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The Connection Between the Resource Models and Process Structure

Analyzing Working Processes for How to Connect Resource 3D Models to the Bill of Process in Current and Future State

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Master's thesis in Master Programme Production Engineering

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DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

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Abstract

In modern manufacturing, seamlessly integrating resources with the process structure is crucial for efficiency and product quality. This study investigates the value and challenges of connecting resource 3D models with the process structure and the consequences if the connection does not happen.

Research quality is ensured by adopting the Design Research Methodology. The study conducted a thorough literature study to give a substantial theoretical background. Provided with the gathered information, semi-structured interviews were conducted, providing interviewees the flexibility to express their views on their terms and get deeper into subjects relevant to them regarding the project. Additionally, observations were conducted to understand how employees currently work in the system.

The findings unfold an opportunity for improvement related to how the case company delivers instructions on how to build upcoming cars to the factory. In the current delivery of instructions and process structures, resource 3D models are not linked, often resulting in only the displaying of resource item numbers or empty fields. This challenge often results in significant time savings once resolved. Connecting resources not only enhances visualization and transparency but also fosters collaboration, breaking down silos within the organization. The project investigates two alternative ways of working for the future and looks into a possible interim solution. Since there are alternative solutions the project concludes with a recommendation for how to tackle this challenge most effectively in the future.

A successful connection would gather all data related to the assembly operation in the same place, diminishing miscommunications and enhancing cross-functional collaboration. Consequently, significant time would be saved that otherwise would be spent on searching and contacting other departments to get an understanding of what is included in the assembly operation.

Keywords: Digitalization, Bill of Process, Bill of Equipment, Product Lifecycle Management, Traceability, Visualization.

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List of Acronyms

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

BOE	Bill of Equipment
BOM	Bill of Material
BOP	Bill of Process
CAD	Computer Aided Design
DRM	Design Research Methodology
EC	Equipment Card
E-BOM	Engineering Bill of Material
FA	Final Assembly
ME	Manufacturing Engineering
M-BOM	Manufacturing Bill of Material
PII	Process and Inspection Instructions
PL-BOP	Plant Bill of Processes
PLM	Product Lifecycle Management
PDM	Product Data Management
PR-BOP	Product Bill of Processes
TC	Teamcenter (Software by Siemens)
VBE	Virtual Build Event
WCE	World Class Engineering

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1
Introduction

In this chapter, the Background of the problem and challenges with the research will be addressed. After that has been conducted, the Case Company will be described for an understanding and definition of their problem. With an overview and definitions defined, the projects Purpose and Aim are presented. Having it specified, the Research Questions used to determine the results are presented and explained. Thereafter, the project scope and focus will be ensured by describing the implemented Delimitations for the project. Lastly, concluding the chapter by describing the Outline of Report, what this report will further cover.

1.1 Background

The automotive industry stands at the peak of transformation. It is driven by stronger government rules, changing consumer preferences, and a global push towards sustainability [1]. This additionally implies that the industry encounters numerous new challenges that demand strategic adaptation. One of these challenges, mostly driven by sustainability, is the transition towards electric and hybrid vehicles [2]. This places pressure on companies in the automotive industry to supply for the new demand and to deliver cars faster by working with new technologies and shorter lead times. The evolving consumer expectation also poses both challenges and opportunities as people are making lifestyle changes and many consumers looking into ride-sharing [3], which creates the need for more servitization in the automotive industry [4]. Digitalization within automotive industries changes the value creation chain as it has already done to other industries [5].

Another challenge is the competitive setting of the automotive industry, forcing companies to become more agile and to adapt to new changes quicker to get in front of their competitors [4]. In today's world, the cars that are produced by car manufacturing companies include tens of thousands of parts from multiple suppliers. In 2022 there were nearly 62 million passenger cars produced which was an around 8% increase from the 57 million produced in 2021 and each of these produced cars contains 20,000 to 40,000 parts [6],[7]. The parts are needed to produce high-quality and safe cars in the competitive car market. To cope with all the parts together with the customization abilities the customers desire, companies in the automotive industry need to have effective data management [8]. The automotive companies need to be modernized and digitalized to keep up with the mature enterprise architecture organizations that are more technologically advanced, agile, and faster [5].

For automotive companies to stay competitive they need to have effective data management, streamline information sharing, and productive project management. One of the approaches to accomplish the above mentioned is through the effective utilization of Product Lifecycle Management (PLM) systems already in place within companies. This entails ensuring that all data within the PLM system should be accessible to all engineers impacted by it [9]. Automotive companies should together with having effective management combine it with fostering a culture of cross-functional collaboration. PLM is a systematic approach on how to manage the entire lifecycle of a product [9]. PLM extends back to raw materials used in production to End of Life management [8][10]. PLM systems include all stakeholders who are part of the process, from engineers to suppliers, and clearly show all stages of the product lifecycle. Having a PLM system in place streamlines information sharing and project management [11]. Since all stakeholders are included, feedback from each individual can significantly enhance the results. In addition, if somebody changes a process or part somewhere during the lifecycle, this can be uploaded to the PLM software to ensure the same mistake does not repeat itself [8].

PLM provide users access to critical data in real-time [8], facilitating smoother project management and workflow by enabling the possibility of linking different car parts together with the equipment and processes for their assembly in the correct sequence. With this link between parts, equipment, and processes it is possible to virtually visualize how it will look in real life, which opens the possibility for virtual verification. By creating this connection in the PLM system, engineers and stakeholders will be able to see the 2D/3D models and other documentation related to building the car in one generic sequence. This in turn reduces process lead times by increasing information visibility and reducing search and duplication processes [9], as it takes up much of the engineer's time [8]. Leading to a smoother and improved development phase to manufacture cars for the innovative future in time, within budget, and improved quality [9].

1.2 Case Company

The Manufacturing Engineering (ME) department connects Engineering, formerly R&D, and the Plant (factory) at Volvo Car Corporation. ME are responsible for securing manufacturability and their responsibilities are to connect the product to the processes, assuring the products fit into current processes with tools, equipment, and production lines. Assessing ergonomic conditions together with assuring the production ability of the car. As seen in Figure 1.1, ME exchanges manufacturing requirements with Engineering and in return get the basis for the Process and Inspection Instructions (PII). These are documents created to outline all information required for assembly and control operations for a component to fulfill the quality, efficiency, ergonomic, and functional requirements. ME also collaborates with the Plants and provides them the PIIs based on their operation requirements. Hence, the PIIs contain important information regarding the assembly operations of the car and are created and stored in the Bill of Process (BOP).

Final Assembly (FA) within ME connects products and processes of the production line such as assembly of the axles, *marriage point*, door assemblies, and many more. Dealing with such large and different operations requires a lot of different suppliers due to the large number of articles to assemble with contrasting processes. Adding to the complexity is also the fact that the company is producing different car models on the same assembly line. Resulting in that the PIIs must be well-written, clear, and provided as early as possible to partner with the suppliers and Plant effectively. Additional challenges exist with suppliers unwilling to share their data with other suppliers or that they are working in different systems. All of these factors contribute to the creation of PIIs in the FA department being complex.

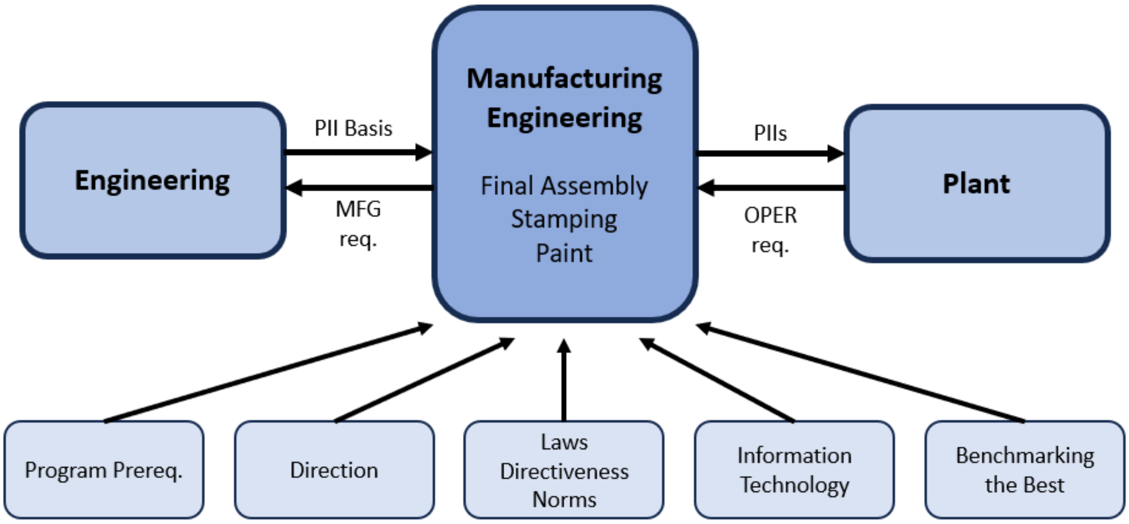


Figure 1.1: The work organization and collaboration between the departments

Since all of these different departments have to work together to create the end product, cross-functional collaboration is essential which is also embedded in their vision, World Class Engineering (WCE). WCE is a digital strategy that Volvo Car Corporation has in place that aims to achieve and sustain the highest standards of excellence in product development, manufacturing, and innovation [12]. WCE emphasizes a common source of engineering data for continuous improvement, efficiency, and a commitment to excellence throughout the entire engineering life cycle. The vision's backbone emphasizes utilizing one PLM system to succeed, minimizing the number of platforms and databases. WCE promotes a culture where Engineering, ME, Plant, and other engineering functions work together. It ensures data access for all users with seamless integration of supplier changes and utilizing a standard library for all products and resources. Effective communication and collaboration among these teams lead to reduced lead times, cost, and most importantly the creation of superior products [13].

Today, the PIIs are the information container and are stored in the BOP, a tree-structure list in Teamcenter (TC) Classic accommodating the planned process approach. The parts together with their 3D models are linked to the PIIs, however, they do not include 3D models of the resources, meaning tools, equipment, and fixtures. This leads to there being no visualization possibilities for the complete operation. Consequently, lacking linkage to the Bill of Equipment (BOE), a tree-structure list containing all of the resources used to assemble the car and all tools and equipment within the factory for manufacturing. Instead, only equipment model numbers are included and are often not updated to the current version of the equipment used. This causes disruptions when the equipment is modified or edited at any point during the process or in production, as ME could remain unaware of the alterations. This results in repeating the same errors, incurring both time and financial losses where the repetitive work can cause workers to become demotivated [14]. The lack of connection between the resources and PIIs is a previously mentioned industrial problem for the case company [15], suggesting the importance of this research topic.

1.3 Purpose and Aim

The purpose of this Master's thesis project is to improve transparency, efficiency, and the connection between the BOE and PII in the BOP for the FA department at Volvo Car Corporation. The purpose is also to increase and improve cross-functional collaboration, assuring that all information during various stages is up-to-date between involving teams to improve the consistency, reliability, and quality of the information flow. Finally, ensuring flexibility for adaptation across different manufacturing plants and engineering scenarios.

This project aims to describe the current issues and problems while simultaneously providing a synthesis of how to navigate these problems with current and future systems, while also assessing the consequences if the aim is lacking or not implemented. Moreover, aiming to provide a work vision covering the business values these improvements can accomplish for the company.

The primary objective of this project is to compile integration methods for their digitalization strategy. This is to visualize the products, tools, and processes together, aiming for a better overview of the connected inputs. Another objective is to improve the work environment for engineers working with processes, product development, and manufacturing plants, by ensuring a common source of all data to reduce waste by removing different data platforms. This includes removing the silo type of work to balance the work process flow, reducing the outcome chances of the FA department being the bottleneck during the work process flow. The last objective is that the synthesis description ensures that all plants and manufacturing engineering teams access accurate and up-to-date information during various stages. Having a standardized process ensures consistency in cross-department collaboration.

1.3.1 Connection to Sustainability Development Goals

The research topic for the case company is connected to multiple of the United Nations (UN) global sustainable development goals. The main goals that the topic is connected to is goal 8, 9, 12, 13, and 17 [16]. Illustrating how the project aligns with broader global sustainability objectives and potential positive impacts on social, economic, and environmental dimensions.

Improving the work environment for engineers and ensuring information access to promote productivity aligns with *Goal 8: Decent Work and Economic Growth*. *Goal 9: Industry, Innovation, and Infrastructure* aligns to the topic through the contribution of enhancing infrastructure by improving the transparency, efficiency, and connection between the 3D resource models and process structures. The project promotes responsible consumption through reducing data waste and promoting a better virtual verification which is connected to *Goal 12: Responsible Consumption and Production*. The projects aspiration is to improve efficiency and indirectly reduce waste in production processes to mitigate environmental impact aligns with *Goal 13: Climate Action*. Lastly, *Goal 17: Partnerships for the Goals* is connected to the topic by fostering cross-functional work and facilitating knowledge sharing.

1.4 Research Questions

The research questions were determined based on the project's aim and scope.

- **RQ1:** *What obstacles exist in linking 3D resource models to the product and process structure?*

The first question is asked due to the diligence of the obstacles at the company in question to describe and understand the present problems. The questions should identify why the 3D resource models yet are not linked to the PII in the BOP. The articles are linked and the aim is to investigate how to also connect the resources to the PII to include all necessary information for the process and assembly. Additionally, to ensure the capability for visualizing and tracing both the part and resource from the BOP.

- **RQ2:** *How can 3D resource models be integrated with product and process structure with current and future methods?*

The second research question aims to explore the existing and prospective methodologies employed within the company, analyzing work procedures in both the present TC Classic system and the forthcoming TC PLM system. To improve the possibility of establishing a connection between the 3D resource model and the PII in the BOP, employing a methodology aimed at systematically reducing redundant and inefficient administrative tasks.

- **RQ3:** *What are the benefits of applying a common connection source, and how does it impact production development?*

The third research question aims to explore the advantages of implementing a common connection source for integrating the 3D resource models with either the PIIs in the BOP or directly into the BOP. Furthermore, it will assess the implications for production and process development.

1.5 Delimitations

The objective of the project is to investigate a methodology that defines a systematic approach to link BOE models to PII in the BOP. This should be universally applicable to all plants, to guarantee reliability and consistency in the flow of information. Hence, the methodology should be designed for long-term use, however, any implementation will be scheduled post-project due to the short timeline.

The project scope only encompassed the department FA within ME, however, FA works towards the assembly of the whole car. Due to the complexity of car assemblies, the project was mostly in collaboration with the department responsible for the assembly of the rear axle area. Moreover, this focus area is a result of the thesis's time constraints and an effort to further define the scope by involving fewer respondents. Ensuring that the scope and information regarding the subject is more precise leads to a better proposition of how the work should be carried out.

The project's outcome will not be physically implemented, tested, and evaluated thereafter at this stage due to the time limit and lack of verification and validation possibilities. However, the proposition findings will be evaluated by company experts in the area. Due to the systems being under constant development, the validity of the result could become outdated. In addition, the common source to store all engineering data is already decided. The project does not seek to include a comparison between different platforms to evaluate. The predefined platforms are TC Classic and TC PLM.

1.6 Outline of Report

The paper is structured chronologically for clarity and ease of comprehension. It begins with the current Introduction chapter to provide background information on the problem and research. Following is the Theory chapter, describing the necessary theory to establish a foundation of knowledge. This is followed by the Methods chapter, where the based method theory is presented alongside the applied method employed to address the research questions. Afterwards, the Results chapter presents the concludes the current state and findings from the interviews. Thereafter, the results are combined in the Synthesis chapter, describing ways of working in different systems. At the end of the paper, the findings and project will be analyzed and discussed in the Discussion chapter before ending with the verdicts in the Conclusion chapter.

2
Theory

This chapter describes the theoretical background used for this thesis to establish a foundation of knowledge to build further on. The theory topics that will be established are Product Lifecycle Management, Product Data Management, Virtual Development, and ending the chapter with Change Management.

2.1 Product Lifecycle Management

Product Lifecycle Management (PLM) is a systematic approach for overseeing product development and product-related information from initial idea to disposal, enabling control of the company's products throughout its lifecycle [8], [9]. Creation, preservation, and storage of information about the company's products is PLM's core purpose for better product structures and product portfolio management with faster information retrieval, distribution, and re-utilization [8], [9].

The controlled information management used with PLM environments enables detailed management of the companies products, removing gaps, contradictory versions of the same data, information silos, redundant data functionality, and product recalls [9]. PLM concerns the whole organization due to its holistic and cross-functional approach to product lifecycle information control. Hence, it is as much an organizational approach as a technological approach [9], suggesting positive involvement from both the horizontal and vertical organizational structure is required.

According to Saaksvouri and Immonen [8], PLM is a wide functional totality and does not represent a software or method. However, there are multiple software available today that help companies control their information processes which is almost without exception, the standard among companies nowadays [8]. Teamcenter (TC) is one of these PLM software developed by Siemens and also serves as the software utilized by the case company. Effective use of the TC software can enable rapid response design which shortens lead times and improves product quality. TC allows for virtual product modeling, collaborative product and process development, enhances transparency across organizations and suppliers, simplifies file retrieval, and provides a comprehensive overview of products, processes, and their interconnections [8], [9].

2.1.1 Traceability

The automotive industry is a highly competitive market, i.e. because of customer demands and globalization, which forces high complexity, specificity, and modularity causing more time and cost-efficient operations while maintaining quality [17], [18]. Additionally, to market expectations, the automotive industry faces safety, legal, and environmental regulations from both regulators and customers [9]. These expectations trigger traceability employment and information management throughout the product's lifecycle of the companies to satisfy the customers and regulators [9], [17], [18]. One of the information technologies that the companies employ is PLM systems [17].

Focusing on the product development phase, it is important to have traceability of all complete information and documentation to reduce the risk of not using the latest versions [9]. Included in that point of view, the traceability of actions taken on data is important to provide documentation security with a possibility of archival and recovery of data [9].

Another important aspect to take into consideration with traceability during the product development phase is when companies use old or already in production tools and equipment. Reusing tools and equipment for new models or updated cars is of utmost importance to save money, time, and training for operators. Hence, the traceability that can be achieved by PLM makes sure that these tools and models can be found easier and faster to test the possibility of reusing them [18]. Lastly, easy product structure traceability beyond the purpose of reuse or documentation retrieval is beneficial to reduce engineers' time spent on non-value-added work [8].

2.1.2 Visualization

Visualization demands collaboration between departments to improve the work procedures and communication through the different departments [19]. Having 3D models for better viewpoints and therefore understanding helps the parties involved, e.g. manufacturing personnel when resolving design issues [19]. Visualization with virtual product representation helps with collaboration, the virtual model allows shared conceptualization between individuals that have different geographical locations by visualizing exactly the same model [20]. The virtual 3D models are also used during the development phase, having the visualization needed for digital mock-ups and virtual verifications [9], [21]. User confidence in simulation results increases with visualization of virtual models [22]. Within manufacturing companies, the operator's apprehension of the process, product, and equipment is a necessity, 3D visualization of the operation processes alongside written instructions enhances a more comprehensive understanding. Utilizing 3D models through the beginning of the product's lifecycle ensures possible usage for later purposes as well if models, later on, are interoperable [23].

Furthermore, as previously mentioned the current automotive industry is complex with different variants and configurations within each vehicle project resulting in more advanced processes and products [24], [25]. Unclear understanding and visualization of the process environments can trigger the need for PLM systems [8]. Moreover, connecting the process tree structure with 3D models for further deployment of visualization to acquire a more holistic view and information gain is of importance to obtain more efficient project performance and time usage [25].

2.1.3 Cross-functional Collaboration

Cross-functional collaboration refers to the practice of bringing together individuals from different functional areas or departments within an organization to work together toward a common goal [26]. For example, if one department is very efficient with its work it will only cause bottlenecks elsewhere in the chain which is why it is so important with cross-functional collaboration [8]. During a PLM transitional phase, there must be cross-functional collaboration since the project touches upon multiple departments [8], [27]. The cross-functional collaboration aims to foster communication, break down silo work, and use diverse expertise to drive success and innovation [28].

By involving stakeholders from different functions in decision-making processes, it can enhance the quality of decisions due to making use of more diverse perspectives and insights [28]. Cross-functional collaboration also increases efficiency by streamlining processes and reducing the accidental double work [8]. By breaking down silo work between departments and fostering communication, collaboration, and openness organizations increase both efficiencies and promote learning [26].

There are also some challenges regarding cross-functional collaboration. The problems and prejudice from the silo type of work can be brought into the cross-functional team if the team's priorities are not aligned. The diverse skills and perspectives can also be reason for conflict if none of the individuals on the team are ready to compromise regarding their department's work [29]. It is therefore essential that the team's priorities are aligned and are receiving strong support from the leadership. Additionally, the leadership from the different departments also needs to work together in a cross-functional way to be able to give good support to the cross-functional team [29]. Another challenge regarding the cross-functional nature of PLM is ownership, since many different departments work in the system it may be unclear who is responsible for what [9].

2.2 Product Data Management

A Product Data Management (PDM) implementation is a specific type of PLM implementation, PDM is a systematic approach to manage and organize information regarding a product throughout its lifecycle. It includes storage, creation, and spreading of product-related data. The data can include anything from structures to 3D models or drawings. PDM systems provide a way to store, and manage data effectively, which allows organizations to streamline collaboration and improve efficiency throughout the whole lifecycle of the product [8], [9].

PDM intends to enable stakeholders who work with a project to get access to accurate and relevant data when needed. PDM increases traceability, control over product information, and visibility by merging all product data into one single accessible platform. PDM streamlines cross-functional collaboration to accelerate decision-making and reduce errors resulting in quicker time to market [9].

2.2.1 Data Democratization

Data democratization means making data more accessible, actionable, and understandable for more people within an organization, this empowers employees at all levels to make more well-informed decisions based on data-driven insights. Additionally, it allows the whole organization to keep up to date with everything happening, which limits the redoing of tasks and miscommunications [30]. The concept of data democratization is grounded in the idea of everybody having access to information and fostering a culture of transparency, collaboration, and data literacy [31].

An effective use of data democratization promotes organizational learning meaning continuous improvement and adaptation in response to environmental changes [31]. data democratization promotes organizational learning by supplying employees with access to relevant data and insights, allowing them to make data-driven decisions, identify patterns, and monitor performance. Organizations can leverage data democratization together with principles such as Lean production or Kaizen to foster a culture of innovation and agility in response to new challenges by promoting a culture of experimentation, reflection, and feedback [31]. Additionally, data democratization helps to remove data silos which not only makes the data more accessible to all relevant employees but takes away the need of having duplicates of documents and ensures that the data seen is always the newest and most relevant data available, while also taking up less storage space which is valuable to bigger organizations [32].

There are also some risks and challenges regarding data democratization. Data must be organized, managed, and cleansed otherwise it could be interpreted in the wrong way [30]. Data democratization can also lead to flawed decision-making if the data is of low quality, or if the employee at hand doesn't understand the context of the data [32]. Additionally, there will be a huge learning curve for employees learning to use and access the new data layout, since they are used to the old data silo way. Data democratization also comes with security risks such as misuse and unauthorized sharing [30].

2.3 Virtual Development

Virtual development or digital/virtual prototyping is a process where designing, testing, and validating products or systems happens only in a digital environment and not in a physical one. This saves both time and costs across various projects by moving physical prototyping to later stages of the development process, resulting in a more precise prototype [33]. Virtual development is supported by Computer

Aided Design (CAD) systems together with simulation, and visualization tools to create digital representation of products [9]. The digital representations can then be tested to assess functionality, manufacturability, and performance in a virtual environment [9], [33], [34].

Virtual development allows designers to rapidly iterate different product configurations through CAD software before making a physical prototype. Different simulation tools can therefore be used to test how the product would perform in the real world [34], by testing, for example, fluid dynamics or mechanical stress. This helps designers find weaknesses and issues early in the development process and with little to no loss in time or money. In summary, virtual development is a great method for optimizing product and process development by minimizing the need for physical prototypes, identifying errors early, and driving innovation forward in today's fast-paced market [33], [34].

2.3.1 Virtual Commissioning

Virtual commissioning is a concept that can be used to verify early on how software, mechanical, and electrical systems interact during the development of production processes [35]. By creating a virtual model of the production system and linking it to the appropriate control technology, process sequences can be replicated, thereby identifying errors [35]. Hence, a shorter commissioning period for the actual production system because suitable optimization techniques can raise the quality of the control software before the actual plant components are prepared for operation [35]. In summary, virtual commissioning reduces the project duration by simulating the real plant with reproduced dynamic behavior earlier in the project, upstream in the process [22]. As Striffler [22] describes it, the development process can be parallelized and accelerated while increasing quality.

The basic requirements are the availability of data, availability of equipment, supplier cooperativeness, and planning time [22]. It is critical to have information about the production facilities, 3D models provided with kinematics, behavior, and material flow, with correct functional aspects [35], [22]. The most extensive parts of virtual commissioning is according to Kampker et al. [35] the creation of virtual models. Hence, re-utilization is an important aspect to minimize the project cost and time, therefore it is crucial to have the same file formats for the 3D models to have the necessary functionality exchange [23]. Additionally, product data is mostly generated at the start of a project [23] and the different control programs used must be capable of cooperation. Therefore, supplier contribution and cooperation are vital, ensuring the accuracy of the virtual commissioning process [35].

Some benefits of virtual commissioning, especially in scalable production systems, according to Kampker et al. [35] are cost savings, reduced commissioning time, and avoidance of delays. Verifying virtual production systems earlier without interrupting existing production entails earlier error identification, different scenario possibilities, minimizing material usage, and better development team cooperation

[35]. Additionally, the creation of virtual models with necessary equipment software allows earlier operator training and feedback regarding the production operations [35]. To comprehend the future demands and complexity of the automotive industry it is fundamental to integrate new processes to verify geometry and functional development with CAD models containing complete product information [21].

2.4 Change Management

Change comes in different forms and is defined as an alteration of people, structure, or technology also called change agents [36]. Change agents can be internal or external and they play a crucial role in driving and facilitating change initiatives. These agents act as catalysts for transformation and lead to overcoming organizational inertia, which creates opportunities for adaptation and innovation.

Two forces create the need for change these are internal and external forces. Internally generated forces originate from within the organization and may include shifts in leadership, introduction of new equipment, organizational culture, and employee attitudes. For example, leadership changes may bring new visions, strategies, or realignment of goals. Similarly, the introduction of new equipment may influence the way people work, responsibilities, decision-making, and openness to change initiatives [36].

External forces have their origin from a wide range of places characterized by factors outside the organization's immediate control including technology advancements, market trends, competition, economic change, and government regulations are a few examples [9]. For example, competition, changing market trends, or government regulations may require adaptations in business models, services, or products to maintain competitiveness [36].

Technology advancements, including digitalization, automation, and information technology are driving organizational change more and more across industries. Embracing these advancements creates the opportunity to improve efficiency, and enhance customer experience. However, technology advancements also pose challenges regarding the hardship of implementation in bigger companies, skill gaps, and cybersecurity risks which all require strategic planning, organizational alignment, and proactive management [36].

Despite the importance of change, organizations often encounter resistance from various stakeholders who see change as an uncertainty, are concerned over personal loss, or believe that the change is not in the organization's best interest [36]. Addressing the resistance to change requires a wide approach, where the ultimate goal is to develop a tradition of change. People who are used to change tend to accept it without resistance however too much change can leave the employees wondering what will happen to them due to the constant change [36]. Furthermore, involving more employees in the decision-making process can improve alignment, commitment, and ownership making employees more positive towards the change [36].

3

Methods

In this chapter, the Method Theory, Applied Method, and Stakeholder Analysis will be presented. The project method theory and interview theory that was established will be described in the methodology theory section. Afterwards, it will be described how the methodology was applied withing the project scope. Last section of this chapter will describe how the stakeholders was mapped and analyzed for this project.

3.1 Method Theory

For this project, two theories were used as basis for the methodology, namely the Design Research Methodology and a Interview Theory. The Design Research Methodology theory was used as a framework for the applied theory during the project and the Interview Theory was used to prepare the conducted interviews.

3.1.1 Design Research Methodology

The project was a qualitative study, employing interviews, observations, and literature reviews which was conducted to gather more in-depth information regarding the current state, concepts, and expectations [37]. Design Research Methodology (DRM) provided that framework to gather information from the system, lifecycle, and knowledge from the stakeholders about the current state and goals/expectations to fulfill the need. To understand and improve the product through knowledge and support [38].

The DRM's objectives are to provide a framework and guidelines to support each researcher's unique process to create a more rigorous and more reliable project [38]. Blessing and Chakrabarti [38] clarify 4 different stages to approach a research project, *Research Clarification*, *Descriptive Study I*, *Prescriptive Study*, and *Descriptive Study II*. The authors describe the importance of iterations between the different stages to execute a project of higher quality [38]. Actions, outcomes, and the different stages are visualized in Figure 3.1.

The first step, *Research Clarification* aims at defining realistic research problems and goals based on the findings from literature analysis and descriptions of existing and future scenarios [38]. The second step, *Descriptive Study I*, refines the researcher's understanding of the current situation by completing a detailed literature analysis and complementing that information with an empirical data analysis [38]. After obtaining enough information, the following step, *Prescriptive Study*, continues the process where the researchers decide the focus areas based on the gained information from previous steps [38]. Lastly, Blessing and Chakrabarti [38] describes the final step, *Descriptive Study II*, as the second study where the research is evaluated to investigate the usefulness based on earlier established goals, success criteria, and user agreement.

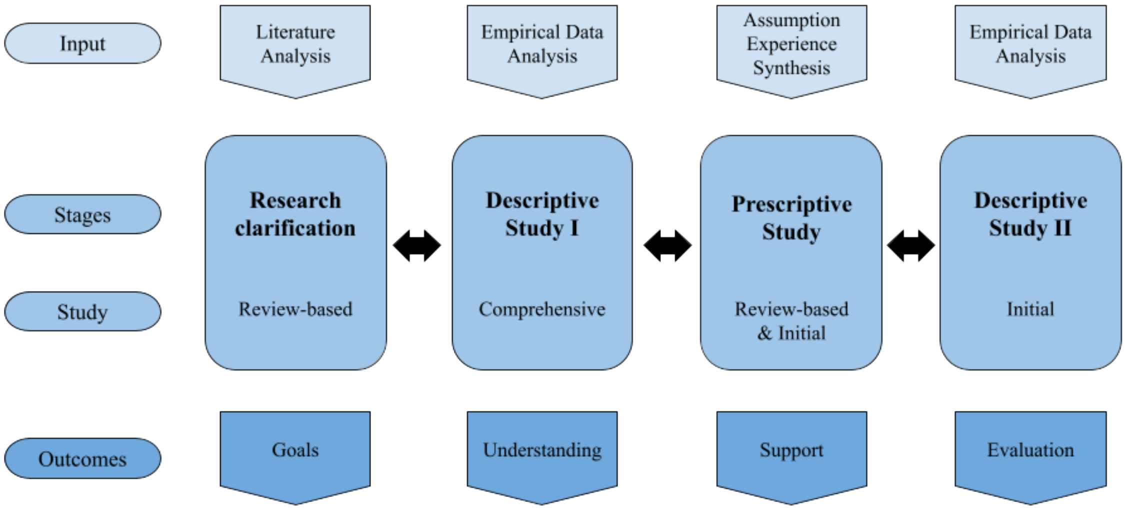


Figure 3.1: The four stages of DRM, interpreted from Blessing and Chakrabarti [38]

Beyond the iteration ability of the framework, Blessing and Chakrabarti [38] derive different types of suggestions on how to conduct the research. As previously mentioned, DRM is a framework that can be adapted to each specific research project, hence Blessing and Chakrabarti [38] provides a selection of seven types of research. The division between the types of design research is based on three studies, *Review-based*, *Comprehensive*, and *Initial*. The *Review-based* study is based only on the literature, the *Comprehensive* study includes a literature review in addition to an empirical study for further development [38]. The *Initial* study involves the first steps of the chosen stage by presenting the result and consequences of the study together with preparing the results for usage by others to close the project [38].

3.1.2 Interview Theory

The creation of the semi-structured interview questions followed the framework established by Kallio et al. [39] to ensure quality. The framework is divided into 5 phases which can be seen below:

1. Identification of prerequisites for using semi-structured interviews.
2. Retrieving and using previous knowledge.
3. Formulating the preliminary semi-structured interview guide.
4. Pilot testing of the interview guide.
5. Presenting the complete interview guide.

The first phase aims to ensure that semi-structured interviews are the correct way to answer the selected research questions. Semi-structured interviews are appropriate when studying people's perceptions, opinions, or emotionally sensitive issues [40]. Additionally, it allows for customization according to the interviewee and allows the interview to focus on subjects important to the interviewee [39].

The second phase focuses on retrieving and using previous knowledge. During this phase, the goal is to gain background knowledge about the subject by reviewing existing literature [40]. To complement the literature review, empirical data will also be collected by consulting experts and inviting experts to seminars [41].

The third phase is about formulating the preliminary semi-structured interview guide. The interview guide includes a list of questions regarding topics around the research questions which are formulated based on previous knowledge [41]. Semi-structured interviews are seen as flexible and hold the ability to adapt to the interviewee, by reordering questions or involving supplementary questions which can be pre-designed or spontaneously phrased. The questions must be non-leading, open-ended, and clear-worded with the interviewee in focus [39]. During the creation of questions, the phrasing is key, typical close-ended questions usually start with verbs while open-ended questions start with words like the five W's which are What, Why, Who, Where, and when [42].

The fourth phase of the framework aims to test the semi-structured interview guide. This is done to ensure the quality of the guide and make sure that the questions are of relevance and cover a sufficient amount of ground. Several different methods can do testing some examples are internal testing, expert assessment, and field testing [39]. This allows for a deeper understanding of the preliminary guide and can improve the guide and find flaws [39]. The last phase of the framework is to present the complete interview guide and use it in real scenarios [39].

3.2 Applied Method

Based on the type of research within the DRM framework, the project approach started with a pre-study with seminars and observations to understand the goal, aim, and scope of the project from the company's perspective. In parallel, a literature review was conducted to supplement the company information. After the conclusion of the scope, goals, and success criteria, semi-constructed interviews were organized and held with accurate stakeholders for an elaborate understanding of the needs and objectives of the research. Based on the gathered requirements and desired solution, a foundation was developed describing different ways of working to connect 3D resource models to process structure. The procedure was evaluated to control usefulness levels and improvement potentials. Where the final step was to update the evaluated synthesis and reflect on its value and achievability. Figure 3.2 presents the interpreted connection between the DRM methodology and how this project unfolded. The following sections describe the project methodology in more detail.

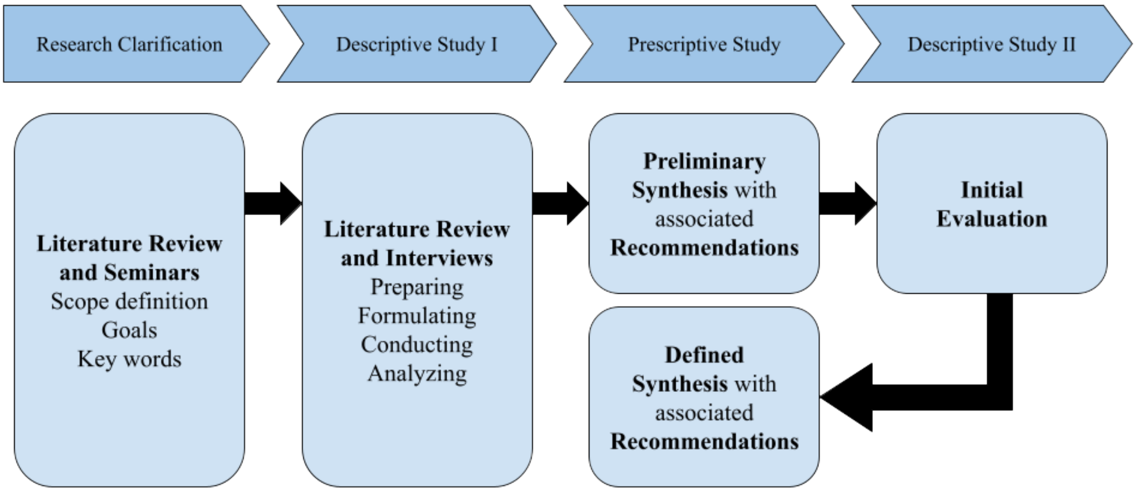


Figure 3.2: Project methodology based on the DRM methodology

3.2.1 Seminars and Literature Review

Connected to Blessing and Chakrabarti [38] the first stage of DRM, *Research Clarification*, a pre-study was completed through seminars, observations, and a literature review. The collected information was a baseline reading of the issue at hand and provided what outputs the stakeholders wanted. Moreover, the gained knowledge helped to clarify and determine the research areas and their relevance and contribution. According to Blessing and Chakrabarti [38], the main source of information is through literature, however, seminars and observations were used in addition. These methods were utilized to ensure the deliverables of current understanding and expectations and overall research plan, of the *Research Clarification* stage, were met.

Firstly, meetings of seminar type with first-tier stakeholders were utilized to unfold the current issues and problems with how documents are handled through the process flow, inspections, etc. The seminars helped with understanding the problem at hand and clarifying the needs, objectives, and expectations to meet stakeholder requirements and ensure a successful thesis. Additionally, to pinpoint key individuals for consultation, either due to their contributions or potential impact from the project in the future. Therefore, to improve the background knowledge, understanding, and expectations, seminars were conducted where scope topics and questions were discussed with the stakeholders.

In parallel to the seminar-type meetings for understanding, literature reviews were conducted to further apprehend the topic areas, frame the research, and create a plan. Furthermore, this helped to connect academia to industry and investigate old research within similar areas for verifying the project's contribution, relevance, and qualification [38]. However, the literature process was a continuous process throughout the project to support assumptions and hypotheses to have a stronger backbone to the reasoning and level of understanding [38].

Used literature throughout the project was gathered through different sources. The main sources of the literature search were conducted through *Google Scholar* and *Chalmers Library*. Used and combined search words that were employed throughout the project were:

- Product Lifecycle Management
- Cross-functional
- Automotive industry
- Virtual development
- Virtual verification
- Virtual commissioning
- Methodology
- Change management
- Traceability
- Visualization

3.2.2 Interviews

After gathering information about the current situation and research, a qualitative approach with semi-structured interviews was conducted to provide details and a basis for further development abilities. This step is connected to Blessing and Chakrabarti [38], the second stage of *Descriptive Study I*. All the interviews were recorded and later transcribed for better understanding. The chosen qualitative approach was due to the need to gain data before formulating hypotheses used to develop theories [38]. The structured and prepared questions together with the unstructured and sudden questions provided meaningful input and stimulated deeper conversations with new ideas [43] [39].

The purpose of the *Descriptive Stage I* according to Blessing and Chakrabarti [38] was to understand the existing situation and problems, and be able to connect that to the research topic. Moreover, based on the current situation to have clear argumentation for improvements of the most suitable factors including support implications [38]. To succeed with the interviews, predefined knowledge was required from literature and seminars to have a grasp of the subject and acquire a research plan [38], [39]. Additionally, success criteria were decided to judge the outcome of the project measurably. Since the chosen empirical study was interviews, an interview guide was formulated, presented in Appendix A, with main subject questions and follow-up questions [43], [39]. The interview got deeper into areas that need extra attention or are important to the interviewee. With the necessary material gathered, semi-structured interviews were held to collect data, after which the results were processed, analyzed, and interpreted [38], [39].

Qualitative research provided the depth needed to understand the challenges related to the model connection to the Process and Inspection Instruction (PII) in the Bill of Process (BOP). This depth of understanding enabled us to grasp the structure and scope of the issue and to formulate a theory based on various viewpoints [37]. Since the previously mentioned instructions and process descriptions are used across different departments in the company, several stakeholders were interviewed. Details about these stakeholders can be found in Table 3.1. The chosen departments which the stakeholders are a part of and why these were chosen are as follows.

- **Manufacturing Engineering Commodity:** The Commodity team is responsible for preparing products from Engineering for the Plant, and their role in creating PIIs makes them interesting candidates for interviews.

- **Manufacturing Engineering Digital:** The Digital team works with digital strategies within ME, including the developing responsibility of the PII solution in TC PLM which makes them interesting candidates for interviews.

- **Plant:** The Plants are the customers of the PIIs, to understand their needs and requirements regarding what the connection between the 3D resource models and PII will do for them, they were selected as interview candidates.

- **Manufacturing Engineering Industrialization:** The Industrialization team works by verifying the process and product solution, validating that the physical product can be built according to the PII description. They are valuable candidates to interview to obtain their insights into the PII content for downstream users.

- **Digital Engineering:** The Digital Engineering team works within IT and can give accurate descriptions of present possibilities with current solutions and possibilities for the future, and future PLM systems which is why they are valuable stakeholders to interview.

Table 3.1: Information about the stakeholder interviews

Interviewee	Department
M1	Manufacturing Engineering (Commodity)
M2	Manufacturing Engineering (Commodity)
M3	Manufacturing Engineering (Commodity)
M4	Manufacturing Engineering (Commodity)
M5	Manufacturing Engineering (Commodity)
M6	Manufacturing Engineering (Commodity)
M7	Manufacturing Engineering (Commodity)
M8	Manufacturing Engineering (Commodity)
D1	Manufacturing Engineering (Digital)
D2	Manufacturing Engineering (Digital)
P1	Plant
P2	Plant
I1	Manufacturing Engineering (Industrialization)
IT1	Digital Engineering (IT)
IT2	Digital Engineering (IT)

3.2.3 Development of Method Foundation

Based on the analysis of the interviews, a synthesis with an associated recommendation was developed. During the project phase, this is connected to Blessing and Chakrabarti's [38] third stage, *Prescriptive Study*. The deliverables of the *Prescriptive Study* stage are documentation of the intended and actual support, results of support evaluation and outline evaluation plan [38].

Since the development of the support, which in this study was a synthesis with an associated recommendation, was based on the stakeholder interviews and existing programs, the type of *Prescriptive Study* stage is Review-based [38]. The first step of this stage was to collect all the earlier results to ensure task clarification with the specifications of the problem and requirements [38]. After the gathering, the concept was developed and given the overall shape, which insinuates to fulfill the need by synthesizing potential solutions [38]. Lastly, the details were finalized to the plans and models, the impact was assessed to reflect over limitations and features.

3.2.4 Evaluation

Before its presentation, the synthesis and recommendations underwent an initial evaluation to ensure its usefulness, correctness, and potential. The evaluation was initially to get an indication of the support because of the lack of user usage since the recommendations will not be physically implemented, which is one of the delimitations. According to Blessing and Chakrabarti [38], the evaluation is to some extent connected to the previously mentioned *Prescriptive Study* stage and mostly connected to the last stage *Descriptive Study II*. In the *Prescriptive Study* stage, the actual support is evaluated for completeness and requirement verification to outline an evaluation plan [38]. After the plan's conclusion, new interviews with the main stakeholders were conducted to determine usefulness, impact, and improvement areas additionally, to validate the implementation possibility and value bringing. In parallel, evaluating with literature, opting to connect and discuss the different synthesis solutions with academia. These steps are connected to *Descriptive Study II*, however, not in a systematic way but as Blessing and Chakrabarti [38] describes it, it is an iteration process with many steps occurring in parallel.

After the conclusion from the evaluations was drawn, the recommendations was updated, resulting in going back to the *Prescriptive Study* stage to round off the research [38]. An initial *Prescriptive Study* was conducted to improve the synthesis and recommendation based on gathered evaluation knowledge, connected to showing the consequences of the evaluation outcome on the support and impact model according to Blessing and Chakrabarti [38]. This was the final delivery to the company to end the project and present the outcome together with the value brought.

3.2.4.1 Other Evaluation Deliverables

In addition, to the evaluation of usefulness, the framework's potential, and value, it is important to investigate the ethical aspect and impact of the suggestion. The

DRM framework provides an evaluation of the design, and framework to fulfill the perceived needs [38]. But beyond the design usefulness, it is today very important to control the sustainability impact, precisely the people, planet, and profit aspects. Hence, the developed framework was examined against the ethical aspect and the people that will be affected by it.

As part of validating the engineering design method, the research quality was discussed during the thesis's final stages. To ensure the rigorousness of the research, the method used will be discussed covering the core method construct of theoretical structure and performance and empirical structure and performance [44].

3.3 Stakeholder Analysis

Stakeholder analysis was an important method used to assess stakeholder's expectations, interests, and potential impact involving the project. It involved identifying key stakeholders, mapping their needs, and finding strategies to keep them engaged throughout the project and to deliver a good result[45], [46]. The stakeholder analysis began with identifying both key groups and individuals with a stake in or affected by the project. Stakeholders were then prioritized based on their level of interest and power to influence in a Power-Interest Grid seen in Figure 3.3 [47]. Understanding their objectives and concerns was crucial to help evaluate their potential impact on the project [45].

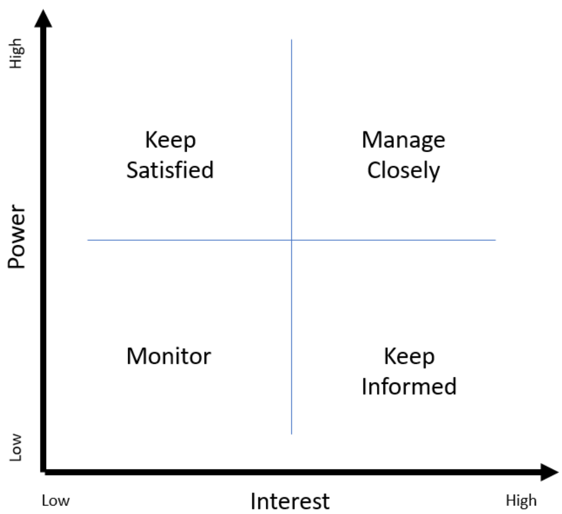


Figure 3.3: Power-Interest Grid interpreted from Olander and Landin [47]

Visualizing stakeholder relationships helped identify collaboration opportunities, potential conflicts of interest, and root causes of problems. These insights helped with tailoring engagement strategies to each stakeholder group. Regular follow-ups with stakeholders ensure engagement and high-quality results. Overall, stakeholder analysis is essential for ensuring project success, mitigating risks, and managing relationships [45], [48].

4
Results

This chapter provides details about how the current work is completed at the company in question, in section Current State. Additionally, the results and core findings from the conducted interviews will be presented in section Interview Results. Lastly, the Stakeholder Analysis will present the result of stakeholder involvement in the project.

4.1 Current State

Based on the seminar-type meetings and interviews, the current work processes at the case company were interpreted. Including their procedure, stages, and information inclusion in their processes and instructions. Additionally, the procedure of new resources and what requirements are desired currently. The subsequent subsections will provide a more detailed description of the current state.

4.1.1 Work Process

The information regarding the product build is structured and saved in multiple different tree structures. These process structures withhold information about the parts consumed and tools used together with the process steps for assembly, namely Engineering Bill of Material (E-BOM), Product Bill of Process (PR-BOP), Bill of Equipment (BOE), and Plant Bill of Process (PL-BOP). The E-BOM contains all the part models for the product and is divided based on the commodities in Engineering, hence divided between part groups such as cables for example. The PR-BOP on the other hand is divided into function groups and their containing products, for example, the door. All information from the E-BOM is also placed in the PR-BOP structure with additional information about the operations and equipment if existing. From the PR-BOP, the information is sequenced according to the assembly flow in the factories in the PL-BOP. The way of working with the information flow of the products and processes is illustrated in Figure 4.1.

After Engineering has released the articles in the E-BOM, Manufacturing Engineering (ME) starts their work of connecting the product to the existing processes at their factories or developing a concept product and process solution stored as a PII in the PR-BOP. This work process is called DPA5, where continuous work is conducted to verify the product from a manufacturing point of view together with verifying the manufacturing processes and facilities and is accomplished virtually.

During this project, ME has different process steps or phases before the completion representing different maturity levels. Completion of these phases is presented through Virtual Build Events (VBE) using the PIIs. These are conducted after DPA5-checks that have the purpose of verifying that the product can be produced in the intended manufacturing facility within the requirements.

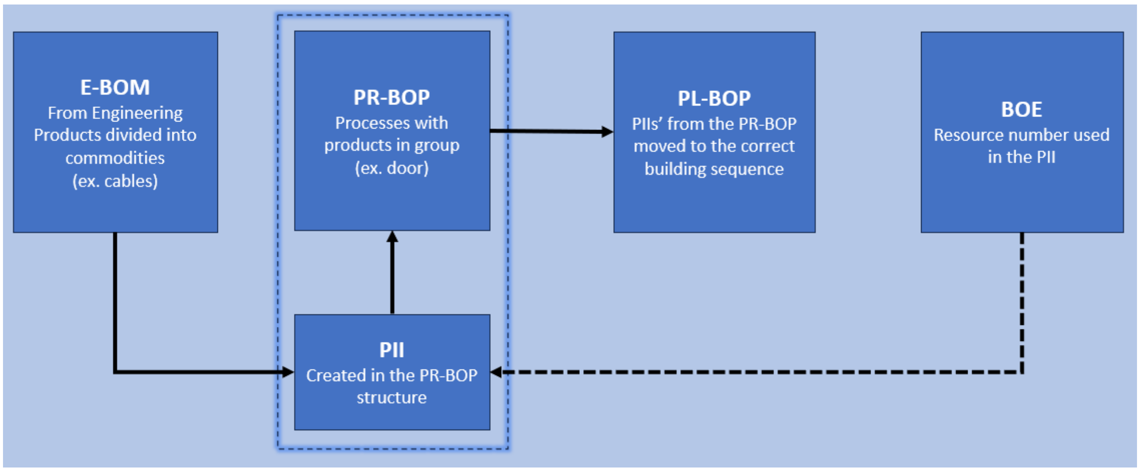


Figure 4.1: Way of working with the current documentation of the products, resources, and processes

During the previously mentioned phases, the PIIs are created and updated continuously. The first draft of the PII is basic and does not yet take into consideration all requirements since these are not yet developed. As soon as more robust requirements are available the PIIs are updated and improved as seen in Figure 4.2. The PIIs are continually updated and finalized until they reach the required maturity level for a handover to the factory. However, before the PII is ready for a final handover, the factory should first be able to do rough balancing and later on station-level balancing based on the PII. It is today established that there will be a system change, moving from a legacy database to a newer and updated one seen in Figure 4.3. The plan is to move the creation of PIIs to the new system in 2025.

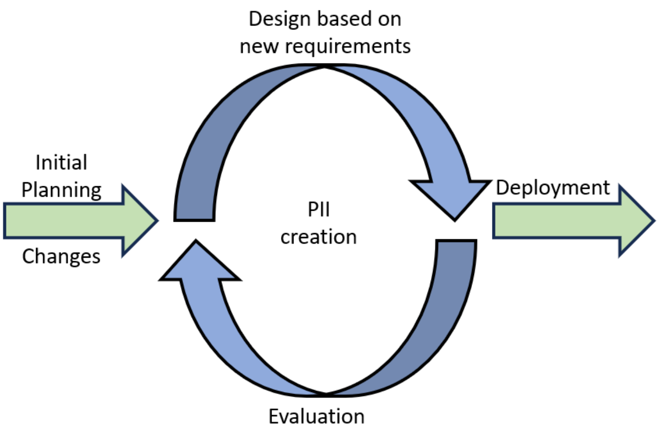


Figure 4.2: Generalized procedure to create the PIIs

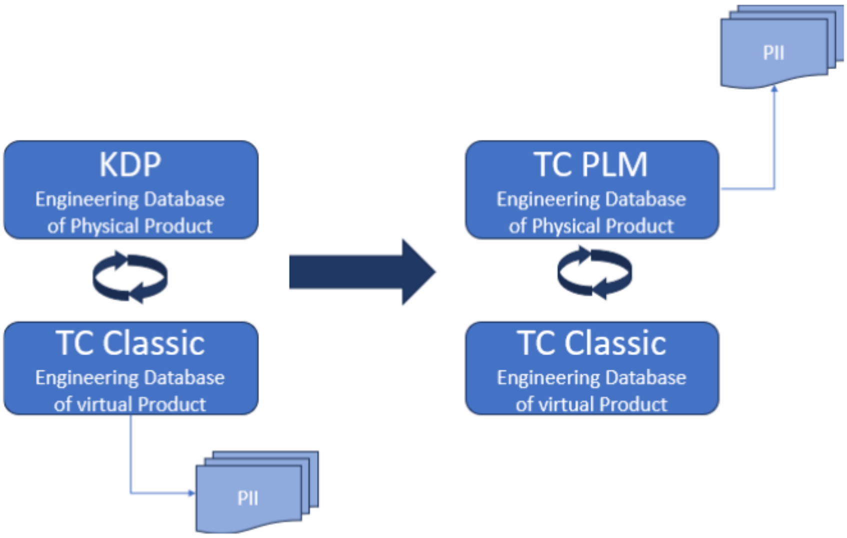


Figure 4.3: System change, moving from KDP to TC PLM

The PII solution that is in place today will probably remain for a couple of years. The ambition is to start working with all new car projects in TC PLM as soon as it is mature enough. It is timely and costly to move projects from one Product Lifecycle Management (PLM) system to another. This is why projects that are only iterated will most likely stay in TC Classic, however, projects where the process starts from the beginning will be started up in TC PLM. Several projects still need multiple iterations, meaning full migration to TC PLM will take several years without additional investment. This is where an interim solution can be of great value since it ensures a more seamless transition from TC Classic to TC PLM due to similar working approaches.

4.1.2 Process and Inspection Instruction

As previously mentioned, the Process and Inspection Instructions (PIIs) are created by the ME department, these documents are delivered to the Plant to have instructions on the processes for planning and balancing the flow. Hence, PIIs is an agreement between involved parties on how to assemble and control a component but MEs are the owners, Engineering is the buyer, and the factories are the customers of the PIIs.

The PR-BOP is currently structured by having the PIIs as the carrier of information, as generalized illustrated in Figure 4.4. Hence, today the mindset revolves around the PIIs where the operations and parts are consumed into the correct PII. Additional information such as resources used is also added to the PII in the PR-BOP structure. However, a drawing number of the resources with the requirements are currently added to the PII but no 3D model is yet connected. It results in there not being a 3D model connected in the tree structure as for the parts, only requirements are connected.

The PIIs are created in Teamcenter (TC) Classic and automatically uploaded to a custom web-based platform called TC Web Search where the plants view the information. From there, PII documents, as exemplified in Appendix B, can be downloaded. The document describes all needed information to be able to perform the assembly and control operations for a component to fulfill the quality, efficiency, ergonomic, and functional requirements. The description includes information about the process, mainly information about the operation, structure, tools/resources, and revision control is covered. Additionally, details about the PL-BOP and PR-BOP are included to differentiate the factories and to specify where it is valid and what articles are designated for it. Lastly, tracking of changes is noted for transparency and traceability.

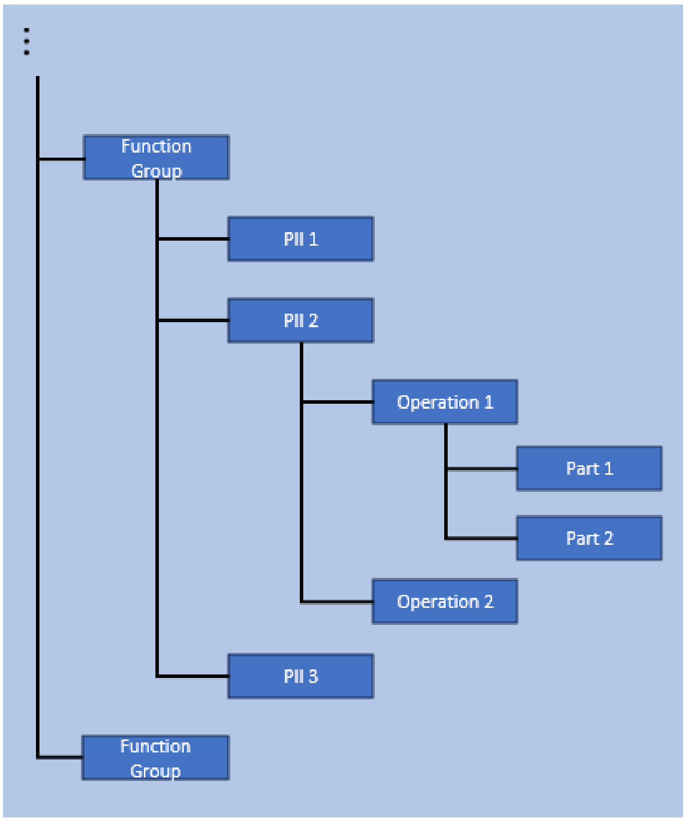


Figure 4.4: A generalized PR-BOP structure regarding the current way of working at ME Final Assembly

The operation section covers the sequence with instructions of the process. The structure involves what materials together with how many and the article numbers are linked to consumed articles visualized by 3D models. The tool field contains the resource numbers with what operation it is used in together with the specification of it. However, the resource numbers are added manually, meaning that they are not connected to the BOE in the same way articles are linked to the BOM, even with an existing BOE with correctly positioned resources to the material being assembled. Instead, illustrative instruction pictures of the 3D-modelled resources should be added to a PowerPoint and saved to a PDF which are uploaded as an attachment to the PII together with other analysis documents.

PIIs are abstract and present the process methods, tools, and instructions, shop engineers translate them to plant operations specific for each plant for the operators to use. Even with the same PIIs for the process assembly, the shop engineers at each plant can interpret them differently which is a problem. Consequently, the operation for the same PII can differ between the plants, suggesting different efficiency, ergonomic prerequisites, and functional requirements for each plant. Some differences are bound to happen due to the factory layout, preconditions, and tact time, however, with the generic operations, it should be a collaboration between the different factories to ensure the best methods are used.

4.1.3 Equipment Card

Equipment Cards (EC) are orders to the tooling department from ME, according to plan for new resources to ensure the assembly of the car. With that being defined, if the belief is that already existing tools at the factories can be used for the new or updated car model, no EC is created or sent to tooling for further investigation. These orders enlist what is needed for what part together with requirements for the operation and tool to ensure process and tool reliability. However, to further work with digitalization with larger possibilities for visualization and traceability, there is a need to require more 3D models with correct positioning as well. Otherwise, the resource delivery should not fulfill the requirement specification, an indication a delivery is not finished and complete. However, when there are 3D models included, they are not released until later on in the process, often when the developed model is in production because that is when they are verified and approved.

As an increased usage of digital models for verification before developing physical products, to both virtually test the commissioning together with verifying the usability of manual tools with the articles. However, even with verified and approved 3D models and physical tools, changes are sometimes made to them to fine-tune their application usage. These modifications made to the physical resources need to be updated in the virtual models as well, reasoning that the resources can be reused again. It is difficult today to ensure that the virtual models are correct and accurate.

4.2 Interview Results

The chosen qualitative research method resulted in semi-structured interviews with different departments to understand their needs and specifications for this project's scope. The results from these interviews are presented in the following subsections divided up between the departments the interviewee belongs to, the division is presented in Table 3.1.

4.2.1 Manufacturing Engineering Commodity

Multiple recipients from the interviews conducted were within the ME department. To clarify the results, the interview data is divided into five themes which are:

Earlier Evaluation Possibilities, How to Work With and Connect Resources, Interim Solution in Teamcenter Classic, Plan and Potential for Teamcenter PLM, and Consequences of Not Connecting the Resources to the Process Structure presented below.

4.2.1.1 Earlier Evaluation Possibilities

With the connection ability between the BOE and PII in both PLM system and the tooling section in the PII report, it was described that it would save daily work time for the responsible employees. However, with it being a possibility that will be valuable for all involved parties, it was explained that the BOE resources must be positioned correctly and updated with every new release to ensure the validity of the models.

As the PIIs are delivered to the factory to create more thorough instructions for the operators, it was described that the earlier the resource 3D models were added to the PIIs the better evaluation and suggestions from the factory departments could be delivered. An earlier description and understanding of the newly developed products and processes from the plant departments will consequently improve ME's work with better preparation and planning of their work.

4.2.1.2 How to Work With and Connect Resources

Value is generated across various departments when connecting the BOE to the PIIs. It has been expressed by multiple interviewees that it is important to connect all the tools needed for all the different PIIs. Together with this, the concern of filtration was raised, when having a VBE where the product is built in sequence, ME wants the parts to stay visible but only the tools relevant to the specific operation should be visible otherwise they will be in the way. Another wish was to be able to filtrate special tools that are not among the standard ones available in the factory.

A concern raised during the interviews was the time issue during the VBE, due to the lack of filtration of only the resources. The VBE's of building the product in sequence are already time-consuming events. Hence, adding resources with a lack of filtration and added description time, it was explained that it will add more time for all parties involved.

4.2.1.3 Interim Solution in Teamcenter Classic

The problems with BOE and the PIIs not being connected have been established for some time. As described by multiple interviewees, it is unknown when exactly the company will shift over to their new platform of TC PLM which is why it is important to try to find a solution that can solve the problem with the current software and resources available today. It is a possibility that some projects and products are stuck in TC Classic for many years looking forward which is also why the company still needs to solve the problem in TC Classic. Moreover, to work with the legacy data in the best possible way until the move and integration to the new system is completed.

4.2.1.4 Plan and Potential for Teamcenter PLM

TC PLM is at the time of writing immature however based on the current state it will be possible to connect BOE to the PIIs, there are some technical constraints with the Computer Aided Design (CAD) models but it is still under development. The full-scale release of TC PLM is not fully set, but the preliminary plan is to start using it during 2025. TC PLM will be focused mainly on the next generation of cars in development. The setup will be different than what is suggested in TC Classic. In TC Classic, the articles are connected to the PIIs, and the resource drawing numbers are written manually into the PIIs, creating a PR-BOP where the product and process can be seen. In TC PLM the PIIs will be created with all information in the PR-BOP as of today but will not as described by the interviewee include any tools. The resources will be connected in the following stage when a PL-BOP is created which is structured in the assembly sequence. With this solution, filtration options will be possible. Additionally, when all resources are connected to the PIIs it gives a usage overview of where all the tools and equipment from the factory are.

4.2.1.5 Consequences of Not Connecting the Resources to the Process Structure

Not connecting the BOE to the PIIs has both long and short-term consequences. In the short term, Final Assembly (FA) will continue to not have an overview of its tools, equipment, and fixtures. The PIIs delivered downstream will still be lacking information and they will be forced to call around different departments to try and find different solutions. Additionally, the downstream users will be hindered in their verification work. Long-term, the case company will not meet its speed-to-market goals due to a lot of waste around the existing PIIs.

If the connection is unsuccessful between the BOE and PII, the interviewees described one of the risks being that the 3D models are not being updated or even created for resources. Further describing that with no incitement, no need or seeing the updating as waste that no one will use, the updating of virtual models after physical modifications of the resources due to different reasons will be forgotten. Hence, the connection and usage of 3D models with the PIIs are of utmost importance to not risk them being obsolete or even not desired.

4.2.2 Manufacturing Engineering Digital

Two main themes were extracted from the ME Digital Interviews: Difficulties of Connecting Resources to the Process Structure, and Working in Teamcenter Classic and Teamcenter PLM.

4.2.2.1 Difficulties of Connecting Resources to the Process Structure

Resources are at the moment not connected correctly or not connected at all which makes it difficult when you open PIIs since the resources and parts are in different locations. Correct placement of resources could enhance visualization, providing a clear depiction of how resources are positioned around the car. If the resources are not placed in the PIIs as a 3D model they need to be searched for which takes valuable engineering time. During the interview it was shown possible to place resources in the correct position however certain resources such as screwdrivers do not have a specific place and will perhaps be placed more freely.

Furthermore, connecting resources to the PIIs can pose challenges during the sequential assembly process in TC Classic. As parts are added to the car, the associated resources automatically follow, eventually covering the car entirely. This makes it necessary to develop a filtering mechanism to manage this issue. The problem arises because the PIIs only contain parts and products specific to each operation, lacking connections to previous steps.

4.2.2.2 Working in Teamcenter Classic and Teamcenter PLM

The existing PII solution was created several years ago. At that time, ME Digital gathered input from employees who worked with PIIs, which resulted in a solution similar to the previous one but still missing some crucial elements. With the release of TC PLM, ME Digital aims to create a significantly improved solution that addresses the needs of all stakeholders, rather than replicating past solutions.

The transition to TC PLM, a web-based platform will facilitate remote work since it was described that the current limitation of optimal performance of TC Classic is primarily at the office but is still very slow then. Being web-based also makes it easier to run TC PLM on computers with worse hardware and lesser computer power. However, with today's setup, there is no need to move CAD data from TC Classic to TC PLM the preliminary plan is to keep all CAD data in TC Classic.

4.2.3 Plant

Two main themes were extracted from the Plant interviews these were the following: Visualization of Resources in the Process Structure and Earlier Change Possibilities.

4.2.3.1 Visualization of Resources in the Process Structure

Plant Launch put a lot of emphasis on the visualizing concern regarding the PIIs desiring that more resource models or pictures were available for better understanding and preparation for future plans. With this desire in mind, the interviewees put the most emphasis on visualizing newly developed or more complex tools. With ordinary tools, such as screwdrivers or hammers, it was described that they did not need to be visualized. Although, if 3D models are used they need to understand how to use them to pick the information they want. Moreover, as previously mentioned, to be prepared even more with both operator training and production changes. Where earlier releases make it simpler for them, even old information is better than none. Hence, working in process models of resources informs them more than no information to have the changeability that they want. Although it is outside the scope of the project, it is worth mentioning that it was described that the PIIs are complicated to understand and that comprehension of them takes training.

4.2.3.2 Earlier Change Possibilities

To improve both the product for the customers and the work environment for the operators, Plant Launch wants to be included as much as possible to provide necessary changes. The employees participate in the VBE, however, a concern was raised regarding the limited visualization of the articles, sometimes only with pictures in a PowerPoint and not as a 3D model. To improve understanding of operator access and installation, there's a proposal to incorporate a more comprehensive environment around the article. This would include resources used, potentially using a human model, and indicating the assembly location within the car, highlighting any obstacles between the operator and the assembly process. By enhancing the presentation of the articles, resources, and process, the response from the other departments involved will be better.

4.2.4 Manufacturing Engineering Industrialization

Two main themes were extracted from the ME Industrialization interview which were the following: Verification Between 3D Models and Reality and Need for Earlier Access to Resources.

4.2.4.1 Verification Between 3D Models and Reality

To do the verifications today, ME Industrialization first examines the PII and then searches for each of the wanted resources in the BOP in TC Classic. If 3D models or pictures were available in the PIIs or BOP structure, it was explained that the verification process would be much faster since less time would be spent searching for the correct tools in TC Classic. It was also expressed that the desire for virtual resource models is of more specialized matter, for example, lifts, fixtures, and specially developed tools.

4.2.4.2 Need for Earlier Access to Resources

Another theme that was lifted during the interview was the wish to get access to tools earlier. Today the resources are put into the PII quite late and there is no visualization of them which is especially important with new or changed tools. If downstream users got access to some visualization of the tools earlier they could catch errors earlier in the process. Additionally, it was described that pictures or 3D models added in the PIIs would increase the knowledge and understanding of the operation, as a supplement to only text instructions. Earlier access together with connected pictures or 3D models would increase the preparation ability.

4.2.5 Digital Engineering

During these interviews, a lot of different approaches to solutions were brought up these were divided into three different themes which were the following: Solving Connection Issue with Existing Method, Worlds Class Engineering Scope, and Ideal Solution in Teamcenter PLM.

4.2.5.1 Solving Connection Issue with Existing Method

During the interview and discussing the current problems at hand, Digital Engineering presented an existing method that could be used to solve the problem of connecting tools to the PIIs. The method intended to connect a 3D model of the resource from the BOE to the PII in the PR-BOP in TC Classic. This could be a possibility for an interim solution to be used during the migration from TC Classic to TC PLM. This method, however, does not place the connected tools in the PII report since they are not consumed items for the assembly, meaning that they are not used in the assembled product.

Digital Engineering discussed the potential for crafting a tailored solution by modifying the code of TC Classic to suit specific requirements. To integrate 3D resource models with the customized PII report, the solution needs to be customized again. While customization offers flexibility, it also poses risks such as compatibility with future updates. It necessitates the involved departments to review and adjust custom code in different applications. Despite the drawbacks, customizing applications internally may be necessary due to the system owner's broad customer base and limited capacity for individualized modifications.

4.2.5.2 World Class Engineering Scope

WCE is primarily focused on virtual development which strives towards speed and flexibility. Virtual development is aimed at CAD and will remain in TC Classic, regarding virtual development there is a lot of new development together with implementing WCE. The PIIs are under physical development which is outside of the scope of WCE and will also be moved to TC PLM as mentioned by multiple interviewees. This results in that most of the WCE development will be aimed towards TC Classic and there will be little to no WCE investments towards TC PLM currently.

4.2.5.3 Ideal Solution in Teamcenter PLM

The ideal solution that Digital Engineering mentioned regarding connecting tools to the PIIs, is in the context of a BOP. In a BOP you need both the parts and the resources from a BOE which unlocks the possibility of creating a placeholder that can consume parts and tools to visualize them differently. The reason it is so difficult to retrieve the right PII solution from the TC developers is that much of the PII solution today is custom for the company.

4.3 Major Findings

This section will present a summary, key points, and takeaways from the interviews.

Resources

- All resources that are impacting the operation should be connected to the buildable process structure.
- When building the car in sequence the parts of the car should stay visible after opening however only the resources that are connected to the latest operation should be visible.
- There should be a filter available that can show only the new resources for the specific car.
- Resources should be positioned correctly from the start relative to the car.
- Resources should be connected already when an EC is created for them to be able to follow the build progress and also give earlier access.

Time saving

- Connecting BOE to PIIs saves lots of time by collecting all the information in the same place.
- Less time will be spent on information searching for resources.

Earlier connection of the resources to the process structure

- Connect resources when EC is created for them.
- Earlier connections allow the downstream users of the PIIs such as Industrialization and Plant Launch to become more prepared.
- Earlier connections help with the verification of resources.
- Earlier connection helps with control checks.

Visualization

- Having 3D models of resources allows for visualization allowing people from the plant to see exactly how the new resources look.
- Having 3D models connected correctly also helps the VBEs by making them clearer and easier to digest.
- Visualization can also down the line help with educating operators.

Verification

- 3D models are used for planning, analysis and to give information that new resources are the way they were ordered.
- Virtual verification with everything connected before physical implementation for a faster and more thorough process.

TC Classic

- Current PII solutions were developed long ago, making them outdated.
- In TC Classic, connected BOE shows up under the article structure and there is no way of connecting it to the tooling field in the PII report.

- TC Classic relies on lots of custom code, especially regarding the PII solution that is in place today.
- The problem can be solved by writing more custom code however this causes further complications and it is uncertain if IT sees it as worthwhile.

TC PLM
- TC PLM is a clean slate allowing for improvements from the current way of working.
- With TC PLM the product articles will be connected to the PIIs which are placed in a PR-BOP in the next step which is the PL-BOP resources will also be connected to the PIIs.

WCE
- WCE is aimed towards virtual development, changing information carriers from the PIIs to the process structure.
- With WCE, the BOE is connected to the product in a PL-BOP which solves the connection issues, however, since the PIIs are a custom solution it is still not possible to connect this in any way to the current PIIs.

4.4 Stakeholder Analysis

Figure 4.5 show the project stakeholders grouped into departments and the level of power and interest they have towards the project. The stakeholders are placed on the grid based on the conducted interviews where they were analyzed based on their involvement in the creation, usage, and interest of the PIIs. Additionally, Chalmers University of Technology was identified as a stakeholder since the project is conducted as a master's thesis and supervised by the university. The stakeholder analysis enhanced the understanding of the interview results.

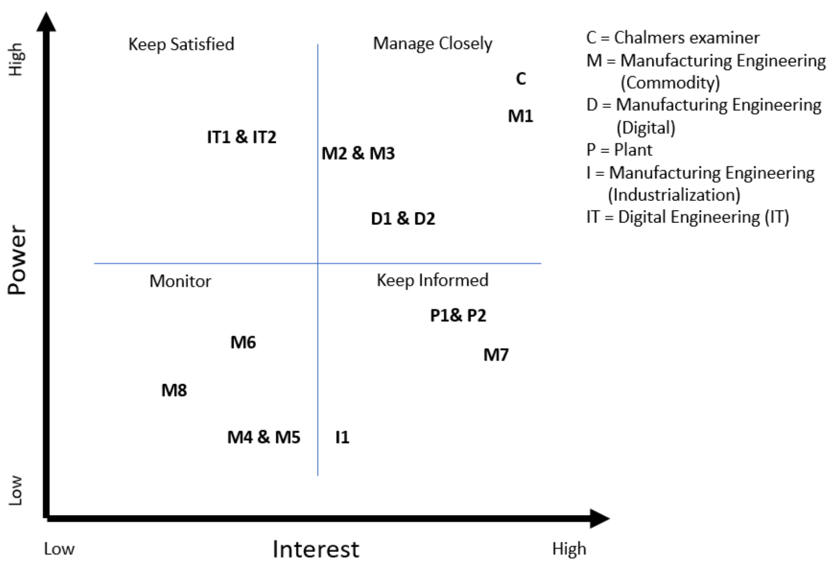


Figure 4.5: Power-Interest Grid stakeholders

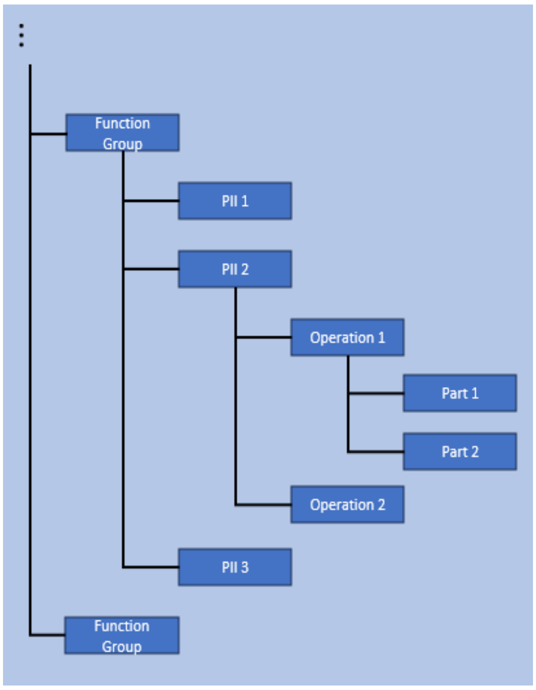
5
Synthesis

This chapter will present ways of working solutions between the Bill of Equipment (BOE) models and the Bill of Process (BOP) structures. The chapter is divided into the Interim Solution in Teamcenter Classic for the current setup later presenting a solution for working with the World Class Engineering Strategy. Lastly, the Teamcenter PLM section will describe how the company will work with it in the future.

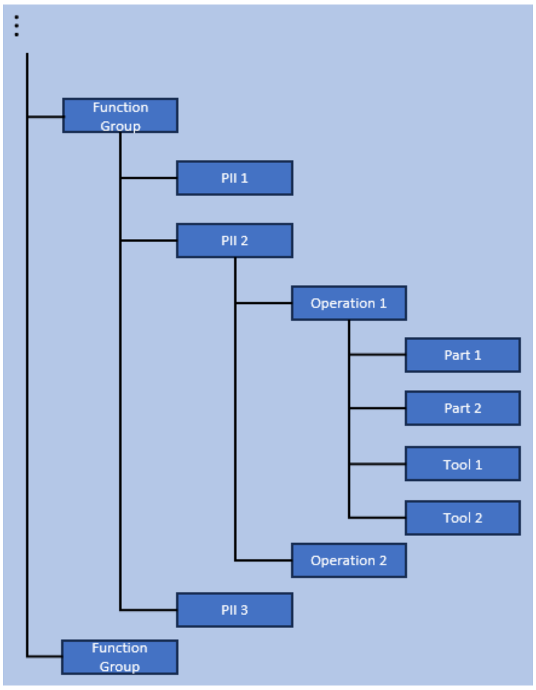
5.1 Interim Solution in Teamcenter Classic

As previously described, one of the aims is to provide a framework to succeed with the current issues and problems regarding the connection of BOE in BOP. Hence, an interim solution will be presented to work with before continuing to newer and more updated systems containing all necessary data. This interim solution is based on semi-structured interviews with responsible stakeholders and evaluation interviews for improvement suggestions of the framework.

During the interviews, a solution for this problem was presented by an already existing method to assign a resource from BOE to the operations in TC Classic. However, this is not a fixed solution as it is not possible to connect the BOE articles to the tooling field in the PII report, Appendix B. During the evaluation of the method testing, it was discussed that a new pilot project of having the Equipment Cards (EC) cards in Teamcenter (TC) Classic was recently introduced. This opens a possibility of connecting work models to the PIIs as well before having the finalized models in the BOE, utilizing better planning. The interim solution will therefore be to connect both finalized models and work models to the PIIs in the PR-BOP structure, way of working with the interim solution is illustrated in Figure 5.2. Figure 5.1a shows how the PIIs look currently with no 3D resource models connected, Figure 5.1b shows the placement of 3D resource models connected to the process structure in TC Classic. However, the wish of having the models linked to the PII report, Appendix B, can not be fulfilled due to the custom PII solution, and only parts consumed in the production can be linked.



(a) Current



(b) Interim solution

Figure 5.1: A generalized PR-BOP structure with the current and new way of working at ME Final Assembly

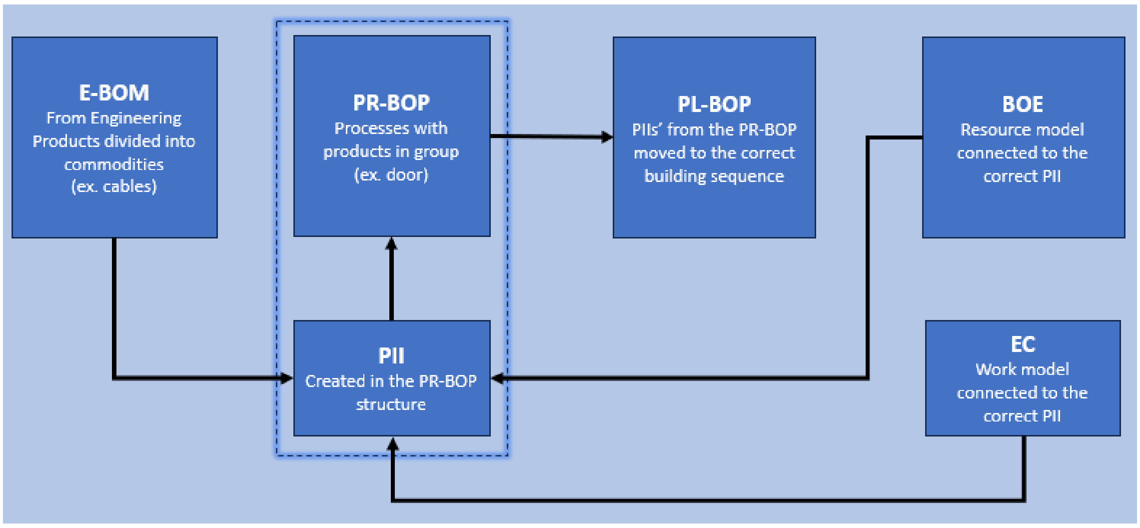


Figure 5.2: Interim solution with connecting the resource model and/or working model from the EC-card

Advantages

- Existing method
- Resources are placed in the BOP structure
- Resources, products, and processes are connected

Disadvantages

- Filtration lacking
- Difficult to do positioning
- Changing the way of working

As mentioned, the proposed method already exists, providing an advantage with existing documentation and instructions. Resources will be placed in the BOP structure ensuring connection between resources, products, and processes enhancing traceability. The disadvantages are the need to change the way of working in an aging system. Additionally, there is no way to effectively filter connected resources or change their position. This leads to overlooking the interim solution since it does not solve any of the major challenges.

5.2 World Class Engineering Strategy

As previously mentioned, the case company is today working in multiple different systems regarding their products and processes documentation. The far future solution is to have everything unified in the same system while the close future solutions are meant to be only two systems. One for the engineering part and one for the manufacturing preparation part, visualized in Figure 5.3. The system for the engineering parts containing Computer Aided Design (CAD) data is TC Classic and the other system for manufacturing preparation containing part information is TC PLM. Hence, everything connected to the virtual development will be in TC Classic and the information connected to the physical parts will be in TC PLM. The information in the different systems needs to be transferred and connected correctly which is an aspect to take into consideration. Moreover, World Class Engineering (WCE), the digital strategy describing future ways of working, is with this division of the systems included in TC Classic.

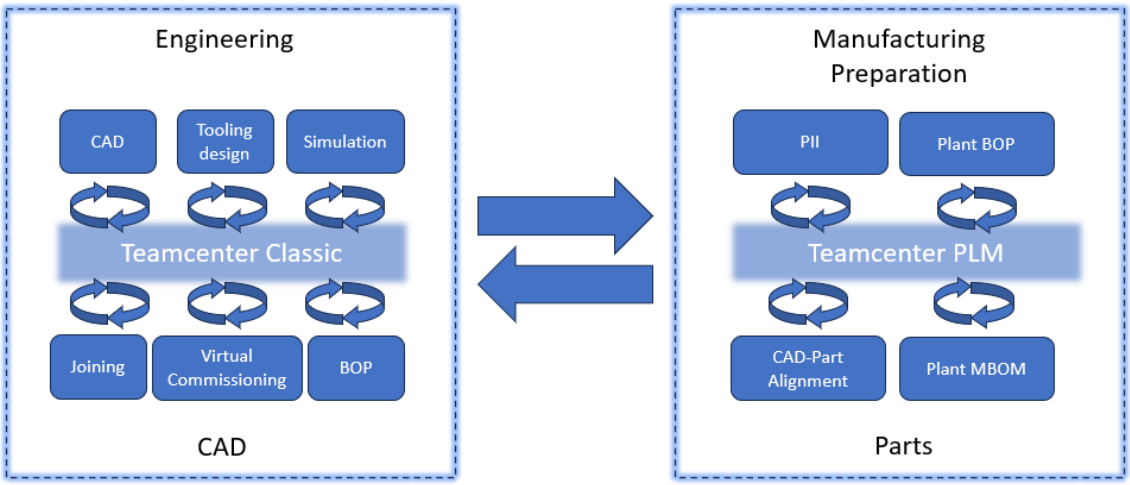


Figure 5.3: Fictional future way of working between TC Classic and TC PLM

It was explained that the way of working with the different process structures will change by working according to the WCE strategy. Instead of having the PIIs as the information container, it will be the structure that is the information container, illustrated in Figure 5.4. Instead of consuming the parts and models into the PII which is in a BOP structure, the parts and models will be consumed into the BOP which will be structured differently. Therefore, the way of creating and delivering PIIs with the WCE way of working needs to be further evaluated.

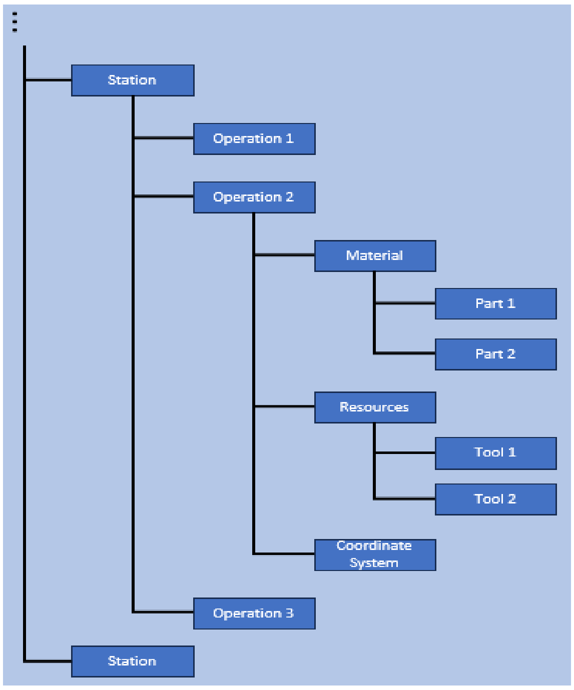


Figure 5.4: The BOP structure when working with WCE

The Engineering Bill of Material (E-BOM) will contain the parts from Engineering as beforehand and the Manufacturing Bill of Material (M-BOM) will be equivalent to the current PR-BOP. But as mentioned above, the parts will be the structure instead of having the PIIs as the structure. In the BOP, the articles with 3D models from the M-BOM and BOE will be connected to the operations. The connection between the structures is visualized in Figure 5.5. As the WCE strategy puts a lot of effort into virtual development there will be a generic BOP in addition to plant-specific BOPs depending on the factory and model. Hence results in a verified product towards Engineering based on the BOP and a verified functional process in the BOP structure to the Plants that reflects reality.

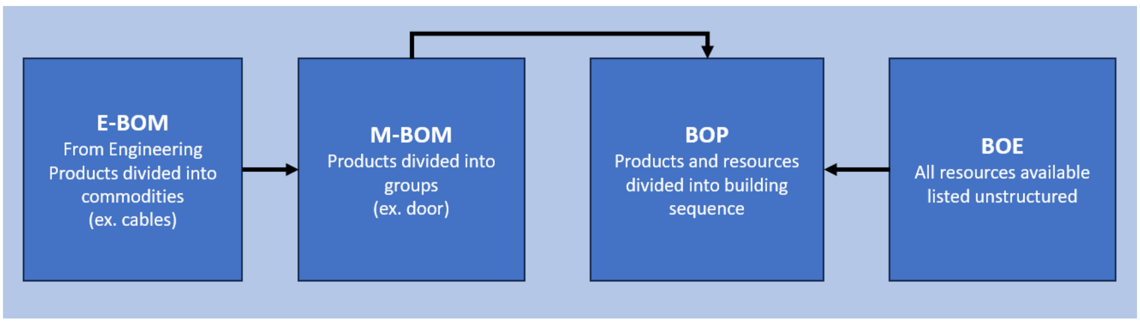


Figure 5.5: Way of working with the different process structures

In the WCE way of working, the operations are interconnected which differs from today's work approach. With the help of TC Classic's built-in functionality called PERT, the processes can be sequenced correctly in a user-friendly drag-and-drop way. By utilizing the tool, every step in the process shows the same state as it is in the assembly, not only visualizing the parts that should be assembled at that station. With this feature, it is easy to filter out unwanted parts, resources, and processes, addressing the current visualization issue effectively.

Advantages
- Makes positioning available
- Enhanced filtration
- Increased visualization, tracking, and correctness
- Structured process with sequence possibilities

Disadvantages
- Changing the way of working
- Different application software
- Transfer the information to another system
- Collaboration across multiple parties can complicate fault investigation.

The listed advantages are more connected to the scope in the way that there are great possibilities for the way of working with WCE. The advantages are the goals of why the organization should work towards connection and visualization. The listed disadvantages of this way of working are more connected to the change and disruptive work with having two systems instead of one. However, moving from multiple systems to only two will still create possibilities that were not achievable beforehand. The collaboration, access, and integration of products and processes will be improved by working in two common platforms while also reducing the waste of data searching.

5.3 Teamcenter PLM

The move to TC PLM is planned for 2025 since there are currently technical constraints since it is under development. As previously mentioned, the system will handle the physical parts and resources of the development, hence two systems will be used, as visualized in Figure 4.3. Even though the main goal is to downsize the number of systems to one, two is better than multiple as of today. From the interviews conducted the way of working will change slightly, connecting the resources to the PII will be later in the process, illustrated in Figure 5.6. However, the importance of connecting resource models to the PIIs for visualization, traceability, and virtual development, as described during the interviews, is brought on and is a needed functionality before software implementation.

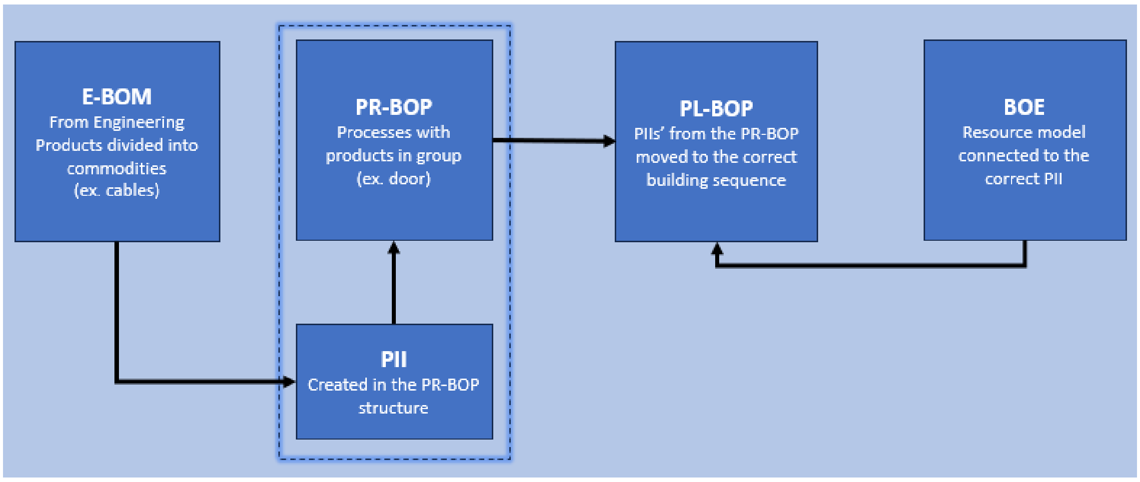


Figure 5.6: Way of working with the parts and process documentation structures in TC PLM

Visualized in Figure 5.7, the PIIs will continue to serve as the primary information carriers, now also incorporating resources but separated with articles. Each of these divisions will contain the necessary information for manufacturing as before and 3D models for visualization. Filtration possibilities are of utmost interest, as expressed during the interviews and the plan for the new system is to have filtration possibilities based on whether it is a standard tool or not. Beyond that, only visualizing the articles and or relevant resources is also included. This solution will solve multiple different issues and wishes that were brought up by the interviewees' such as building the product in sequence but only visualizing the tools from the latest PII.

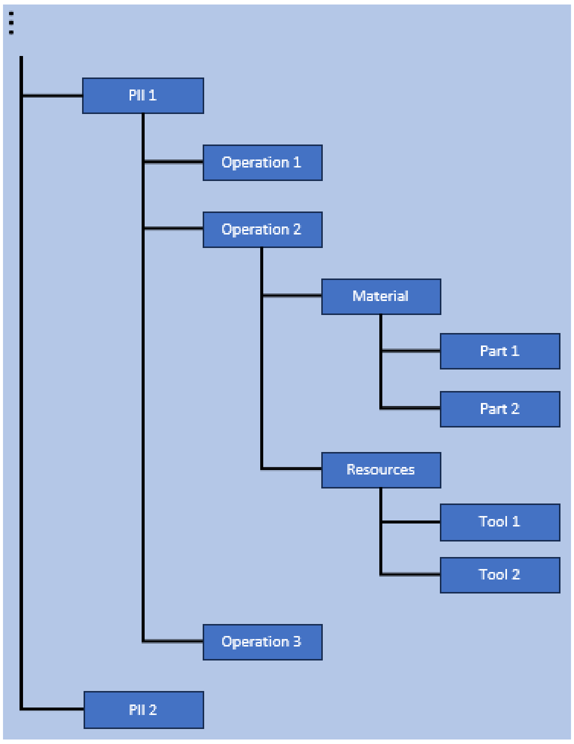


Figure 5.7: A generalized PL-BOP structure for the developing TC PLM

The current PII report accessible via TC Web Search will not integrate with TC PLM. Nevertheless, plans are to develop a comparable search concept integrated into TC PLM. Due to the lack of linkage to the resource models in today's solution, there must be a linkage to them in the newer version as it is a significant information source. Utilizing the linkage will allow downstream users to be more prepared and easily find the correct information.

Advantages

- New canvas for improvement potential
- Resources will be connected to PIIs
- Filtration possibilities
- Transparency
- Accountability checks
- Web-based

Disadvantages

- Different application software
- Changing the way of working
- Transferring the information to another system

As previously noted, TC PLM offers a fresh start with significant potential. Key advantages of TC PLM include connecting resources to PIIs, enhancing transparency, and facilitating accountability checks. Additionally, TC PLM addresses current filtering issues and, being web-based will be accessible with lower computing power. Disadvantages of TC PLM is the need to change to a new software which brings challenges such as transferring data to the new system and changing the way of working. The transfer of legacy data into TC PLM and the alignment between the CAD models and the process structures is posed with technical challenges but it is still under development, hence there are still great opportunities.

5.4 Recommendations

Based on this synthesis, the recommendation for connecting resources into the process structure is to prioritize the WCE methodology in the short term. At the same time, efforts should be made to develop support within TC PLM, ensuring compatibility with the established WCE approach.

The decision to overlook the interim solution originates from the inefficiency of repeatedly altering work processes, especially within larger organizations. Given that the WCE methodology is already being implemented successfully in specific areas, directing resources towards implementing WCE faster and making it better. Furthermore, it is better to invest in the future strategy of WCE and to educate employees on this instead of having a non-complete middle step of an interim solution.

To manage the change to WCE effectively, it is recommended to conduct a comprehensive pilot. Potential issues can be identified and addressed by transitioning select employees entirely to the new work methodology before full-scale implementation. Pilot participants can also serve as advocates for the change, sharing their experiences and insights to facilitate a smoother transition for the rest of the organization.

Moreover, TC PLM's flexibility as a new canvas allows it to tailor its development to support the WCE way of working. This ensures a seamless transition from TC Classic to TC PLM, even if direct data transfer is not feasible, the working method stays the same. WCE allows for a more user-friendly interface with drag-and-drop features for resources, solving positioning challenges. Furthermore, leveraging the PERT functionality addresses filtering issues, promoting enhanced visualization and progressing towards a more digitalized plant.

6
Discussion

This chapter will discuss the project's result connecting it to the theory used and previously described. Additionally, the method and quality of the research will be discussed while ending the chapter by discussing ethical and sustainability aspects and future research connected to the given project and areas within.

6.1 Value of Connecting

It does not matter which of the proposed solutions will solve it but it is a must for the company's digital development. Connecting the resource models from the Bill of Equipment (BOE) to the process structure, the Bill of Process (BOP), offers significant value, enhancing transparency by collecting everything within a unified tree structure. Connecting BOE to the BOP will also make it easier to visualize the product, resource, and process together, and it will help save a lot of time during both verification and preparation of the factory for a new product. The different ways of achieving the connection are not taken into consideration for the value discussion since the primary focus and root problem is achieving connection.

6.1.1 Transparency

Integrating product and process enhances transparency by having everything in the same place and altering how stakeholders, locally and suppliers perceive and engage with the product. This connection empowers all stakeholders to get a deeper knowledge of their part within the broader ecosystem leading to more effective and understanding collaboration [31]. Centralizing data in a connected system fosters data democratization and minimizes misunderstandings. Additionally, it opens up for inviting suppliers into the system enhancing their understanding of their respective roles.

The connected landscape creates a sense of ownership and responsibility among stakeholders. It removes silo work and individuals are no longer isolated in their roles but part of a larger connected system enhancing cross-functional collaboration. This transparency and change foster a collaborative mindset, where individuals can see their contribution to the overall success of a product [28].

Moreover, integrating suppliers into this connected system creates a shift in the mindset of suppliers. By giving suppliers access to see how the whole system is built up it enhances their understanding of their role within the project scope. This not only strengthens supplier relationships but also motivates alignment with the organization. Suppliers therefore become partners instead of just external entities.

Furthermore, transparency facilitates traceability since everything is in the same place, providing stakeholders always with the most relevant versions. With traceability double working is decreased which saves lots of resources, and stakeholders can confidently navigate the product landscape knowing that every part is as updated as possible. While also allowing history traceability in the system to provide controllability and visibility of the change and development process [8].

6.1.2 Visualization

By integrating and connecting everything to the same platform, the possibility of streamlining the organization occurs. It opens the capability of visualizing the product, resource, and process together, facilitating a better collaboration, verification, and understanding [19]. Hence, by connecting the product, resource, and process for visualising, the efficiency and precaution work can be improved while providing the foundation for further strategies involving digital representations such as digital plants or digital twins.

Utilizing the intended Product Lifecycle Management (PLM) systems of Teamcenter (TC) Classic and TC PLM to a greater extent with the connection for better visualization will effectively improve a holistic view and information gain both from the individuals working with it on a daily basis and user's downstream [25], as found during the study. Allowing quality assurance of the process by visualizing it while also receiving downstream feedback to implement all perspectives to produce the highest quality process with all included. Additionally, findings proposed virtual visualization would create perception of the system before physical implementation allowing an earlier error identification [35].

Earlier visualization creates better verification and controls of resources and products together while integrating improved cross-functional work. Where one common platform with visualization possibilities creates one single source of truth and inputs along the information flow can develop to a greater extent. Having the visualization as the basis for decision-making, areas of refinement, and control identification between departments. This collaborative approach eliminates the need for time-consuming meetings and email chains, accelerating development and reducing time to market. Allowing a reduction of challenges and miscommunication by having the priorities and support aligned. Furthermore, the visualization perspective of connecting the resources to the process can enhance the progress for future solutions of virtual verification and build the foundation of digital plants.

6.1.3 Verification

Verification is crucial for ensuring quality when the product is interconnected with the BOE. It becomes significantly easier to verify that the tools and equipment delivered to the plant match the specifications outlined in the Computer Aided Design (CAD) drawings making downstream users work a lot more efficient [35]. Since everything is connected it leads to real-time monitoring and control where changes and updates can be seen instantly. This integration streamlines verification processes, minimizes errors, and enhances overall operational effectiveness.

Integrating the process and BOE enables automation in certain areas further driving efficiency and saving time. Routine tasks such as file management, version control, and finding the right resources will be eliminated since everything will be in the same place from the beginning. This frees up valuable human resources to focus on more value-adding activities, not only reducing the risk of errors and miscommunications but also ensuring consistency and reliability throughout the entire development [9]. Additionally, connection ensures that all intended parts are accurately included, further improving error-proofing and quality assurance.

As mentioned the connection of resources to the process can help with virtual verification in the future. Virtual commissioning is one of the concepts that can increase the speed to market [22]. An extensive part is the creation of virtual models [35], the already existing and connected products and resources can mitigate the creation process. This results in shorter commissioning time, cost savings, and allows testing of different scenario possibilities, enhancing product and process quality.

6.2 Challenges of Connecting

There are challenges to overcome to connect resources to the processes. The interim solution has been studied due to the technical hindrances if the connection is established with the current way of working and setup in TC Classic. Changing the PLM system to TC PLM still presents technical challenges as presented in section 5.3. Hence, the primary challenges, independent of the strategy or systems used, are technical and organizational.

The current way of working in TC Classic lacks filtration and positioning capabilities, posing technical challenges in the existing workflow. Positioning issues can be addressed by requesting new EC cards or allowing access to positioning for everyone. Moreover, the World Class Engineering (WCE) strategy in TC Classic offers a different approach to working that resolves these technical limitations. The challenges in TC Classic largely stem from organizational and departmental operations indicating that both internal and external forces still are not strong enough for a change within Final Assembly (FA).

Associated with the previous is the investment to move forward to TC PLM, a newer, faster, and cleaner canvas PLM system compared to TC Classic. The far future strategy of condensing down the systems used to one PLM system is clear but the way there is not aligned. There is a need for organizational alignment during the transition time between TC Classic and TC PLM to improve commitment and faster advancements. Where the challenges are connected to the way of working in TC PLM, either continue working as currently or integrate the WCE strategy way of working from TC Classic into TC PLM. Additionally, as the CAD models are released in the TC Classic, the procedure further on needs to be established to improve the transitioning time. Whether the connection issue is solved through TC PLM or TC Classic with an interim solution to the current way of working or with WCE does not matter since there is great potential in connecting the BOE to the BOP. The key is that the organization is in agreement regarding the approach to solving the connection problem and comprehends its critical aspects for the future, especially for larger organization [36].

6.3 Consequences of Not Connecting

This section will cover the consequences of failing to establish a virtual connection between resources and the process structure. It includes the consequences of not connecting the resources from the BOE to the PIIs in the BOP in TC Classic with the current way of working and also the consequences of not achieving the connection into the soon newly implemented TC PLM. The way of working with WCE in TC Classic is already defined, established, and proven successful in other departments than FA within ME. Hence, it will not be discussed from the viewpoint of the consequences of not achieving the connection.

In the existing TC Classic way of working not achieving this connection means the organization will continue to operate in silos. Different departments will work independently with little to no cross-functional collaboration, leading to double work and inefficiencies. This separation worsens communication and collaboration issues across teams, leading to increased administrative tasks, inefficient information retrieval, and a lack of a digital foundation for future developments.

Looking ahead to the TC PLM system, all the consequences from the previous paragraph remain, and failing to establish this connection poses even greater consequences. In an industry where agility and efficiency are of great importance [4], the case company could find itself falling behind competitors who have successfully integrated their processes. Additionally, there will continue to be no effective way for visualization and traceability. This could lead to slower time-to-market compared to competitors, decreased adaptability to market change, and ultimately a loss of competitive advantage.

6.4 Research Question Answer

The answers to the research questions are based on the results, synthesis, and previous discussions about connection value, challenges, and consequences if unsuccessful.

6.4.1 Research Question 1

What obstacles exist in linking 3D resource models to the product and process structure?

- **Technical constraint:** There are technical constraints regarding the filtering and positioning of connected resources in TC Classic. Additionally, TC PLM has technical constraints since it is still in the development phase.

- **Organizational challenges:** During the study it was entailed that there were organizational challenges in addition to the technical ones due to different ways of working approaches. It is important to make employees aware of contradictory investments such as WCE and TC PLM to collaborate and reduce double work effectively. It does not matter which of the strategies the company is going with, there will be changes to the working approaches within the organization.

6.4.2 Research Question 2

How can 3D resource models be integrated with product and process structure with current and future methods?

- **TC Classic:** In the system, two different work methods can be applied to integrate 3D resource models to the product and process method. The presented interim solution resolves the connection in TC Classic while not in TC Web Search, however with some issues of filtration and positioning hardship. The WCE strategy also ensures connection in TC Classic and allows for filtering and positioning, however, it requires a change of work methods within the FA department.

- **TC PLM:** TC PLM is still in the development phase, however, the plan is to integrate the BOE with the BOP. Since there has yet to be a decision regarding how to address the issue, various approaches can be considered. One approach involves designing the system to align with the established and proven WCE way of working. Alternatively, a new methodology could be developed within TC PLM based on the current methodology in TC Classic.

6.4.3 Research Question 3

What are the benefits of applying a common connection source, and how does it impact production development?

- **Efficiency:** Transparency, traceability, and visualization together with cross-functional collaboration will increase the efficiency and speed to market at the FA department.

- **Quality:** Work planning, cross-functional collaboration, and visualization would increase the quality of the process with indisputably the product. While also improving the verification and control checks.

6.5 Method Discussion

In evaluating the methodology it is crucial to consider its appropriateness and relevance to the research objectives. The chosen method, Design Research Methodology (DRM) was deemed suitable for the study as it provided a structured framework for investigating complex organizational processes and identifying areas for improvement. The iterative nature of DRM allows for continuous refinement of the research approach based on emerging insights, therefore allowing for more effective and deeper answers to the research questions [38]. It is worth noting that as mentioned under delimitations the project outcome was not physically implemented due to time constraints and low maturity in TC PLM. Instead, the result was presented to experts and improved based on their input.

A majority of interviewees were chosen by the case company supervisor which could introduce some bias into the result. However, interviewees were asked to help identify further interview subjects to mitigate bias besides conducting a stakeholder analysis. Additionally, the bias should be reduced due to interviewing various departments. Preferably more interviews with Industrialization and the Plant department should have been conducted to increase validity and get a deeper understanding of their needs regarding PIIs and to evaluate solutions.

It is acknowledged that alternative methods could have been used to get a different result. For instance, a purely quantitative approach could have provided more statistical rigor however it may have overlooked some qualitative insights. Similarly, a purely qualitative approach would have provided deeper information however it would have lacked the systematic analysis present in DRM.

Throughout the study, a handful of challenges were encountered, primarily related to data collection. Securing interviews with key stakeholders proved to be time-consuming and occasionally challenging due to scheduling conflicts and organizational constraints. Additionally accessing certain documents and tools was restricted mainly related to TC, limiting the depth of analysis in some areas and forcing the research to rely on data from interviews. Finally, as there is ongoing internal development for both WCE and TC PLM, the findings are most relevant to the maturity levels observed at the time of the research and may not reflect the current or future realities.

6.6 Ethical and Sustainability Aspects

The conducted research has ethical aspects to take into consideration, both regarding the project's execution and results. The research basis was the conducted interviews and the purpose was to understand and propose improvements to the inefficiencies of current work. Ensuring the interviewees' anonymity was of importance where only department belongings have been disclosed to minimize the fallout of this project.

While there was mostly positive feedback regarding the study, problems of why it should be implemented and challenges of implementing the connection of product and resource arose. While not identified, the change in the way of working within larger operations opens the possibilities of a chain reaction where improving one's work could increase another one's workload. Even though not evaluated it can create controversial reactions to the suggestions.

The delivered PIIs are the basis for the instructions for the assembly operators. It can be discussed that BOE and PII connection together with earlier collaboration with PII customers allows a better work environment for the assembly operators. While also allowing greater use of virtual verification's to improve physical quality and minimize scrap.

The project scope and results are connected to multiple sustainability development goals, as presented in subsection 1.3.1. Multiple of the different connection values are incorporated into several goals. Improved cross-functional collaboration can enhance transparency, efficiency, and connection to foster innovation and infrastructure aligned with both goal 9 and 17. The integration of resource models and processes improves the work environment for the engineers with accessible data, visualization, and traceability which promotes efficient use of resources and reducing redundant waste aligns with goal 8, 9 and 12. These improvements lay the base for better virtual development which indirectly in the future minimizes the physical development to mitigate the environmental impact and improve time-to-market by enhancing the productivity, aligned with goal 8 and 13.

6.7 Future Development and Improvements

During the thesis project, future areas of development have been identified, both intersecting with the scope of this study and other interesting areas. Starting with a future project investigating the differences between the then implemented TC PLM and TC Classic, examining and evaluating the aspects of the way of working regarding the new and old way. Because TC PLM is not implemented yet, there could only be discussed how the change will be, making a comparison investigation with evaluation and possible improvement areas interesting. The introduction of a new system is time-consuming, allowing an evaluation during the transition phase.

The customers of the PIIs raised awareness of the difficulties interpreting the PIIs. An evaluation of how different automotive companies work with similar instructions could be investigated if possible. In the time of updating the PII creation system, is an excellent opportunity to change the content and layout of the PIIs, ensuring that they support everyone involved in the best way.

As the process structure is the information carrier instead of the PIIs in the WCE way of working, the creation and delivery of the PIIs were not investigated. The investigation needs to be performed, where focusing on the process structure instead. Future possible solutions for example automatically generating the PIIs as a delivery should be explored to potentially error-proof the PIIs more while improving the efficiency and time to market.

It is acknowledged that the company in question is downsizing the number of programs for a common source, reducing search waste in different platforms, improving efficiency, and decommissioning old systems. This integration analysis should be performed, collecting the plan and investigating the necessary steps to enhance the interaction between the different departments. The main reason is to have the required organizational alignment and communicate efficiently.

7
Conclusion

This chapter presents the project's conclusions based on the different examined implementations selections.

This project has successfully identified the integration abilities of the virtual resource 3D models to the process structures necessary for the company to improve efficiency, quality, and digital transformation.

The project's findings conclude that the presented interim solution would help with planning and performing control checks however it does not help with visualization or verification due to the filtering issue. There is no way to effectively filter out wanted tools and resources with that way of working. Additionally, the linkage of resource models in the PII report in Teamcenter (TC) Web Search was not identified, affecting the customers of the PIIs.

Investigating the new ways of working with the World Class Engineering (WCE) strategy revealed that the strategy will solve multiple different current challenges and issues. The implementation of the WCE way of working together with the PERT function in TC will solve the filtration issue at hand in the current interim solution. Hence, the WCE strategy will solve and develop the issues at hand, however, it needs an organizational change within the department.

The implementation of TC PLM is planned to happen during 2025 but the findings conclude an uncertain time plan. Continuous uncertainties with the system implementation, way of working, and changes are recurring as it is still in the development phase. On the other hand, the distinguished problems and issues today are established and purposed to be settled.

Lastly, this report describes the current issues and problems while simultaneously providing a synthesis of how to navigate these problems. The future recommendation for the case company is to prioritize the way of working to WCE strategy, connecting the resources to the product and the process in the process structure. Additionally, employing PERT for accurate sequencing of operations. This solution of connecting the resources to the process structure with WCE should later be moved to TC PLM when sufficient maturity is reached. In addition, TC PLM must be tailored to the WCE way of working and not counteract with WCE as it is the digital strategy for the case company.

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A

Interview Guide/Template

This appendix presents the interview guide used during the interviews, the appendix is divided up between the different questions asked to the stakeholders at each department. Starting each interview, general questions was asked to each stakeholder before proceeding with the interview guide based on department association.

General Questions

- Is it okay if we record this interview?
- What is your work description and how long have you had this position?
  - What are your main tasks?

A.1 Manufacturing Engineering Commodity Questions

- What value would it give to connect BOE to the PIIs for the company?
  - Who benefits from the connection of BOE and PIIs and why?
- How can it help with your work by adding 3D models to the PII?
  - Why is it a need? Cross-collaboration, control checks, etc.?
  - How would you like to have the resources connected with the process?
  - How can the issue of connecting equipment to the tooling field in PII in TC Classic be addressed? Is there a solution?
  - What is the difference in PII and BOE connections between different departments?
  - If 3D models of resources are connected to the PIIs does it reduce information search?
- How does the connection affect the employee doing the work?
  - Does it have any drawbacks of having BOE and PIIs connected?
  - What do you do when tooling information is missing from the PIIs?
  - Should all resources be connected or only a select amount?
- What are the consequences of not connecting the BOE and PIIs?
- Do you experience a lot of silo work between different departments?
- What is covered in a VBE today? Are resources shown?
- How will TC PLM address what TC Classic does not solve? What does it replace besides PII creation?
  - What value does TC PLM add?
  - What value does an interim solution add before TC PLM is operational, and why not wait?

  - How do you envision the PII solution regarding tooling information in TC PLM?
  - What new features in TC PLM regarding BOE and PIIs are most important within tooling?
  - How will the filtering and positioning issues be solved in TC PLM?
- How will TC Classic and TC PLM relate to each other in the future regarding tooling?
- What are the consequences and risks if TC PLM does not succeed?
- What is the future regarding the BOE and PII connection?
  - From your perspective and the company's, why is it value-adding to move towards WCE?
  - How do you envision it with WCE in the picture?
  - What challenges exist in implementing WCE? Why are these challenges present?
  - Will WCE affect how tooling is linked to PIIs in TC Classic/PLM?
  - How will the filtering and positioning issues be solved with WCE?
  - What is the timeline for WCE in each PLM system?
- From your perspective and the company's, what are the consequences of not implementing WCE?

A.2 Manufacturing Engineering Digital Questions

- Why is there a need to connect BOE to the PIIs?
  - Who benefits from the connection of BOE and PIIs and why?
  - How would you like to have the resources connected with the process?
  - If 3D models of resources are connected to the PIIs does it reduce information search?
- What is the difference in PII and BOE connections between the different departments?
- What are the challenges of connecting the BOE and PII?
- What are the consequences of not connecting the BOE and PIIs?
- Does it have any drawbacks of having BOE and PIIs connected?
- What value does TC PLM add?
  - How do you envision the PII solution regarding tooling information in TC PLM?
  - How will the filtering and positioning issues be solved in TC PLM?
- What are the challenges with implementing TC PLM? Why?
- What are the consequences and risks if TC PLM does not succeed?
- Why is WCE important?
  - How will WCE be approached in TC Classic and TC PLM?
  - What is the timeline for WCE in each PLM system?
- What challenges exist in implementing WCE? Why are these challenges present?
- From your perspective and the company's, what are the consequences of not implementing WCE?

A.3 Plant Questions

- What are you using the PIIs for?
  - When during the process are you receiving the PII?
  - What is the most important information from the PII?
  - What do you use the tooling information from the PIIs for?
  - Is there any information missing from the PII?
- What do you do when tooling information is missing from the PIIs?
  - Do you experience a lot of silo work between different departments?
- How can it help with your work by adding 3D models to the PII?
  - What value would it add to your work?
  - If there are 3D models of resources connected to the PIIs does it reduce information search?
  - What other advantages can you think of? Cross-collaboration, verification etc.?
- What are the consequences of not connecting the BOE and PIIs?

A.4 Manufacturing Engineering Industrialization Questions

- What are you using the PIIs for?
  - What is the most important information from the PII?
  - What do you use the tooling information from the PIIs for?
  - Is there any information missing from the PII?
- What do you do when tooling information is missing from the PIIs?
  - Do you experience a lot of silo work between different departments?
- How can it help with your work by adding 3D models to the PII?
  - What value would it add to your work?
  - If there are 3D models of resources connected to the PIIs does it reduce information search?
  - How would you like to have the resources connected with the process?
  - What other advantages can you think of? Cross-collaboration, verification etc.?
- How would you like to have the resources connected with the process?
- Do you see any challenges of connecting the BOE and PIIs?
- What are the consequences of not connecting the BOE and PIIs?

A.5 Digital Engineering Questions

- How can the BOE be connected to the PIIs in the BOP structure?
  - What value would it give to connect BOE to the PIIs for the company? What is the need?
  - Should all resources be connected or only a select amount?

  - How can the issue of connecting equipment to the tooling field in PII in TC Classic be addressed? Is there a solution?
- Who benefits from the connection of BOE and PIIs and why?
  - How does this affect the employee doing the connection?
  - Does it have any drawbacks of having BOE and PIIs connected?
- What is the future regarding the BOE and PII connection?
  - How does current working process and WCE differ?
  - Why is it value-adding to move towards WCE? From your perspective and the company's?
  - How will the filtering and positioning issues be solved with WCE?
  - What is PERT? And what is its significance?
- What challenges exist in implementing WCE? Why are these challenges present?
- What are the consequences of not implementing WCE? From your perspective and the company's?
- How will WCE be approached in TC PLM?
  - Why is it worth putting resources towards WCE in TC Classic when TC PLM is under development?
  - What is the timeline for WCE in each PLM system?

B

Process and Inspection Instructions

The Process and Inspection Instructions template created from the information given in Teamcenter Classic software.

Operation

Type	EL	No	Ref	CC	Operation description	Key Symbols	Work Height	Work Zone	Station no	Variant	TMU	Intro Week
O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	

Structure

Ref	QTY	Part No	Part Name	Traceability	Variant	CO No	CO Issue	Intro Week
S1	S2	S3	S4	S5	S6			S7

Tool

Drawing No	Tool Name	Operation	Plant	RPM	Torque [NM]			Angle [Deg]			Gradient Control		Inspection			
					Target	Min	Max	Target	Min	Max	Gradient Shift [%]	Extra Final Angle [DEG]	LCL/ LC PSE	UCL/ UC PSE	LIL/ min PSE	UIL/ max PSE
Tg1	Tg3	Tg5	Tg6	Tg7	Tg8	Tg9	Tg10	Tg11	Tg12	Tg13	Tg15	Tg16	Tg18	Tg19	Tg20	Tg21

Notes

N1

Attachments

Attachment Name	Modified Date	Type
A1	A2	A3

PL BOP Information

Effectivity	Type Designator	Plant/Line
PL1	PL2	PL3

PR BOP Information

Effectivity	Type Designator	Type Designator-ART-Function Group
PR1	PR2	PR3

Revisions

Effectivity	Change Date	CN Number	Changed By	Reason for Change
Rev1	Rev8	Rev9	Rev2	Rev6

General variant	Title (Description)
H7	H8

Issuer	Issue Date	Intro week	Type	PII no
H9	H4	H3	H2	H1

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