMEA and how it is used to mitigate risks is explained in this chapter.

3.1 Banks Methodology

Model building is learnt over time and experience, and requires special training. The important steps to perform a simulation study are preparation, model building and analysis. The steps are further elaborated as follows and is shown in 3.1.

1. Preparation Phase
   - Problem formulation- A study should begin with the statement of the problem which is clearly defined. The problem should be understood and agreed upon by all the stakeholders.
   - Objectives and project plan- Objectives are the questions which has to be answered by the simulation results [18]. It is required to create measurable project goals, project time frame, delimitation and level of detail which are required to formulate the model and decide the future plans and actions.
   - Model conceptualisation- A conceptual model is to be created to reduce the complexity of the system and to make it easy for understanding the problem and the methods to deal with it [18]. Generally, all the required data for building the simulation model are mentioned in the conceptual model which makes it easy for the user. It is always recommended to start with a simple model and build upon with increasing the complexity of the system for common understanding.
   - Data collection- Collection of data and model conceptualisation are interrelated events. There is always a constant interplay between them. Data collection takes up a larger time in building a simulation model and is also a crucial step [18]. This decides the future of the model, it is necessary to know what kind of data are required for the simulation and should be based on the project objectives.

2. Model Building phase
   - Model translation- This is the stage where the data collected from the real

world are transferred into a computer recognisable format. The data collected in the previous stages are utilised and a simulation base model is created. It is the decision of the engineer and the management to select a suitable software which facilitates easy modelling of the system[18].

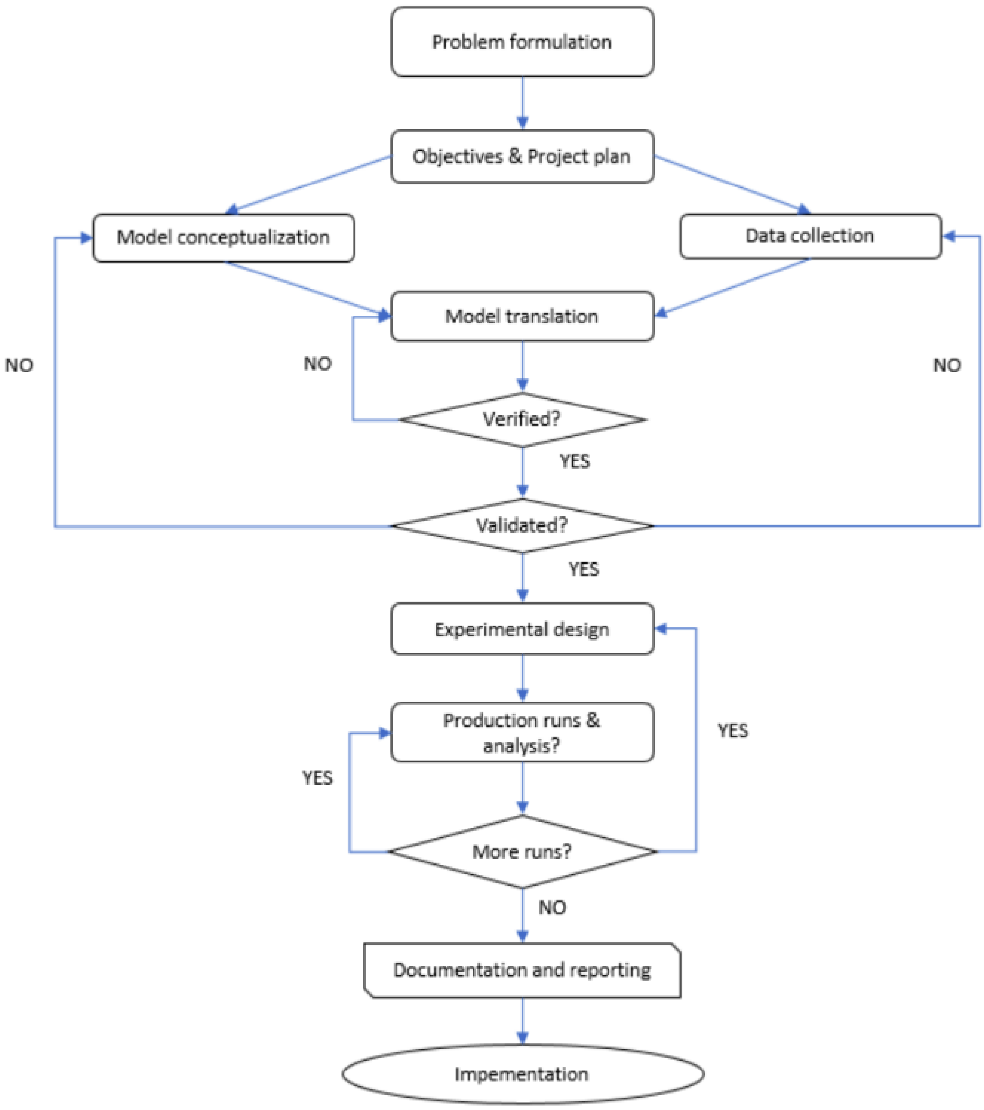

Figure 3.1: Flow chart for developing a simulation model

- Verification- It is necessary to verify every step of the model, to check for errors and see if the model behaves as expected. The verification is complete if the input parameters and logical structure of the model are correctly represented in the simulation model. Some of the verification methods are: observing the animation and the variables when the model is in run, running the program step by step and following the principles of structured programming, making the model self-documenting as much as possible and finally verifying the model by experts [18].
- Validation- It is done to make sure that the behavior of the model is similar to

that of the real world system. Few ways of validating a model are, using the historical data and comparing it with the simulation output, Degeneracy test- to test the model in extreme conditions, i.e by changing the variables, having the highest and lowest of inputs and check if the system behaves properly [32]

3. Analysis Phase
   - Experimental design- The alternatives that are to be simulated must be determined. The decisions concerning which alternatives to simulate will be a function of runs that have been completed and analyzed [18]
   - Production runs and analysis- Production runs and analysis are done to estimate the performance of the system design that is to be simulated. Certain number of runs are carried out to get valid results [18]. To find the problems in the current system and to further improve the system
   - More runs- the analysis done in the previous steps, determines if extra runs are needed to be performed to validate the results [18]
   - Documentation and reporting- It is required to save and document the results obtained from the simulation model. It is necessary to do so, such that stakeholders will be aware on why and how the changes have been made and what are the end results. The results of the analysis should be reported clearly and concisely in a final report and should be written in such a way that it can be understood.
   - Implementation in the real world.

3.1.1 Implementing Banks Methodology in the Project

The change in demand and available space for the production, has made it essential for the project team to be more precise and definite in its material and production planning. Here comes the need of a Discrete Event Simulation model, which helps to analyze and predict the variations in the material flow that might be caused once the production starts in the future.

A detailed analysis of the capacity, throughput, work-in-progress, bottlenecks and costs can be made with the simulation output.The modelling procedure has three main stages, the preparation, model building and the analysis phase. Starting from the preparation stage, problem formulation is the first step that should be done in order to know the project requirements and expected results. Followed by setting up objectives and an overall project plan. Building a conceptual model and data collection are the most crucial steps in preparing a simulation flow and are the supporting pillars of the model. Focus is made on collecting more and accurate data required to run the simulation and thus, should be properly incorporated in the conceptual model. Data collection and preparing a conceptual model are done in parallel.

Once the project plan and objectives are properly defined and agreed upon by the stakeholders, the next stage is the model building phase where the data collected for the simulation and the conceptual model are transferred onto a software system and in this project it is the Siemens Tecnomatix Plant Simulation software. Once the data has been updated on the software, it is important for the project team to verify and validate their task and to compare the actual output to the simulation output. Verification can be done by analysing and comparing the daily material requirement status of the previous production line with the results obtained from the simulation model. The model is verified if the material requirements are the same. Production runs can be analysed for 1 day, 1 week, 1 month and for a year. The simulation is modelled such that the parts in the assembly line will not leave the stations until all its requirements are fulfilled (for example- number of parts required for assembly, cycle time, product variants, buffers) This is a cyclic process, from collecting data and improving the model up to verifying and validating, unless we get the expected results.

The final stage is the model analysis phase where different kinds of experimental designs are performed by varying the parameters. Several production runs and analysis are carried out until satisfactory results are obtained. The results are documented and reported for further validation and confirmation, and later implemented on to the real system for actual changes. A flow chart representing the project methodology can be seen in fig 3.1.

In each step followed in the banks methodology, there is another assessment performed to evaluate the risks associated with it. The risk assessment is performed with the help of FMEA tool. In this project, the team performs FMEA to mitigate the risks completely or from reoccurring again. Risks are identified in each step, and is managed by following the risk management process principle i.e risk definition, identification, assessment, risk response planning, monitoring and control. For example, risk events are defined and identified in the model building phases, these risks are clearly assessed and a response action is created on how to minimise the risk or how to completely eliminate it. Depending upon the response plan, the risk are further monitored and controlled. A detailed information of the objectives considered while performing FMEA and its outcomes are explained in the result section.

3.2 Conceptual Model

For the new production line, around 500 different parts are being received from the goods receiving area and are transferred to three different locations based on their usage, either to the logistic area, high-bay warehouse or to the production line. Once the assembly line sends a request for the materials, the parts are moved from their current location and are sent to either a kitting/washing zone or a direct drop-zone next to the assembly stations. The parts arriving at assembly and pre-assembly should be consumed within one ore two days of arrival due to quality and dust issues. Once the parts are assembled, they are packed and sent to customers based on the orders. In this master thesis, the focus of material flow is done mainly on the assembly and pre-assembly lines, the kitting/washing area and the drop-zone. This is because the assembly line is an important zone and material stops in this area can cause severe problems in the overall throughput. Moreover, with the limited amount of time, it is feasible to concentrate more on the assembly and pre-assembly lines rather than focusing on the entire flow. A general flow of materials throughout the manufacturing process can be seen in 3.2 and a detailed view of the focused area, i.e the assembly and pre-assembly line can be found in 3.3.

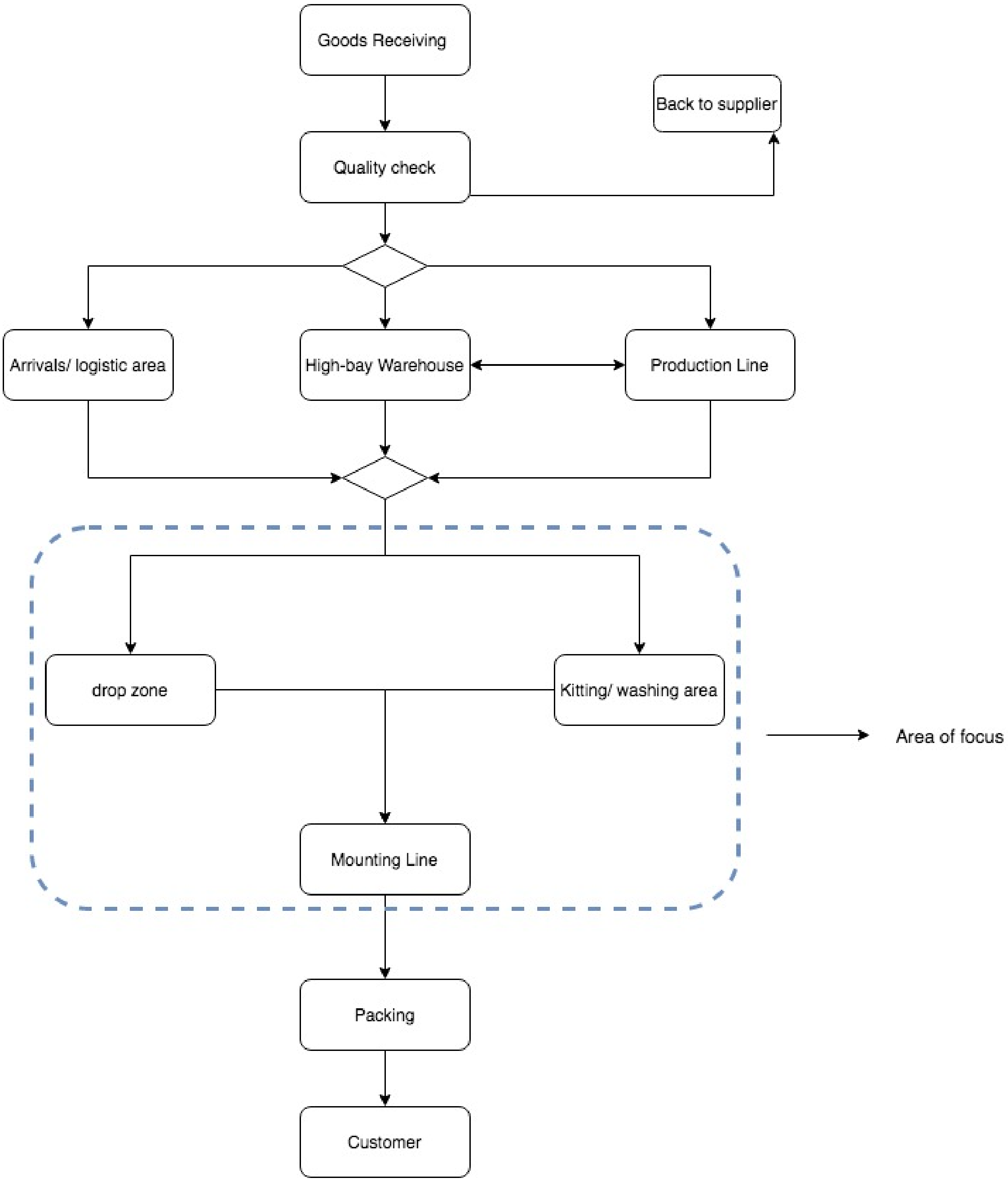

Figure 3.2: Material flow in the plant and area of focus

Narrowing down has to be done for the purpose of clear understanding and proper data collection of the product flow in the assembly, pre-assembly, drop-zone and kitting area. Data are collected in terms of material required, operators, failures, batch size, buffers etc. Though the data are available and the product quantities are the same, one main challenge that the new factory faces is that the production layout is being scaled down.

The production and logistic area available for the production line will be reduced nearly to 50% of what was available in the previous production site. This urges the project team to be more precise on the production planning as it has to deliver the same amount or even higher volume of throughput as it is doing today.

The assembly line has 10 main stations and each station has its own pre-assembly lines. The current line runs at a takt time of 21.11 minutes with an average throughput per day of 16-17 and an annual throughput of approximately 3157. The maximum capacity of the line would be 18 products/day. Each station has buffers for each part and the quantity varies depending upon their daily usage. It is the responsibility of the project team to make sure that the right parts are delivered to the right place on right time or simply “JIT”. Three operators work to deliver the parts from the kitting area to the production line and the assembly operators pick parts from the drop-zone whenever required. There are a total of 18 operators working in the assembly and the pre-assembly lines and are multi-skilled to do different operations. Production is done in a single shift, except the washing machine which has a higher takt time of 40 minutes and is used for two shifts a day.

There are a total of 18 different variants of products that will be assembled in the plant and this makes the modelling of the assembly line complicated. Proper care has to be taken such that correct parts reach the assembly line at correct time which might otherwise lead to line stops. The different variants and their quantity can be see in table 3.1.

Table 3.1: Variants and quantities produced

Variant	Percentage of volume produced/year
Variant-A	0
Variant-B	51
Variant-C	37
Variant-D	1
Variant-E	2
Variant- F	0
Variant-G	0
Variant-H	0
Variant-I	0
Variant-J	0
Variant-K	3
Variant-L	1
Variant-M	0
Variant-N	0
Variant-O	3
Variant-P	1
Variant-Q	1
Variant-R	0

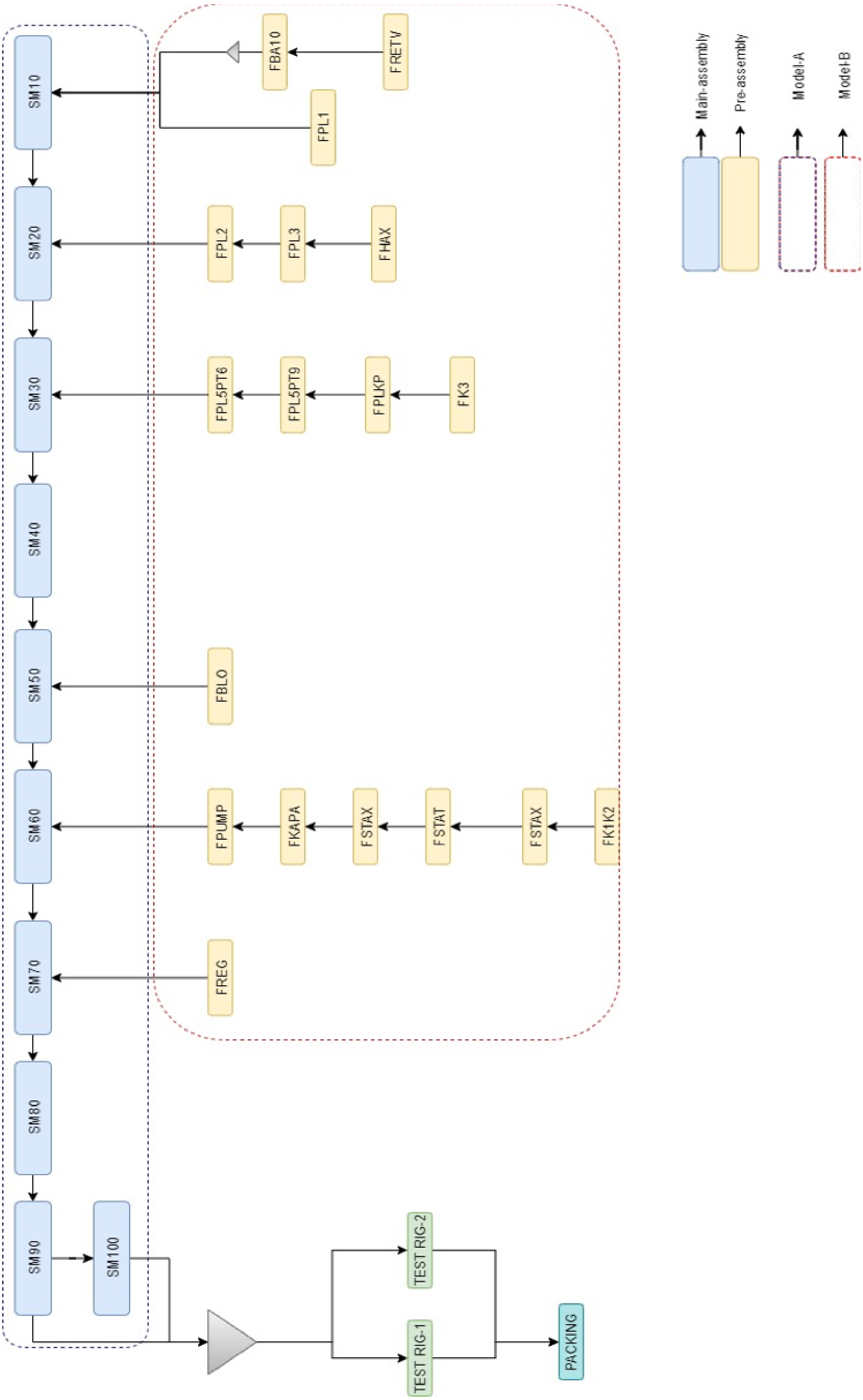

Figure 3.3: Detailed view of the mounting line

The number of variants required and their quantity can vary every year or even every month. This depends on the customer orders and market demand. Also, there will be several new generations of variants that would be introduced in the market every year and the assembly line needs to fulfill the product requirement of these new variants as-well. The project team has taken this into consideration and the model is simulated in such a way that the percentage of variants can be varied to get the details of the number of parts which would be required for assembly. Depending on this details the material planning team can decide on the number of parts required and its ordering time. Table 3.1 is just an example of one of the iterations which was taken during the simulation process and 5 other different iterations were carried out to explain the project stakeholders that the simulation can be used in various conditions.

Since, the product to be assembled are special components, proper care should be taken to limit dust and grease on the materials. A wall is being built between the preparation area and the assembly line to minimise dust and to have better quality of materials. The operators collect parts from the drop-zone whenever required and scans the bar-code on the Kanban. This scanning generates a new order for the logistic personnel to deliver the parts to the drop-zone. Whereas parts from the Kitting area are transported through a moving conveyor line after leaving the washing machine. A detailed view of the Conceptual model can be seen in figure 3.3 and in appendix A.4

The simulation model is divided into two parts Model A and model B for the ease of modelling by the project members. Model A consists of the main assembly line and B consists of the pre-assembly stations. Both these models are connected such that the variant moves to the next assembly station only when all the parts are received from their respective pre-assembly stations. This functions like a typical assembly line in an industry.

3.3 Modeling and Simulation

In this section, the vital process for building a simulation model is illustrated with the steps involved in it. Modelling helps in visualising and developing the system. The more complex the system, the better chance to fail. Therefore, to systematically carry out the procedure, modelling is divided into three main phases, which are as follows,

3.3.1 Data Preparation

To obtain the required data, firstly the company explained the processes in the assembly line: whereabouts of the material supplies, the layout of the production systems and in-flow, out-flow of the materials to kick start the modelling process. To support the material flow details, data is retrieved from the company's database to perform the simulation model. The first vital step after the data is collected, is the formulation of the model and acquisition of the software. Here, it is important for the user to understand the relation between the shop-floor and data provided. One should check for any discrepancies in the data provided otherwise completion of the simulation model would be delayed. To kick off with the simulation model, the conceptual model supports in binding with the step-by-step procedure, from the initial step of formulation until the end step of improvements.

For the simulation, it is not only important to collect data, rather more important to collect good quality which are specifically needed to build the model. The data provided for the simulation is in the form of bill-of-material in which a user can retrieve data about the number of materials going into the assembly line, the number of parts involved in a variant, buffer capacity and total output. The data such as the processing time, machine failure, operators, takt time and material transportation time are provided by the company. With all these data provided, the user is bound to perform the simulation to obtain the desired output.

3.3.2 Model Generation

A major portion of time is dedicated to thoroughly learn the software and simulating simple examples before starting with the main task. In the model generation phase, the data collected from the conceptual model will be used to build the model. In this project, the simulation model consists of a total of 28 stations, out of which 10 are main assembly and the 18 are from pre-assembly lines. The parts from the pre-assembly line are stored in a small buffer before it enters the main line. Buffers are used to make sure that there wont be any line stops due to part shortage from the previous line. There are a total of 18 different variants of products produced in the assembly line. A source is the main region in the simulation model where the variants are created and it commands other pre-assembly stations to produce and send the exact variant part to the main line. The source produces variants for every 21 minutes. The simulation model built by the project team is represented in figure 3.4.

The simulation work is divided into 2 models, model-A and model-B. The task of model-A is to design and simulate the main assembly line, from SM10 to SM100 along with test rigs and drain,and for model-B is to create pre-assembly stations and to connect them to the main line.

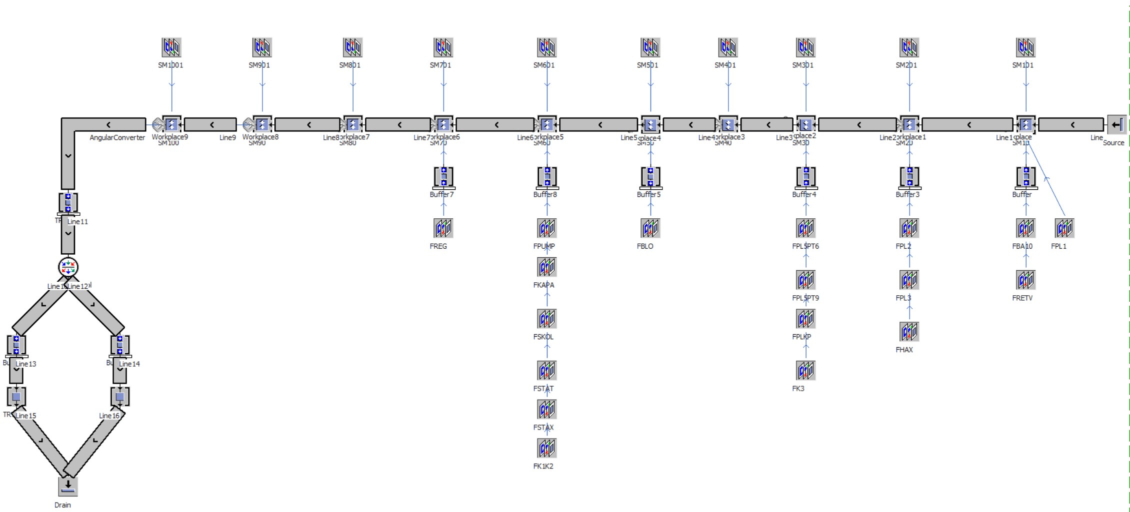

Figure 3.4: Model representation of the assembly line

Each variant has unique parts and quantities to be assembled in each assembly station and the tricky part in the simulation is to bring this logic into function. It is to be modelled such that the variant, Variant-A does not leave station SM10 unless and until all their parts have been delivered (from their pre-assembly station, drop-zone, kitting area) to the line side and with a processing time of 21 minutes. It should also be taken care that wrong delivery of parts or shortage of parts would lead to line stops. The simulation is modelled in such a way that the variant does not move to the next station if there are any part shortage or wrong parts in the line side. An approximate of 500 parts needs to be delivered to the production line either through the drop-zone or through the kitting area. Parts coming from the kitting zones needs to undergo a thorough washing process for 35 minutes before it reaches the assembly line.

Here, it must be noted that, simulation model is generated based on the dynamic information input and user‘s interpretation of the tool. With the model, any dynamic changes can be made at any instance according to the end-user. This sways path for flexibility in future for reference with different production changes possibly being implemented.

3.3.3 Model Validation

This is the most important task after building the base model to know if the model is up-to the expectation of the stakeholders and therefore, verification and validation is performed. It is better to know the terminology of validation and verification before moving into tasks performed by the project team in the base model. Verification is the process of "determining that the computer program of the computerized model and its implementation accurately represents conceptual model and specifications" [33]. Validation "affirms that the simulation model is an accurate representation of the system with the modeling objectives, within its domain of applicability" [33].

One way of validating the result is by generating wrong syntax and checking if the model detects the mistake and if the production stops. This test is done with our model.If wrong quantities are defined to the parts, it should work in such a way that the simulation stops the variant to move to the next station because of wrong part or part shortage. Different trials are carried on in several stages of the model to thoroughly validate the model and check for errors. An example of how the assembly stops due to an error can be found in 3.5. Along with this, the results of the output were analysed when different input data were given to the model. Five different trials and production iterations were carried out, each trial has different variant capacity to prove that the simulation model is flexible, to support the changes in the production forecast. By this way the company can use this model when the production demand fluctuates and can easily determine the number of parts required for the production over any given time (week, month or an years forecast). The results of different trials are explained in the result section.

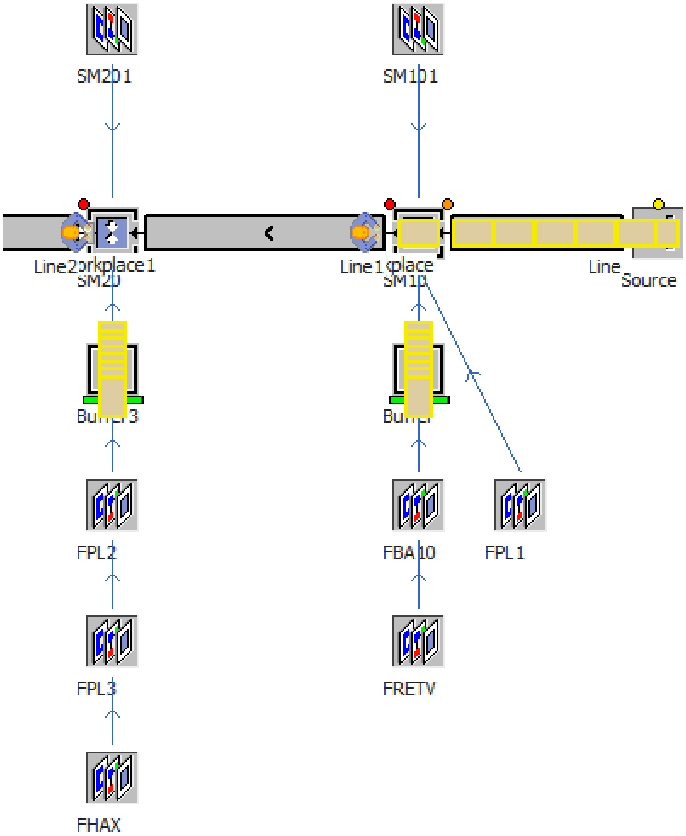

Figure 3.5: Line stop due to part shortage/wrong part

After understanding the terminology, in the thesis project, the project team performed various verification process at different segments. For instance, the team checked the processing time for each station, debugging the syntax for errors or simulation stops and verifying the part quantities moving from the storage area to assembly line. After performing verification, there were less throughput that did not satisfy the team. Therefore, the team decided to optimize the model by increasing the part quantities in the storage area for producing more products and obtaining the desired throughput. Once the desired throughput is obtained, the model is presented to the company supervisor for validating the model to check the throughput obtained matches with their demanded throughput.

3.4 FMEA as Risk Management tool

One of the techniques of risk management is to multiply the probability and impact of the risk occurring in the project. Therefore, Pritchard (2001), Raz and Michael (1999) provides valid information about applications and requirements to analyse risk techniques. As mentioned earlier, the multiplication of probability and impact of risk yields to risk evaluation and also, there is another way of analysing the risk, in which risk detection to the previous technique is added. For analysing the risk pertaining to design, process and service planning, FMEA comes front which comprises of product of probability, impact or detection [36]. This technique is used for assessment of risk management due to the ease of use, simple format and comprehensive structure [36]. FMEA has ISO-9000 and QS-9000 quality certification [36]. They are also used for product and process development with the help of other tools, such as FTA, APQP, QFD. [36].

FMEA is a tool used not only for risk assessment for the present situation but used to prevent the risk from spreading and occurring once again in the future. This includes terminology, methodology and graphical analysis technique to assess the risk management. This is quite helpful for the project engineers, engineering managers and team members as they need them the most to avoid risks. As a team we interpret risk analysis in every phase of the project, to minimise or eliminate the problems from occurring. The method which encompasses of product of probability (occurrence), impact (severity) and detection is known as Risk Priority Number (RPN) and it is denoted as;

$$RPN = Occurrence * Severity * Detection \tag{3.1}$$

It is known that the risk assessment is the multiplication of likelihood, impact and detection and this likelihood has a scale of which it measures the occurrence. The following table gives the guideline of the likelihood scale [38].

Table 3.2: Likelihood Guidelines [38]

Range	Likeliness
9 or 10	Very likely to occur
7 or 8	Will probably occur
5 or 6	Equal chances of occurring or not
3 or 4	Probably will not occur
1 or 2	Very unlikely

As mentioned in the above table, the likelihood guidelines will help the thesis in analysing the risk occurring in different phases. Similar guidelines is followed for impact factor and their guidelines are as follows [37],

Table 3.3: Impact Guidelines [37]

Range	Impactness
9 or 10	Schedule— Major milestone impact and > 20 percent impact to critical path Technical—The effect on the scope renders end item unusable.
7 or 8	Schedule— Major milestone impact and 10 percent – 20 percent impact to critical path Technical—The effect on the scope changes the output of the project and it may not be usable to client
5 or 6	Schedule— Impact of 5 percent – 10 percent impact to critical path Technical—The effect on the scope changes the output of the project and it will require client approval
3 or 4	Schedule— Impact of < 5 percent impact to critical path Technical—The effect on the scope is minor but requires an approved scope change internally and maybe with the client
1 or 2	Schedule— Impact insignificant Technical—Changes are not noticeable

Therefore, with these guidelines it is quite possible to identify the high risk factors by multiplying the likelihood and impact numbers, which will be further discussed in the result section of the report. Further, detection guidelines are followed while analysing risk factors and they are as follows [38];

Table 3.4: Detection Guidelines [38]

Range	Detection
9 or 10	There is no detection method available or known that will provide an alert with enough time to plan for a contingency.
7 or 8	Detection method is unproven or unreliable; or effectiveness of detection method is unknown to detect in time.
5 or 6	Detection method has medium effectiveness.
3 or 4	Detection method has moderately high effectiveness.
1 or 2	Detection method is highly effective and it is almost certain that the risk will be detected with adequate time.

With the help of these guidelines, a framework is made to check how the FMEA methods are obliged in this project. The task, for performing FMEA process are categorized into eight different steps. B.S. Dhillon (1999) has elaborated the significant steps to follow while conducting risk assessment and these steps are followed in the thesis. Before moving onto the risks that were analysed in the thesis, it is better to understand the steps influencing the assessment. In the following figure 3.6, it show the essential steps to be followed:

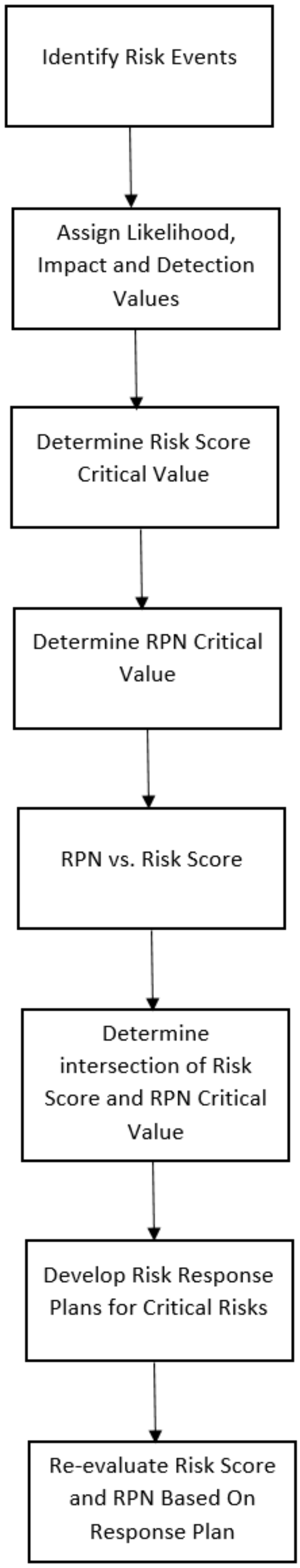

Figure 3.6: FMEA Process Steps [37]

Thomas.A and Donald.T (2004) has signified each step of risk assessment based on the the guidelines as mentioned in 3.2, 3.3 and 3.4, one should scale likelihood, impact and detection for determining the RPN value. Based on this RPN value, determine the level of risk and there has to be a threshold number for these to cause any major risks in a project. If the risk occurring falls beyond the threshold then it is called the "Critical Value". A graph of RPN versus risk score is plotted to determine the critical risk, for this the team has to discuss the threshold range to set a critical value. There are some risk that could be of higher risk but since they are anticipated in advance,counter measures can be taken and the RPN can be minimised.

The risk with high range of RPN value will apparently fall beyond the critical value, and must therefore be addressed first. The sixth step is very important for determining the intersection of the two critical points to define an initial set [37]. The points will trigger risk values for the user to respond quickly based on the critical level. Once the necessary steps are taken for the risk, the valuation must be done by the user to understand where these risk fall, above or below the critical line. The above FMEA steps are followed by the project team to analysis the risk related to the simulation process.The FMEA is performed again based on the critical level, if it is highest then becomes first priority and the least becomes less important.

4
Results

This chapter explains the results obtained from the simulation model and its flexibility. A detailed discussion of FMEA in different stages of simulation model, its methodology and results are discussed. Improvement recommendations for the company are given in this chapter.

4.1 Simulation Analysis

The company has a target takt time of 21 minutes for each assembly station and the required throughput per day is 19. Once the model is built, the simulation results showed that the average throughput per day (24 hours of production which is equal to 3 shifts) is 59.09 and thus each shift (8 hours of production) can produce an approximate of 19-20 products. The results shows that the future assembly line can produce the required demand of the company. The results of the simulation model can be seen in 4.1.

Average lifespan:	14:38:10.5606
Average exit interval:	24:16.3268
Total throughput:	3157
Throughput per minute:	0.04
Throughput per hour:	2.46
Throughput per day:	59.09

Figure 4.1: Throughput of the Simulation model

A total of 6 different trials were conducted to verify that the simulation model works good in every condition. The details of different parameters varied can be seen in table 4.1. The first row in table 4.1 is the actual forecast. Out of the 18 variants that can be manufactured in the site, only 9 variants are currently being produced and the detailed variant demand can be seen in figure 4.2. The remaining iterations are different trials which were carried out in the simulation model to validate that this simulation model can be used to analyse different scenarios for the company i.e when the demand is more or less, when new variants are added or when older ones are eliminated. The remaining five iterations shown in the table 4.1 is an example of variations that might be faced in the production forecast.

Table 4.1: Different trials to validate the model

No of iteration	Number of variants produced out of 18	Throughput/year
Actual forecast	9	3157
Iteration 1	9	3200
Iteration 2	9	3000
Iteration 3	8	3157
Iteration 4	9	2900
Iteration 5	11	3300

Explaining the figure 4.2, there are a total of 9 variants of components being produced in the assembly line and is mentioned in the first column, the throughput column represents the number of parts that can be produced in an year and the third column represents the percentage of each variant being produced.

	Type	Total throughput	%Parts
1	V	31	0.98
2	V	63	2.00
3	V	94	2.98
4	V	32	1.01
5	V	95	3.01
6	V	32	1.01
7	V	32	1.01
8	V	1610	51.00
9	V	1168	37.00

Figure 4.2: Main Iteration

As mentioned earlier, there are nearly 500 parts which are being used in various stages of the assembly process. The simulation result helps us to identify the quantity of each parts required for production, results can be obtained for any number of products or for any number of days of production. The data of the parts which needs to be assembled for each variant and its corresponding quantities are added in the model.

An example of a code which commands the variant to pick a specific part from the specific station can be seen in the fig 4.3. The figure shows an example where the BOM is given for SM10 assembly station, Case 'Variant-A' is a variants and the part ID and quantity of each part are mentioned below each variant.This is written for all the variants which will be produced in that station. When a specific variant enters the assembly station, the operator picks up the parts according to this table. Several parts are used in more than one station, For better understanding, a simple example is shown below.

For a particular iteration, the number of parts (ID-11418288) used in station SM60 is 9471 and the available quantity is 141 and is shown in figure 4.4. The result from other stations obtained from the simulation model are shown in appendix A.7. Once the simulation is complete, the results obtained shows the total number of parts required for production of these components. The results can show the material required to produce 1 to 3000 components or from 1 day to an year's production demand. This helps the production department to forecast the number of parts required for production. If proper inventory data are maintained, the company can easily identify the availability of each part by using the results from the simulation run.

```
var BOM:table

BOM := SM10.AssemblyList
switch  @.name
case "V22420"
        BOM[1,1] := "A11418288"
        BOM[2,1] := 3
        BOM[1,2] := "A1650419"
        BOM[2,2] := 4
        BOM[1,3] := "A944457"
        BOM[2,3] := 3
        BOM[1,4] := "A1650401"
        BOM[2,4] := 3
        BOM[1,5] := "A15132551"
        BOM[2,5] := 1
        BOM[1,6] := "A15001704"
        BOM[2,6] := 12
        BOM[1,7] := "A17205750"
        BOM[2,7] := 8
        BOM[1,8] := "A17399899"
        BOM[2,8] := 2
        BOM[1,9] := "A1650335"
        BOM[2,9] := 1
        BOM[1,10] := "A15067333"
        BOM[2,10] := 4
        BOM[1,11] := "A15067334"
        BOM[2,11] := 1
        BOM[1,12] := "FPL122420"
        BOM[2,12] := 1
        BOM[1,13] := "FBA22420"
        BOM[2,13] := 1
case "V22443"
```

Figure 4.3: Code for different variants

Taking an example, part ID-11418288 is used in two different assembly stations, SM10 and SM60 for assembling several variants. The simulation results can provide us the details of the number of parts used, number of parts remaining in the station as well as the total number of parts used during the entire assembly process.

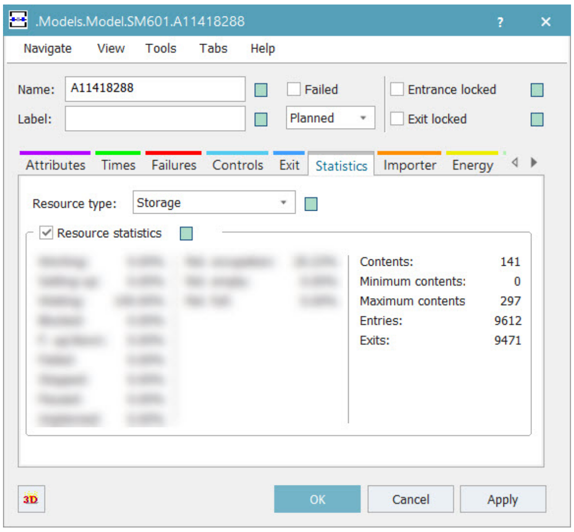

Figure 4.4: Example for number of parts used

Also, the efficiency of each station were not available for the project team, instead the efficiency of the entire assembly line was available, which is 88%. But for the simulation to determine the bottleneck in the system, it requires the efficiency details of each station. Since, this data was not available an assumption of 88% efficiency for each station is considered and is shown in the appendix A.6.

The throughput from the simulation model is 68 parts per 24 hours of production without any failures in the line, whereas the actual calculated throughput for the line is 68,24 (1440/21,1 where 21.1min is the actual takt time, 1440min=60*24). But after implementing failures, the throughput decreases to 59 parts per 24 hours. The main objective of the project team, is to get the material flow running uniformly without any disturbances or shortages and the focus is to supply materials to produce around 3150 parts to the assembly line per year. This does not have any concern to external factors such as failures or manpower. However, the time to produce the required throughput increases after implementing failures because of longer assembly time. Subsequently, the throughout per hour decreases from 2,8 to 2.5 parts. From previous years data on the failures at Location-B, it can be understood from the appendix A.5, that the average availability of the stations is 88% and the remaining 12% are the failures. The downtime is not constant, it varies every month and is calculated as an average for a year. Downtime of the line is calculated as:

$$Downtime = (T + A + K) \tag{4.1}$$

Where,
T is categorized as equipment failure disturbances
A is the disturbances even though the equipment is available
K is categorized as quality disturbances

From the appendix A.5, it can be noted that the downtime of the line in January is around 22%. The disturbances for January is
T-Disturbance = 0%, A-Disturbance = 17% and K-Disturbance = 5%.

Therefore, the failure is calculated based on the disturbance persistence:

$$Failure = (0 + 17 + 5) = 22\% \tag{4.2}$$

By calculating the average of failures occurring every month, the average disturbances occurred at location-B over the past one year is 12%. This information is available from the data obtained from production engineers at the plant. There are a total of 4 operators working on the assembly line (2 operators assembling each part) who start their task from station 1 and continue up to station 10. Implementing this on the simulation model, would decrease the overall throughput to less than 20 parts/ 24 hours, which would not be a feasible throughput to the company. To optimise this throughput, 1 operator is assigned to work individually on each station.

4.2 Risk Assessment

Risk assessment of the project is done by taking into consideration of the different steps in the risk management process as shown in 2.2. Co-relating the FMEA tool to risk management process, it can be said that identifying the risk events and classifying them are the stages involved in definition and risk identification phase. Ranking these risk events according to their likelihood, impact is the risk assessment. Response planning involves detection of the severity of the risk and final phase is the monitoring and control where the risks are ranked according to their RPN and the higher risks are given more importance.

4.2.1 FMEA for Preparation Phase

In this process, a table is created to analysis the risk factor, where for each risk an identity is given and along with it, its occurrence such as what and when it happens are described. For risk assessment, the likelihood, impact and detection scores are given based on the guidelines mentioned in the 3.2, 3.3 and 3.4. The project group uses this method to analysis the risk for all three phases i.e preparation, development and analysis phases. The risk ID is in alphabetical series starting with G in preparation phase as shown in 4.5 and continues until the last risk in the analysis phase.

In the table, it is the risk assessment for preparation phase in which, the highly rated risk in this phase, is to understand the dynamics of the production system. It comprises of plant layout, properties of machines such as breakdown time, set-up time etc. The plant layout is provided showing different section of the plant such as drop-zone, kitting area, washing area and the assembly station. The layout comprises of 10 main stations and 18 sub-stations and it is quite a challenge to understand the connection between the main station and the sub-stations supporting it.

The details of material flows from drop-zone, kitting and washing area are provided. Any misinterpretation of plant layout and material flow could lead to a disruptive start of the simulation process. Due to the fact of misunderstanding, the plant layout is quite hard to interpret in the beginning of the project, the likelihood and impact score is given 8, for it has immense effect on the project that could hinder the start of the project.

Risk ID	Risk Event	Likelihood	Impact	Risk Score	Detection	RPN
G	Detailed Conceptual model	6	4	24	2	48
H	Analysis of Input Data	8	5	40	2	80
I	Acquirement of simulation tool knowledge	9	9	81	2	162
J	Understanding the dynamics and complexity of production system	8	8	64	4	256

Figure 4.5: FMEA for Preparation Phase

Understanding the plant layout could be easily solved by visiting the layout frequently until the layout is understood. Moreover, the team could have a plant layout in a A4 drawing sheet to understand the material flow better. Therefore, it is quite easy for the project team to form solutions for the problems faced in understanding the production systems and hence the detection score is 4.

Also, details such as part number and names were missing to identify a part, as it moves from one station to another. The buffer capacity where assumed while building the simulation model. Hence, it was quite uncertain while drafting the conceptual model and the likelihood score is 6 and it‘s impact is 4, for it affects minimally on the project. For a conceptual model, adequate data should be available, that could allow a user to freely draft their conceptual model. Proper data required for the conceptual model can be collected at the start of draft and therefore, the detection score is 2. But the team has to ensure the data provided are certainly adequate.

The assembly of products are done in a sequential order, but proper data regarding this were not available from the previous production site, this made the project team to assemble parts and send materials to the line in random orders. This wouldn't have any impact on the material flow since the material used remains the same. Finally, understanding the simulation tool and production, for it should be feasible together. But for learning the simulation and production system knowledge, time consumption is immense. A dedicated time must be allotted for learning the simulation software and with the acquired knowledge it can be decided what type of data are required. Fast learning to save time leads to improper learning and inadequate knowledge. While learning, there is a tendency for humans to commit unforced errors caused due to lack of concentration, spending less time and misinterpretation of the tool, which leads to likelihood and impact of 9. Tecnomatix has its own standard for coding, for instance the syntax for material flow between the assembly stations is unique. Therefore, it is time consuming and one takes time to understand the syntax. Once the syntax for material flow is incorporated in the model and if any error occurs, the detection of uncertainties in the coding is little hard, leading to a score of 5. This is a stage where the project team has to take the right decision with the available data otherwise it could be turmoil in latter stages if the team misunderstand the data or the production system. Therefore, interpretation of data regarding the material flow, incorporating and verifying the code is absolutely vital in this stage.

4.2.2 FMEA for Development Phase

In the development phase, there are several risks in verification and validation, for one should verify each step of modelling process in different parameters such as the assembly station sequence, processing time of the stations, product variant percentage, syntax of coding and flow control. The risk of checking each step in different parameters are quite high and any human ignorance of checking in such a huge simulation model would affect the project at high rate. The disruption rate is high and therefore the likelihood is high as well which is 9 and so does the impact, which is 7. To avoid this disruption, during verification in the simulation process, each step is double checked for obtaining the desired result, but, any problem occurring during modelling of the simulation, would cause difficulty for a user to find a problem and therefore, the detection score is 6.

The consumption of time during modelling the simulation is immense as it requires discussion and analysis of the layout, and implementing it in the simulation tool: Tecnomatix Plant Simulation. For this to occur, data are required, as it involves collection and analysis; time is spent immensely in collecting it and any data missing, should be communicated with the superior officials to obtain, which would take time. Therefore, model development is time consuming as it involves several tasks, the likelihood is 9, but contrarily, the impact of this task is mild: a score of 5, for it does not disrupt the model at a high rate.

The aim of the project is to simulate the material flow in the assembly line and therefore, it is important for the project team to have the necessary material data required. But, there was some data missing about the material flow from the warehouse, kitting area and drop-zone to the assembly line. Data such as part number, sequence, part replenishment time and buffer capacity were missing at the preparation phase, putting the project team in a hard situation in understanding material flow. However, the likelihood is 8 and for it has an adverse effect on formulating ideas on material flow, the impactness is 9. While figuring out one problem after another pertaining to material data, it is understood that the detection is 5, for it is not easily identified. During the simulation process, data for failures of the assembly line were missing and it required two weeks to collect the necessary data. This disruption caused stalling of the simulation process, rising the question on the quality of the data. This leads to likelihood score of 7 and for it‘s impact on the project, the impact score is 8. Also, this could be detected through less effective ways and is a bit time consuming, leading to detection score of 6.

The human unforced error should also be considered, for it could occur while building the simulation model. For instance, in the project, the team committed many unforced error such as misplacing the resources or assembly stations in the model, syntax error, improper setting of the control flow, processing time etc, that conflicted the production system leading to disruption of throughput or stalling the simulation model. Based on this disruption, the likelihood is 6 and it‘s impact is quite high as 7. The detection of these problems are moderate, for it to score a 4. It is evident that the problems faced in the development phase are more disruptive and time consuming for it to be solved.

Risk ID	Risk Event	Likelihood	Impact	Risk Score	Detection	RPN
L	Model Development Time	9	5	45	3	135
M	Knowledge on Material Flow	8	9	72	5	360
N	Quality of Input Data	7	8	56	6	336
O	Conflicting production systems modelling	6	7	42	4	168
P	Model Verification and Validation	9	7	63	6	498

Figure 4.6: FMEA for Development Phase

4.2.3 FMEA for Analysis Phase

After developing a base model the next stage is the analysis phase, where huge risk is likely to occur in decision making, as it is important for the project team to make the necessary iterations to check for flexibility of the model. For this, it involves time consumption and numerous changes of part quantities to achieve different throughput’s. Since experimentation involves risk and impact on the project, the likelihood is 8 and impact is 6. The detection rate is less effective but influential, so a score of 6. There is a chance for human to cause unforced errors such as wrong decision that would cause a vital change in the result. Once the results are obtained, it is in the hands of the company to validate and accept it. The chances of rejection is really low as each step is verified with the company‘s official during the development phase. Therefore, the likelihood of accepting is quite high and therefore it is 9, impact is 2 and detection is 2, for there could be less chances of detecting problems or rejecting the project in the final stage. It is the duty of the project team to acquire the desired result as the company intents. During analysis, any careless or non-intuitive decisions would cause dissatisfaction for the company. Since it is the final step of the simulation process, the project team should spend more time in analysing the process and results.

After the simulation is performed, it is vital duty for the company to safe guard the model in their data base for their future reference, in case of making any changes in the simulation model. Chances of misplacing the simulation model is quite impossible but if it does happens then it would be significant loss for the company in terms of data, time and investment. Therefore, the impact score being 9 but the detection of this risk is quite easy, therefore the detection score is 2.

Risk ID	Risk Event	Likelihood	Impact	Risk Score	Detection	RPN
Q	DES Industry Acceptance	9	2	18	2	36
R	Decision Making/ Experimentation	8	6	48	6	288
S	Simulation Model Maintenance	2	9	18	2	36

Figure 4.7: FMEA for Analysis Phase

Finally, after performing analysis task, two graphs are plotted: one for the risk score and another for the RPN as shown below in the figure 4.8 and 4.9. The graph shows the significance of the risks. To analyse the critical level of the risks, a graph of risk score versus RPN is plotted by assigning a threshold limit to it. If any point falls beyond the threshold, then it is understood that these risks must be addressed priory. After addressing and solving the problems, FMEA process must be re-conducted to assure the risk score and RPN level of risk are within the threshold limit. This process must be conducted again and again, as the risks occurs in a cyclic manner, meaning that once a risk is addressed then there is another risk waiting in the queue to occur. In the figure 4.8, it signifies the risk score on the Y-axis and risk ID on the X-axis. And, the figure 4.9 signifies the RPN on the Y-Axis and risk ID on the x-axis.

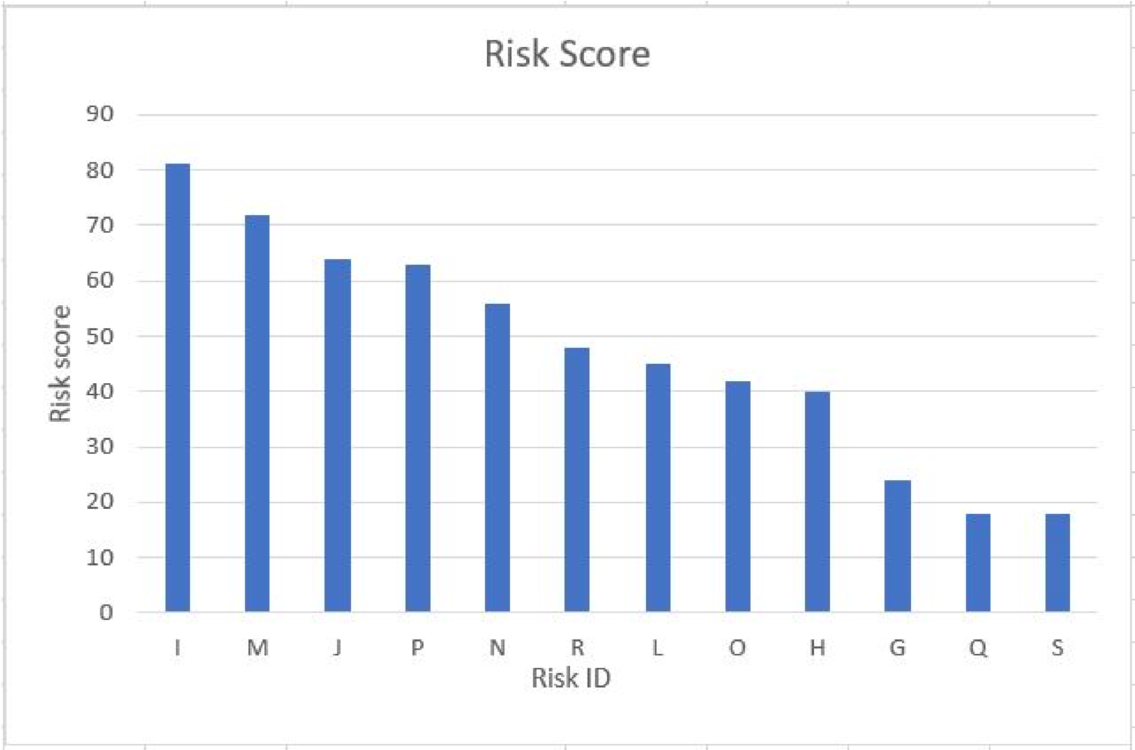

Figure 4.8: Risk Score Graph

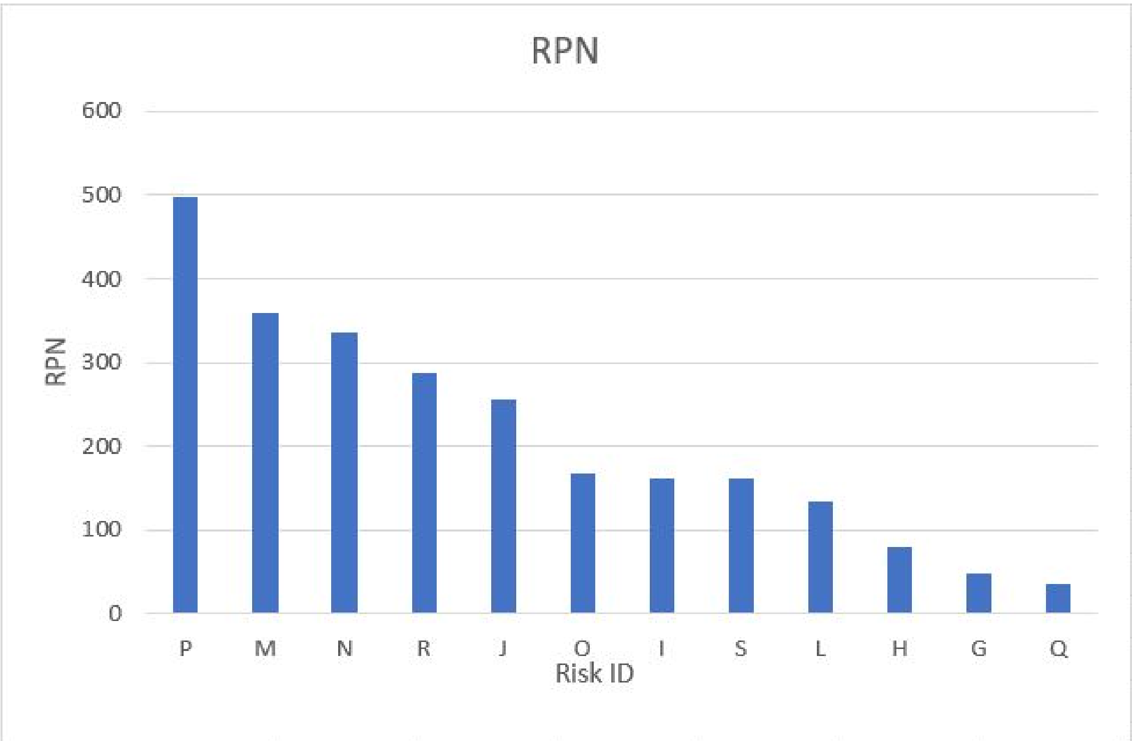

Figure 4.9: RPN Graph

In the below graph 4.11, it indicates the critical level of the risks that persist while performing the simulation model. Out of all the risks, five risks falls beyond the critical level i.e risk ID: P, M, N, R and J as shown in the figure 4.10.

Risk ID	Risk Event	Likelihood	Impact	Risk Score	Detection	RPN
P	Model Verification and Validation	9	7	63	6	498
M	Knowledge on Material Flow	8	9	72	5	360
N	Quality of Input Data	7	8	56	6	336
J	Understanding the dynamics and complexity of production system	8	8	64	4	256
R	Decision Making/ Experimentation	8	6	48	6	288

Figure 4.10: Critical Risks Analysis

These risks must be addressed first, otherwise it would disrupt the project, severely leading to abrupt stall or insignificant result. As it could be noticed that, the majority of the risks beyond the threshold are pertaining to the development phase, which means that the development phase is the most potent stage of the simulation process. The risks are verification and validation, material flow knowledge and quality of input data. For verification and validation, since the main model is used for the future reference, it is necessary to check the output corresponds to the input. Also, the assembly line consist of 28 stations, there are chances of committing mistakes while coding the part quantities and it‘s variant, could be due to, human unawareness. Therefore, checking the steps of the model, double-checking the syntax or code and reviewing the modelling at regular intervals is an optimal solution for verification. Also, for validation, it is important the model is flexible, for which, different iterations are performed with variant and part quantities, yielding different throughput as seen in appendix A.8, A.9, A.10, A.11, A.12. For this, it is important the model obliges the changes made by the user. When any change in the part quantities or variants is made, the material flow changes in the model, however, the user has to make the required adjustments of the materials in the buffers to make the materials flow properly. Without the material flow knowledge, the simulation model is incomplete. Only the assembly line is built, but the important aspects of the model, which is the material flow could not be integrated. For this, it is important to have the adequate knowledge of material flow, by visiting the plant and understand the dynamics of the production system. Also, from the simulation perspective, a conceptual model is build to understand the material flow in the assembly line. The company also supports the team with material details encrypted in a BOM, which provides the details of part variant, part number, buffer capacity and pallet/boxes carrying parts. But, with the given data, the team experienced interpretation problem with the BOM while developing the model, which was mitigated by immediately communicating by the superior officials to straighten the data discrepancies.

Besides the risks in the development phase, there are other risks evolved in the preparation phase and analysis phase. In the preparation phase, as the team were new to the company, it took some time for the team to understand the dynamics of the production systems. Without the prior knowledge of the production system, the simulation could not be started. The optimal solution is to understand the production system by analysing the plant layout in the drawing sheet, perceive the different dimensions of the material flow and the properties of the assembly line. Last but not the least, the risk persisting in the decision making process is quite potent, as it could make the model a success or failure based on the decisions made by the user. It is vital that the user uses the right decision i.e cognitive skills to optimise the model in final stage before presenting it to the company. As a team, the decisions were discussed and concluded on what is best step to optimise the model. The FMEA is performed until the risks fall below the critical level, indicating that there are no risks that could disturb the simulation project, but, there could still be unprecedented disturbances which could not be predicted by the project team. Therefore, it is better to perform the FMEA periodically to mitigate the risks as much as possible.

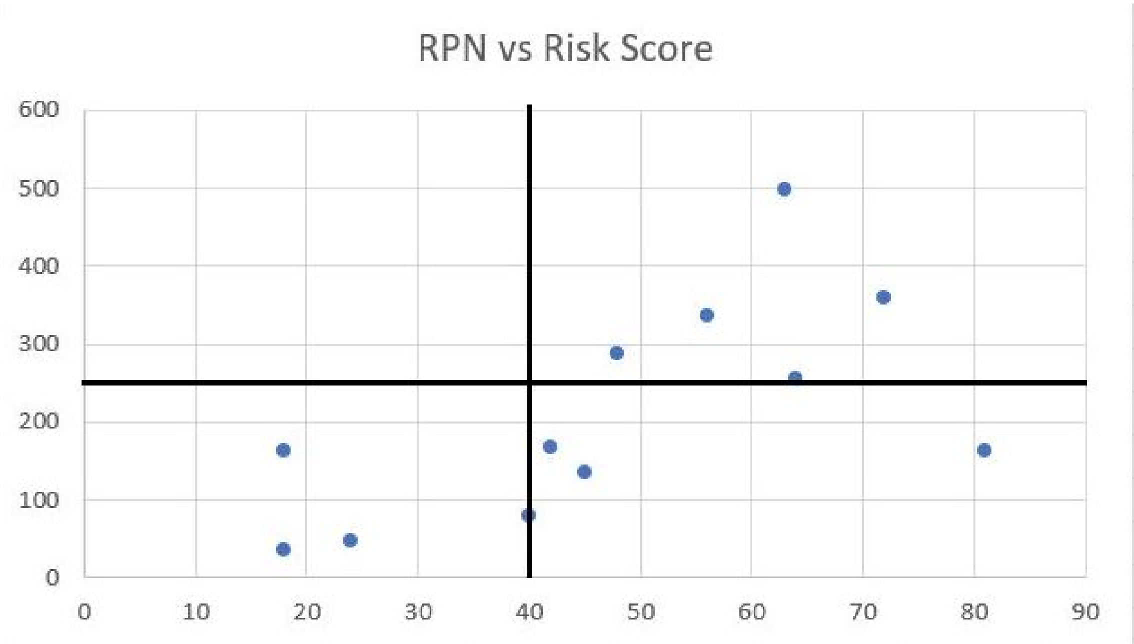

Figure 4.11: RPN vs riskscore

5

Discussion

A detailed discussion of the simulation results, FMEA in different stages of simulation model, its methodology and results are discussed. Improvement recommendations for the company are given in this chapter.

Building a simulation model by following the banks methodology as well as performing a risk analysis using a risk assessment tool has been performed earlier. But the project team would like to mention that there are no previous research for integrating the banks methodology with FMEA to conduct a simulation project. Performing these kind of projects would help the companies to be more informed about the risks which might occur in different stages of a project and make suitable responses so that the risk wont occur again or the risk wont have a considerable amount of impact on the project outcomes. This thesis work also provides a way for experimenting more ideas for integrating the simulation methodology with FMEA. Any new risk events other than the ones found now can be added and can be used as a document for future references. Below section has a brief discussion on how the thesis was conducted.

The project is conducted according to the Banks methodology. Once the objective and project plan are decided, a conceptual model is created by using the data collected by the team. It is important to make sure that the collected data are relevant and true. With the help of this conceptual model, a simulation model is built, verified, validated and experimental runs and analysis are conducted on the model. Once the desired output are obtained the results are documented and implemented. On the other hand, FMEA is carried out in every step of the above mentioned process. Important events, which was felt as crucial are documented as risk events and analysis are carried out as explained above.

One of the most important consideration to be made while building the model is the flexibility of the assembly line. For which, the company decides to implement all 18 variants in the model even though only 9 are currently being used. At any circumstances, the company has decided not to have any missing variant in the assembly line. This has urged the project team to incorporate all 18 variants in the simulation model, leading to time consumption in the development stage. For those variants not in use, are incorporated in the information flow by coding their parts numbers and quantities and mentioning them as zero. So when the demand arises for a particular variant, the user can add it to the model by just changing the values. However, this leads to flexibility of the assembly line.

Since all the stations in the assembly line have the same processing time of 21.11 minutes, there are no discrepancies in the assembly process which leads to no-bottleneck in the system as in the appendix A.6. The two test rigs after the assembly line also has a processing time of 40 minutes each. It is clear, a bottleneck occurs when there are different processing time at each station or at least one station, paving the way to blocking and waiting, subsequently resulting in a discrepancy of takt time of stations. It is clear, the production might be disturbed by T, A and K kind of disturbances, but not by the functionality of the equipment.

For validation, as mentioned before, the project team performs 5 additional iterations along with the intended one. As can be seen in figure 4.2, and appendix A.8, A.9, A.10, A.11, A.12, the main iteration is the one, which is the desired output required by the company. The additional iterations are performed to validate and to show the flexibility of the simulation model, by changing the input material percentage, in case, if the company wants to increase or decrease the throughput in the future. In all the iterations, the variant type, number of variants or the throughput of each variant is changed. For example, in the first iteration throughput is varied in small quantities, i.e between 50 to 100. In the second iteration, throughput of Variant-B is decreased by 400 parts and that of Variant-C is increased by 200 parts. In the third iteration, a new variant Variant-E is added to production and two older variants Variant-F and Variant-G are removed. An addition of two more variants Variant-I and Variant-L is added for production in the fifth iteration. Along with changing the variants, the throughput is also varied. The iterations have a maximum throughput of 3300 products/year in iteration 5 and a minimum throughput of 2900 parts in the fourth iteration.This is the method followed by the project team to validate the simulation model for flexibility.

Since the objective is clear, which is to simulate the logistic flow, the project team performed the steps of the banks' methodology, as it can be noticed, how the team obtained the required data and simultaneously sketched out the conceptual model for the team to precisely build the same in the tool. Once the conceptual model is built in the software, the relevant data are integrated into the model, such as the inflow materials and equipment‘s processing time. For the simulation, the project team should understand the integrity of the tool. One of the challenging parts of the simulation is the coding of the variant and it's part quantities, as it involves numerous variants of parts and quantities for each variant at each station. Therefore, integrating the variants and it's part quantities in the model is the key in the simulation. Once overcoming the challenges, the results are verified and validated by the company supervisor to check if the result meets their demands. However, the demand is 3157 products for one year. After the demand is met, the model is run at different iterations such as varying the inflow material percentage and variants, to check the flexibility of the model. These are documented in this report for the company to reference and implement it for future projects.

With the completion of the model, the project team performed the FMEA, to outcast few risks based on the RPN values. In the analysis, the team found few risks that should be immediately mitigated, otherwise the drawbacks would profoundly affect the throughout of the line. The drawbacks are mentioned along with the risk in the risk assessment section, it is time to discuss the influence of FMEA in the project. The risks evolving during the development phase are more, than the ones during the preparation and analysis phase because the development phase involves transforming the data and information of assembly lines, resources, operators into a virtual model, and coding for the material flow, changes in variants and demands have more challenging circumstances that disrupts the throughput of the system. The FMEA requires an open discussion within the project team and also with the supervisors and leaders for formulating new ideas and solutions, that draws foundation for mitigating the risks.

Last but not least, there could be unprecedented circumstance, in this case, it is the Covid-19 crisis, which caused a huge disturbance on the thesis work. Due to this crisis, the company was shutdown for a prolonged time, leaving the project team idle for over a month. This in-fact changed the course of the project, as it was first planned to provide improvement suggestions for the new assembly line. Due to limited access to interact with the employees and to visit the company, the project team focused on risk management analysis rather than improving the model. Such conditions must be considered as one of the huge disturbance and in the future any team performing a thesis, shall consider one such alternative for their benefit and be prepared for the challenges.

5.1 Advantage of FMEA in the project

The reason for the project team to select FMEA, to analyse the risk assessment is because of its numerous advantages, some of them are explained below,

1. The time spent in finding the risk is reduced due to score value of the likelihood, impact and detection. The occurrence of the risk are chalked-out to know where and when a risk might occurs, to reduce the time spent in identifying the risks occurring at the latter stages. Instantly the scores are given to identify the level of risk persisting with the process.
2. The detection value in the RPN, provides time for the project team, to respond towards the risk. The earlier the detection, the earlier would be the mitigation of risks.
3. This allows the team to prioritise the risk, as to which one should be addressed first based on the critical value. Risks with higher critical value are addressed first, meaning the risks which fall beyond the threshold limit are given more importance.
4. The detection process enhances the team to come up with innovative ideas, as how and when they have to detect the risk. Therefore, it builds creativity and confidence on how to tackle risks.
5. Another way of preventing the risk to occur in the future, is by documenting the risk and it‘s analysis in a report. This would avoid the future user to cause the same mistake or perhaps, can learn what not-to-do .

On conclusion, DES is critical for the company to obtain the real world into simulation tool. But, while performing this, lot of uncertainties emerge, which should be immediately taken care off. A suitable risk assessment tool which is FMEA is used, for its significant effect on the risk mitigation. Therefore, the research question is justified, by demonstrating the usage of the FMEA in DES and its advantages on the project. Proving that FMEA is vital source for mitigating problems in DES, that could benefit the company‘s business.

5.2 Recommendations for the company

Here are some of the company specific recommendations which the thesis team thought would be helpful for the improvement of the company for simulation as well as the risk assessment process.

1. The company has OEE details for the entire assembly line, instead it is important to determine the OEE for each assembly station to determine the bottleneck in the assembly line.
2. In the current model, the buffer capacity, delivery time and operator‘s performance are not defined. It is better to incorporate these parameters in the model, to obtain precise throughput.
3. Simulation is a flexible and powerful tool, it could be used for future project and in other domains such as production, supply chain logistics, finance as well.
4. Due to diversity and complexity, it is important that the company trains the person who deals with the simulation tool. This could help the person to make necessary changes in the product and process.
5. Continue to improvise and build the model, by integrating this with new projects.
6. In simulation tool which the company uses, cost of each parts could be incorporated, which could be helpful for the finance department to estimate a budget required for the materials.
7. From FMEA perspective, it is better to perform for each phase, because it helps in formulating new solutions.
8. It is vital that FMEA is performed until the critical score of the risks are reduced. This ensures that the risks are mitigated.
9. FMEA is flexible tool, as is could be used at phase of the simulation to mitigate risks.
10. It is vital that the company documents the results of the FMEA, for the betterment of the company‘s purpose.
11. Once the FMEA is performed at the company, it is important to convey the implications and results to the project team, to make them understand the importance of FMEA.
12. Also, the company had used Process FMEA, but has not been further emphasised it lately. It is better to uses them as reference for the present FMEA, like a supporting tool, which could ease the efforts of the user while using FMEA.

6
Conclusion

In this thesis, FMEA is conducted on an ongoing simulation project, and demonstrated on what steps have to be carried out while performing FMEA. Further, the key take away points are mentioned in this chapter. It is known that, the aim of the thesis is to simulate the internal logistics flow of materials to the assembly line, which is accomplished by achieving the desired throughput with the help of the simulation model.

For the simulation process, the project team should understand the integrity of the tool. The purpose is to obligate improvements, such as the bottleneck, material requirement and buffer capacity, in which, one of them is achieved i.e material requirement. Also, the purpose to mitigate risk to overcome barriers for more easy flow of materials in the future is also been addressed in this work. From the result, information such as the material required for the assembly can be obtained, which is one of the objective of this thesis (seen in fig 4.4). Bottleneck and buffer capacities could not be analysed in the simulation model due to the unprecedented COVID-19 situation. This is suggested as a recommendation for the company, to further build the model and integrate other improvements in the line. The risk prevailing during and after the simulation has led the project team to understand the drawbacks of risk and the importance of risk management.

The project team understands, defines, evaluates and plans the risk events, with a suitable tool. Paving way for improvement and a platform to learn. The FMEA tool has enabled the team to overcome the barriers, by performing a systematic procedure for risk analysis. It explains why it is needed and how to use it explicitly as mentioned in section 3.4. The most important is that it allows the user to analyse deeply, understand and evaluate the severity based on the score scale. From the score scale, the project team becomes alert on the high-risk factors and sooner, tries to mitigate them.

Integrating the variants and it‘s part quantities in the model, is the main key point in the simulation. One of the most benefited stakeholder from the simulation project is the companies logistics and production planning department, as they will use the model for analysis based on the fluctuating demands. The new project teams can use the FMEA results as a reference while conducting their projects and be well aware of the risks that might be faced in the course of the project. Overall, from the experience with Siemens Tecnomatix plant simulation, the software is diverse and highly-flexible, for it could be used at wide range in the production field and other domains as well. And hands-on experience of risk management, perhaps FMEA, has boosted the confidence of the project team to tackle any hurdle in a simplified manner in an industry.

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A

Appendix 1

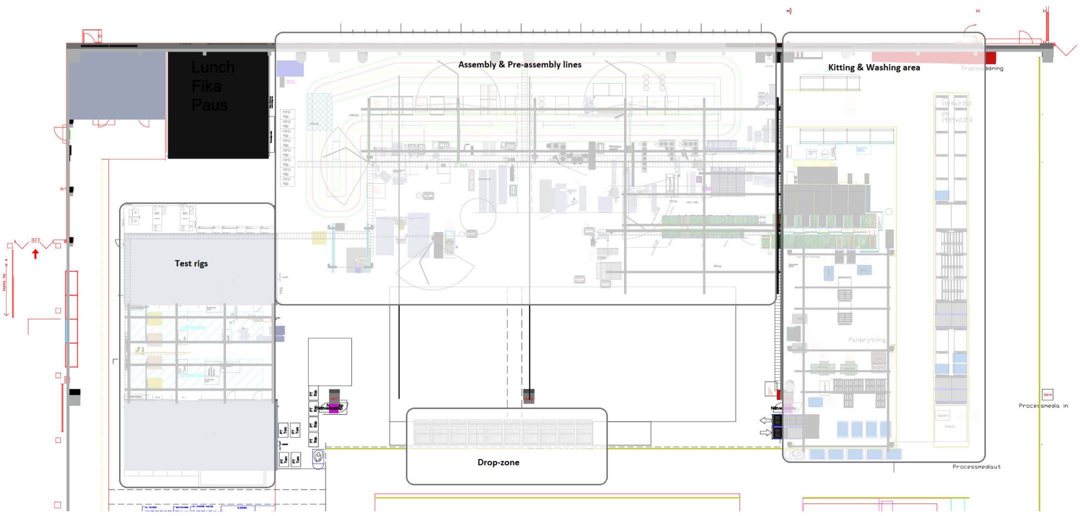

Figure A.1: CAD layout of the proposed assembly line

Figure A.1 represents the layout of the plant and the impotant areas to be considered while building the assembly line. parts are brought in to the assembly line from two regions, the Drop-zone or from the kitting and washing area. once the components are assembled, they are tested in the test rigs and further sent for packing.

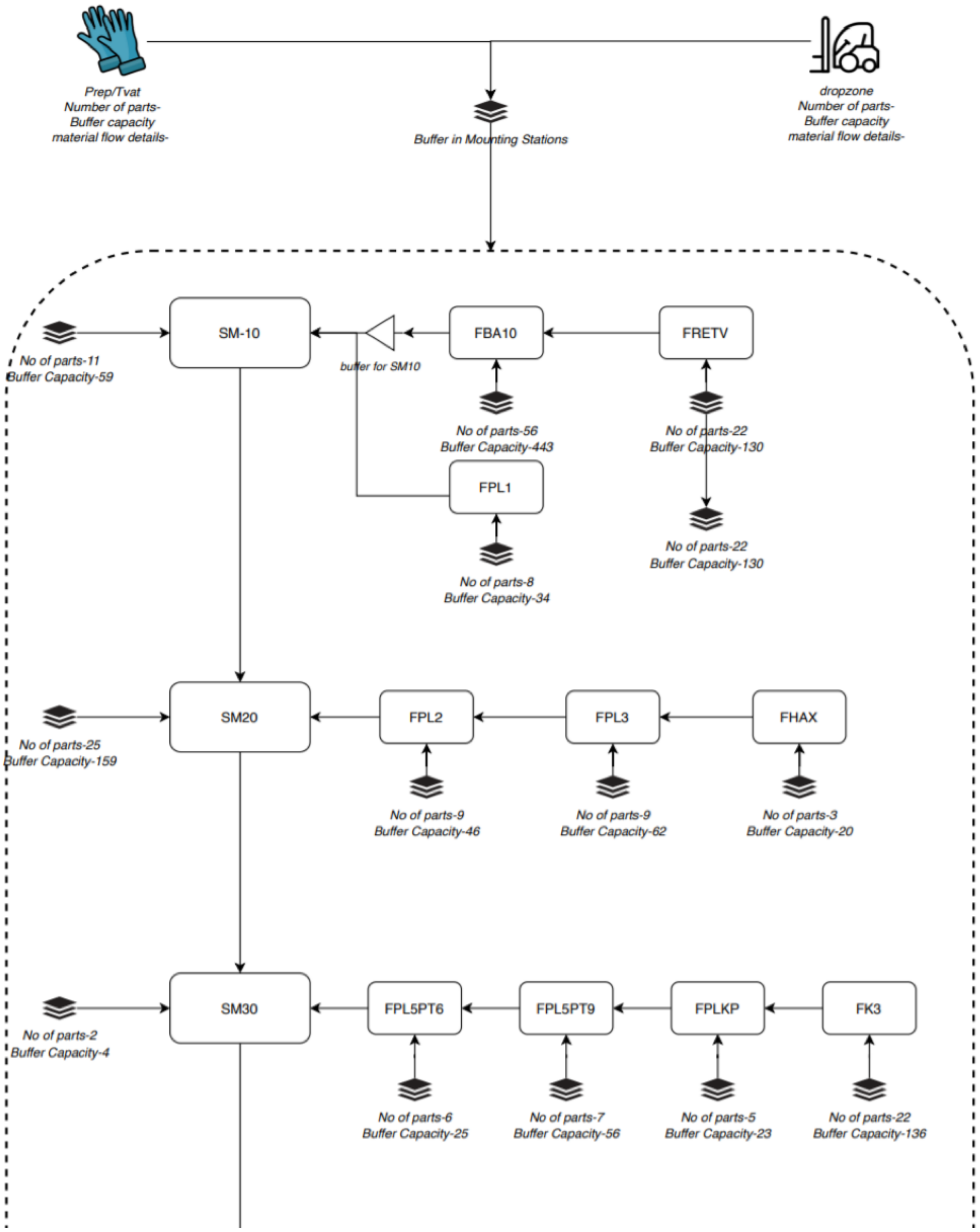

Figure A.2: Detailed conceptual model of the assembly line

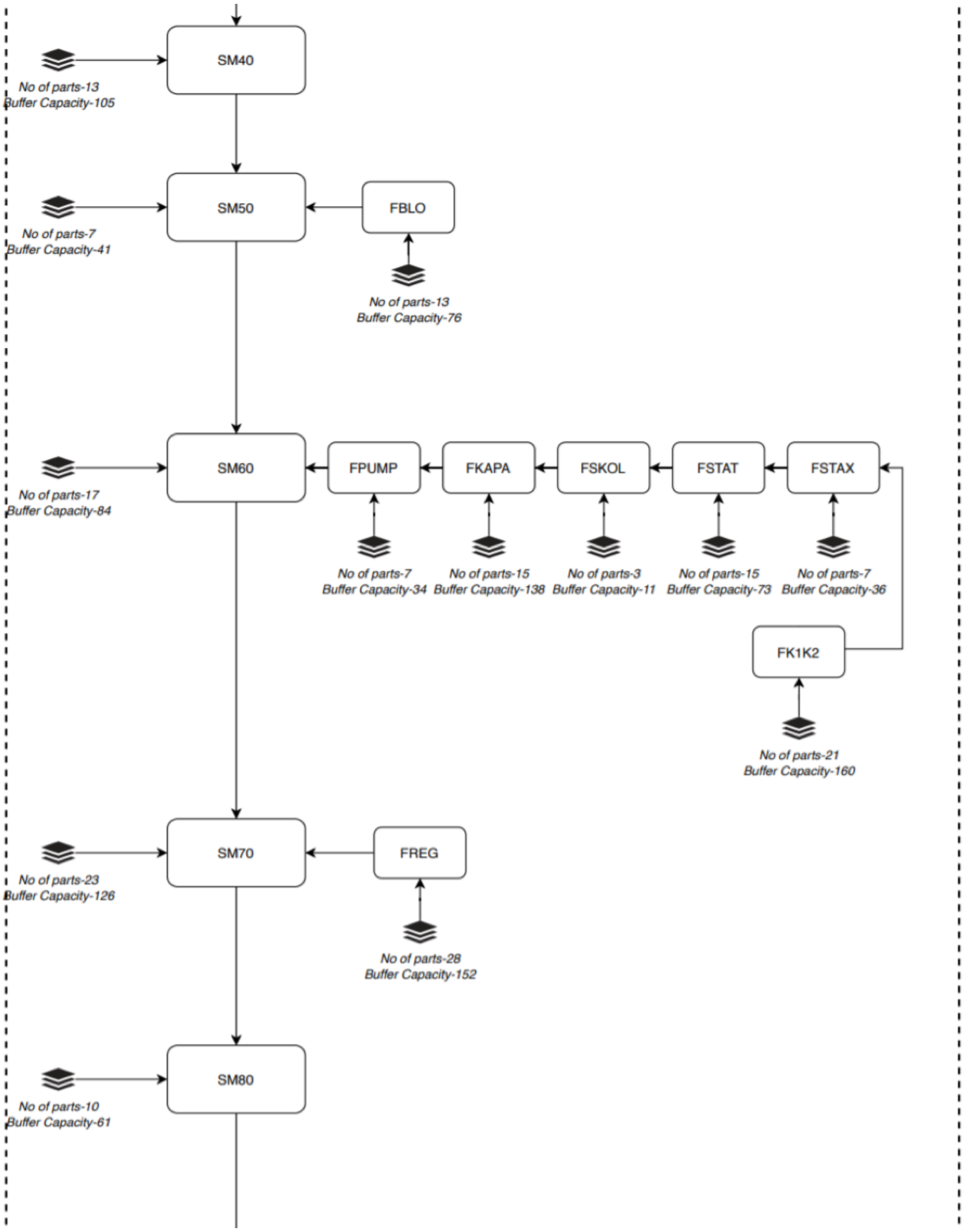

Figure A.3: Detailed conceptual model of the assembly line(continued)

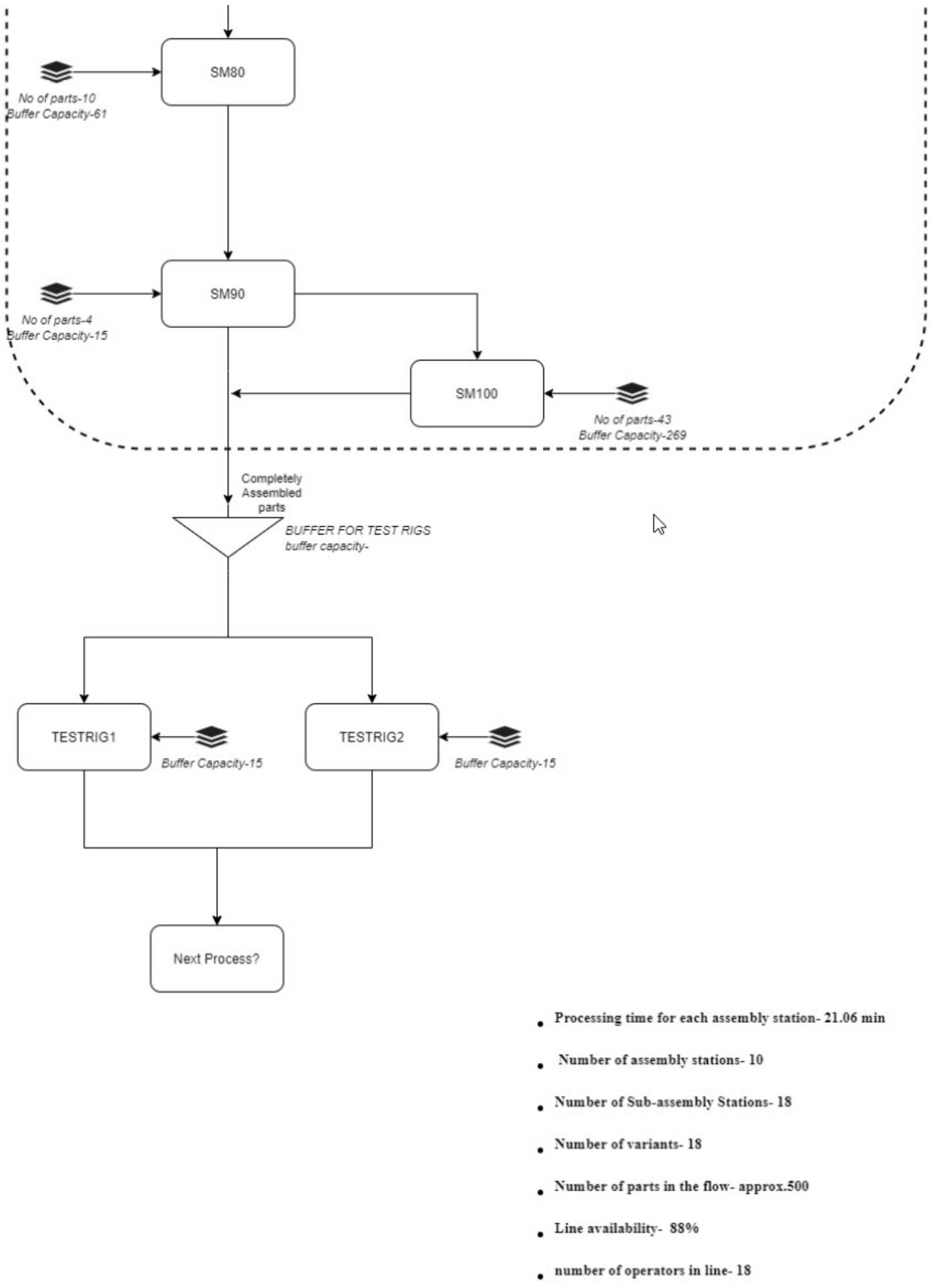

Figure A.4: Detailed conceptual model of the assembly line(continued)

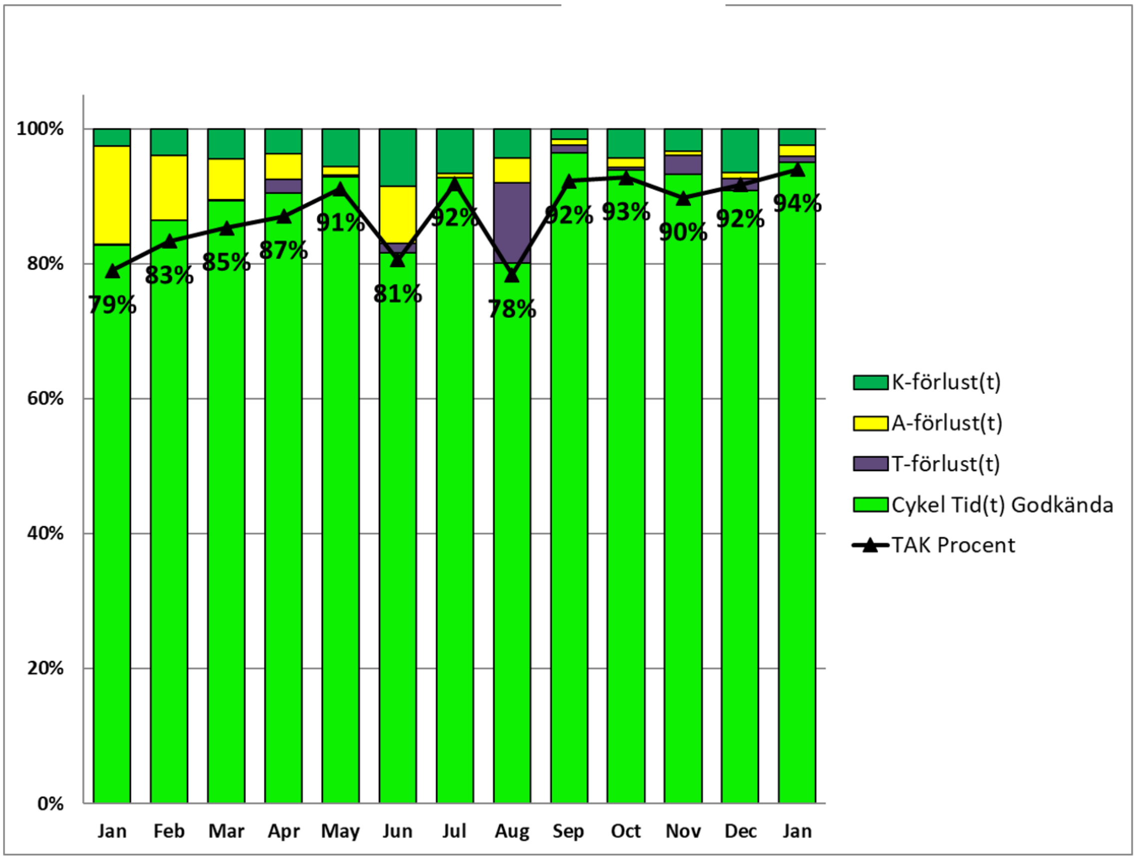

Figure A.5: Efficiency of line in the previous production facility

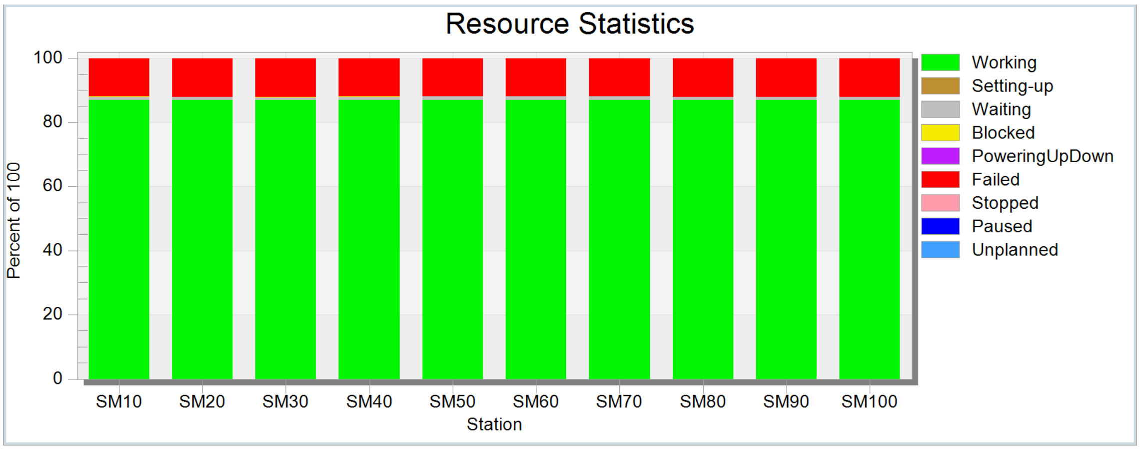

Figure A.6: Bottleneck Analysis

In the figure A.7, both station SM10 and SM60 use 9471 parts and shown in the first two tables. Therefore total requirement of the part is 18942 for a years production. Similar results can be obtained for all the 500 parts used in the assembly line.

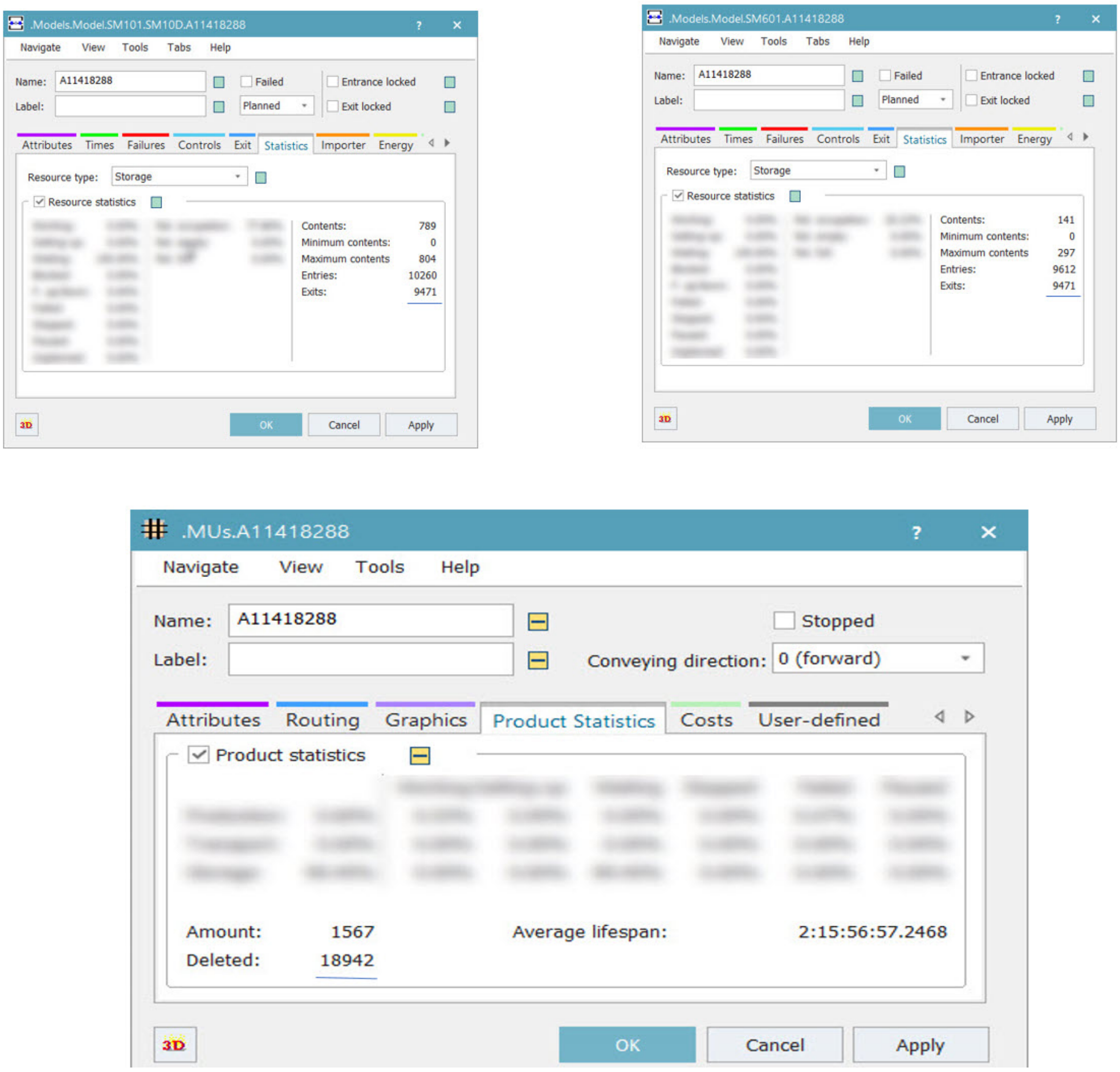

Figure A.7: Part 11418288 total consumption

	Type	Total throughput	%Parts
1	V[illegible]	32	1.00
2	V[illegible]	95	2.97
3	V[illegible]	126	3.94
4	V[illegible]	32	1.00
5	V[illegible]	63	1.97
6	V[illegible]	32	1.00
7	V[illegible]	32	1.00
8	V[illegible]	1647	51.48
9	V[illegible]	1140	35.64

Figure A.8: No.1 Iteration

	Type	Total throughput	%Parts
1	V[illegible]	27	0.90
2	V[illegible]	134	4.47
3	V[illegible]	27	0.90
4	V[illegible]	27	0.90
5	V[illegible]	134	4.47
6	V[illegible]	27	0.90
7	V[illegible]	214	7.13
8	V[illegible]	1607	53.57
9	V[illegible]	803	26.77

Figure A.9: No.2 Iteration

	Type	Total throughput	%Parts
1	V[illegible]	30	0.95
2	V[illegible]	60	1.90
3	V[illegible]	30	0.95
4	V[illegible]	150	4.75
5	V[illegible]	30	0.95
6	V[illegible]	241	7.63
7	V[illegible]	1353	42.86
8	V[illegible]	1263	40.01

Figure A.10: No.3 Iteration

	Type	Total throughput	%Parts
1	V[illegible]	51	1.76
2	V[illegible]	77	2.66
3	V[illegible]	103	3.55
4	V[illegible]	51	1.76
5	V[illegible]	103	3.55
6	V[illegible]	51	1.76
7	V[illegible]	51	1.76
8	V[illegible]	1386	47.79
9	V[illegible]	1027	35.41

Figure A.11: No.4 Iteration

	Type	Total throughput	%Parts
1	V[illegible]	32	0.97
2	V[illegible]	64	1.94
3	V[illegible]	32	0.97
4	V[illegible]	32	0.97
5	V[illegible]	96	2.91
6	V[illegible]	32	0.97
7	V[illegible]	96	2.91
8	V[illegible]	32	0.97
9	V[illegible]	64	1.94
10	V[illegible]	1634	49.52
11	V[illegible]	1186	35.94

Figure A.12: No.5 Iteration