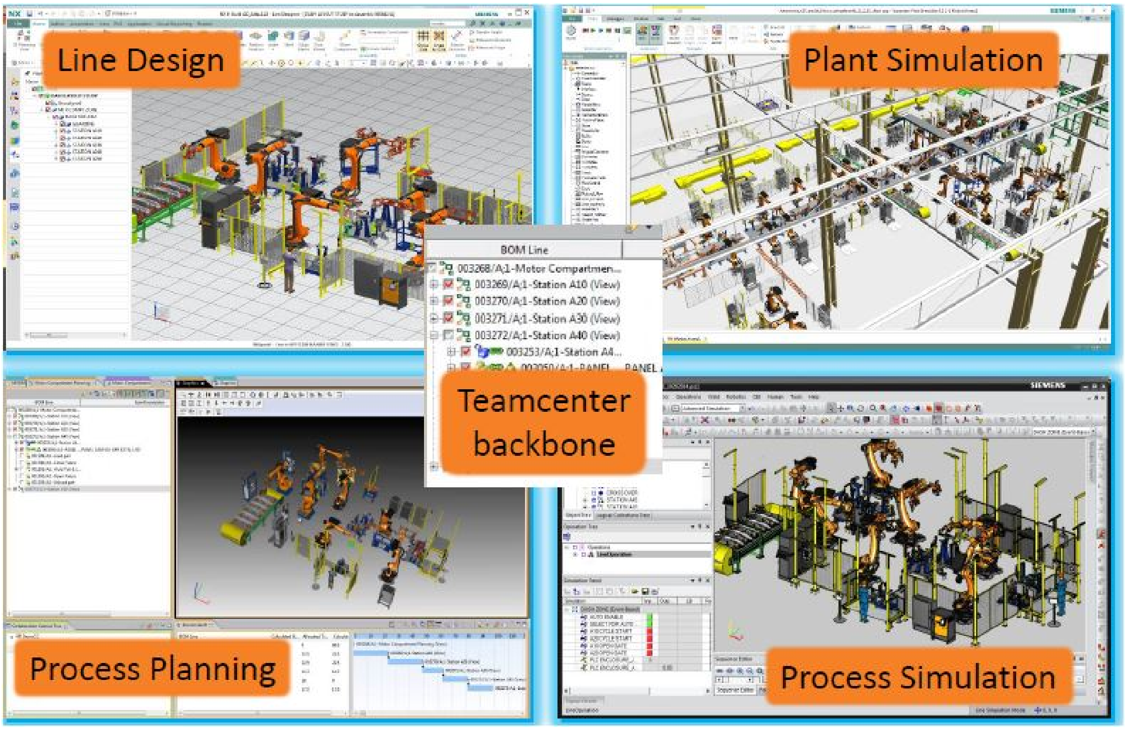


# Data Enhancement in Teamcenter for DES (Discrete Event Simulation)

Master's thesis in Production Engineering

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DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2024
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Master's thesis 2024

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A case study at Volvo Car Corporation (VCC), Gothenburg

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Master's Thesis 2024
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Cover: Digitalization in Siemens PLM
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Printed by Chalmers Reproservice
Gothenburg, Sweden 2024

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# Abstract

As a result of the world economy's rapid growth, global competition and challenges are increasing for companies. Consumer demands become sophisticated, insisting on flexible and short product lifecycles. To meet these demands companies strive to optimize their operations, enhance product quality, and meet growing customer expectations, making the demand for data management throughout the product lifecycle critical. Therefore, companies have introduced product lifecycle management (PLM) systems. PLM is not only the evolution and succession of Product data management (PDM) but also holds the greatest future potential for company information solutions.

The lack of required data and the inability to transfer the same to another system has always been a drawback of a PLM system. This thesis looks into enhancing the efficiency and accuracy of Discrete event simulation (DES) in a manufacturing environment by augmenting data integration techniques into Teamcenter, a widely used product lifecycle management tool. The study examines the difficulties in integrating real-world data into Teamcenter and extracting it from Teamcenter for DES applications. It focuses on the problems of the current data structure and the need for enhancing data management techniques. The study identifies the absence of critical data for simulation through a thorough qualitative study.

A case study is carried out to show how the suggested methods improve the efficiency and accuracy of DES models. Also, improving decision-making and process enhancement in manufacturing. The results of this study propose ideas to include required data inside Teamcenter, extract them, and prepare them using a data management software tailor-made for performing Discrete Event Simulation.

Keywords: Input Data Management, Interoperability, Teamcenter, PLM, DES.

# Acknowledgements

The completion of this thesis would not have been possible without the support and encouragement of our academic supervisors Maja Bärring & Paulo Victor Lopes and Industrial supervisors Anton Albo & Dennis Andersson.

We would like to express our gratitude to Maja Bärring who gave valuable support before her departure. We would like to extend our gratitude to Paulo Victor Lopes for filling Maja's position so well and encouraging us toward the final goal.

We are thankful to David Freed, Isabella Steen, Simon Wandebäck, Puranjay Mugur, Dan Li and other employees at Volvo Car Corporation for their support during the thesis. We extend our heartfelt gratitude to Isabella Steen & Puranjay Mugur for patiently responding to all of our queries throughout the thesis. A special thanks to David Freed, our main point of contact, for acting as a customer and for his steady insights.

We express our sincere gratitude to Frederic Larsson for his effort and patience with Teamcenter training. His advice and guidance have been important for our skill development and successful completion of the thesis.

A big thanks to Dennis Andersson and Anton Albo who introduced this project and provided the necessary tools and resources. A special thanks to Dennis Andersson for sharing knowledge and providing invaluable insights.

We are also grateful to Anders Skoogh, our Examiner for his guidance and motivation, which greatly inspired us to commit and complete our thesis.

We are deeply thankful for our family's constant encouragement & support and their love & belief in us.

This report has been written with the help of AI tools like Copilot to study VBA code & new commands and Grammarly to check grammar & structure.

Aakarsh Sudhakaran
Vaishal Solanki
Gothenburg, June 2024

# List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

| | |
|---|---|
| AWC | Active Workspace |
| BOE | Bill of Equipment |
| BOM | Bill of Material |
| BOP | Bill of Process |
| CAD | Computer-Aided Design |
| CC | Collaboration Context |
| CIM | Computer-Integrated Manufacturing |
| DES | Discrete Event Simulation |
| EBOM | Engineering Bill of Material |
| J2EE | Java 2 Enterprise Edition |
| MBOM | Manufacturing Bill of Material |
| MPP | Manufacturing Process Planner |
| PERT | Program Evaluation Review Technique |
| PLC | Product Life Cycle |
| PLM | Product Life Cycle Management |
| RAC | Rich Application Client |
| SDGs | Sustainability Development Goals |
| SQL | Structured Query Language |
| TC | Teamcenter |
| VCC | Volvo Car Corporation |

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# 1
# Introduction

This chapter presents the current research gap in the automotive industry and how that will affect the case company. The rest of the chapter describes the aim of the study, research questions and limitations.

## 1.1 Background

Products! Humans use an enormous amount of products every day. These Products usually have a long life which is not seen by the user. Therefore, to understand the life of a product, it is required to understand the processes that take place between its manufacturing and applications as well as the actions taken by people who work with those processes. The structure of these processes and method to find key activities is called Product life cycle (PLC) (Crnkovic et al., 2003).

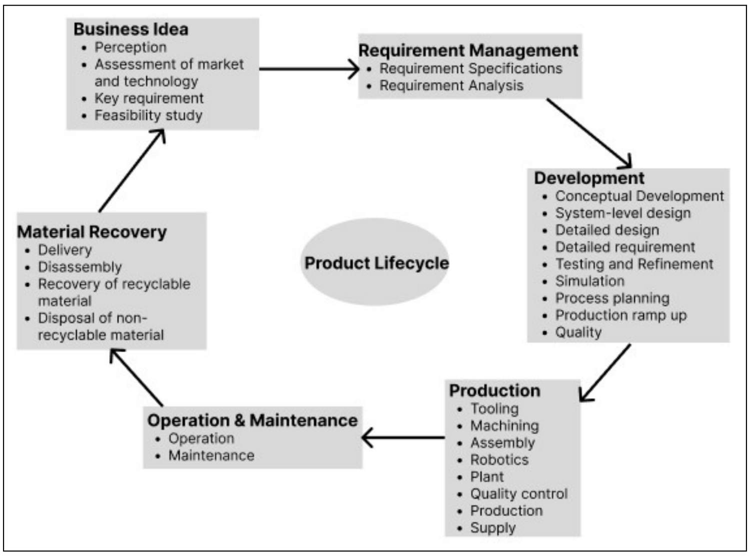



**Figure 1.1:** Phases of Product life cycle (Crnkovic et al., 2003)

PLC is divided into six general phases in Figure 1.1 - Business idea, Requirement Management, Development, Production, Operation & Maintenance, and Material Recovery. Business idea where perception, key requirements for the new products are made and later feasibility study is performed. Requirements are specified and analyzed in requirement management. After that, the development phase covers the steps from conceptual design to manufacturing of the product and later the product is manufactured during the production phase. After manufacturing, the product is purchased and used by users. For longer use, some product requires maintenance as it depends on the material used to develop the product and how the operation is performed by a user. In the last, Material recovery is where the product is delivered to recycling after using it for a certain time or after finding a better product. At recycling, recyclable materials are recovered and non-recyclable materials are disposed of by using a suitable method.

Product life cycle management (PLM) or Product data management (PDM) is becoming more and more important, particularly for companies in high-tech, industrial, and service sectors (Stark, 2020). Companies are facing faster product life cycles and the need to get new products to market quickly, makes it recognize the importance of embracing circular economy principles. They are moving towards offering customization rather than mass production. This means forming networks where each team specializes in different aspects like planning, manufacturing, and integration (Subrahmanian et al., 2006). Sharing information between teams needs to be faster, more accurate, and automatic that is why product life cycle management is crucial in today's industrial production to handle these challenges and meet growing customer demands. PLM is known as a tool for managing the life cycle and creation of products as well as for collaborating within the supplier network (Liang et al., 2006).

PLM is a digital methodology where computers are used to manage products throughout their life cycle. Computers do the calculations and store the information in digital memory which is shared through digital networks. In the previous methodology, people used slide rules and typewriters for calculation and communication. Moreover, communication and information are stored mainly on paper (Stark, 2020).

Product life cycle management allows companies to oversee the entire lifespan of a product and its associated information. Companies are looking for PLM to deliver strategic and operational benefits because of its product-focused approach. With efficient product lifecycle management, companies can effectively compete in the international market. PLM solutions facilitate collaboration among teams, regardless of their location by providing a shared repository of enterprise product data including parts and material requirements, engineering changes, workflows, and regulations (Terzi et al., 2010). PLM helps companies create forward cost models and offers a comprehensive view of the product life cycle to teams involved in procurement and manufacturing, enabling them to identify durable and cost-effective materials and parts (Troiano, 2023).

A PLM system can provide a strong link between engineering and production. Designers provide information about revised components, changed plans, and the release of updated drawings to the production with the help of change management tools. In response, production engineers specify planning modifications using change management to enhance the product's manufacturability. Integrating production processes through computer-integrated manufacturing (CIM) can benefit from PLM systems as it provides a means to seamlessly connect various manufacturing systems with engineering tools. With the help of PLM, production can effectively manage changes to information regarding production devices which leads to enhancements in quality control, device calibrations, traceability, and ultimately overall operational efficiency (Saaksvuori and Immonen, 2002).

Teamcenter® software is a modern and adaptable PLM system that uses a digital network enabling advancement to link people and processes between different teams (Zhang and Cai, 2012). Using Teamcenter (TC), companies can combine product information from several sources into a company's database. From there, different teams can quickly locate, edit, share, and work together on product design while improving parts, processes, and information (Siemens, 2008). More than 170,000 customers worldwide have started using Siemens Teamcenter as a solution for PLM as of 2023 (Lawrie et al., 2023).

Discrete event simulation (DES) is intended to simulate systems where events occur at specific or separable instances in time (Choi and Kang, 2013). DES is used for several purposes such as estimating inventory and optimizing bottlenecks (Mesquita et al., 2017).

Now some challenges come into account while implementing the PLM system such as interoperability between different systems (TC & DES) reflecting general issues. A study has been carried out at Volvo Car Corporation (VCC) that demonstrates how to use the PLM system to address these general issues.

## 1.2 Problem Formulation

This study focuses on gaps related to Semantic interoperability and input data management. The following paragraphs describe how both are related to the landscape of this study and to each other.

Semantic interoperability is understanding and interpreting information transferred between two systems. The semantic interoperability between computer-aided applications and data management software such as PLM systems is identified as a critical need (Diana et al., 2014). Often PLM system lacks effective data transfer to other systems such as DES software. Section 2.3.4 describes different types of interoperability challenges. Additionally, the lack of depth in data that is incorporated within the PLM system has not been addressed well in the researched community so far. A previous study ranks the lack of interoperability among various systems as a major barrier to PLM institutionalization in an automotive firm (Singh et al., 2021). In addition to that storing, transmitting, and reusing engineering knowledge within the industry is still considered a major challenge (Colombo et al., 2014).

The input data management can be described as preparing quality data suitable for simulation in this case (Skoogh and Johansson, 2008). Section 2.5 shows the probable methodologies for data input for DES. The studies conducted in the 2010s found that 80% industries rely on manual work for data input into DES, they also predicted that this number will drop below 30% by 2020 (Skoogh and Johansson, 2008). It is also important to identify to which methodology the current working method in the case company falls under in order to suggest an improvement strategy for gradual growth.

## 1.3 Case Company

The study is conducted at Volvo Cars, an automotive industry based in Gothenburg, and strives to excel in cutting-edge technologies. The study is conducted at Volvo Cars, an automotive industry based in Gothenburg, and strives to excel in cutting-edge technologies. One of the key aspects of a sustainable future is becoming a circular business, and Volvo is well aware of the rising societal and regulatory pressures. They aim to improve efficiency, making materials circular and extracting maximum value from them in their value chain. An effective PLM interface is crucial while adopting circular business principles to track the whole life cycle of a product and streamline the associated processes. There comes the importance of PLM software, Teamcenter; which they use for various applications in the product development process, cycle visualization, requirements handling and process management, etc. The usage of Tecnomatix tools such as Teamcenter reduced 50% of total engineering cost for Volvo (Siemens, ). However, the interoperability among various systems in the company is still a major challenge. Such a challenge is also present in Volvo as well, where the DES engineers are not able to obtain the required data for virtual simulation from Teamcenter.

This study is focused on the automotive industry which is experiencing an enormous transformation in data management towards shared platforms such as Siemens' Teamcenter for managing data related to products and process equipment. The DES (Discrete event simulation) engineers are looking for a way to make the process of integrating CAD datasets for virtual production systems more efficient. To do that, DES engineers will need more insight into production dynamics including machine availability, machine data, layout data, etc., rather than just basic geometrical data. This paper addresses the above-mentioned opportunity to integrate more data into the PLM system, exporting the same and preparing it for DES purposes.

## 1.4 Aim

The study aims to develop a structured work method for integrating enriched CAD model data into Teamcenter, while also seeking to develop a data extraction method from Teamcenter to meet the requirements of DES engineers.

## 1.5 Research Questions

Based on the difficulty developing structured work methods for integrating enriched

CAD models and extracting data for DES engineers described in Section 1.4, the study intends to answer the following questions:

- *What are the existing procedures, challenges and gaps in the industry's CAD-PLM integration and extraction for DES?*
- *How can the CAD integrated data in the PLM software be enriched to suit the DES requirements?*
- *How can the enriched data in the PLM software in the next step be extracted to be used for DES?*

## 1.6 Limitations

This study acknowledges significant limitations despite its high aims:

- The findings might not be immediately applicable to other data management platforms as the study focused on the integration of additional data to CAD items in Teamcenter.
- The efficiency of suggested approaches can depend on Teamcenter's unique features, capabilities, and version.
- The complexity of the solution is reduced by solving the problem at a higher abstraction level

# 2
# Frame of Reference

This chapter presents Simulation and PLM systems in general and explains Discrete event simulation and Teamcenter in detail.

## 2.1 Production Systems

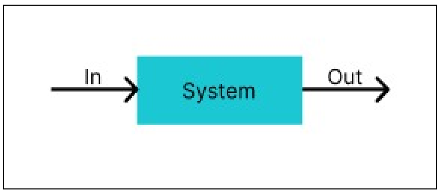



**Figure 2.1:** Black box, Transformation of input to output (Bellgran and Säfsten, 2010)

A production system can be explained as a transformation of input to output (See Figure 2.1). This transformation appears as a black box that gives output in a way that it differs from input (Ilar, 2024). A production system uses several processes to transform raw materials into components or complete products. There are generally five ways to achieve the transformation of raw materials into components or products (Mattsson and Jonsson, 2003) (See Table 2.1),

**Table 2.1:** Different ways to transform input to output

| Name | Description |
|---|---|
| Separating | One item enters and two or more exit. |
| Putting together | Several items enter and one exit. |
| Detaching | An item enters and exits shaped differently, alongside waste. |
| Forming | An item enters and exits in a different shape, without waste. |
| Quality adaption | An item enters and exits with different characteristics. |

## 2.2 Simulation

Simulation is the process of creating a mathematical or logical model of an actual system and performing computer-based experiments in order to predict, describe and explain the actual system (Hoover and Perry, 1989). Figure 2.2 shows different ways in which a system might be studied.

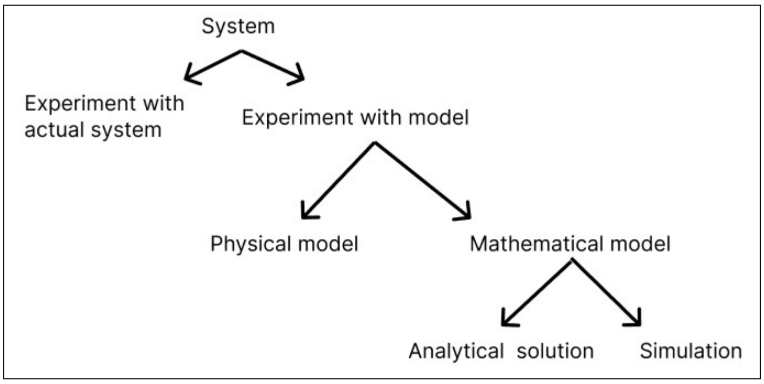



**Figure 2.2:** Different ways to study a system (Law, 2014)

- **Experiment with actual system vs. Experiment with model**
  It is possible to alter the system and perform experiments. However, such experiments can be costly and disruptive to the system. For example, The automotive industry wants to improve the fuel efficiency of a specific car so they modify the engine's fuel injection system by adjusting the fuel-to-air ratio, to test these changes they modify the system in actual cars on the assembly line but trying this could lead production line to disruption and modifying actual cars to conduct tests could be expensive. Now for the same case instead of modifying the actual cars, engineers create a model of the car's engine which has parameters like engine specifications, fuel type, and driving conditions. This way the automotive industry can run thousands of virtual tests without going over budget.
- **Physical model vs. Mathematical model**
  Experimenting with a model has two sides, experimenting with the physical model is useful for studying engineering or management systems but when it comes to operations research and systems analysis, mathematical models are more useful. For example, A company wants to optimize the conveyor's efficiency and minimize the bottlenecks so engineers create a scaled-down physical model of the conveyor which includes miniature conveyor belts and moving parts to observe the effect on material flow, speed and potential bottlenecks by considering different settings. However, mathematical models are mostly used when it comes to experiments as it create a model using conveyor parameters with variables like flow rate, processing time and bottleneck identification. In addition, mathematical models can run more tests as it is possible to adjust the parameters instead of making a new physical model.
- **Analytical solution vs. Simulation**
  After making a mathematical model, there are two ways to get results by either an analytical solution or a simulation. In an analytical solution, desirable variables are directly calculated by deriving mathematical formulas or expressions whereas in simulation, a system's digital model is created and experiments are conducted to see how the system works.

### 2.2.1 Types of Simulation

The simulation models tend to fall into different categories. The basic differences between categories are explained below (Law, 2014) and the most commonly used simulation is explained further in detail.

- **Deterministic vs Stochastic**
  Input and output variables are fixed values in deterministic whereas in stochastic at least one of them can change randomly with individual probabilities.
- **Dynamic vs Static**
  The simulation evolves over time and variables change without external influence in Dynamic whereas the static model shows a system at a particular time.
- **Discrete vs Continuous**
  Discrete models jump between events when a new event occurs a new event for the system is calculated whereas a continuous model shows variables that change continuously with respect to time.

### 2.2.2 Discrete Event Simulation

Discrete event simulation is to create a model of a conceptual framework that demonstrates a system by modeling, simulating, and analyzing systems using computational and mathematical approaches (Babulak and Wang, 2008). As per (Fishman, 2001) DES is a kind of simulation where several aspects of a system are modeled and then combined into an integrated set of operations. The features are connected by a mathematical link that depicts the function of a machine, for instance in real life. These mathematical links are transformed into data by computer and software's procedures use the data to estimate factors affecting the system performance.DES represents the real world and provides a comprehensive performance report by simulating its dynamics event by event (Law, 2014).

### 2.2.3 Advantages and Disadvantages of DES

The main advantage of DES is its capacity to carry out experiments that are impractical for actual manufacturing systems and create a simulation model that helps to gain knowledge that could potentially improve the actual system (Sharma, 2015). As said earlier in Section 2.2, it can be costly to interrupt daily operations to perform experiments in the actual system. Moreover, it is time-consuming to perform physical experiments on the actual system and the effects of the experiments may take a while to stabilize where a DES engineer can perform experiments without interrupting the actual system, and analysis of the DES model can be performed quickly compared to the actual system. DES models are easier to manipulate and conduct experiments than the actual system (Fishman, 2001; Banks et al., 2005). DES can also be performed even if the actual system doesn't exist where DES helps with designing the new system.

The main disadvantage of DES is that it heavily relies on data provided by engineers and suppliers. Moreover, the available data often requires significant analysis before using it for a simulation model, and collecting missing data requires time and money. Furthermore, DES software can have an expensive license and requires expertise such as programming, conceptual modeling, validation, and statistics which will make it hard to find someone with all skills, and providing software training to current engineers can result in time-consuming and costly (Law, 2014; Banks et al., 2005).

## 2.3 PLM System

There are several PLM software solutions available today like PTC Windchill and ENOVIA. Let's talk about Teamcenter which is a widely recognized and popular PLM solution.

### 2.3.1 Teamcenter

Teamcenter software of SIEMENS is the most widely used PLM system. The current version that is being used is Teamcenter12. The software uses the architecture of JAVA 2 Enterprise Edition (J2EE) (Roman, 2002) which significantly improves flexibility, maintainability, and modification of the company's application system and also helps different kinds of companies to adapt more complex information management. In addition, users find it easy to conduct research, create new products, and oversee them as the company is being digitalized.

### 2.3.2 Functions of Teamcenter

In Teamcenter, all users can share and utilize the product information throughout its lifecycle in order to ensure the continuous flow of product information and fulfill the company's goal of resource sharing. The main functions of Teamcenter are shown in Figure 2.3.

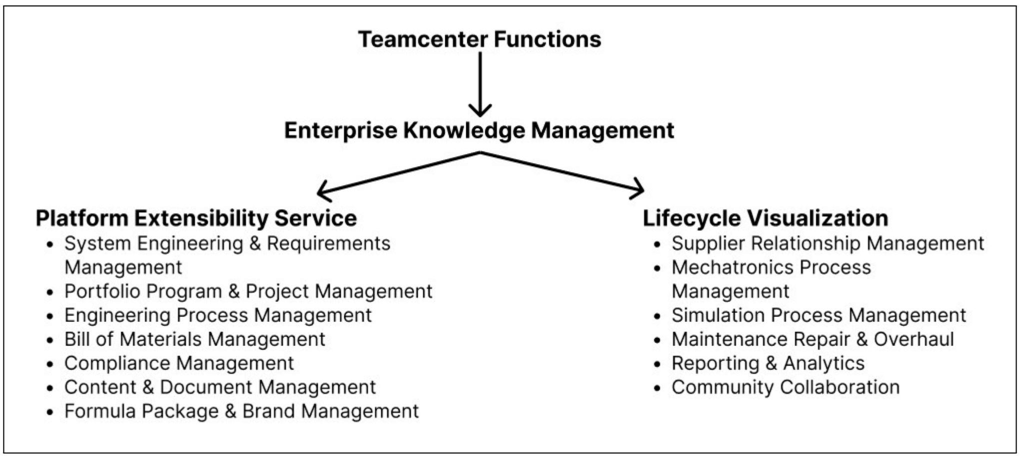



**Figure 2.3:** Main functions of Teamcenter (Zhang and Cai, 2012)

These Functions represent the main features of Teamcenter Software which resolves a wide range of issues throughout the enterprise's product life cycle (PLC) and updates solutions when applicable to other areas. Through Teamcenter, employees can manage more official data, work on additional assignments, and effectively realize the enterprise's product life cycle management system.

### 2.3.3 Types of Teamcenter

Currently, there are two variants of Teamcenter, the modern variant Teamcenter PLM and Teamcenter Classic. The former works mostly on the web browser application; AWC (active Workspace), while the latter works on the eclipse framework; RAC (Rich Application Client).

The classic variant is known for its proven reliability and stability; also as it is typically deployed on-premises the integration among other software like CAD tools and heavy tasks work seamlessly. On the other hand, the modern variant usually works on the cloud, which enables cross-functional collaboration and in turn nurtures digital twin as well. However, the doubt in stability to handle heavy tasks and the steep learning curve make the classic variant of Teamcenter still the favorite among industries.

### 2.3.4 Advantages and Disadvantages of PLM system

In earlier days, PDM ( Product Data Management) systems existed solely in industries. Over time, the PLM system developed from this system by making PDM an important component of it (Stark, 2020). This system combines product data, processes, people, etc in the industry. Most industries have a large information system environment which is heterogeneous. This is where a PLM system comes into play, a platform offering direct communication, file transfer, and even external stakeholder communication within the same network.

Figure 2.4 depicts the percentage of time used by engineers for various purposes outlined by Coopers & Lybrand as cited by (Saaksvuori and Immonen, 2002). Here almost half of the time is utilized to retrieve old data and if not possible do the work that has already been done before. While meetings mainly to share information also take around 14%. The time consumed by pauses, vacations, and other activities is in a negligible range. But the most important thing to note here is less than a third of the total time is being used for the actual engineering work, which lights up the room for improvement in managing working time. This is where a PLM system comes in.

A product life cycle management system in a manufacturing industry stores different types of data, or information on daily basics, and arranges them for easy retrieval and sharing. According to (Saaksvuori and Immonen, 2002) advantages of implementing a PLM system in a company are; less time consumption, quality enhancement, reduction of inventory-tied capital, better knowledge management, easy storage and reuse of existing product data and product knowledge, efficient change management, etc.

On the other hand implementation of PLM systems has some disadvantages as well, such as resistance to change, complexity in implementation, and the lack of flexibility of the majority of PLM systems (Saaksvuori and Immonen, 2002). The interoperability among different systems and applications is identified as a key enabler by (Ruggaber, 2005) of a proper business network. There are different interoperability challenges; Conceptual, organizational, and technical. Conceptual interoperability is the ability to share and understand concepts, while organizational interoperability projects the ability of the organization to connect processes effectively (Diana et al., 2014). In the case of PLM systems, technical interoperability is critical, it is the ability of different technical systems such as software applications to exchange and utilize information seamlessly.

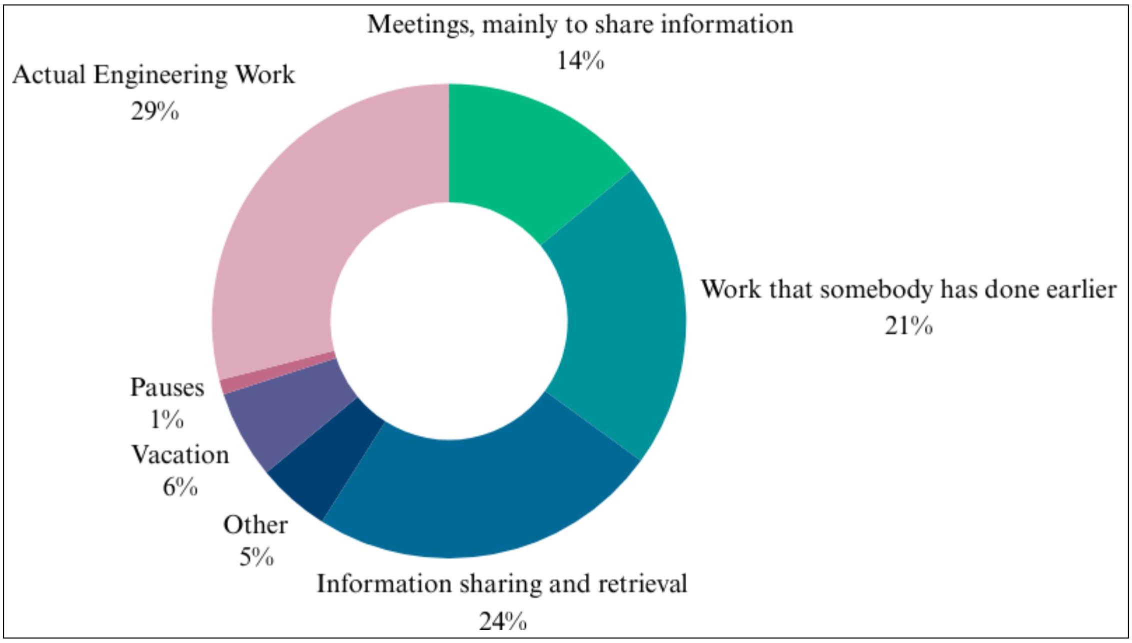



**Figure 2.4:** Time usage distribution of Engineers by Coopers & Lybrand (Saaksvuori and Immonen, 2002)

## 2.4 Production line: TC vs DES

Figure 2.5 is a diagrammatic representation of same production line in Teamcenter and a Discrete Event Simulation software. The top layer shows how the line is currently represented in Teamcenter and the bottom layer shows how the corresponding line is modelled in DES. The pull zone indicated in the Teamcenter representation is a collection of stations, which is usually represented as a single station in DES. There are two types of zones, pull and push. In the pull zone, the finished product waits for another product to arrive at its station so the finished product can move to the next station whereas in the push zone finished products move to the next station when the job is done (Ghrayeb et al., 2009). The industry changes the zone as per their requirements it can be any from push, pull and hybrid. The different processes of each zone are introduced as substations. These substations can be different small stations in DES as the name of the single station (See figure 2.5) where conveyors are used as means of transport between those small stations and buffer to hold parts temporarily.

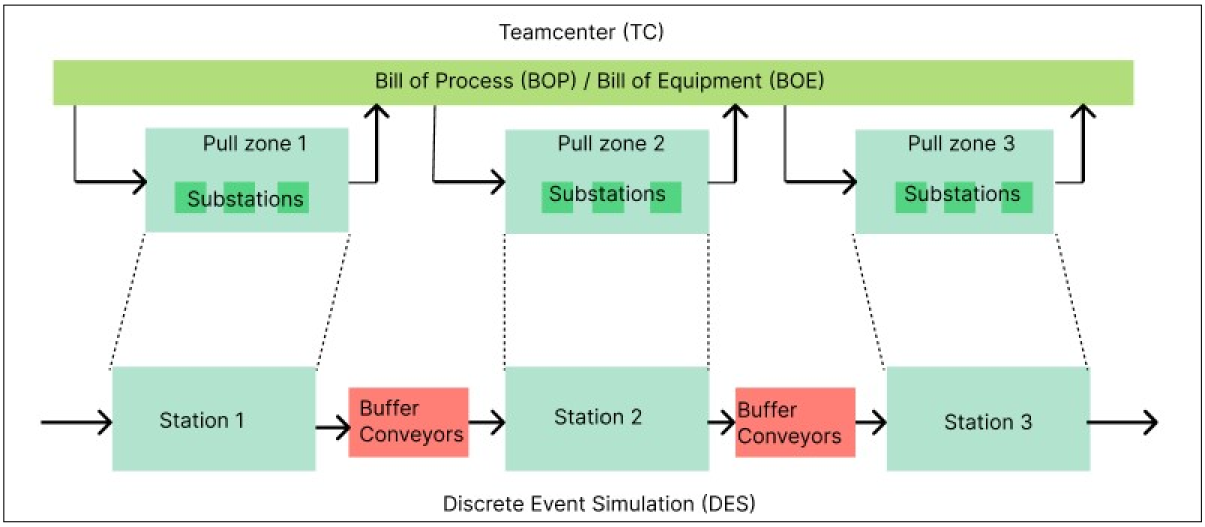



**Figure 2.5:** Layout of Teamcenter and Discrete Event Simulation

The bill of process (BOP) and bill of equipment (BOE) contain information on each pull zone about the various processes and equipment used as substations respectively.

- **Collaboration Context (CC) Object**
  The data related to plant, product and processes like EBOM, MBOM, BOP, BOE etc are stored in a container inside Teamcenter, and the container is called CC object.
- **Engineering bill of material (EBOM)**
  The engineering BOM is created by engineers using CAD. The EBOM contains custom parts and purchased hardware, showing how a product is designed.
- **Manufacturing bill of material (MBOM)**
  The manufacturing BOM shows what is needed to assemble a product. It contains all the parts and assemblies. For example, it has details regarding where are the weld points and where to use bolts/screws.
- **Bill of process (BOP)**
  The BOP shows how to make the product. It contains production line configurations, tools, machines, and equipment needed to make the product. BOP is an add-on to manufacturing BOM (MBOM).
- **Bill of equipment (BOE)**
  The BOE is a part of BOP which shows the equipment needed to make the product.

BOP and BOE show sequential steps required to manufacture a product therefore it doesn't have a buffer or means of transport between two pull zones whereas

DES always has a buffer and means of transport between two stations (Pull zone). Figure 2.6 shows a structure of the bill of equipment (BOE). A BOM line is created for each material and the processes also define various attributes that are related to those materials and processes. The attribute named "Item Type" shows the type of the BOM line where "Line", "station" and "MECompResource" indicate production line, pull/push zone, and substation respectively.

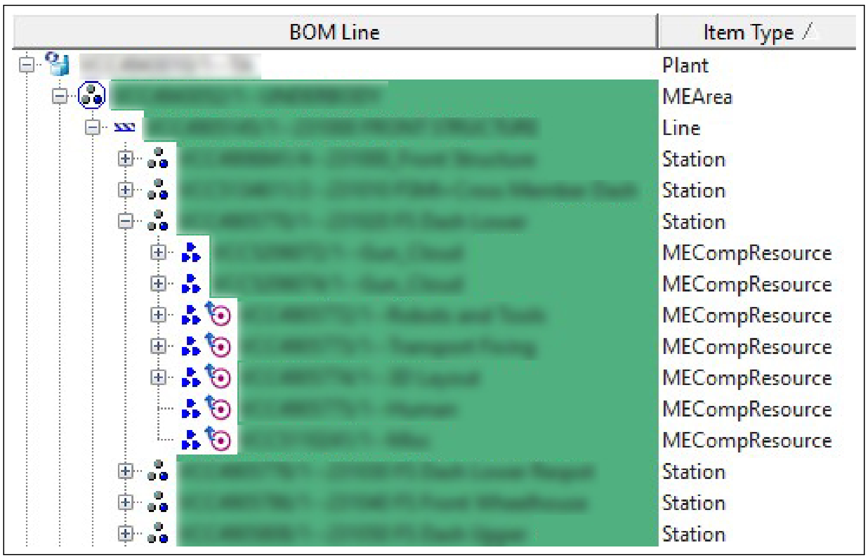



**Figure 2.6:** Example of BOE

## 2.5 Methodologies for DES data input

Simulating a real-world production line in DES software requires several parameters relating to that line, and the methodology deployed to input them has a significant impact on the model's overall efficiency, flexibility, and accuracy. (Robertson and Perera, 2002) identified four possible fundamental methodologies for data input in simulation software.

- **Method A**
  This is the method where most manual involvement exists. Figure 2.7 shows this method's workflow, where the data exchange mode between the project team and simulation model can be seen.

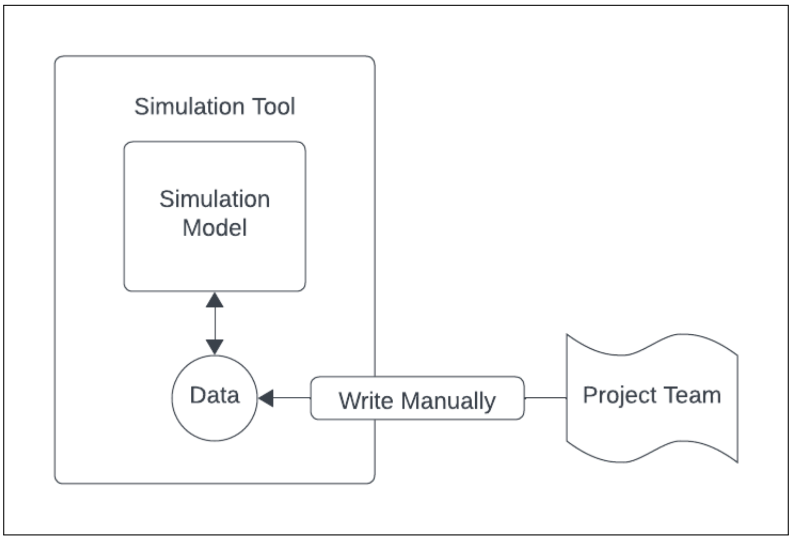



**Figure 2.7:** Method A of the data collection method for simulation

Here, the engineer or the project team manually collects required data through various sources of different data templates populated by other teams in the industry. Later, the same data is entered into the simulation model. This method is highly time-consuming, intensive, and error-prone. Also, the data input method makes it inflexible for any changes occurring.

- **Method B**
  This method is similar to method A but uses a computer application to input data into the simulation model. Figure 2.8 depicts that the project team collects the data and populates them into a computer application before reading it in a simulation tool.

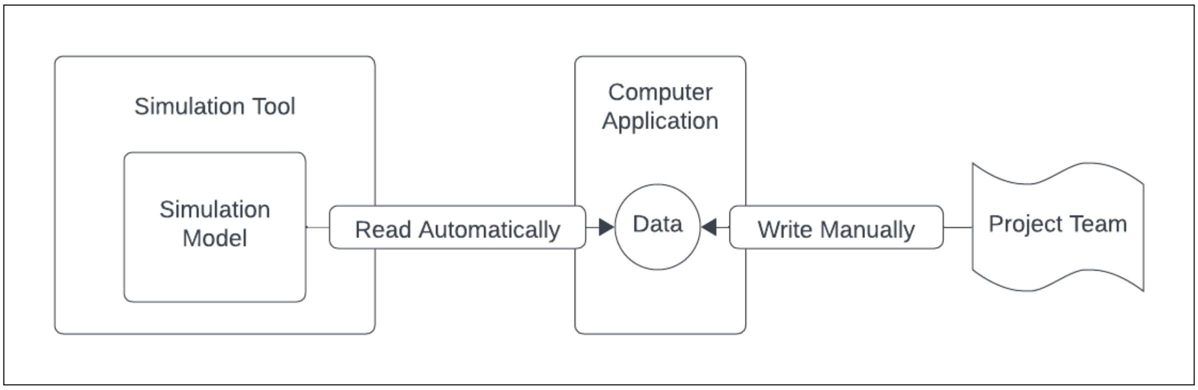



**Figure 2.8:** Method B of the data collection method for simulation

In this method, the project team populates all data into a formatted master spreadsheet or any similar tool which is automatically imported into the model. Due to the external storage of data, this method has more flexibility and less overall manual work compared to method A. However, this method still needs a huge amount of time to populate and arrange the master data set.

- **Method C**
  Figure 2.9 shows how the method C of data input operates. Here, a new corporate business system is introduced, which can be a PLM system. The connection between this corporate business system and the simulation model is shown in this figure.

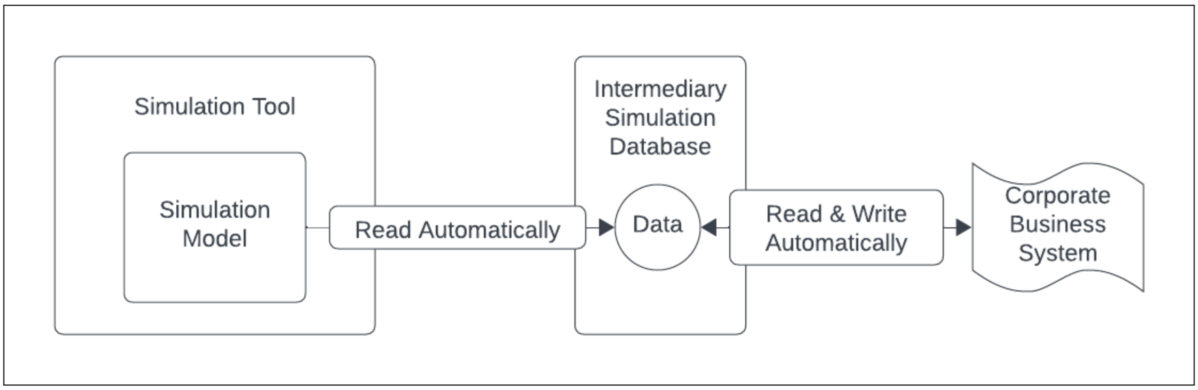



**Figure 2.9:** Method C of the data collection method for simulation

The primary source of data is the corporate business system and it is automatically retrieved into an intermediate software or database which can be Microsoft Access or any similar database. The model automatically reads data from this database. This method drastically reduces time, effort, and errors in data handling, while enhancing the flexibility of the process as well.

- **Method D**
  The fourth methodology is shown in Figure 2.10, where it avoids the need for an intermediate between the corporate business system and the simulation tool.

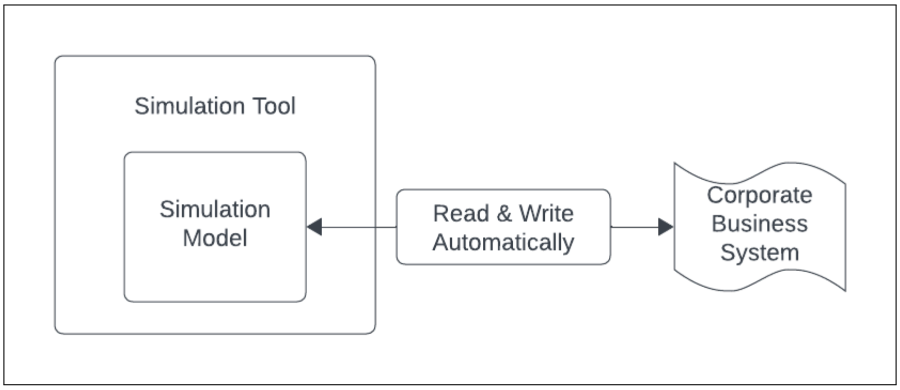



**Figure 2.10:** Method D of the data collection method for simulation

The model automatically retrieves data from the corporate system. This provides the highest level of integration and efficiency, by eliminating manual work and reducing potential errors. This fully automated integration also ensures that the data used is up to date, but the need for a sophisticated infrastructure makes the implementation harder.

Figure 2.11 shows the outcomes of an earlier study where the methods described above are analyzed in industrial practices, it had data till 2010 and forecasted the same till 2020 as well (Skoogh and Johansson, 2008). The Y-axis shows different years and the X-axis shows the percentage existence of each method in the corresponding year. The methods are indicated by different colors.

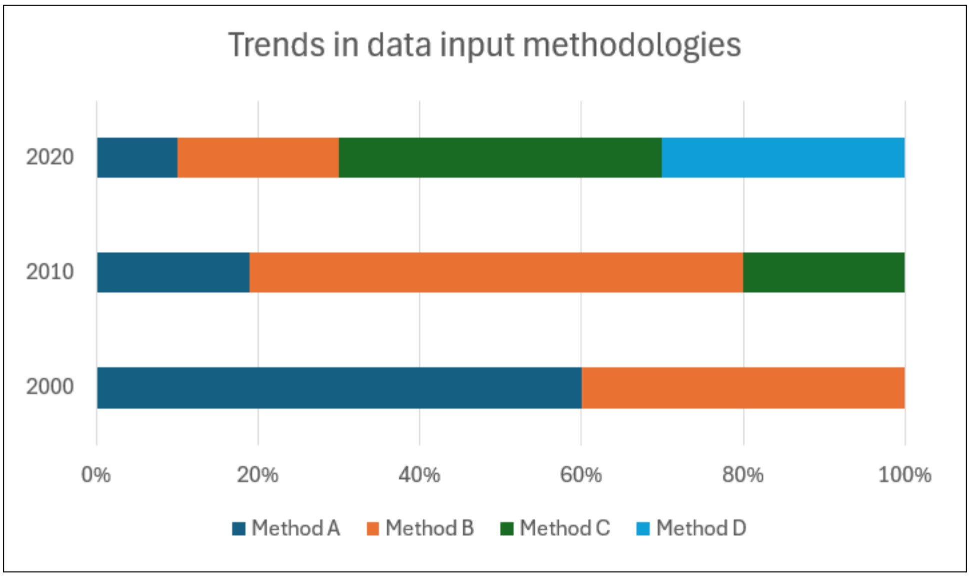



**Figure 2.11:** Trends in data input methodologies

From Figure 2.11, it is clear that in 2010 60% of industries involved in that study used method B for data input into the simulation tool, which includes a significant amount of manual work. Also, 20% of industries used methods A & C in 2010. The existence of method D in 2010 was negligible considering all industries. The forecasted stats for 2020 say that manual involvement in data input into simulation tools will be reduced below 30% and usage of method D is expected to be common in around 30% of the industries. Moreover, it shows in the year 2020, method C will be the most used method for data input into the simulation tool.

# 3
# Methodology

This chapter presents the methodologies used in this project to produce results. It starts with explaining the work procedure and later shows detailed mixed research methodology (Qualitative and Case study) where the Case study acts as a Quantitative Study.

## 3.1 Project Methodology

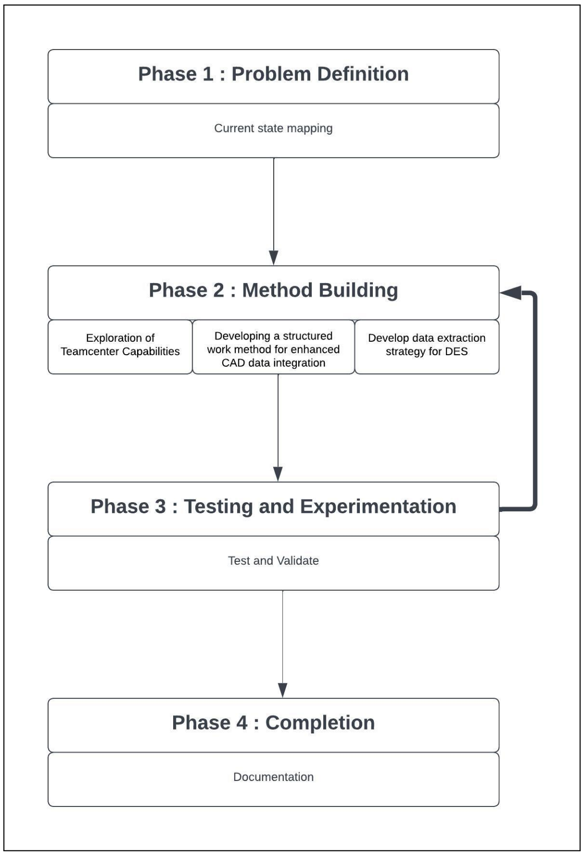



**Figure 3.1:** Overview of phases of project with including activities (Robinson and Bhatia, 1995)

(Robinson and Bhatia, 1995) propose in their paper how a simulation project should be carried out. There are four main steps as shown in Figure 3.1. First, it is important to understand the current scenario by identifying the problem. The second is to structure a method by collecting and analyzing the data. The third is the experiment phase where the structured method will be tested and validated by running several experiments. In the end, the fourth phase documents the results obtained from the third phase. This thesis is built on the same framework shown in Figure 3.1 and detailed steps are explained in section 3.2

## 3.2 Work Procedure

The steps taken are described in detail in this section. The study started with a solid problem definition and planning which was then followed by a comprehensive literature study.

A Teamcenter training has been taken for better understanding and practice in using the software to answer the research questions. Later, a qualitative study was done to understand the needs and wants of the DES engineers, and an analysis was carried out by comparing the needs and what they are getting from the Teamcenter at this stage.

Teamcenter's capabilities have been explored to find possible ways to enhance data in TC for DES engineers. The Teamcenter model was created with possible enriched data as the data is filled by CAD engineers and it is not possible to fill all the required data as data can be changed and required data calculated at a later stage. After exporting data from Teamcenter, software like Excel and Access is used for preparing the data and a work method is developed for extracting the data from TC after getting a positive result analysis. Figure 3.2 shows the flowchart of the work procedure.

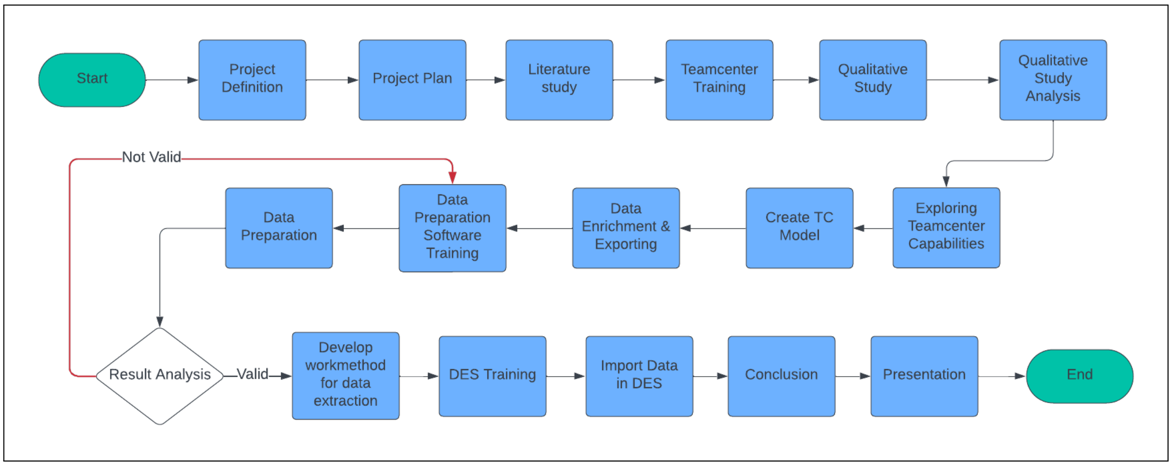



**Figure 3.2:** A flowchart of work procedure

## 3.3 Qualitative Study

Understanding the current operational landscape of the company is the pivotal step in this study. The proper understanding of current practices, structures, and collaborative approaches made the platform for addressing this case-specific challenge. Conducting interviews and analyzing them using an affinity diagram was the proposed plan.

The affinity diagram or KJ analysis is a tool to organize data and ideas, developed by Kawakita Jiro in 1953 (Cheng and Leu, 2011). The data obtained through qualitative method can be grouped using their natural relationships and information can be obtained for the studies. This analysis organizes ideas in the following steps (Plain, 2007):

1. Transfer the obtained data into distinct sticky notes or cards.
2. Create different groups according to the theme of information we need.
3. Create header cards for each group.
4. Sort the cards or notes into their corresponding groups.

This analysis is subjective, but it is a bottom-up approach, also, in this case, it didn't consume too much time as the volume of data is comparatively less (Cheng and Leu, 2011).

### 3.3.1 Interview Design

To map the entire processes inside the industry a semi-structured interview with 7 open-ended questions, which potentially collects data regarding the way of doing DES, the method of data collection for DES, missing data in Teamcenter, and their integration and extraction methods was designed, (See Appendix A.1 for interview questions)(Bryman and Bell, 2011). The questions were slightly rephrased and the order of questions was changed during different interviews depending on the interviewee's expertise and the flow of each interview. Nevertheless, the intending insights from each question were similar in every interview. The stakeholders of this study were selected for the interview (Total 5 interviewees), Three of them were directly involved in DES and PLM while others were mostly into data preparation for DES.

### 3.3.2 Interview Analysis

The interviews were transcribed and read meticulously, followed by an analysis using a qualitative research method, KJ analysis as described in Section 3.3. The whole interview content has been divided into two clusters; Current state & Gaps and Improvement Recommendations. Where the first cluster consists of current working procedures at the case company and the gaps in this work method; while the latter contains suggestions by stakeholders to fill the gaps. These large clusters are divided into specific affinity groups where the real classification of data is done.

Output from all interviews are copied into notes, where each notes contains only one idea; and the ideas having some natural affinity or connection is brought under the corresponding affinity group. Figure 4.1 depicts the KJ analysis of the interviews conducted.

## 3.4 Case Study

To develop effective solutions, it is important to conduct a detailed case study after qualitative analysis. It focused on how the data can be enhanced in Teamcenter and how the enhanced data can be extracted for efficient DES.

### 3.4.1 Data Understanding

In this step, a comparison has been made between the currently available data in Teamcenter, an Excel sheet used by DES engineers, and outcomes of qualitative data to understand the quality of the data and find the gap needed to address the requirements of DES.

### 3.4.2 Teamcenter: Exploration & Modelling

After understanding the DES requirement, Teamcenter exploration was done to find possible solutions for enriching data. To explore and work with the Teamcenter, a training session course was completed. After figuring out the possible solutions, a model of BOE was created in Teamcenter, showing two stations on a process line. Moreover, it showed how data can be enriched in Teamcenter for DES by adding specific attributes and using available functions.

### 3.4.3 Data Preparation

Some experiments were conducted to export enriched data from Teamcenter and prepare it to perform DES. Data was prepared by using Microsoft Excel with the help of Visual Basic. Teamcenter's ability to export to an Excel format and the overall flexibility make it an ideal tool for intermediate data manipulation.

For preparing the data for DES, explored the possibilities, and used Visual Basics coding by creating its different modules to get station-wise calculated data in a particular order to facilitate DES data import.

### 3.4.4 Testing & Validation

A suitable method for extracting enriched data from Teamcenter was selected and verified by debugging the code. Possible solutions were shown to the interviewees and the extraction method was tested and validated by the interviewees through performing the extraction method.

### 3.4.5 DES: Training & Data Importation

After testing and validating methods for enriching and extracting data from Teamcenter for efficient DES, DES training was taken as an additional step to learn how to import the extracted data in DES software. The training was provided by the current DES engineer.

# 4

# Results

This chapter presents the analysis of the Qualitative study and the Case study showing the result of the Teamcenter exploration, the Model of the Teamcenter, and the result of the experiment.

## 4.1 Qualitative Study Analysis

This section describes Discrete Event Simulation practices and the extent of using Teamcenter for this particular use case. The insights from KJ analysis of interviews are used to make a proper understanding here. Figure 4.1 depicts the interview results, and it is grouped after performing the KJ analysis of the raw data. The overall data is divided into two clusters Current State & Gaps and Improvement Recommendations. These clusters are further classified into seven affinity groups to group the interview data.

Currently, engineers obtain data for simulating one production line in DES software through various sources such as a process description for understanding the process, an output description, an Excel file for machine parameters, and a CAD file for the equipment positioning. The second affinity group talks about the content, which is currently inside Teamcenter, where readily usable simulation data is unavailable. The next group declares that the stakeholders demand the following data to be included in Teamcenter: Machine Losses, Transport information, pull zone data, expected simulation results, Safety Zone, Process sequencing, position coordinates, expected simulation results, and safety zone. Here the expected simulation results and safety zone are less frequent answers.

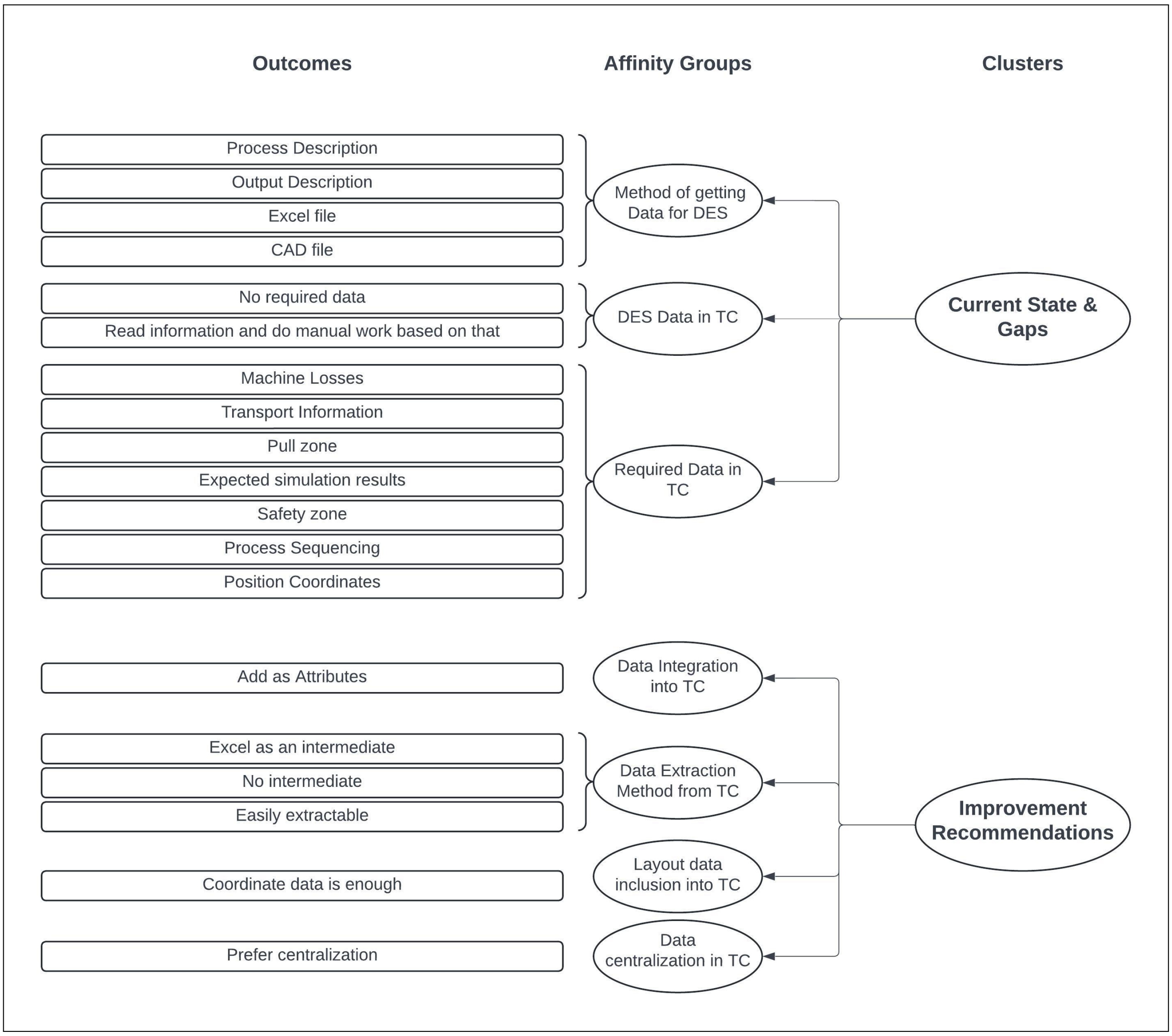



**Figure 4.1:** KJ Analysis of interviews

The second cluster illustrates probable solutions for the existing gaps. Where the vast majority agreed upon adding the needed data as attributes inside Teamcenter. All of them agreed that only position coordinates are required to understand the layout of a production line. Even though there are some contradicting opinions regarding the data extraction method from Teamcenter, the majority agreed upon Excel. But still, there are very less frequent outcomes preferring no intermediate in between, to make a smooth data interoperability between Teamcenter and the corresponding Discrete Event Simulation software. However, it is pretty significant that all stakeholders who took part in this interview agreed on the idea of centralizing data to a collaborative PLM system. The data from this analysis will be utilized for further representations in this section regarding the current working landscape inside the industry.

The current method of performing DES in the industry is portrayed in Figure 4.2, focusing on the data collection perspective. It was derived from the outcomes of the qualitative study of interviews.

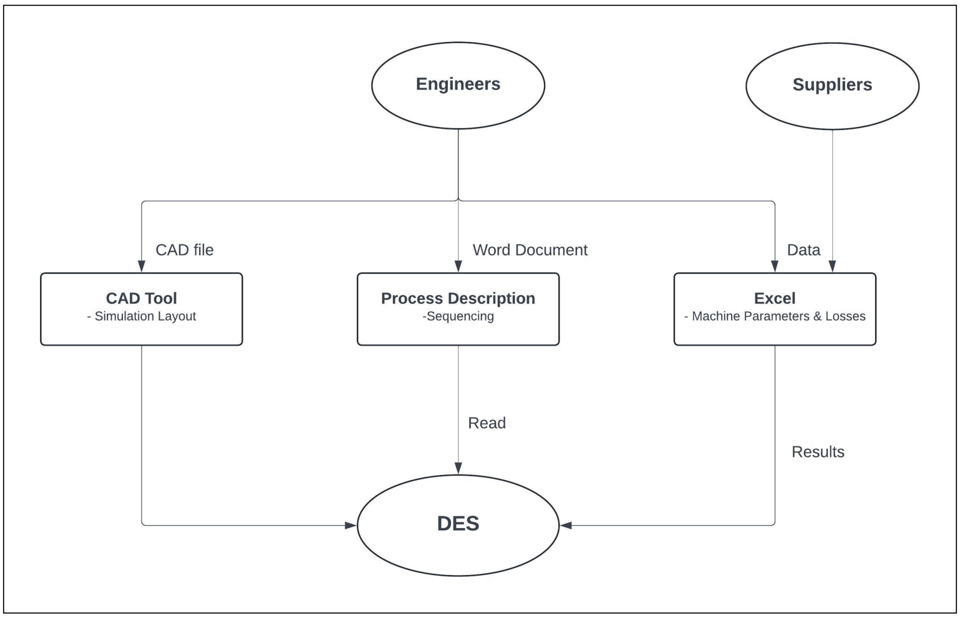



**Figure 4.2:** Current method of working for DES

Figure 4.2 shows the information needed for making a production line's virtual model obtained from three sources. A CAD tool and a process description which is populated by engineers are used to get layout data and an understanding of the process respectively. The equipment parameters and losses are provided through an Excel file populated by both suppliers and engineers. This highlights the diverse variety of data sources for performing simulations.

Figure 4.3 shows the overview structure of BOP which is available as a hierarchy/tree structure of the whole plant. It is a replica of the BOP to show the basic structure. It shows the process area, process line, and process station; on the process line, required process steps and station where station contains the data of BOE (See Item Type in Figure 2.6).

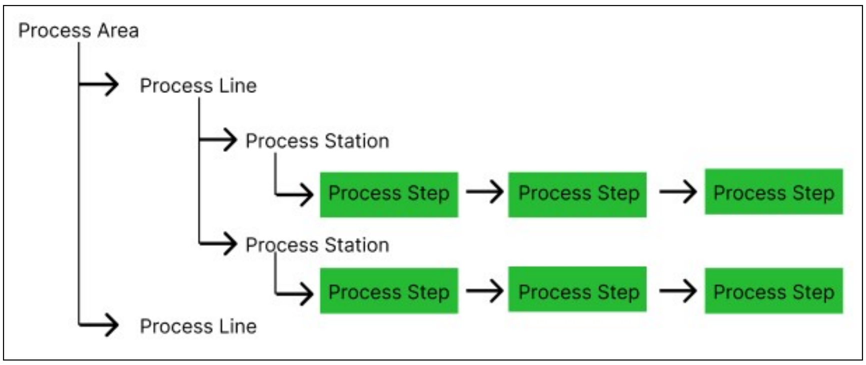



**Figure 4.3:** Overview structure of BOP

It can be seen in Figure 4.3 that the structure in Teamcenter is seen as a linear flow of the material. As illustrated there is a process area and inside there are process lines, and the first line has two Process stations and both have three process steps. This pattern is consistent across other process lines or any nodes as well.

## 4.2 Case Study Analysis

This section shows the result of Teamcenter exploration, Teamcenter model, and experiment to find the possible solution, to set a study example showing how data can be enhanced, and to extract the enhanced data from Teamcenter for efficient DES respectively.

### 4.2.1 Teamcenter Exploration

After exploring Teamcenter, a few capabilities came to light which can be used for enhancing data inside Teamcenter. For example, using functions named PERT (Program Evaluation Review Technique) which determines the sequences of process steps and stations. The PERT function in the current Teamcenter doesn't show any connection (See Figure 4.6). However, it is possible to go backward and frontward by using "Drill Up" & "Drill Down" respectively.

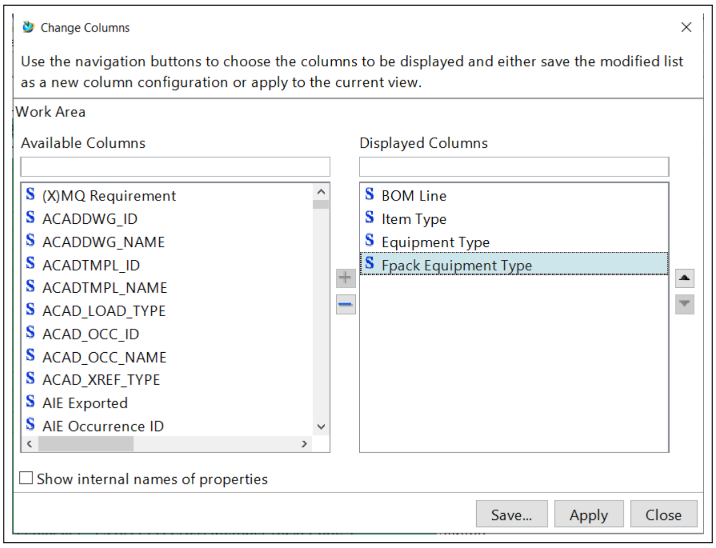



**Figure 4.4:** Attribute window in Teamcenter

In addition to that, a function named work instruction was also found during the exploration. Work instruction was not populated with any texts or data hence it is found that the function is not in use. The function can be seen in Appendix B.6 which shows available data inside the function named work instruction.

Figure 4.4 shows the attribute window where all available attributes can be seen in "Available Columns".

It is found that attributes can be added as per the requirement and information can be read after applying correct attributes. The order list of attributes is also customizable by using the "Up" & "Down" arrow keys in "Displayed Columns" (See Figure 4.4). Here, the letter "S" at the beginning of the attribute shows the type of attribute where S stands for a String.

### 4.2.2 Teamcenter Model

Figure 4.5 presents the Teamcenter model. The model was created to show how data can be enhanced in Teamcenter. The model shows BOE with a line and two stations where transport between two stations has been added as a station "Item Type". Here, "FPack" from Item Type shows a robot with equipment on it, for example, a spot welding robot which can only be seen by adding the extra attribute "FPack Equipment Type".

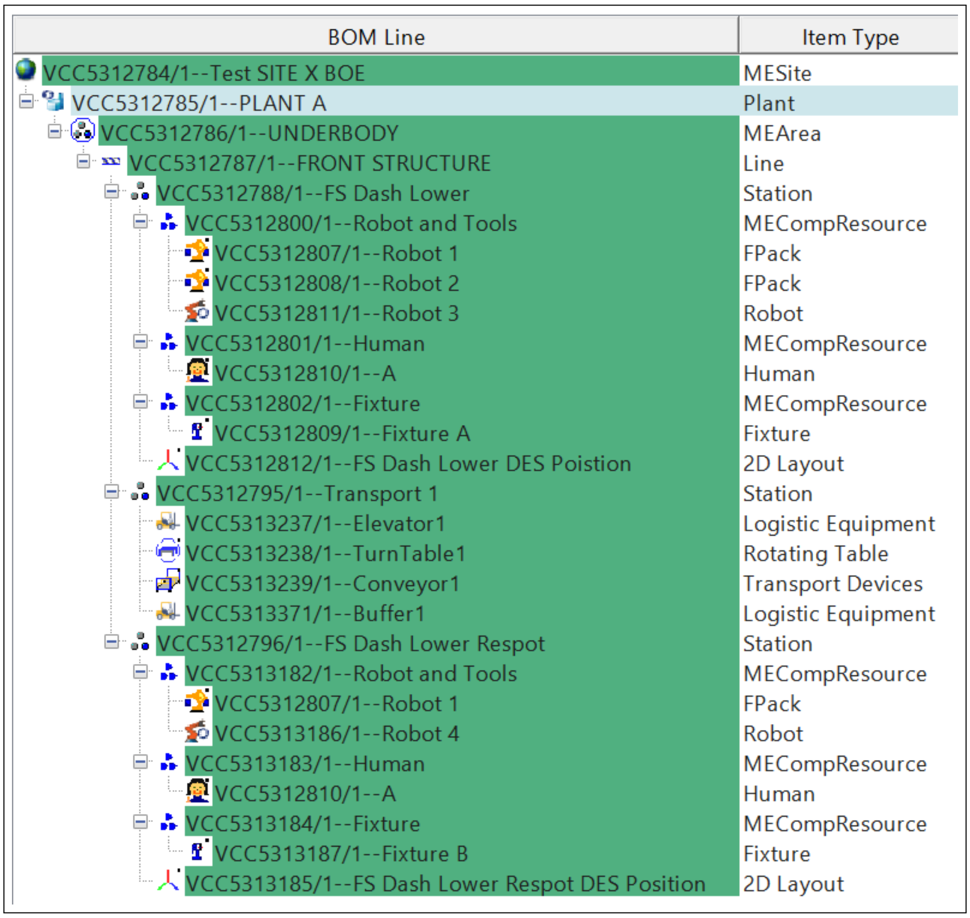



**Figure 4.5:** Teamcenter model (with generic names)

Moreover, unlike the current Teamcenter, the Teamcenter model shows how stations are connected in PERT. Figure 4.6 shows the station FS Dash Lower is connected to Transport 1 and Transport 1 is connected to FS Dash Lower Respot. It shows that the line starts from the station named FS Dash Lower then the material moves to FS Dash Lower Respot through Transport 1.

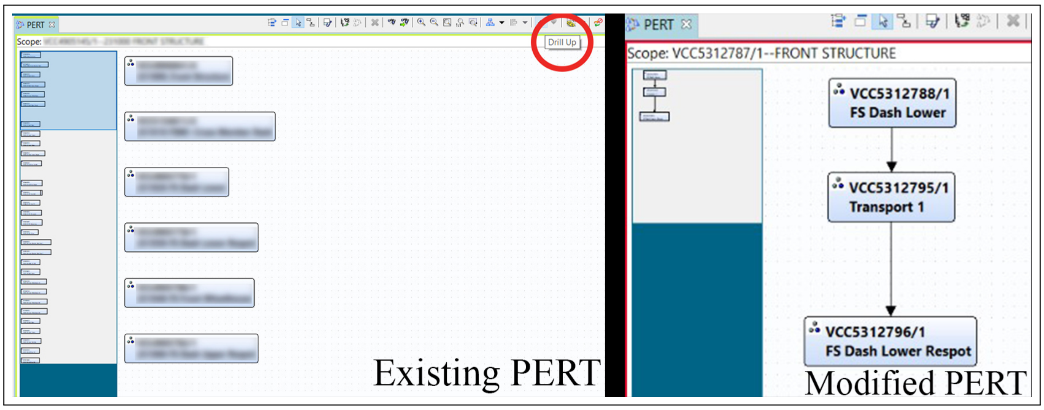



**Figure 4.6:** Existing PERT view with Drill up feature (Left), Proposed PERT view (Right)

**Table 4.1:** Name of the attributes and their usage

| Attribute | Usage |
|---|---|
| Item Type | To show what BOM is presenting if it is a station or fixture etc. |
| Quantity | To know the quantity of the equipment. |
| TAvail | To know the technical availability of the equipment. |
| T_MDT | To know the technical mean downtime of the equipment. |
| T_MDT_max | To set the upper boundary of technical mean downtime distribution |
| T_MDT_min | To set the lower boundary of technical mean downtime distribution |
| TNonAVAIL | To know the non-technical availability of the equipment. |
| TNonMDT | To know the non-technical mean downtime of the equipment. |
| TNonMDT_max | To set the upper boundary of non-technical mean downtime distribution |
| TNonMDT_min | To set the lower boundary of non-technical mean downtime distribution |
| OAVAIL | To know the organizational availability of the equipment. |
| O_MDT | To know the organizational mean downtime of the equipment. |
| O_MDT_max | To set the upper boundary of organizational mean downtime distribution |
| O_MDT_min | To set the lower boundary of organizational mean downtime distribution |
| TT | To get Throughput time of transport equipment |
| DT | To get Delay time of transport equipment |
| Buffer_capacity | To know the capacity of the buffer. |
| Speed | To know the speed of the conveyor belt. |
| Length | To know the length of the conveyor belt. |
| X | To know the position of the station in X direction. |
| Y | To know the position of the station in Y direction. |

Table 4.1 shows a list of the attributes and their usage that were added to the

Teamcenter model. Here, the attribute "Item Type" is already available in the Teamcenter where others are introduced to enhance the data in the Teamcenter for DES. The "Item Type" is a string type attribute where other attributes are integer type attributes. The Teamcenter model contains the data obtained by engineers and suppliers, for example, quantity and technical, non-technical & organizational availability of the equipment.

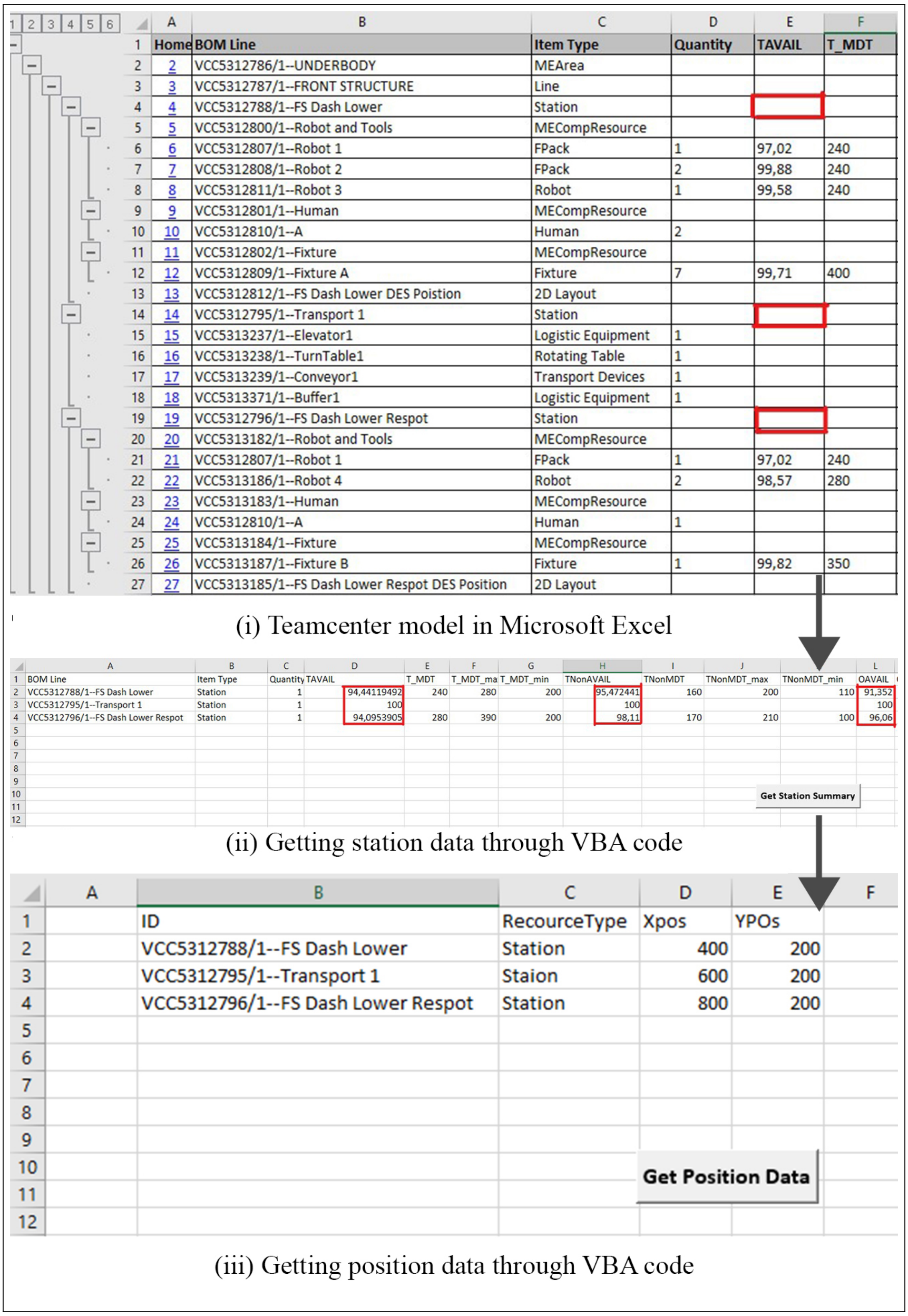
Later, this enriched data was exported into Microsoft Excel as an intermediate for extracting the data from Teamcenter and preparing the data for DES. Figure 4.7 presents the data of the Teamcenter model in the worksheet of Microsoft Excel. The data can be seen in the hierarchy level as it is seen in the Teamcenter model (See Figure 4.5). The left side of the figure illustrates the hierarchical structure of the exported data, which is called "Outline" in Excel. The attributes from the Teamcenter model are automatically identified as headings and occupy the first row. The number of attributes in the first row is according to the DES requirement.

Moreover, Figure 4.7 shows the need for data preparation before using it for DES. The required data like technical availability are not available in Teamcenter which needs to be calculated. There are other data like non-technical availability and organizational availability are also not available. The full data can not be seen in Figure 4.7 as it contains data of 21 attributes.

### 4.2.3 Experiment

This exported data (See Figure 4.7) serves as the foundation for developing VBA logic for data preparation. The prepared VBA code is divided into different modules according to the output produced. As seen in Appendix B.5, Figure 4.7, modules are used to extract values, calculate station values, calculate total, get station summary, and get position data.

Here, the button "Extract Values" extracts the data of the stations including data of equipment which are part of the station. The button "Calculate Station Values" calculates the station losses from the given data of the equipment. After getting the needed data for the DES, the button "Calculate Total" calculates the total availability of the station by generating a new column "Total Availability". After calculating the losses of the stations and the total availability of the stations, the button "Get station summary" generates the data that was calculated in the previous stage in a new worksheet. At last, the button "Get Position Data" generates the (x,y) position of the stations by reading the exported worksheet (See Figure 4.7).



| | Home | BOM Line | Item Type | Quantity | TAVAIL | T_MDT |
|---|---|---|---|---|---|---|
| 2 | 2 | VCC5312786/1--UNDERBODY | MEArea | | | |
| 3 | 3 | VCC5312787/1--FRONT STRUCTURE | Line | | | |
| 4 | 4 | VCC5312788/1--FS Dash Lower | Station | | | |
| 5 | 5 | VCC5312800/1--Robot and Tools | MECompResource | | | |
| 6 | 6 | VCC5312807/1--Robot 1 | FPack | 1 | 97,02 | 240 |
| 7 | 7 | VCC5312808/1--Robot 2 | FPack | 2 | 99,88 | 240 |
| 8 | 8 | VCC5312811/1--Robot 3 | Robot | 1 | 99,58 | 240 |
| 9 | 9 | VCC5312801/1--Human | MECompResource | | | |
| 10 | 10 | VCC5312810/1--A | Human | 2 | | |
| 11 | 11 | VCC5312802/1--Fixture | MECompResource | | | |
| 12 | 12 | VCC5312809/1--Fixture A | Fixture | 7 | 99,71 | 400 |
| 13 | 13 | VCC5312812/1--FS Dash Lower DES Poistion | 2D Layout | | | |
| 14 | 14 | VCC5312795/1--Transport 1 | Station | | | |
| 15 | 15 | VCC5313237/1--Elevator1 | Logistic Equipment | 1 | | |
| 16 | 16 | VCC5313238/1--TurnTable1 | Rotating Table | 1 | | |
| 17 | 17 | VCC5313239/1--Conveyor1 | Transport Devices | 1 | | |
| 18 | 18 | VCC5313371/1--Buffer1 | Logistic Equipment | 1 | | |
| 19 | 19 | VCC5312796/1--FS Dash Lower Respot | Station | | | |
| 20 | 20 | VCC5313182/1--Robot and Tools | MECompResource | | | |
| 21 | 21 | VCC5312807/1--Robot 1 | FPack | 1 | 97,02 | 240 |
| 22 | 22 | VCC5313186/1--Robot 4 | Robot | 2 | 98,57 | 280 |
| 23 | 23 | VCC5313183/1--Human | MECompResource | | | |
| 24 | 24 | VCC5312810/1--A | Human | 1 | | |
| 25 | 25 | VCC5313184/1--Fixture | MECompResource | | | |
| 26 | 26 | VCC5313187/1--Fixture B | Fixture | 1 | 99,82 | 350 |
| 27 | 27 | VCC5313185/1--FS Dash Lower Respot DES Position | 2D Layout | | | |

(i) Teamcenter model in Microsoft Excel

| BOM Line | Item Type | Quantity | TAVAIL | T_MDT | T_MDT_ma | T_MDT_min | TNonAVAIL | TNonMDT | TNonMDT_max | TNonMDT_min | OAVAIL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| VCC5312788/1--FS Dash Lower | Station | 1 | 94,44119492 | 240 | 280 | 200 | 95,472441 | 160 | 200 | 110 | 91,352 |
| VCC5312795/1--Transport 1 | Station | 1 | 100 | | | | 100 | | | | 100 |
| VCC5312796/1--FS Dash Lower Respot | Station | 1 | 94,0953905 | 280 | 390 | 200 | 98,11 | 170 | 210 | 100 | 96,06 |

Get Station Summary

(ii) Getting station data through VBA code

| ID | RecourceType | Xpos | YPOs |
|---|---|---|---|
| VCC5312788/1--FS Dash Lower | Station | 400 | 200 |
| VCC5312795/1--Transport 1 | Staion | 600 | 200 |
| VCC5312796/1--FS Dash Lower Respot | Station | 800 | 200 |

Get Position Data

(iii) Getting position data through VBA code

**Figure 4.7:** Results Visualization of Data Preparation

## 4.3 Work-method for Extracting Data

These steps outline the process of extracting enriched data from Teamcenter and processing it to produce the required output dataset for DES. The steps were created after getting positive outcomes from the experiment.

1. Customize the BOE in the MPP window in the prescribed order of attributes as shown in Table 4.1.

2. Select the line that needs to be replicated inside DES software.

3. Follow the path to export the data into an Excel file. Tools » Export » Objects To Excel.

4. Open the exported Excel file and the Excel file for data preparation.

5. Drag the sheet from the exported file to the Data preparation Excel file.

6. Click on the Extract values.

7. Click on the Calculate Station Values.

8. Click on the Calculate Total.

9. Click on the Get Position Data.

The list shows the correct order for data preparation using the buttons provided in Microsoft Excel's spreadsheet. Adhering to these steps is critical to obtain the desired outcome. However, some vital things should be considered while executing the process. Firstly, having a different order of attributes from the figure won't generate any results as per the algorithm behind Visual Basics. Secondly, the execution of buttons in the correct order is also recommended, the sequential use of buttons ensures accurate calculations as some commands are designed to clear or assume values according to the values inside the cells which could lead to issues if not followed correctly. Finally, remember that the data needed to be processed should be named "Sheet1".

# 5 Discussion

This chapter discusses the results, answers the research questions, and shows the connection to sustainable development goals (SDGs).

**Question 1:** What are the existing procedures, challenges, and gaps in the industry's CAD-PLM integration and extraction for DES?

**Answer:** The interviews provide a comprehensive understanding of the current working landscape and gaps to be addressed. For performing the Discrete Event simulation of a particular line, engineers need several parameters of that particular line, to make a virtual model, which is close to the real-world model. Figure 4.2 shows how the various parameters or data required for simulation are obtained.

One of the crucial pieces of information is where each and every station is placed, this kind of layout data is separately made by engineers for simulation purposes inside CAD software. Machine parameters and losses are provided through an Excel sheet, which is manually populated by suppliers and engineers inside Volvo. While making this Excel, they are also referring to Teamcenter as well. There are two types of losses in production, planned losses, and unplanned losses. For example, the technical, non-technical & organizational availability of the station and the total availability of the station & equipment are calculated manually. Moreover, data like the mode of transport between two stations, sequencing of the process, and positions of the station to build a virtual model of the production line are not available in the Teamcenter. Process sequencing and overall ideas about the particular line are gained through a Word document called process description which is also manually populated by another engineer. The simulation engineer has to refer to this process description while modeling the respective line.

The existing model of working in the industry can be considered equivalent to method B as explained in Section 2.5. Method B doesn't have any corporate business system or a PLM system. Instead, the project team populates a master file, which can be automatically read in a DES tool (Robertson and Perera, 2002). Briefly, to perform DES for a particular line it is necessary to have a proper understanding of the line and have to gather the data from multiple sources even after having a collaborative platform like Teamcenter. Due to the diverse nature of sources simulation engineers have to spend additional time gathering and understanding the data. Apart from them, some engineers gather machine data and prepare it in an Excel sheet.

In the existing circumstances, Teamcenter contains a vast amount of data regarding plant expansion to its very minute details. Usually, the top data node is a CC object and it usually contains Plant MBOM, Plant BOE, and Plant BOP. The BOP is represented in Figure 4.3. However, from looking at the BOP structure it is hard to tell which process will be running first, how the materials will be moving to the stations, and the location of the stations & buffers. Additionally, there is no data regarding the machine parameters and its losses as well.

Tree structures are made sequentially however, it is not specified in the detail. It can only be seen as a linear flow (See Figure 4.3) which is troublesome for DES engineers to understand the flow of the material and whether the processes are parallel or not.

Based on the interviews, Teamcenter currently lacks data readily usable for DES, but there is some information that requires manual interpretation before it can be used. According to the interviews, stakeholders require the following data to be available within Teamcenter; machine losses, transport information, pull zone data, expected simulation outcomes, safety zone, sequencing of processes, and position coordinates as depicted in Figure 4.1.

Method A and Method B are considered the most labor-intensive techniques in data input methodologies. Earlier studies predicted that by 2020 only 30% or fewer industries would still be following these methodologies (Skoogh and Johansson, 2008). From the interview, it is found that the current working method is B. When asked about the preferable solution to the gaps, interviewees preferred to have centralized data in Teamcenter. Therefore, it is necessary to determine the method for centralization as it is the preferred solution. There was a unanimous answer during interviews which is to add data as attributes as a solution for centralization. However, the extraction of these data from Teamcenter and its preparation for DES produced various opinions; where the majority suggested Excel as an intermediate, while a few preferred no intermediates between these processes.

**Question 2:** How can the CAD integrated data in the PLM software be enriched to suit the DES requirements?

**Answer:** The data in the Teamcenter can be enriched by attributes and using functions like PERT & work instruction. As seen in Figure 4.6 & Table 4.1, PERT can be improved by providing connections and a list of new attributes can be introduced in the current system to enrich the data for DES. The PERT shows the test model (BOE) however, it is possible to use this function in BOP to understand the sequencing of the process steps on each station. Also, it is possible to understand if any process is running parallel or if any station is parallel to another by looking at the PERT. Here the Teamcenter model presents two stations which is in a line.

About the work instruction, the function is not accessible currently however, it will be possible to write a process description about station & line and general instructions for extracting the enriched data for DES. As an alternative to work instruction, the company 'Network' can be used to provide the information or a PDF can be added as a node in BOE which can be seen before opening BOE in the MPP window. And last, the data regarding transport between two stations can be shown by introducing transport as a station and providing a connection through PERT.

**Question 3:** How can the enriched data in the PLM software in the next step be extracted to be used for DES?

**Answer:** The enriched data in Teamcenter can be extracted by adding suggested attributes (See Table 4.1) on the BOM line and following the steps given in Section 4.3. As an alternative, Microsoft Access was used instead of Microsoft Excel. The first and most important reason behind this was, that Microsoft Excel is a worksheet where Microsoft Access is DataSet and at a time Microsoft Excel will not have more than 1,048,576 rows (End, 2024). So if the company has larger data or a DES engineer is trying to get whole process line data then there can be a chance that they will not be able to see or read the whole data. Now, to use Microsoft Access as an intermediate, Microsoft Excel still needs to be used to export the data as there is no other way to export data directly to Microsoft Access. Moreover, the exported Teamcenter data looks a bit different in Microsoft Access as it does not show the hierarchy or tree structure as seen in Microsoft Excel (See Figure 4.7). Therefore, it is difficult to understand the data, and to make it easier, hierarchical data can be made manually inside Microsoft Access but it results in not being able to make any SQL (Structured Query Language) for data preparation because of the absence of hierarchical data.

The suggested solution closely resembles method C as discussed in Section 2.5, where the primary source of data is a corporate business system like Teamcenter. Here, Excel serves as an intermediate between this system and the DES tool. This can be considered as a step towards method D, which is at the highest level of integration. In method D, there is no intermediate between the primary data source and simulation tool which ensures seamless and automated data transfer (Robertson and Perera, 2002).

## 5.1 General Discussion

The solution presented in this thesis operates at a higher abstraction level so it is impractical to implement the work directly in the industry. Additionally, it is challenging to convince the higher authority to implement the result of this thesis in the current setup as it is time-consuming to change the PLM system in the industry where it is already in use (Saaksvuori and Immonen, 2002) because for them implementing this thesis will be like starting again from scratch. In addition to that, there will be resistance to change while convincing the engineers (Saaksvuori and Immonen, 2002). This can be due to the existing work method, which creates a higher inertia to change due to the steep learning curve involved. However, it will give an idea to the new industry about the things they should keep in mind while implementing the PLM system.

The solution suggested in this thesis is not generic as a whole, but it can be divided into three parts. Firstly, the solutions provided in Teamcenter are not generic as they strictly follow the architecture of the Siemens software mentioned, to generalize those solutions an attempt should be made to understand the infrastructure of other PLM software. Secondly, the solution made with Excel as an intermediate can be generalized. Thirdly, Importing data into DES software is a generalized solution as the same method can be adapted to any simulation tool, but the only thing to do here is to prepare data according to the simulation model demands. Briefly, to generalize the whole solution it is necessary to dig deep into various PLM systems.

## 5.2 Alignment with Sustainable Development Goals (SDGs)

This study aims to enhance the data in Teamcenter for efficient DES is directly connected to the two sustainability development goals.

- **Goal 9: Industry, Innovation, and Infrastructure**
  The usage of an affinity diagram to structure qualitative data enhances the quality of the interview outcomes which offers development in the industry and infrastructure. Moreover, data enhancement makes the data accurate and reliable which is necessary for innovative solutions.
- **Goal 12: Responsible Consumption and Production**
  The data managed by affinity diagram, enhanced data in Teamcenter, and data prepared by Excel worksheet improves decision-making which shows efficient data management and sustainable production methodologies.

# 6
# Conclusion & Future Work

This chapter initially states the conclusions drawn from this thesis, and later discusses the possibilities of further work.

## 6.1 Conclusion

The thesis has addressed the gaps in a product lifecycle management system from the perspective of Discrete Event Simulation to enhance the efficiency and accuracy of simulating a particular line. A deep qualitative study exposed critical gaps in existing data inside Teamcenter and an extraction method from the same. The combination of literature study and qualitative study highlights the need for having a smooth data management and transfer strategy among PLM systems and other systems.

The proposed work method utilized various inbuilt features of Teamcenter, such as attributes, to integrate the required data for simulation. For extracting and preparing data into a tailor-made form for simulation, Excel was chosen as it is compatible with both the PLM system and DES software. VBA code laid the base for data preparation and the prepared table is read using a method developed in DES software. This approach ensured smooth data integration and preparation.

The conducted case study validated solutions by illustrating that they enhance the simulation process by reducing both the time consumed and the complexity of the procedure. Even though the solutions are presented at a higher abstraction level, they outline the basic steps that can be developed further in the future. From a research perspective, the insights from this thesis can be a pioneer in addressing semantic data interoperability among various systems.

## 6.2 Further Work

Given the extensive scope and detailed nature of this work, further development is achievable using the work methods suggested in the former sections. The following points will give insights on some points that can be followed for more efficient data enhancement in Teamcenter and continuous improvement for efficient data extraction for DES in the future.

- Find a way to get hierarchy data in Microsoft Access as it is a data set and good for handling larger data and extraction of multiple lines or whole plant can happen if Microsoft Access is working.
- Include losses like tip dress and barrel change to make the data more detailed.
- Include simulation results to Teamcenter for keeping records for future work.
- Make the "Item Type" attribute more specific so an attribute showing the type of FPack equipment can be removed.
- Use and test the available option "Add Excel Template" while exporting data from Teamcenter to check if you can export the data directly into the given Excel file with VBA code.
- Figure out a method to automate the connections between stations while creating BOP or BOE by defining sequencing more concretely and removing the manual process of making connections in PERT.
- Modify the code in Visual Basics to extract the data from Teamcenter without following the attribute list order.

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# A

# Appendix 1

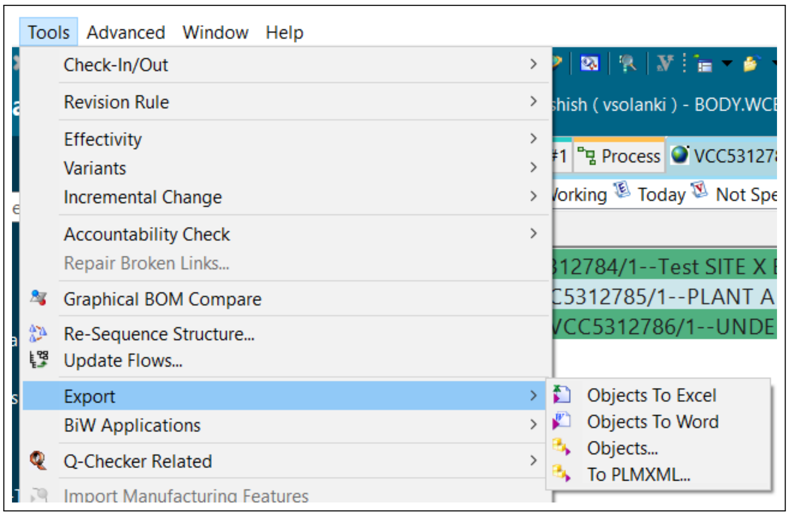
## A.1 Interview Questions

1. Can you explain your experience with performing DES using Plantsim for a production line?
2. Which data from Teamcenter do you think is critical for conducting DES?
3. How do you obtain further relevant data for simulation that is not available in Teamcenter?
4. Would you prefer centralizing all data within Teamcenter, or do you see benefits in the current approach? (of getting data from various sources) Why?
5. In your opinion, what specific data should be included in Teamcenter to increase DES efficiency and accuracy?
6. How would you recommend integrating this data into Teamcenter, considering the file type or extraction methods for Plantsim?
7. How do you incorporate layout data for simulation now? How do you think it should be in an ideal case and how can that optimize the work?

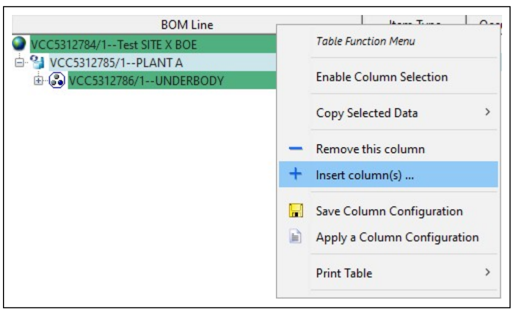
# B

# Appendix 2

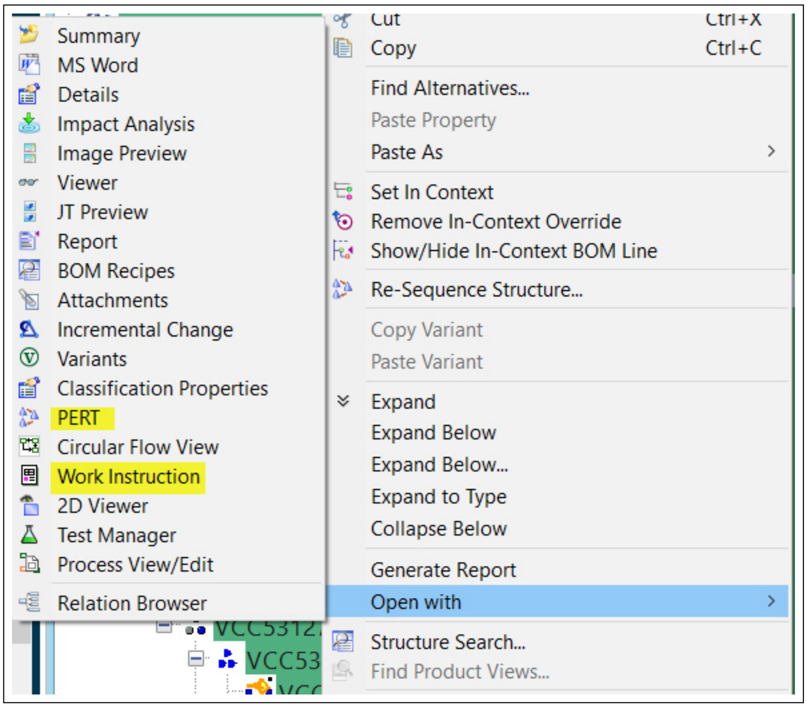
## B.1 Select "Objects to Excel" to export line or Plant data from Teamcenter.




## B.2 Right-click on BOM Line to get list of attributes.



## B.3 Right-click on any line or station to open PERT and Work instruction.



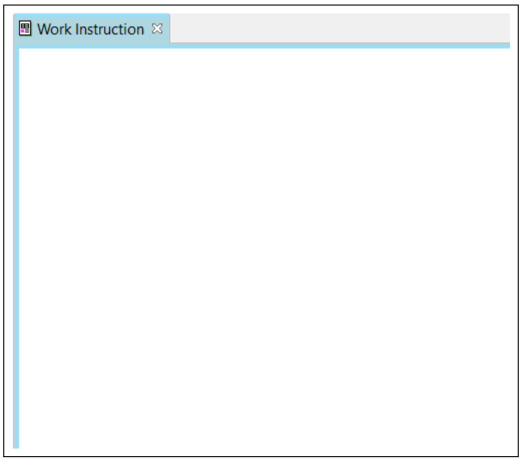

## B.4 List of attributes

```
1. Item Type
2. Quantity
3. TAVAIL
4. T_MDT
5. T_MDT_max
6. T_MDT_min
7. TNonAVAIL
8. TNonMDT
9. TNonMDT_max
10. TNonMDT_min
11. OAVAIL
12. O_MDT
13. O_MDT_max
14. O_MDT_min
15. TT
16. DT
17. Buffer_capacity
18. Speed
19. Length
20. X
21. Y
```

## B.5 Calculation phase showing Extract Values, Calculate Station Values, Calculate Total

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Home | BOM Line | Item Type | Quantity | TAVAIL | T_MDT | T_MDT_m | T_MDT_m | TNonAVAI | TNonMDT | TNonMDT | TNonMDT | OAVAIL | O_MDT | O_MDT_m | O_MDT_m | TT | DT | Buffer_ca | Speed | Length | X | Y | Total Availability |
| 2 | VCC5312788/1--FS Dash Lower | | Station | 1 | 94,4412 | | | | 95,4724 | | | | 91,3517 | | | | | | | | | | | 82,05043583 |
| 3 | | VCC5312807/1--Robot 1 | | 1 | 97,02 | 240 | 270 | 200 | 100 | | | | 99,98 | 30 | 50 | 10 | | | | | | | | |
| 4 | | VCC5312808/1--Robot 2 | | 2 | 99,88 | 240 | 280 | 210 | 100 | | | | 99,57 | 30 | 60 | 20 | | | | | | | | |
| 5 | | VCC5312811/1--Robot 3 | | 1 | 99,58 | 240 | 260 | 220 | 100 | | | | 99,61 | 30 | 50 | 10 | | | | | | | | |
| 6 | | VCC5312810/1--A | | 2 | 100 | | | | 97,71 | 160 | 200 | 110 | 99,01 | 30 | 60 | 20 | | | | | | | | |
| 7 | | VCC5312809/1--Fixture A | | 7 | 99,71 | 400 | 420 | 360 | 100 | | | | 99,41 | 110 | 130 | 80 | | | | | | | | |
| 8 | VCC5312795/1--Transport 1 | | Station | 1 | 100 | | | | 100 | | | | 100 | | | | | | | | | | | 100 |
| 9 | | VCC5313237/1--Elevator1 | | 1 | 100 | | | | 100 | | | | 100 | | | | 450 | 310 | | | | | | |
| 10 | | VCC5313238/1--TurnTable1 | | 1 | 100 | | | | 100 | | | | 100 | | | | 280 | 250 | | | | | | |
| 11 | | VCC5313239/1--Conveyor1 | | 1 | 100 | | | | 100 | | | | 100 | | | | 300 | 20 | | 0,15 | 600 | | | |
| 12 | | VCC5313371/1--Buffer1 | | 1 | 100 | | | | 100 | | | | 100 | | | | | | 8 | | | | | |
| 13 | VCC5312796/1--FS Dash Lower Respot | | Station | 1 | 94,0954 | | | | 98,11 | | | | 96,0596 | | | | | | | | | | | 88,62430811 |
| 14 | | VCC5312807/1--Robot 1 | | 1 | 97,02 | 240 | 270 | 200 | 100 | | | | 99,98 | 120 | 140 | 110 | | | | | | | | |
| 15 | | VCC5313186/1--Robot 4 | | 2 | 98,57 | 280 | 300 | 270 | 100 | | | | 99,31 | 130 | 140 | 100 | | | | | | | | |
| 16 | | VCC5312810/1--A | | 1 | 100 | | | | 98,11 | 170 | 210 | 100 | 98,82 | 180 | 220 | 130 | | | | | | | | |
| 17 | | VCC5313187/1--Fixture B | | 1 | 99,82 | 350 | 390 | 310 | 100 | | | | 98,88 | 100 | 120 | 70 | | | | | | | | |
| 18 | | | | | | | | | | | | | | | | | | | | | | | | |
| 19 | | | | | | | | | | | | | | | | | | | | | | | | |
| 20 | | | | | | | | | | | | | | | | | | | | | | | | |
| 21 | | | | | | | | | | | | | | | | | | | | | | | | |
| 22 | | | | | | | | | | | | | | | | | | | | | | | | |
| 23 | | | | | | | | | | | | | | | | | | | | | | | | |
| 24 | | | | | Extract Values | | | | | Calculate Station Values | | | Calculate Total | | | | | | | | | | | |
| 25 | | | | | | | | | | | | | | | | | | | | | | | | |

## B.6 Work Instruction



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