JÖNKÖPING UNIVERSITY
School of Engineering

Analysis of Simulation Modeling

A Study of Simulation Modeling Programs in the Context of Manufacturing Processes

MAIN AREA: *Production Systems*
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This thesis is conducted at the School of Engineering at Jönköping University within Production Systems. The author is responsible for the opinions, conclusions, and results herein.

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Abstract

Purpose: The main goal of this master thesis consists of the study and comparison of simulation modeling programs. Specifically, two different programs will be analyzed. The research also concerns the development of a general decision matrix to guide the selection of simulation programs in the context of manufacturing processes. The emphasis lies on semi-automated manufacturing processes.

Method: The applied methods within the master thesis focus on the usage of a literature review as well as two single case studies. The literature review forms the foundation for the selection of the simulation modeling programs and the definition of the benchmarking criteria. While one case company shows how the study can be implemented in realistic scenarios, the other case is used to underpin the findings from the literature review with opinions from the industrial context. The second one regards the development of the benchmarking criteria. The data is collected through observations, time studies, interviews, and a questionnaire.

Findings: The findings cover the case study which was chosen as a semi-automated manufacturing process. The example is divided into four distinct workstations which include manual handling, robotic interactions, and a conveyor system as transportation. The selection process for the simulation modeling programs was mainly based on the conducted literature review. Due to the focus on manufacturing processes, the decision was made to the programs *Visual Components* as well as *3D Experience – DELMIA*. The development of the benchmarking criteria was also part of the findings and represents a crucial aspect for the following analysis of the simulation modeling programs. The results were drawn from the literature review as well as the conducted interviews. In total six criteria groups, each with three sub-criteria were defined. The questionnaire allowed the ranking of the importance level for the defined criteria.

Implications: The research identifies the strengths and limitations of both simulation modeling programs. The analysis was conducted based on the selected criteria groups and sub-criteria which take the perspective of experts from the industry into account. Furthermore, a general decision matrix is part of the outcome. It enables transferability for other companies with the same focus on manufacturing processes.

Delimitations: The master thesis focuses on the comparison of two simulation modeling programs within the manufacturing context. One semi-automated manufacturing process of the case company builds the foundation for the analysis. However, the thesis will not provide completely developed simulations. The focus lies on a broad comparison and analysis that takes several distinct criteria groups into account. The depth of the analysis and findings is influenced by the timeframe of the master thesis project.

Keywords: Simulation modeling; 3D Experience – DELMIA; Visual Components; manufacturing processes; decision matrix; criteria

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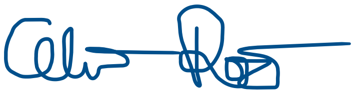

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List of Abbreviations

Abbreviation	Full Name
ABS	Agent-Based Simulation
AGV	Automated Guided Vehicle
AR	Augmented Reality
CAD	Computer-Aided Design
CPU	Central Processing Unit
DES	Discrete-Event Simulation
DT	Digital Twin
KPI	Key Performance Indicator
IoT	Internet of Things
NASA	National Aeronautics and Space Administration
OLP	Offline Programming
SD	System Dynamics
SEK	Swedish Krona
SME	Small and Medium-Sized Enterprise
VDI	Verein Deutscher Ingenieure
VR	Virtual Reality

1. Introduction

This chapter provides the reader with an overview and background of the entire thesis conducted in the context of modeling simulation software as digital twins. The problem statement is presented by the author, followed by the purpose and research questions that guide the execution of the work. Finally, the delimitations and the outline of this thesis are depicted.

1.1. Background

In recent years, the manufacturing industry has been subject to a constantly changing environment and demanding requirements. Digitalization as part of the technological transformation, and globalization presents crucial influencing factors leading to greater efficiency and improvement possibilities *(Kraus et al., 2021)*. However, increased competitiveness and customer satisfaction are shaping the landscape of the manufacturing industry and setting high expectations *(Sahu et al., 2023)*. Besides continuous improvement and high performance, important deliverables within this area consist of autonomy and modularity. Nevertheless, recent global crises have strongly moved resilience, which is defined as the adaptability of changes, and sustainability to the fore *(Höse et al., 2023)*.

Both resilience and sustainability describe central aspects of the recent Industry 5.0 development introduced by the European Commission during the global COVID-19 crisis in 2020. Based on Industry 4.0 which has mainly dealt with modern technologies and big data, the following industrial transformation focuses on a sustainable and highly adaptable industry with the well-being of the worker at the center of manufacturing processes *(Breque et al., n.d.)*. The European Commission defined enabling technologies that present the technological framework of Industry 5.0. The focus lies on human-machine interaction, artificial intelligence, and sustainable materials. Moreover, digital twins and simulation are also defined as one of the enabling technologies *(Müller & European Commission. Directorate-General for Research and Innovation., n.d.)*.

The concept of digital twins, introduced by Dr. Michael Grieves in the early 2000s, defines a virtual reflection or mirroring of a physical object as well as a system *(Grieves, 2005)*. Its dynamic nature allows the analysis of real-time data which leads to a greater understanding of the characteristics and behavior of the focus area. Additional benefits relate to faster decision-making processes, predictive maintenance, and ease of optimization procedures. Digital twins enable high connectivity across several industries, a virtual representation of physical systems, and real-time monitoring. Therefore, they contribute to the sustainability shift *(Rosen et al., 2015)*. Within the manufacturing industry, simulation modeling is often used as a representation of the existing production processes and systems. The analysis of dynamic data and real-time calculations combined with illustration and visualization of complex scenarios facilitate optimization efforts. In addition, efficient error localization and adjustment studies are possible without having to adapt the physical production system. Consequently, simulation modeling as part of the digital twin concept has the potential to foster modularity, flexibility, and sustainability in manufacturing *(Ebni et al., 2023)*.

1.2. Problem Statement

The integration of simulation modeling to analyze and optimize processes within the manufacturing industry holds several advantages. As industries aim for efficiency, sustainable decision-making capabilities, and cost-effective productivity, the usage of simulation modeling programs becomes crucial. Due to those requirements, the significance of those programs is experiencing significant growth *(Senn-Kalb & Mehta, 2023)*. With around 3,200 million U.S. dollars, the biggest market value of the simulation program market lies in North America, while Asia-Pacific, Japan, and Europe lie around a similar value with a little bit more than 2,200 million U.S. dollars *(BIP Research, 2022)*. As proven in a statistical analysis, the revenues from the simulation and analysis market grew steadily and will continue to do so. It is assumed that in 2024 the market will reach a revenue of 10.3 billion U.S. dollars which represents almost one billion dollars more than in the previous year *(Statista, 2020)*. This development also leads to an increased number of available software simulation tools. A list of discrete-event simulation programs illustrates just an extract of potential solutions available in the current market. The author presented 39 different simulation programs, analyzed them, and drew conclusions based on the comparison *(Felkl, 2023)*.

Despite the growing importance of simulation modeling programs and the dynamic nature of technological advancements, the lack of a comprehensive framework for supporting the evaluation and selection processes of appropriate simulation programs is evident within the research. To name some examples, in the early 1990s, Jerry Banks carried out research on criteria and methodologies for the evaluation of simulation tools. The result consists of a comprehensive list of features that can be defined as the basic framework that is still applied these days *(Banks, 1991)*. Similar analyses were conducted by Lesley Davis and Glyn Williams with the usage of an analytic hierarchy process *(Davis & Williams, 1994)*. In comparison, Vlatka Hlupic and Amardeep Singh Mann focused more on the development of a system for the selection of simulation programs *(Hlupic & Mann, 1995)*. However, the technological landscape has changed over time which has produced some of the outdated evaluation techniques. In addition, several studies have compared specific simulation modeling programs while others were left out. In 2016, a list of the world's most popular and used discrete simulation modeling programs for the application of manufacturing processes was created to analyze which programs are used most frequently *(Dias, Vieira, Pereira, & Oliveira, 2016)*. Other researchers focused on the development of a framework comparing 20 different simulation modeling programs *(Cimino et al., 2019a)*. Another study specialized on the benchmark of the programs called FlexSim and GPenSIM *(Krenczyk, Davidrajuh, & Skolud, 2019)* and a project focused on the programs ARENA and AnyLogic *(Leng et al., 2023)*. Even though there is a notable number of comparative studies available that address the suitability of several simulation programs, other widely used tools such as the 3DExperience DELMIA, Siemens Plant Simulation Tecnomatix, or Visual Components are barely analyzed. As the analysis above illustrates, there is a need to close the considerable gap in comprehensive evaluation frameworks that support the selection and decision-making process of suitable software programs. Moreover, the key criteria and appropriate selection factors require an update to deal with the constantly changing environment of technologies and requirements in the manufacturing industry.

1.3. Purpose and Research Questions

The presented master thesis aims for developing knowledge and supporting organizations in the selection of simulation modeling programs within the manufacturing context. The focus lies on a comparative analysis between two different modeling programs based on a concrete example of a semi-automated manufacturing process. The latter presents the main application area the master thesis addresses. Moreover, the development of a general decision matrix deals with the complexity of the selection process for simulation modeling programs. The matrix aims for transferability to other organizations with the same focus on manufacturing processes. To reach the purpose of the thesis, the following list shows the research questions that will provide guidance toward the main outcome and will be analyzed in-depth during the master thesis.

RQ1: What are the most relevant application areas for simulation modeling programs?

RQ2: What kind of simulation program is suitable for manufacturing process planning and optimization and what are the reasons for this suitability?

RQ3: What are the key criteria and features required from the simulation program to contribute to manufacturing process planning and optimization?

RQ4: How can the analysis and comparison of the key criteria and features be used for supporting organizations with the selection of simulation modeling programs?

1.4. Delimitations

The delimitations of the presented master thesis will be listed below:

1. The scope of the study lies in the broad analysis between two chosen simulation modeling software programs. Therefore, a universal application to all simulation tools will not be guaranteed.
2. The manufacturing industry presents the focus area of the studies. More specifically, the case study example of a semi-automated manufacturing process will be the field of interest.
3. The thesis covers only a limited, temporal snapshot. Due to ongoing changes in technology, demands, and success factors, the presented study does not guarantee long-term applicability. Continuous research and further studies are recommended.
4. The methodology used combines a literature review as the foundation. In addition, a qualitative and quantitative analysis is based on two case studies. The data will be collected through interviews, a questionnaire, observations, and time studies.
5. The usage of both simulation programs will be guaranteed based on the case study example. However, it doesn't imply a complete development of simulations. The focus lies on chosen features, criteria groups, and sub-criteria.
6. The thesis will be conducted by one master's student of the program *"Production Engineering and Management"*. The thesis is constrained by a period of approximately 20 weeks. Both limitations will influence the detailed degree of the analysis and the conducted findings.

1.5. Outline

The report is based on the following structure:

Chapter 1: The first chapter deals with the introduction of the master thesis. It provides the reader with background information and explains the problem addressed during the thesis. The overall purpose and research questions give clarity to the outcome that will be aimed for. The delimitations and the basic structure of the report form the end of the introduction.

Chapter 2: The focus of the second chapter lies in the theoretical framework. A fundamental and general understanding of the addressed theories is required. It analyzes the research questions based on available literature and supports the background knowledge of the author and reader.

Chapter 3: The methodology used for this master thesis will be presented in the third section of the report. The framework is split into three methods. The literature review provides background information regarding the selection of the simulation programs as well as the development of the benchmarking criteria. The case study mainly targets the third research question, forms the foundation of the entire master thesis, and provides the manufacturing process to be analyzed. The conducted interviews aim for a deeper understanding of the criteria groups based on industry-related expert opinions, while the questionnaire supports the importance level ranking of the criteria.

Chapter 4: The fourth chapter summarizes the data collected during the qualitative and quantitative studies described in the previous section. Besides a current state analysis of the process flow of the case study, the decision for the simulation programs will be justified. The selection process of the benchmarking criteria and key features also constitutes a part of the presented chapter.

Chapter 5: The main part of the report will be addressed in chapter five and depicts the results of the case study. The observations of the current state analysis combined with the findings of the simulations using both simulation programs will be part of this chapter. Both programs will be analyzed based on the criteria groups and sub-criteria selected. Moreover, the development of a decision matrix for the selection process of those simulation programs will be conducted. The matrix aims for transferability for other organizations within the manufacturing context.

Chapter 6: In the sixth chapter, a critical reflection will be carried out. The methodology, the findings, the research questions, as well as the analysis, present the focus areas of this technical discussion.

Chapter 7: The conclusion presents the last chapter of this report. The first part covers the reflection of the findings and the overall thesis procedure. In addition, an outline will be drawn which will contain suggestions for future research and analyses.

2. Theoretical Framework

The second chapter focuses on the fundamental and general understanding of the topics and areas addressed during the thesis. It analyzes the background information on which the research will be based.

2.1. Manufacturing

The manufacturing industry represents the second-largest sector of the general economy *(Baudin & Netland, 2022)*. The term is translated to *made by hand* from Latin and is defined as a repeatable transformation process from material into finished goods conducted within factories and production facilities *(Chandler, 1977)*. The profit generation through the sale of the finished goods to customers or consumers presents the main target of this industrial sector *(Marsh, 2018)*. Therefore, it is often displayed as the input-output model while the process in between is represented by manufacturing *(Baudin & Netland, 2022)*. Often, manufacturing is equated with the term production and classified by the production quantity and the product variety *(Groover, 2010)*. The factories as manufacturing facilities are mostly equipped with a variety of machinery, tools, and information systems that support the manufacturing process *(Badiru, 2006)*. Moreover, the human operator is crucial for production. Various skills are needed which combine manual processes with the usage of machines and tools. The automation level constantly increases which leads to a close collaboration between robots, automated machines, and the human operator *(Holweg, Davies, Meyer, Lawson, & Schmenner, 2018)*. Consequently, the manufacturing plant represents a combination of methods, materials, machines, and humans. Its procedures can be divided into processing operations as well as assembly operations which depend on the main outcome of the manufacturing company *(Groover, 2010)*. That's why systems thinking is indispensable for getting a holistic understanding of the connections and dependencies of all elements within the production process *(Baudin & Netland, 2022)*. While the idea of an effective and efficient factory is a vision, the improvement of optimization and productivity are common goals. Factory layout planning presents one significant option for process analysis and continuous improvement *(Esmaeilian et al., 2016).*

2.1.1. Factory Layout Planning

Factory layout planning represents one aspect of manufacturing operations. The main goal consists of the achievement of a high throughput. Different scenarios will be planned and compared to identify the most efficient layout. This evaluation process will lead to a reasonable decision which will increase the productivity level of the manufacturing processes *(Süße & Putz, 2021).* While inadequate factory layout planning causes an increase in logistics and operating costs *(Pourhassan & Raissi, 2017)*, the research discovered that effective planning and factory design might be responsible for fundamental cost savings in the industrial context. Consequently, the conduction of the factory layout planning requires an efficient approach to enable maximum improvement and profitability *(Besbes et al., 2021).*

To achieve the mentioned targets, a standardized planning process might be beneficial. For instance, the German Association of Engineers (VDI) developed guidance 5200 which describes the most important steps taken for factory layout planning *(Verein Deutscher Ingenieure, 2011)*:

1. Preparation
2. Structure planning
3. Detailed planning
4. Execution planning
5. Execution *(Clauss, 2013)*

This structure matches another approach which divides the planning into two phases. While the first phase focuses on the basic block layout with the structure and arrangement, the material as well as the information flow will be carried out within the second phase *(Jerin Leno et al., 2012)*. The former relates to the structure and detailed planning, the latter more to the execution planning. However, the general planning process can be almost always applied to all different types of factory layouts. A well-designed layout plan holds the importance of reducing material flow expenses, achieving desired production rates, and enabling continuous material movement *(Xu et al., 2012)*. Broadly speaking, it can cover manual, semi-automated, or fully automated manufacturing processes, which primarily vary depending on the product throughout the entire production process *(Zhang et al., 2022)*. Overall, layout planning constitutes a complex task balancing out the expectations of all stakeholders and taking regulations and norms into account *(Schenk, Wirth, & Müller, 2014)*. Traditionally, it was done in a 2D approach *(Melcher et al., 2020),* either manually or digitally *(Aurich, Stonis, & Nyhuis, 2018).* Recently, a shift from 2D layouts to 3D models and simulations is visible. Three-dimensional layouts offer various benefits such as a higher illustration level and therefore a better understanding and communication *(Nafors et al., 2020).*

2.1.2. Trends

The mentioned shift to a higher illustration level in the previous section responds to the overall development in the manufacturing industry. To increase the productivity level, predictive strategies, higher flexibility, and digitalized optimization are required *(Machado & Davim, 2023)*. While the main goal is improved productivity and competitiveness, it still represents one of the most significant challenges for manufacturers *(Abdulnour et al., 2022).* Reconfigurability and flexibility are becoming increasingly important for the success of a production company *(Inkulu et al., 2022).* Additionally, a simulation model might support the productivity level of the general manufacturing processes *(Caggiano et al., 2015).* Digital technologies enable the development of the digital landscape of the industry *(Frank et al., 2019).* Driven by the technological transformation *(Rebentisch et al., 2018),* more data arises and requires improved management systems *(Biffl et al., 2017).* Meanwhile, the Industrial Revolution continued based on the trends described previously. Manufacturing is under pressure to deliver several aspects such as mass customization, higher individualization, and a human-centric approach combined with the ability to react quickly and the improvement of products and processes. This leads to a change in the industry *(Leng et al., 2022).*

2.2. Industry 5.0

The industry develops constantly and has reached the fifth paradigm shift which is framed by human-machine collaboration, the ability to adapt to changes, and the focus on sustainable actions *(Breque et al., 2021)*. Besides the transformation process to Industry 5.0, characteristics and enabling technologies such as the Digital Twin and simulation modeling programs will be discussed in the following sections.

2.2.1. Transformation Process

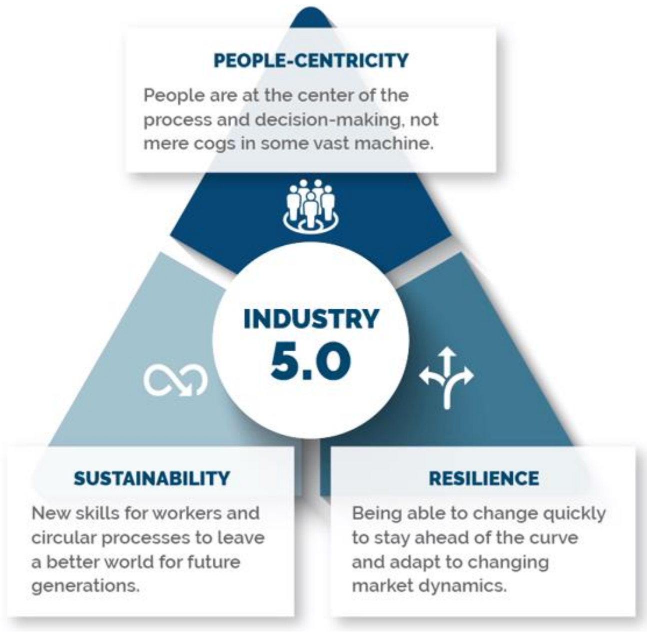
The fourth industrial revolution was presented for the first time at the Hannover Fair in 2011. The increase in automation and advanced technologies are key points that aim for improved efficiency in the fourth industrial revolution was presented for the first time at the Hannover Fair in 2011 *(Hayat et al., 2023; Kagermann, 2015)*. Industry 4.0 includes three main facets: the smart factory, which integrates data-driven processes and intelligent automation to drive innovation and productivity *(Kusiak, 2018)*; Logistics 4.0, which focuses on digitizing logistics and supply chain management through technologies like Big Data Analytics and Internet of Things *(Winkelhaus & Grosse, 2020);* and Operator 4.0, emphasizing human-machine collaboration and data-driven decision-making for enhanced ergonomics and safety *(Romero et al., 2020).*

Even though Industry 4.0 provides benefits such as efficiency improvements and innovative technologies, the challenges cannot be neglected *(Frank et al., 2019)*. Higher throughput rates combined with reduced decision-making control lead to resistance within the workforce. Furthermore, the integration of automation increased job loss fears *(Jacob et al., 2023)*. The need for improved sustainability based on the global climate crisis affects the manufacturing sector as well *(Nahavandi, 2019)*. Productivity, quality, and automation represent key aspects of Industry 4.0 *(De Felice et al., 2021)* while Industry 5.0 focuses on a human-centric approach *(Nahavandi, 2019).* It is only the question of whether Industry 5.0 can be seen as a continuation or a new revolution *(Machado & Davim, 2023)*. However, the characteristics and the importance of Industry 5.0 will be discussed in the following.

2.2.2. Definition and Characteristics

The European Commission mentioned Industry 5.0 for the first time in 2021 and defined it as a new paradigm shift within the industrial sector *(Breque et al., 2021)*. Since then, several definitions have evolved which focus on three key factors. A human-centric approach is the change to a higher degree of sustainability, and resilience to deal with uncertainty and risks *(Ivanov, 2023)*. The following *Figure 1* depicts those aspects in an illustrative way. Industry 5.0 promotes an increase in efficiency without the replacement of operators and a high trust level based on collaborative human-machine interactions. Compared to the previous industrial stage, the safety and autonomy of the workforce are crucial *(Enang et al., 2023)*. Operator 5.0 ensures the occurrence of Industry 5.0 *(Müller & European Commission. Directorate-General for Research and Innovation., n.d.).* People-centricity is closely linked to resilience, which underscores the significance of adaptability and mass customization in a time of evolving demands and conditions *(Enang et al., 2023).* Aligned with the third pillar of Industry 5.0, sustainability initiatives combine waste reduction, the transition to alternative materials, and the optimization of energy resources, among other measures *(Bag & Pretorius, 2022)*.

Figure 1: Three Pillars of Industry 5.0 (Raiche, 2022)



Industry 5.0 emphasizes human-centric manufacturing and fosters collaboration between automated systems, robots, and operators *(Nahavandi, 2019)*. It prioritizes green and sustainable practices for environmental protection and resource conservation *(Demir et al., 2019),* while also focusing on resilience to adapt to market dynamics *(Javaid & Haleem, 2020) (Ivanov, 2023)*. Essential technologies are crucial for realizing Industry 5.0's potential in the manufacturing industry.

2.2.3. Enabling Technologies

With the promotion of the circular economy, the workforce, and resilience, within Industry 5.0 new technologies play a crucial role *(Machado & Davim, 2023)*. The following list explains the most important technologies.

1. Intelligent *cobots* which stand for collaborative robots enable the work of human operators in a shared-automated environment. Constant safety and interactions are the most important aspects of this human-centric approach *(Castillo, Ortiz, Velásquez, & Saavedra, 2021)*.
2. The blockchain technology emerged from the finance sector but is often used in manufacturing. Transparency and traceability enable an optimized management of supply chains and manufacturing processes *(Yli-Huumo et al., 2016)*.
3. Cognitive artificial intelligence combines cognitive human skills with AI systems. The improvement of decision-making and collaboration between humans and machines is highlighted by this technology *(Bundy et al., 2023).*
4. Dynamic simulation and digital twins are essential technologies in Industry 5.0. By combining physical systems with the virtual world, proactive analysis and the monitoring of complex environments are supported *(Lu et al., 2020)*. In addition to optimization possibilities and predictive maintenance, the sustainable focus is useful for cost and resource savings *(Kaewunruen & Lian, 2019)*.

Several benefits of the mentioned technologies will be highlighted in the following. First, the monitoring and improved analysis of industrial data offer manufacturers an opportunity for preventive maintenance at different stages. This leads to an increase in productivity and efficiency. The usage of cobots supports human-machine collaboration in required situations *(Machado & Davim, 2023)*. On the one hand, innovative systems allow more functionalities and an improved focus on sustainable factors. Nevertheless, the adoption of new technologies involves risks that are important to analyze and manage. They require a huge amount of energy consumption which stands in a critical contrast to the sustainability approach *(Machado & Davim, 2023)*. Besides the environmental concerns, the dependency on technology grows which is accompanied by privacy and cybersecurity risks *(Saeed et al., 2023)*. Addressing these risks requires an improved effort from policies and standards to balance out the requirements of new technologies that might approach a higher level of industrial growth *(Cheatham, Javanmardian, & Samandari, 2019)*. In the following sub-chapters, the focus will lie on digital twins and simulation modeling as part of the enabling technologies for Industry 5.0.

2.3. Digital Twins

Digital Twins (DT) represent one enabling technology of the fifth industrial revolution. The combination of physical systems and virtual worlds provides the manufacturing industry with several benefits which will be discussed in the following sub-chapter.

2.3.1. Characteristics of Digital Twins

In the recent decade, the interest in Digital Twins constantly grew. Each year, more papers and articles are published which makes the mentioned technology a subject of discussion *(Lv & Fersman, 2022).* Within the manufacturing industry, DT has gained increasing significance due to Industry 5.0 and innovation requirements *(Sahal et al., 2021)*. The concept of DT was introduced by Dr. Michael Grieves for the first time in the early 2000s *(Grieves, 2005)*. Based on his introduction, NASA adopted the DT definition and technology for the space industry and developed it further *(Glaessgen & Stargel, 2012).*

Digital Twins can be defined as virtual representations of existing physical systems. Mirror, as a substitutional term, is also often used in combination with this technology *(Rosen et al., 2015).* In most cases, DT are split into three parts. The physical object or system represents the foundation in the real world. The virtual component illustrates the reflected entity and the connection between both *(Kritzinger et al., 2018).* Typically, DTs are categorized into three different levels. On this basis, the digital model describes the visualization of physical objects into simple models. It doesn't have to include a sophisticated illustration level. The digital shadow represents the second stage and builds up on the digital model level. It already allows monitoring based on data from sensors and other sources which are combined with the digital model approach. At the highest level, the digital twin is placed *(Kritzinger et al., 2018)*.

While the applications of DT started in the space and aviation sector, it is also used for the visualization of smart cities, the healthcare sector, and educational training. However, the manufacturing industry represents the most popular sector for the usage of DT *(Hu et al., 2021).* The main application areas within production systems are split into three segments. First, production planning and control which includes monitoring and the analysis of manufacturing processes *(Rosen et al., 2015).* The maintenance covers mostly the predictive and proactive assessment with strategies to extend the lifespan of processes *(D'Addona et al., 2017)*. The layout planning and design allow another area in which DT is commonly used within the manufacturing industry *(Uhlemann et al., 2017)*. The mentioned applications enable a high level of accuracy and sophisticated intelligence on the shopfloor *(Nee & Ong, n.d.).* The following section will discuss the benefits and challenges faced while using DT in the main areas.

2.3.2. Benefits and Challenges of Digital Twins

The usage of DT for manufacturing purposes aims for higher productivity and efficiency. In production planning, DTs are commonly used for simulating, monitoring, and optimizing production areas and manufacturing processes to ensure well-functioning operations. Its dynamic nature allows the analysis of real-time data which leads to a greater understanding of the characteristics of the focus area *(Rosen et al., 2015).* However, the main benefits and enablers of DT can be summarized in three keywords.

1. Modularity
2. Autonomy
3. Connectivity *(Rosen et al., 2015)*

Simulations and the focus on the optimization of production processes offer manufacturers the opportunity for continuous improvement based on facts. Furthermore, error handling can be done without manual efforts and the dynamic analysis of data. Another benefit can be seen in optimal decision-making due to the real-time data synchronization. Autonomy and flexibility will be improved as well *(van Dyck et al., 2023)*. Other benefits can be defined in resource savings, the adaptability to simulate changes on shopfloor layouts, the prediction of product dimensions, and the enabling of preventive maintenance. Consequently, DT technology provides a solution for improving the competitive position of companies by increasing productivity and accuracy *(Attaran & Celik, 2023)*. Manufacturing processes can be optimized without using many materials based on the simulation of different scenarios *(Mäkitie et al., 2023)*. Depending on the usage of DTs, sustainability aspects and predictive maintenance approaches can be improved *(Chen et al., 2023).* Therefore, the lifespan of equipment and other resources will be increased and the need for replacement reduced. This concept meets some principles of the circular economy and the expansion of the lifetime of products *(Chauhan et al., 2022).*

However, besides those benefits, some challenges must be addressed as well. Constant data integration and synchronization are required to keep DT up to date. This leads to a demanding usage of resources, not only in terms of complex networks and systems but also in the context of human abilities. Therefore, effective data management is indispensable, otherwise the storage and processing can lead to several problems. Especially for small and medium-sized enterprises (SMEs), the data management as well as the lack of standardization increases the complication of implementing DT *(Attaran & Celik, 2023).*

2.3.3. Enabling Technologies for Digital Twins

The key components of DT include several technologies. Modeling and simulation represent the main aspects of fostering the DT approach of representing the physical system in the virtual world *(Qi et al., 2021)*. To collect the data, which is required for building virtual entities, devices such as sensors are used in the manufacturing industry. The data, implemented manually or via importing features, is used in simulation tools or software programs. Cloud computing and management systems are responsible for data storage, analytics, and fast processing *(Berisha et al., 2022)*. In recent years, the development of AI, advanced analytics, and machine learning contributed to DT technology as well *(Ergün, Kocabay, Yesilcimen, & Parlaktuna, 2023)*. Moreover, Augmented Reality (AR) and Virtual Reality (VR) can also be combined with DT to improve visualization possibilities *(Azizi et al., n.d.)*. While other technologies and devices are required to fully utilize DT, simulation tools play a key role in this environment and will be discussed in the following.

2.4. Simulation Modeling

In recent years, the challenges for manufacturing industries have become increasingly interrelated, digitalized, and complex. As one aspect of the enabling technologies for DT systems, simulation modeling offers several benefits but also challenges which will be discussed in the following sections *(Borshchev & Filippov, 2004)*.

2.4.1. Definition of Simulation Modeling

Even though simulation modeling can be seen as one example of an enabling technology of DT, it is crucial to differentiate both *(Cimino et al., 2019b)*. However, in most cases, simulation modeling focuses on the investigation of scenarios while DT provides insights into real-time performance *(Murphy et al., 2020)*. Sakr et al. defined the difference between those two as DT presents "*what is happening*" while simulation modeling only focuses on "*what may happen*" *(Sakr et al., 2021)*.

Simulation modeling can be described as the process of developing a model to analyze certain variables, behaviors, or scenarios. Providing different input factors while analyzing their effect or the general outcome *(Bratley, Fox, & Schrage, 1987)*. It is mainly based on existing cases, but it doesn't have to be. While brownfield projects focus on already existing processes, greenfield projects cover plans or explorations. Overall, simulation modeling provides valuable insights that can be used for complex systems and situations *(Alcácer & Cruz-Machado, 2019)* but also in problem-solving or decision-making processes *(Shannon, 1992)*. Often, simulations are used in cases with a high uncertainty rate and in a low-budget environment to make use of the analyzed scenarios *(Malec, 2018)*. Simulation modeling is often structured into the system and processes as a foundation. The model will be created on top, while the experiments and simulations of the model enable the evaluation of the results and support optimization developments *(Burduk, Łapczyńska, & Popiel, 2021)*.

2.4.2. Application Areas of Simulation Modeling

Even though there is a need for educational and training purposes, manufacturing remains the key application area *(Axelrod, 1997).* Simulation modeling is often used in various research areas such as information and computer science, as well as mathematical and other scientific environments *(Shannon, 1983).* However, engineering, production, and manufacturing are by far the most common application areas of simulation modeling *(Shannon, 1992).* In terms of management and organizational areas, simulation modeling supports the integration of product design teams with production-related fields which enables certain communicative potentials *(Hughes et al., 2012).* In conclusion, simulation modeling is a useful tool that can be applied to various purposes. Furthermore, the importance and areas of use are growing due to technological change and the demand for high productivity and efficiency.

2.4.3. Benefits and Challenges of Simulation Modeling

Simulation modeling offers a list of benefits within all application areas. Due to its nature, simultaneous evaluation and experiments can be run without interacting with the actual system *(Mourtzis, Doukas, Vlachou, et al., 2014)*. Based on the statistical results, it allows the decrease of uncertainty while increasing the understanding as well as illustration level of the system's complexity. However, it always depends on the quality of the implemented data *(Unold, n.d.).* In general, forecasts, discoveries, and evaluations before implementation of an actual system are possible. This provides already valuable insights and supports a valid decision-making process *(Chung, 2004)*. Overall, three major benefits of simulation modeling can be pointed out:

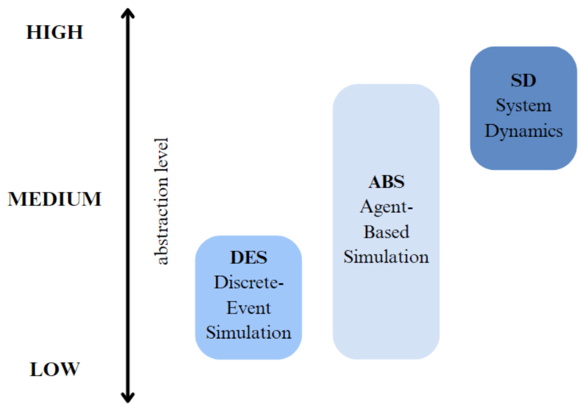
1. A rapid and affordable development and analysis of real-case scenarios while the risk assessment is considered *(Borshchev & Grigoryev, 2013).*
2. Experiments and simulations can be repeated as often as requested *(Banks, 1998).*
3. The graphical illustration level of simulations enables a quick understanding, exchange, and communication for all related stakeholders *(Galvão Scheidegger et al., 2018).*

Nevertheless, simulation modeling is associated with some challenges that delay its adoption and effectiveness across all industries. One significant challenge is the shortage of simulation engineers who can develop and implement complex models. This shortage limits the efficiency and scalability of simulation projects due to the potentially insufficient illustration of the reality. Moreover, it results in extended development times and increased resource demand *(Banks, 1998).* The high costs associated with licenses for simulation programs present a financial barrier for several organizations. Especially, SMEs cannot afford additional costs and the development length of simulation models *(Kagermann, 2015).* Combined with the fact that developed simulations are only linked to one specific case study, the reusability of the simulation models is low *(An et al., n.d.).* Moreover, challenges such as the lack of standardized frameworks or approaches *(Malec, 2018)* and the difficulty in representing models understandably prevent the reproducibility of simulations and increase the skepticism regarding the effectiveness level *(Robinson, 2020).* Finally, it is crucial to mention that it might be difficult to illustrate complex systems, human behavior, interrelationships of process flows, and unpredictable scenarios realistically. It is important to note that simulation modeling has its limitations *(Taylor et al., 2015)*.

2.4.4. Types of Simulation Modeling

Starting from a historical perspective, simulations emerged already with the development of the Monte Carlo simulation in the late 18th century and the first flying simulations around 1900. However, with the start of the digitalization era in the 21st century the virtual simulations as it is used nowadays began to grow *(Mourtzis, 2020)*. Based on the abstraction degree and the illustration level it is possible to distinguish different types of simulation modeling. Three major concepts focus on the modeling of manufacturing processes and material flows: System Dynamics (SD), Discrete-Event Simulation (DES), and Agent-Based Simulation (ABS) *(Tram, 2022)*. The following *Figure 2* clusters the three types within a common illustration and depicts their similarities.

Figure 2: Types of Simulation Modeling adjusted from (Tram, 2022)



System dynamics is a method for analyzing dynamic systems while utilizing continuous simulation to study their behavior over time. Developed by MIT Professor Jay Wright Forrester in the 1950s, it examines complex business and environmental systems *(Borshchev & Filippov, n.d.)*. The emphasis lies on so-called feedback loops. This concept uses stock and flow diagrams to illustrate dynamic relationships and interconnections within the system *(Galvão Scheidegger et al., 2018)*. As already depicted in *Figure 2*, the abstraction level is high. However, it includes strategic modeling and can focus on quantitative and qualitative perspectives *(Kunc, 2017)*. In SD modeling, inventories are seen as concentrations of resources. The flows in between those illustrate the influence factors on these clusters. The dynamics of the system are created with differential equations which emphasize the importance of a global perspective and systems thinking approach *(Sterman, 2000)*.

DES presents one of the most significant types of simulation modeling. In DES, systems are shown as processes, while steps of operations can include characteristics such as throughput, delays, and resource usage *(Borshchev & Grigoryev, 2013)*. Each operation is graphically represented in a process flowchart. Start and end events are labeled, and adjustments between these events are possible or allowed *(Vieira, Dias, Santos, Pereira, & Oliveira, 2018)*. The predefined events occur at specific time spots which can cause changes in the system's state and illustrate crucial information for the entire behavior

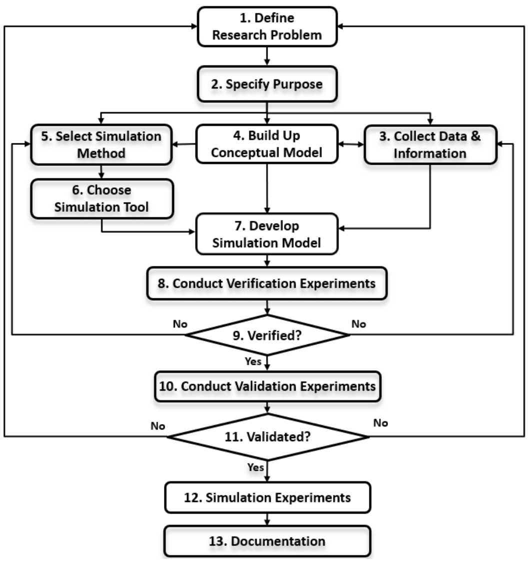
(Banks, 1998). The most used components in DES models are source and sink for the start and end, operations, human resources, and queues *(Galvão Scheidegger et al., 2018).* The input data requires an objective perspective. Entities in the simulation are interconnected process steps that influence each other and therefore the overall system's performance through their relationships *(Yin & McKay, 2018).*

Agent-based simulation focuses on creating models of complex systems and interacting agents *(Nicolae & Wagner, 2011).* These agents are characterized by specific attributes but operate autonomously to achieve pre-settled purposes within their defined environment. In comparison to the already mentioned simulation modeling methods, the behaviors of individual agents, their relations, and their interactions are at the center of interest *(Abar et al., 2017).* In this method, conditions and states for the agents are included which influence their actions and reactions. Rules and defined environments restrict specific events and occasions *(Barbati et al., 2012).* Individualism is emphasized. Therefore, subjective data and specific theories are often the foundation for the developed agents and their behavior. This allows the agents to make decisions in different designed environments *(Siebers, Macal, Garnett, Buxton, & Pidd, 2010).*

2.4.5. Process of Simulation Modeling

The procedure of the modeling is crucial for the overall success of the simulations and evaluations. A structured approach is required. The following *Figure 3* demonstrates and recommends a step-by-step process of how simulation modeling can be conducted. The process of simulation modeling begins with defining the research problem, identifying the stakeholders' interests, and specifying the overall purpose. Based on collected data and information, the conceptual model will be created followed by the selection process of the simulation method and tool.

Figure 3: Process of Simulation Modeling (Yin & McKay, 2018)



After the first six steps, the creation of the simulation model is performed. The concept will be translated into a detailed representation as a simulation model. A careful approach and a high level of detail are required. Overall, the development of simulation models represents a crucial and time-intensive phase within the entire process. However, it lays the foundation for the following analysis and optimization potentials. The verification as well as the validation follow the development phase. They are necessary to prove the reliability of the designed model. The simulation experiments are conducted, and the results are analyzed. While the final documentation represents the most important report of the modeling efforts, interim documentation is required throughout the entire modeling process. At various stages, data collection and reporting are indispensable to facilitate critical reflection and further improvement possibilities *(Yin & McKay, 2018).*

2.5. Software Tools

Simulation modeling can be divided into distinct types based on specific business sectors. However, the analysis, planning, and optimization remain at the center of the applications. The following section mainly focuses on Discrete-Event Simulation software tools that enable usage within the manufacturing industry. The development of potential simulation programs started in the 1990s. The researchers Nwoke and Nelson gave an overview of available computer simulation programs within the manufacturing industry in 1993 *(Nwoke & Nelson, 1993).* Two years later, an article showed a comparison of simulation tools used for production systems *(Kosturiak & Gregor, 1995).* At the end of the 20th century, a study was conducted that listed and compared eleven different simulation programs available and relevant for the industry at this point *(Klingstam & Gullander¨, 1999).* Those analyses laid the foundation for subsequent advancements in the same field. It can be seen as the starting point for a period of rapid innovation and expansion. By 2014, an intensive comparison of five distinct simulation programs was published. To name them shortly, the authors covered the DES simulation software AnyLogic, Arena, FlexSim as well as Witness. The fifth tool, Plant Simulation, was newly introduced. This analysis illustrates the dynamics in terms of simulation technology and the continuous development of innovative solutions to address industrial challenges *(Mourtzis, Doukas, & Bernidaki, 2014).* Moving to the year 2021, researchers categorized simulation modeling programs based on their approaches and application areas. Within the DES section, six programs were listed: AnyLogic, Arena, SIMUL8, FlexSim, Tecnomatix Plant Simulation, and WITNESS *(Kovbasiuk et al., 2021).* The reasons for this growth can mainly be explained by the improvement in computing power and the growing demand for data analysis and predictions *(Seyedan & Mafakheri, 2020).* However, the increasingly high complexity of systems also impacts the need for innovative simulation programs *(Kovbasiuk et al., 2021).* That's why the amount of available software simulation programs has increased as well. In 2023, an author presented a list of 39 currently used discrete-event simulation programs which illustrates just an extract of potential solutions available *(Felkl, 2023).*

The following paragraph focuses on some concrete examples of simulation programs that were analyzed in different research and journal articles. Tecnomatix Plant Simulation was developed by Siemens, a German company. Manufacturing companies can analyze production processes and optimize workflows or issues such as bottlenecks *(Bangsowmi, 2020). This* simulation program is categorized in the field of DES. The main application field lies in production engineering and logistics. One conducted research concluded that the Tecnomatix Plant Simulation presents a useful tool to increase the throughput of production processes and optimize overall resource consumption *(SIDERSKA, 2016).* In general, the program was often the center of research. To name some examples, one paper focused on the creation of an assembly shop *(Russkikh & Kapulin, 2020)* while other researchers developed and optimized a reworking station *(Daneshjo & Malega, 2021)*. In most cases, the software enables improved scenarios that can be used in realistic case studies for manufacturers *(Pekarcikova et al., 2021)*. While the previously presented simulation program focuses mainly on manufacturing, the program FlexSim provides several packages for various industries such as the healthcare sector and manufacturing operations *(Kliment et al., 2022)*. However, it is similarly structured as the Teconmatix Plant Simulation and supports companies with their optimization and productivity achievements *(Yaser et al., 2021)*. Another program is called Visual Components and was designed by a Finnish software company. This software tool aims for the development and optimization of manufacturing lines which include a certain level of automation and robotics *(Visual Components, 2024)*. Even though there is only a limited amount of research available, this software provides manufacturing companies with diverse programming options for robotic cells and offers similar functions and features compared to previously mentioned simulation modeling tools *(Mikhail, Bharti, & Alavizadeh, 2020)*. The software DELMIA developed by Dassault Systèmes represents one part of the 3D Experience platform. Two distinct master thesis projects discussed and analyzed the usage of DELMIA for the manufacturing field. The first study focused on the evaluation of the simulation programs for production flows with the main goal of further optimizing and implementing them in real-world settings *(Bernérus & Karlsson, 2016)*. The second master thesis emphasized production optimization in the context of DES. One selected manufacturing process was the center of the analysis *(Malmsjö & Nilsson, 2022)*. In general, DELMIA also allows production engineers to conduct detailed analyses of manufacturing processes to optimize production workflows. More in-depth studies are needed to cover the available functions and features of this simulation program *(Bernérus & Karlsson, 2016)*. The paragraph above described only a few examples of simulation programs, some of which are frequently used as subjects of research. Other ones are often analyzed in industry-related projects. In the end, all simulation programs aim for the optimization of processes, mainly in the manufacturing industry.

2.6. Summary

The manufacturing industry is constantly changing. Recent developments regarding increased digitalization, flexibility, and modularity as well as the Industry 5.0 shift towards a more human-centric, resilient, and sustainable manufacturing environment support the evolution of innovative technologies. DT and simulation modeling enable the analysis of real-case scenarios and the representation of entire processes as well as factories. The growing market for DES programs is reflected in an increased demand for predictive analytics, improved decision-making, and continuous monitoring of the existing processes. Overall, simulation modeling is deeply rooted in literature with Jerry Banks as a crucial researcher who shaped the foundation of this topic area. His work includes valuable comparisons between different simulation programs as well as the development of benchmarking criteria to set a standard for evaluating and selecting simulation programs. Therefore, Jerry Banks also presents the key author for the underlying master thesis with the main statements referring to his findings.

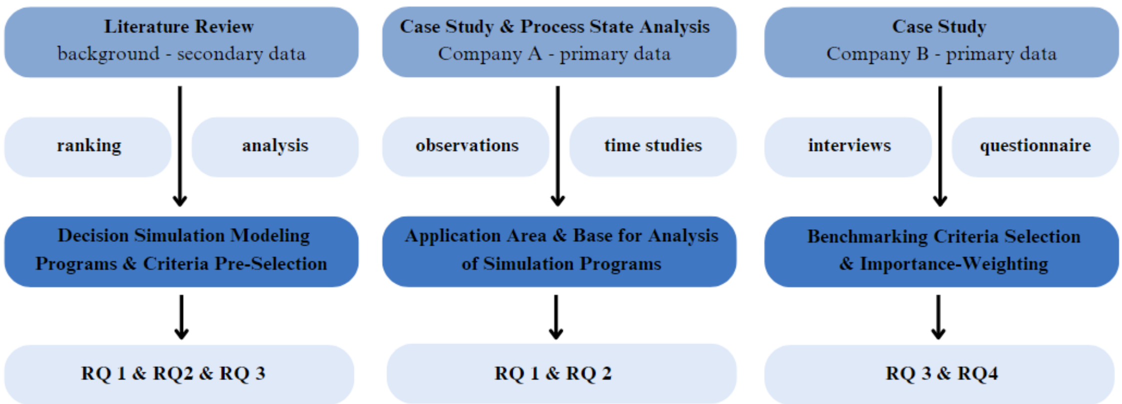
3. Methodology

The third chapter presents the methodology used for the conduction of the written master thesis. To begin with, the research process will be explained, followed by the literature review and the qualitative study. The latter is split into the first case study which included observations and time studies and the second case study including the conduction of interviews and a questionnaire. The topics regarding validity, reliability, and ethical considerations will close this section.

3.1. Research Process

The research approach used for this thesis is building on prior research findings in the industrial field *(Kumar, 1999)*. Both quantitative and qualitative data were collected during the research process. Qualitative data offers insights into the studied area. Interviews with experts of a case company present the used methodology for gathering the required information, mainly focusing on the development of suitable benchmarking criteria for the analysis of the simulation modeling programs. In comparison, quantitative data enables numerical measurements, which guarantees that simulations are based on representative data and realistic industrial cases. The latter is collected through observations and time studies based on one case study company *(Creswell & Creswell, 2022)*. Moreover, primary and secondary data sources were utilized. Primary data, collected through methods like interviews and observations, directly addresses the research questions. Secondary data, which presents the pre-existing and not directly collected data, was filtered out from research sources such as articles, journals, and other papers *(Säfsten, Gustavsson, & Ehnsiö, 2020)*. The following *Figure 4* illustrates how the utilized data collection methods contribute to the overall goal of the thesis and the fulfillment of the underlying research questions.

Figure 4: Graphical Illustration of the Research Approach (own illustration)



As it is depicted in the illustration above, the research approach can graphically be divided into three different areas. The literature review with the secondary data, the case study of company A, as well as the case study of company B with primary data. All three parts of the research approach use different data collection methods and aim for other purposes. However, all together contribute to the fulfillment of the purpose of the presented master thesis.

3.2. Literature Review

In this study, the literature review presents the foundation for gathering secondary data. This review approach developed throughout the research process and can be split into two main topics. Initially, it lays the theoretical foundation by providing insights and an understanding of the subject area. The literature review is developed to explain the background information and base the collected data on facts. To collect deeper insights and the latest findings, an iterative approach was adopted. Overall, the literature played an important role in gaining background knowledge and enabling a theoretical framework *(Ridley, 2012)*. This master thesis provided a comprehensive understanding of the main topic areas such as simulation modeling and manufacturing processes. Moreover, it facilitated the integration of background information and enabled the identification of state-of-the-art developments in the field of interest. This identified the latest trends, methodologies, and research findings. Crucially, the relevance of the literature review covered three research questions to different degrees. For the presented thesis the ten-stage process of literature review of *Säfsten et al.* was applied. The process is designed to systematically collect and analyze relevant data *(Säfsten, Gustavsson, & Ehnsiö, 2020)*.

First, the literature review aims to identify the most relevant application areas for simulation programs, and the potential simulation programs that are suitable for manufacturing process planning and optimization. It served as guidance and built the foundation for the subsequent decision-making process. To follow the ten-stage literature review process, the definition of suitable keywords is important at the beginning *(Säfsten, Gustavsson, & Ehnsiö, 2020)*. For the presented case, the keywords were split into three different areas. *Simulation* which includes *simulation modeling, DES*, and *software programs*; then *application* area with *manufacturing, process planning, process optimization, engineering, industrial production, manufacturing processes*; and *comparison* which focuses on *benchmarking, criteria, comparison, analysis, ranking*, and *comparison list*. The definition of the inclusion and exclusion criteria represents the third step. Engineering and manufacturing remained the focus area while the fields of healthcare, management, social sciences, and education were excluded. Articles, books, journal articles, and conference papers are used as document types. *Scopus, ScienceDirect*, and *ProQuest Central* are the chosen databases. Letters, notes, or organizational documents are not part of this literature review. Additionally, language parameters are set to include all English documents and partly include German ones as well. Documents written in other languages are excluded. The selection of the databases was based on several reasons. ScienceDirect offers a broad collection of books and journals with engineering and manufacturing as focus areas. Scopus includes primarily scientific and technical journals and conference proceedings, while articles and reports can mainly be found at ProQuest Central. The mix of those databases offers the possibility of an informed decision-making process. The search strategy for the conducted literature review covers different combinations of keywords that are taken out of the predefined areas of simulation, comparison, and application. The primary focus lies in the identification of potential simulation modeling programs. To name some examples, the searches covered the following keywords *simulation modeling* AND *manufacturing*; *DES* AND *software programs* AND *ranking*; *DES* AND *comparison* AND *criteria*.

Additionally, backward snowballing was used for filtering relevant articles based on already identified ones. To ensure the validity of identified resources, forward snowballing was occasionally utilized. While ensuring the cross-check with this approach, Jerry Banks stands out as a dominant author across various articles and papers. The researcher can be seen as a foundational source of information regarding simulation modeling programs. All selected articles were documented in an Excel list. After selecting the most relevant literature documents, the review process began with the creation of short summaries of identified literature. The focus mainly lay on keywords, abstracts, and introductions while the inclusion and exclusion criteria were considered. Based on a quick scan of the chosen articles, a detailed examination was conducted. A summary of each article was generated, which included bullet points with key information and personal comments to address the main statements of the article. Especially for the decision process of the potential simulation modeling programs, the final steps of the literature were based on a four-stage approach. First, all programs were listed in a table and divided into the three types of DES, ABS, or SD. Afterward, the purpose of the simulation modeling programs was defined. The types of projects and industries were the key criteria for this identification process. To name some examples, manufacturing processes, ergonomics of operators, manual assembly, or robotics were mentioned. Additionally, comments were included regarding case studies where these programs were utilized. Finally, the results of this analysis were presented in the findings chapter, providing a structured overview of the identified simulation programs and the final decision for two programs which will be analyzed in-depth.

The second part of the literature review focused on benchmarking criteria for simulation modeling programs. The aim was to identify and define common criteria groups essential for structuring comparison and benchmarking analyses within the field. This focus area followed the same procedure as the one above. While the keywords, the including and excluding criteria, as well as the databases remained the same as for the first search process, the comparison and benchmarking were moved to the center of interest. The search strategy focused on a similar approach; however, different combinations of keywords were used such as *benchmarking* AND *criteria* AND *comparison*; *software programs* AND *comparison* AND *list*; *DES* AND *criteria* AND *benchmarking*; *analysis* AND *simulation modeling* AND *software programs*. Furthermore, both backward and forward snowballing techniques ensured a broader identification of relevant resources as well as insights and new perspectives. As described above, short summaries of the identified literature were then created. They focused on abstracts, keywords, and introductions to determine key areas. These summaries were organized into clusters connecting to predefined areas of simulation, application, and comparison. As the seventh step, a detailed review of the identified literature was conducted which was followed by the extraction of data and the creation of comprehensive summaries. For the final stages of the literature review, a two-step content analysis approach was adopted to synthesize the findings. This involved listing the mentioned criteria groups and sub-criteria along with further observations in an Excel list based on the authors. Finally, these criteria were compared to filter the common criteria, combine similar terms, and select the most appropriate criteria groups as well as sub-criteria. The findings will be presented in the following chapter.

By reviewing studies and methodologies from existing literature, the aim was to identify frameworks that could effectively include a research and academic foundation for both areas. The decision of simulation modeling programs aims for suitability within the manufacturing process planning and optimization while the selection of benchmarking criteria supports the later analysis of those programs and data. The literature review aimed to ensure that conclusions in terms of simulation programs were based on research findings. Furthermore, it works as a roadmap, guiding researchers toward more informed research outcomes *(Bairagi & Munot, 2019)*.

3.3. Case Study – Observations and Time Studies

The methodology of a case study aims to collect data and analyze phenomena and scenarios that happen in their natural settings *(Williamson, 2002)*. It is not only used to collect information about specific processes within a manufacturing environment but also to investigate the behavior of people and an entire organization *(Yin, 2017)*. The most common data collection techniques focus on the conduction of interviews or questionnaires. Observations can also be supportive to gain a deeper understanding of the current problems and optimization possibilities *(Säfsten, Gustavsson, & Ehnsiö, 2020)*. A comparison between theoretical and practical aspects is an important benefit of case studies. The outcome is closely related to reality and therefore provides practical solutions *(Säfsten, Gustavsson, & Ehnsiö, 2020).*

In the presented master's thesis, a case study is conducted with a SME. For a better understanding and a consistent approach, it is classified as *Company A*. Company A is represented by a local, Swedish manufacturer of mesh wall systems which serve as protection and division items mainly in industrial as well as logistical production areas. The entire process, from product development to packaging is performed in a small town in the south of Sweden. The creation of innovative products stands at the center of the company's focus. The other key points are represented by high safety and security measures for both the product as well as the manufacturing process. Most of the production is automated to handle large volumes and heavy weights effectively. Besides the mentioned aspects, sustainability and quality have a high value for the company and its customers. The selection of this company was based on the focus area of the study program within production systems. Furthermore, the provided case of one specific manufacturing process includes automation aspects, manual work, and production steps. This represents the center of the application this master thesis concentrates on. The relevance to real-world industrial operations enables a concrete context for the study but also forms the basis for addressing the second research question. Due to the aim of the thesis regarding the analysis of simulation modeling programs for the application area of manufacturing process planning and optimization, it is recommended to use realistic scenarios within the industrial area of production and manufacturing. The approach to the case study involved the conduction of observations and time studies to collect data. The description of the required process steps as well as the identification of patterns, daily challenges, and technical details relevant to the manufacturing process represented the aim of this research. Overall, this formed the foundation for the following simulation, analysis, and comparison of simulation modeling programs.

Observations were used as the first step for data collection. The observations aimed to gain knowledge about the semi-automated manufacturing and packaging process within the case study of company A. The process as a whole and the various steps required for performing tasks were the center of interest. By observing where each task started and ended, the observations are required to provide insight into the sequence and duration of activities within the process. The focus area of the observations includes all workstations, product types, as well as various order sizes within the provided process. The roles and responsibilities of the operators were observed. This ensured an understanding of the dynamics within the manufacturing process. The observations were conducted over an entire working week to gather as many details as possible. The first three days were only used for observations. The last two days were used to work in the production line. This helped to clarify the understanding of problems and get a better knowledge of how the process steps can be divided for the following studies. In general, the daily shift work was followed constantly, including the appropriate breaks. Moreover, taking notes enabled the documentation of observations, which were later organized into a structured table format to outline the steps at each workstation. To ensure accuracy, the confirmation of the supervisor of the manufacturing process was considered. Based on this respondent validation, adjustments could be made. At one workstation, each product type was observed individually. The main goal consisted of splitting the process into the steps the operators always perform. Additionally, observations also included problems, downtime, and additional tasks in case they occurred. Those unpredictable situations were recorded to provide a comprehensive overview of operational dynamics. In the beginning, a notebook was used for documentation purposes. Later, a prepared Excel spreadsheet on a laptop presented the measurement tool. In the end, the collected information from the observations was transformed into structured tables to ensure accuracy and completeness.

Based on the observations, a detailed time study form was created and carried out in all the stations of the observed and analyzed manufacturing process. To briefly explain the terminology, time studies can be described as a method that involves closely monitoring and recording the time taken to complete essential tasks within the production environment. Time studies aim to record and analyze the times required for completing essential tasks or activities. Insights into productivity, efficiency, optimization potentials, and bottlenecks can be gained from time studies as well. Moreover, they are the foundation for a realistic representation of the processes analyzed in simulation modeling *(Williamson, 2002)*. In the case study of company A, the conduction of the time studies fulfilled different purposes. Primarily it aimed at replicating the manufacturing process accurately in simulations as well as identifying bottlenecks and optimization opportunities based on the collected quantitative data. The goal was to ensure that simulations and statistics were based on reality to provide the necessary data to improve and optimize operations effectively. Focused on the provided manufacturing and packaging line of company A, the entire flow was split into four workstations, with each workstation further divided into process steps to ensure accurate time measurement and analysis. Based on initial observations, the tasks at each workstation could be divided into different process steps. Excel spreadsheets were created, and each product type was assigned to a specific spreadsheet. This allowed the division of the times according to the product types. The application of iOS phones, Time & Motion Study, was used as a measuring tool due to the user-friendly interface and proven calibration. That’s why it was suitable for collecting the data during the time studies. The sampling strategy focused on one product type at one workstation at a given time to ensure a systematic approach. Additionally, a representative sample was enabled through measured times *(Säfsten, Gustavsson, & Ehnsiö, 2020)*. Therefore, 20 measurements were collected for each workstation, defined process step, and product type. Additional comments and notes were taken to provide extra context and details for the subsequent analysis phase. The average of all 20 measurements for each product type was calculated to receive accurate time samples. Problems, downtime, and extraordinary tasks were recorded as additional measurements to obtain the reality of operations. The last step of the entire time studies approach focused on the analysis. The collected, quantitative data were analyzed based on the average data and exceptions. This data will play a crucial role in the later stages of the study, including simulation development and statistical analysis of simulation modeling programs. Consequently, the time studies build the foundation for the comparison of the simulation modeling programs due to the industrial insights in realistic scenarios.

3.4. Process State Analysis

Process state analysis is a systematic approach used to understand and improve processes. First, the different states and the transitions of a process are examined and identified. The main characteristics and phases of process steps can be classified in active, idle, waiting, broken, and completed. Each step is defined, and the transitions mapped. The data collection methods mainly focus on process flow diagrams, event logs, and state charts. Those enable the possibility to capture detailed information about the entire process. After the mapping, the data is analyzed towards the identification of bottlenecks and potential improvement areas. The main goal consists of understanding the dynamics and the optimization of the process *(Gunnell, 1994)*.

In the presented master thesis, the process state analysis played an important role for understanding the provided case study example. The observations and the conducted time studies provided the foundation. Based on the findings of these data collection methods, the entire process was mapped. For a better understanding and overview, the case study example was split into four different workstations according to the manufacturing line and the observations. Each workstation was observed, analyzed, and mapped separately. The selected data collection method is presented as a combination between the event log method and the process flow diagram. The former involves a systematic recording of events and activities which occur within the process. Each entry includes a description of the event, the required resources and tools, and a timeline. It can be defined as a useful method to enable a detailed and chronological sequence of process activities. They offer accurate and real-time insights into the actual execution of processes. The latter focused more on the visualization of the distinct process steps. It captured the current state of the process and depicted the relationships between certain steps. The combination of both data collection methods enabled a detailed insight into the entire process of the case study. Furthermore, the later conducted analysis and simulation are based on the presented process state analysis. The verification of the data was performed through weekly discussions with the supervisor of the case study process.

3.5. Case Study – Interviews and Questionnaire

The other case study organization is defined as *Company B*. It is also a Swedish company, located in the southern part of Sweden. In comparison to the previous organization, company B is represented by a local consultancy while the main field of interest also lies in the manufacturing sector. Customizable consulting services are used to fulfill the customer's demands and requirements. Technical solutions, optimization projects, and innovative advancements are the key areas of the conducted projects. Consultants, production engineers, and project managers are available for the customers to improve manufacturing processes and engineering problems. The selection of company B as the second case study was based on the study program's focus area as well as its commitment to the utilization of simulation modeling. The simulations and their analyses are used for the investigations and optimizations of the consultancy's clients. The different expert roles of the organization improve the range of perspectives and insights available for a detailed analysis. The connection between company A and company B relies on the interest and usage of simulation modeling programs within manufacturing process planning and optimization activities. The primary purpose of the case study is to aim for two focus areas. Firstly, to gather opinions and insights from five different experts within an industrial organization based on expert interviews. Secondly, to lay the foundation for addressing the third research question by comparing the information and data gathered to select relevant benchmarking criteria. Moreover, it was used to develop a decision matrix and to answer the fourth research question. In addition to the interviews, a questionnaire was distributed to several participants of company B as well as outside of the organization to particularly focus on the importance-weighting of the selected criteria.

An interview is a qualitative research method used to collect original insights and information through a conversation. Particularly in the context of expert interviews within a company, employees are considered specialists in their respective areas which provides valuable input data *(Rubin & Rubin, 2005)*. Expert interviews are used to understand professional perspectives and experiences of a specific problem. They are part of empirical social research *(Kaiser, 2014)*. Interviews can be split into different types. In structured interviews, predefined questions guide the participants through the whole discussion which doesn't offer a lot of flexibility in questioning. Even though there are limitations, the structured interviews ensure that the conversation remains focused on the research topic. On the other hand, semi-structured interviews include a predetermined set of questions that guides the discussion, offering both guidance and flexibility to investigate new aspects. The third group of interview types can be defined as unstructured interviews. Without any prepared questions or guidance, this interview type seems more like an open discussion with one focus area *(Williamson, 2002)*.

For this master thesis, semi-structured interviews were conducted to support the creation of benchmarking criteria regarding the simulation modeling programs. The aim of the conducted interviews consisted of collecting valuable options from experts who are actively part of simulation modeling in the manufacturing context. The emphasis laid on functions, features, and reasons for using and selecting those programs to identify insights that support the development of benchmarking criteria for the comparison of simulation modeling programs. In total, five different interviews with experts from company B were conducted. Based on the profession, each participant offered a distinct perspective, focus area, and connection to simulation modeling. Consequently, a broad understanding of simulation modeling and the benchmarking criteria selection were ensured. The procedure of the interviews was planned to ensure the relevance of the responses. According to the respective professions, the interview questions were adjusted for each participant. Afterward, the interviews were scheduled, conducted, and recorded which allowed the possibility to replay and clarify the results of the responses. The following analysis of the interviews enabled the sorting of the answers by topics and the identification of similar responses or clusters. All results and uncovering trends across different professions were considered. The focus of the analysis was to identify relevant criteria for the selection and comparison of simulation modeling programs. This procedure enabled a detailed investigation of the focus areas and gave valuable insights to fulfill the research objectives. The following *Table 1* lists all of them and enables a structured approach, also for further addressing and descriptions.

Table 1: List of Interviews

Expert	Position	Focus Area
Expert A	Production developer	Optimization of manufacturing processes One company case
Expert B	Production developer	Optimization of manufacturing processes Multiple, changing projects
Expert C	Consultant	Illustration possibilities Customer/sales focus
Expert D	Manager / CEO	Broader organizational standpoint Ease of program for training
Expert E	Project leader	The interests of several stakeholders Coordination function

To explain *Table 1* briefly, expert A works as a production developer for company B. The conducted interview provided insights into the specific needs of a constant project, emphasizing detailed functionalities and features essential for its success. Expert B also works as a production developer. However, the interview offered a contrasting viewpoint due to the involvement of the expert in different, smaller, and changing projects. Compared to expert A, the level of detail is lower but other criteria might be more essential. The next interviewee, expert C, works as a consultant with a sales focus. Simulation modeling offers different benefits to customers, mainly focused on the illustration possibilities. The manager of company B is defined as the specialist D. The manager was interviewed due to a broader organizational standpoint. Additionally, the last interview with expert E, a project manager, brought a different perspective by integrating various functions and stakeholders' interests. Consequently, these interviews offer broad insights into the diverse software needs and perspectives based on a real-world scenario within the company B case study. The collected data will be used in the later stages of the presented document.

The purpose of the questionnaire in the master thesis was to gather valid, industry-related feedback regarding the importance of predefined criteria necessary for selecting and comparing simulation modeling programs. The results aimed to provide a weight ranking for the significance of these criteria. Finally, the contribution to the development of a general decision matrix for industries and the fulfillment of the fourth research question were the goal. The questionnaire targeted the same five experts from the case study company B, as well as other professionals with an understanding of simulation modeling programs. Finally, this ensured several perspectives to include the levels of importance from different angles. The questionnaire was based on the criteria predefined from the literature review and the interviews. The questionnaire aims to rank the importance of these criteria. Besides the criteria groups, the sub-criteria will be ranked as well. The questionnaire was directly distributed to the participants in the interviews as well as external experts to represent a diverse range of opinions. However, all participants focus on simulation programs due to a direct usage or another connection to the programs. This ensured that the collected information was relevant to the general objectives of the master thesis. Furthermore, it reflected the targeted manufacturing context. The questionnaire was prepared in Google Forms which served as an analysis tool. It offered a user-friendly platform for responding quickly and analyzing the results easily. The analysis of the collected answers enabled insights for the following development of the aimed decision matrix. Color-coded presentation of the results allowed the identification of patterns and the importance level among the responses.

3.6. Validity and Reliability

In the research process, both reliability and validity play crucial roles in ensuring the integrity and credibility of the findings. Reliability concerns the consistency of results when repeated under similar conditions over time, while validity focuses on accurately measuring what is intended to be measured *(Mackey & Gass, 2022)*. To support these aspects, researchers often use triangulation. The term refers to the utilization of multiple methods, data sources, and researchers to confirm findings. To improve validity, researchers often establish a logical methodology framework beforehand. This procedure ensures that the research approach aligns with the intended objectives and facilitates accurate interpretation of results *(Säfsten, Gustavsson, & Ehnsiö, 2020)*. By prioritizing both reliability and validity, researchers can increase the trustworthiness and robustness of their findings. It contributes to an increased confidence in the study's outcomes within the academic and professional focus areas *(Mackey & Gass, 2022)*.

In the current case and master's thesis, a structured approach was adopted to ensure both validity and reliability throughout the research process. Firstly, literature served as a foundational source of background information. It provided a comprehensive understanding of the concepts and theories which are relevant to the research topic. The literature review was highly crucial in establishing a solid theoretical foundation and strengthening the study of existing knowledge. To ensure the validity and reliability of the collected data of the case study of company A, a structured process was followed. Three weeks were spent conducting the case study. Weekly meetings were held to present and validate the collected data. Respondent verification with two responsible supervisors improved the accuracy and consistency of the information. The validity of the observations was prioritized through several measures in the form of weekly meetings to ensure the accuracy and consistency of the data. Observations were conducted over three different days to increase the representation of the sampling of the manufacturing process. Additionally, direct involvement in the line provided valuable firsthand experience of the process steps. Overall, it allowed a deeper understanding and enabled necessary adjustments to be made based on practical observations. Furthermore, discussions with the coordinator and supervisor of the production line served as reconfirmation and validation of the observed information and data to increase the credibility and reliability of the findings. The validity of the time studies was achieved through several measures aiming for higher accuracy and consistency of the data. To mitigate biases and to ensure a fair representation, times were taken from all operators equally. Additionally, efforts were made to mix order sizes and therefore diversify the data sample by checking product types and orders beforehand. By proactively addressing these factors, the time studies sought to produce reliable and robust data that accurately reflected the operational realities of the manufacturing process. Similar limitations compared to the ones from the observations were associated with the time studies. Despite these challenges, efforts were made to mitigate their impact and ensure that the findings were interpreted within the appropriate context.

The validity of the case study of company B was maintained through the interviews of multiple experts within the organization. Clear objectives and a semi-structured interview guide supported the correctness of the data through the interviews. This provided diverse perspectives and insights into the usage of simulation modeling programs. To further support validity, cross-verification with the manager was conducted to ensure the correctness of the information collected from the interviews. This iterative process of sharing results and documents for re-confirmation supported the validation of the findings and ensured their reliability while improving the credibility of the case study's outcomes. The limited time of the master thesis led to a specific number of interviews conducted. It might be helpful to improve validity and reliability by increasing the scope of the data collection. The validity of the conducted interviews was carefully structured. The interview questions were not sent out beforehand to prevent bias and pre-fixed preferences, particularly in terms of the criteria formulation for the simulation modeling programs. It fostered a more neutral and open exchange during the interviews which led to authentic and uninfluenced responses based on their expertise and perspectives. However, the participants were aware of the overall topic and purpose of the interview. More general preparation for the overall topic was ensured so that participants could answer the questions without feeling constrained by predetermined expectations. Firstly, the validity of the conducted questionnaire was maintained through the selection of the participants from various professions and positions which were targeted to broaden perspectives and insights into the topic area. The wide range of participants allowed for a comprehensive exploration of the topic. Before the questionnaire was sent out, a verification with the supervisor of the case company was conducted. Additionally, the questionnaire was distributed to a considerable number of participants, ensuring a sufficient sample size for statistical analysis. However, the sample size was limited to the number of resources who had knowledge of simulation modeling programs.

3.7. Ethical Considerations

Ethical considerations are significant in any research approach, including master's theses. Those aspects maintain the integrity and credibility of the study while protecting the rights and ethics of all parties involved *(Säfsten, Gustavsson, & Ehnsiö, 2020)*. Guidelines are created continually which form the necessity to get the permissions from the companies as well as the staff involved in the research process. This ensures compliance with ethical standards. Particularly in studies conducted within a company setting, the fulfillment of ethical guidelines becomes even more crucial. The focus lies on navigating issues of privacy, organizational, and individual rights *(Sochacka, Walther, & Pawley, 2018)*. Moreover, the subjectivity and moral position of researchers should not influence the quality of research and its ethical aspects. To conduct studies that match the ethical considerations, researchers must follow the established principles and guidelines. All of them can be categorized into different aspects, for the presented thesis in the field of manufacturing *(Rana, Dilshad, & Ahsan, 2021)*. The planning stage of the project should include ethical considerations from the beginning on. While some factors focus on the problem-oriented approach, the other ones highlight ethical documentation. Consequently, values such as responsibility and respect support the credibility and integrity of the research *(Sochacka, Walther, & Pawley, 2018)*.

In the current master thesis, ethical aspects were constantly considered to ensure integrity and respect for all involved parties. In the case study of company A, ethical guidelines were carefully maintained. The company granted permission for the case study which involved observations and time studies. The strict emphasis lay on maintaining the anonymity of the company's name in all reports and publications to ensure the privacy of organizational data. Operators were informed throughout the observation period. To increase the level of trust, the standard routines were followed constantly. Furthermore, anonymity was offered. Time studies were conducted with similar ethical standards, ensuring operators were aware of the measurements being taken. Minimizing the observer's presence to reduce any potential influence on their performance was achieved by standing far away from the center of the action. Similarly, in the case study of company B, ethical guidelines were kept as well. The company consented to the conduct of interviews and the questionnaire. The commitment to preserving the anonymity of the company's identity and organizational data supported the ethical considerations. Interview participants were informed in advance about the conduct. Based on their consent, confidentiality, and restricted usage of the outcome for this master thesis were ensured. With the participation of the questionnaire, anonymity was guaranteed so that the data just supports the findings of this thesis. Overall, ethical standards were followed with a focus on transparency, respect for rights and privacy, as well as confidentiality.

4. Findings

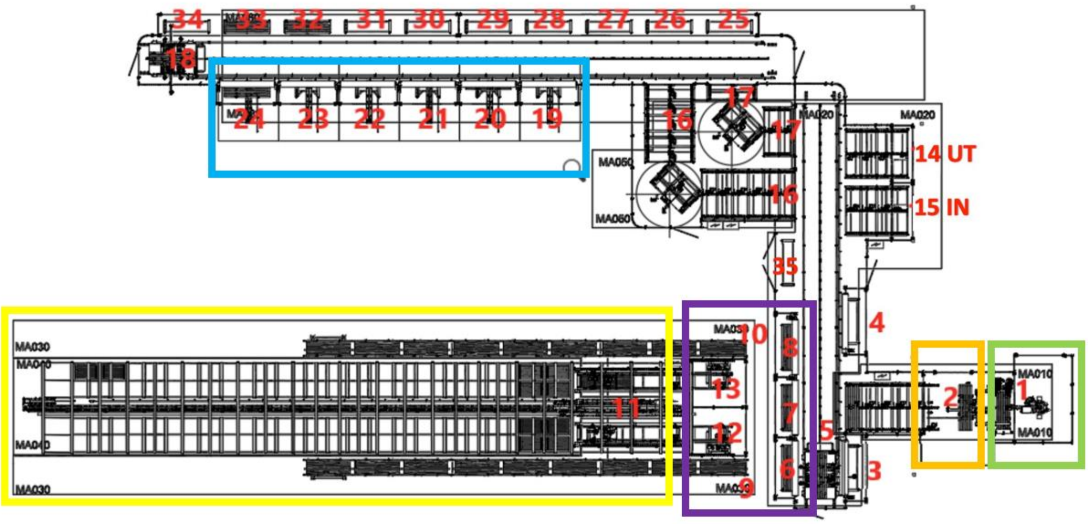
This chapter presents the data collected to address further aspects of the research questions. It offers insight into the case-study company as well as the process which was analyzed. The gathered data is based on a literature review, conducted interviews, observations, and time studies. The first section is followed by the decision process regarding the selected simulation tools. The development of the benchmarking criteria which mainly regards the third research question forms the end of the fourth chapter.

4.1. Process State Analysis

The process state analysis can be seen as one of the most crucial components within the framework of the entire master's thesis. Due to its focus on one specific process flow, it covers the main topic of the application area for the simulation modeling tools. The case study of this manufacturing process has significant importance in addressing the first research question of this master thesis: *What are the most relevant application areas for simulation modeling software programs?* The process state analysis conducted within this case study focused on a specific process flow within the manufacturing industry. Therefore, it served as a realistic example of an application area for simulation modeling tools. As a real-case scenario, it not only forms the foundation for creating realistic simulation models but also enables an accurate evaluation of these models against the actual performance. Overall, the process state analysis builds the base for addressing the first research question. It exemplifies how simulation modeling software programs can be used effectively for analyzing manufacturing processes.

The conducted case study focused on a specific production line, in Swedish known as Packautomation, within the previously presented *company A*. This line addresses a series of stages aimed at achieving a continuous production flow. Firstly, the process begins with the pallet building of three different pallet types based on their measurements, followed by the cardboard assembly. Subsequently, the filling of the cardboard boxes with posts and supplementary materials occurs. At the end, the cardboard boxes will be closed. Additionally, a side process involves the construction of empty pallets for subsequent picking processes. In total, the entire process can be divided into four distinct workstations, each station plays an important role in the overall Packautomation process. To provide a comprehensive understanding of this process, the following *Figure 5* depicts a basic 2D layout provided by the company. The Packautomation process represents a semi-automated system with integrated manual handling for the analyzed process flow. The process comprises several integral components with a conveyor system throughout the entire analyzed process flow. The automated conveyor system is constructed and installed by a local Swedish machinery manufacturer. It starts directly after the first workstation and ends after the final close-up of the cardboard packages. Consequently, the purpose of the conveyor system can be described as the connection between the several workstations and aims to ensure a continuous flow of products. Furthermore, the conveyor system can be split into multiple sections due to the different workstations and areas. It consists of various elements such as two 90° turning conveyors, a small rail vehicle, and two larger rail vehicles, capable of transporting entire pallets and their content.

Figure 5: Layout of Packautomation Process



Besides the conveyor system, a robot is employed and used for nailing pallets. The system incorporates a Kuka robot with six axes and a maximum reach of 2701mm. This robotic technology plays a crucial role in the first workstation. Further in the process, an automated warehouse is integrated which is framed in yellow. It features two distinct conveyor tracks as output and one main rail vehicle responsible for retrieving materials from a five-floor storage. In total, there are ten storage places on both sides of the rail vehicle which sums up to approximately 98 potential positions filled in a two-pallet system. Besides the automated warehouse, an additional supermarket provides the last workstation with the required material. Racks serve as storage possibilities for it while 48 positions on three floors are filled. Consequently, around 144 different parts can be stored in the warehouse. As already mentioned, the entire Packautomation process is a semi-automated system with four distinct workstations used for manual handling. To ensure smooth operation, the process ideally involves four operators, each assigned to different manual tasks at those stations. An extra coordinator is responsible for the functioning of the system, technology, problem-solving situations, and the maintenance of the logistical workflows.

All workstations are named based on their main operation's purpose. Therefore, the first one is called the nailing station, and the working steps are illustrated in *Table 2*. This station contains the Kuka-robot which was previously mentioned.

Table 2: Process Steps of Nailing Station

Resource	No.	Operation	Tools
Operator	1	Get the order, check the order type	Display
Operator	2	Get 5 wood chunks and place them	-
Operator	3	Get 2-4 wood basis-boards and place them	-
Operator	4	Press the *Reset* and *Start* buttons (2 times)	Display
Robot	5	Nailing process	-
Operator	6	Get 3 wood backboards	-
Operator	7	Nail wood backboards to wood chunks	Nailing gun (1)
Operator	8	Press the *Reset* and *Start* buttons	Display
Conveyor	9	Transportation	-

In the 2D layout, the dimensions of the nailing station are marked with a green rectangular shape. As it is listed in *Table 2*, the workflow includes several essential steps to ensure a smooth nailing operation. The start of the conveyor presents the workbench for all conducted tasks. Besides the robot, an operator is mainly responsible for performing the operation steps including another nailing operation to fix the backboards to the wood chunks. Therefore, the first workstation is additionally equipped with a nailing gun. An interactive display is used for presenting the instructions to the operator as well as for confirming the conducted process steps. At the end of the nailing operation, the conveyor is activated by pressing the start button and confirming the successful conduction of all process steps. It transports the built pallet automatically in one flow to the second workstation.

The second workstation aims for the cardboard building on top of the built pallets. It is connected to the nailing station with a conveyor belt section. The orange rectangular in the layout above borders the outline of the cardboard building station, while the following *Table 3* lists the required procedure split into various operation steps.

Table 3: Process of the Cardboard Building Station

Resource	No.	Operation	Tools
Conveyor	10	Transportation	-
Operator	11	Check order	Display
Operator	12	Press the *Reset* and *Start* buttons	Display
Conveyor	13	Transportation	-
Operator	14	Get 2 cardboard sheets	-
Operator	15	Place cardboard sheets on pallets and fold	-
Operator	16	Nail cardboard and order sheet on pallet	Nailing gun (2)
Operator	17	Get 2 metal clips, fold the cardboard, and clip them	-
Operator	18	Nail cardboard together	Nailing gun (4)
Operator	19	Get a label, control and place it	-
Operator	20	Press the *Reset* and *Start* buttons	Display
Conveyor	21	Transportation	-

The entire cardboard box assembly is done manually by one operator. In this case, a small rail vehicle functions as a workbench. The station is equipped with three different nailing guns only two of them are needed for completing the nailing and fixing of the cardboard sheets with each other. As well as at the first workstation, the cardboard building section also requires the confirmation of the process steps by using a display screen and manual buttons. Occasionally, an extra confirmation is required. In the table, these steps are highlighted in grey. After the entire operation, the transportation of the pallet including the cardboard box is conducted by another conveyor belt and one of the big rail vehicles.

The third workstation can be called the post-picking station. It forms the foundation of the material which fills up the cardboard boxes. The area highlighted in the purple rectangle covers the post-picking section. Although it forms only one station, it is split into three different gates with the same operations. Currently, one operator is designated for this position. However, there might be the potential to increase the number of workers. As already addressed, the third workstation relates to the previous entity by a big rail vehicle. Furthermore, the automated warehouse mentioned in the first paragraph plays an essential role in providing the third station with the required posts of various part numbers.

Table 4: Process of the Post-Picking Station

Resource	No.	Operation	Tools
Conveyor	22	Transportation	-
Operator	23	Press the Reset and Start buttons	Display
Conveyor	24	Transportation	-
Operator	25	Check order	Display
Operator	26	Pick poles	-
Operator	27	Put a paper layer for protection	-
Operator	28	Confirm picked items	Display
Operator	29	Press the Reset and Start buttons	Display
Conveyor	30	Transportation	-

The list in *Table 4* above depicts all necessary steps manually undertaken by the operator at the post-picking station. Confirmation points are also included in the procedure as well as additional check points which are highlighted in grey.

The transportation process of the pallet to the final workstation, named the B-picking station, is split into several sections. One big rail vehicle covers the first part and transports the pallets to two distinct conveyor belt sections which are connected by two 90° turning conveyors. This part serves as an existing buffer possibility before another rail conveyor picks the pallets up and ensures the last transportation to the B-picking workstation.

Table 5: Process of the B-Picking Station

Resource	No.	Operation	Tools
Conveyor	31	Transportation	-
Operator	32	Check and scan the station	Hand scanner
Conveyor	33	Turn button & Transportation	Display
Operator	34	Scan the order and confirm	Display
Operator	35	Search, get, and scan requested material	Hand scanner
Operator	36	Place new material in cardboard	-
Operator	37	Put paper layer/material for protection	-
Operator	38	Cut, fold, and adjust the cardboard box	Cutter
Operator	39	Get 3 chunks and 1 little board	-
Operator	40	Take metal clips away	-
Operator	41	Place chunks	-
Operator	42	Nail chunks to pallet	Nailing gun (5)
Operator	43	Nail little board to chunks and pallets	Nailing gun (5)
Operator	44	Confirm order, turn the button, and press the Reset button	Display
Conveyor	45	Transportation to Exit/buffer	-

Compared to the third workstation, the final section is constructed similarly. There are six spots where pallets can be placed and need to be filled with additional items provided on a three-floor material storage. Initially, only one operator is responsible for conducting the operations listed in *Table 5*. An increase of workers up to the number of six is feasible. Besides a hand scanner and a nailing gun, additional tools such as a cutter are essential for a successful procedure. The already mentioned rail vehicle is also responsible for placing the completed pallets at the exit buffer positions.

The process flow explained in *Tables 3, 4*, and *5* illustrates the usual production and assembly procedure of the three different pallet sizes. However, there is a fourth pallet type that only follows the first station process like the other ones. It could be defined as an empty pallet since there are no additional cardboard boxes or materials attached to it. The following *Table 6* lists the steps that are conducted at the second workstation before the built pallet is transported out to a separate Exit spot. As usual, the grey rows represent the tasks that occasionally occur if an extra confirmation is required in case the system requests it.

Table 6: Empty Pallet Process

Resource	No.	Operation	Tools
Conveyor	10	Transportation	-
Operator	11	Check order	Display
Operator	12	Press the Reset and Start buttons	Display
Conveyor	13	Transportation	-
Operator	14	Get the order sheet and extra board	-
Operator	15	Nail order sheet	Nailing gun (2)
Operator	16	Change tube for tools	-
Operator	17	Nail board	Nailing gun (3)
Operator	18	Get a label, control and place it	-
Operator	19	Press the Reset and Start buttons	Display
Conveyor	20	Transportation	-
Conveyor	21	Transportation to Exit	-

In addition to the regular operations, there are extra tasks outlined. The tasks can be split into two different focus groups: repetitive tasks for the operators and organizational ones for the coordinator of the Packautomation. The former includes aspects such as refilling nails to the nailing tools while the process coordinator is responsible for the overall functioning of the system and technology. Problem-solving and maintaining the logistical workflows is also part of the coordinator's position. Details of the tasks are listed in a table attached to *Appendix I* and *Appendix II* of this document.

The underlying thesis is primarily focused on conducting an analysis of the manufacturing and assembly process presented. As such, the logistical flows occurring before and after the implementation of Packautomation are out of scope. However, it is crucial to acknowledge that these logistical flows are indispensable for gaining a comprehensive perspective on the entire operational framework. This broader perspective enables a more in-depth comprehension of the interrelations within the production system, facilitating informed decision-making, and the identification of optimization areas. Even though the processes before and after the Packautomation procedure will not directly be incorporated into the analysis, the consideration of previous and subsequent logistical flows has to be kept in mind for a holistic understanding. This manufacturing process has been selected for its relevance to real-world applications. By utilizing the Packautomation as a case study, the purpose is to provide a manufacturing process as a reference point for the following simulation. Thereby a solid foundation for further investigation will be established. The simulation of parts of the process will serve as the cornerstone for the analysis as well as the comparison of the selected simulation modeling programs. Through the examination of this semi-automated process, the master thesis aims to base the analysis on realistic scenarios. Therefore, the described process steps of the four workstations will be included. Moreover, the time studies conducted on the Packautomation process serve as essential inputs for the simulation modeling efforts. The time studies are split into four different product types and the results are attached in *Appendix III* to *Appendix VI*. By analyzing the time taken at each workstation, including manual handling tasks and automated processes facilitated by the conveyor system, insights can be collected into the productivity and efficiency of the overall process. Especially, the cycle times at each workstation, the utilization of the robot, and other statistical KPIs can be based on reality. Additionally, the understanding and the coordination of tasks between the four operators is possible to be simulated in the real-world dynamics of the Packautomation system. Overall, the time study is crucial as a foundation for the subsequent analysis of the selected simulation modeling programs.

4.2. Decision Process of Simulation Tools

The presented chapter focuses on addressing and answering the second research question. The focus lies on the decision process of simulation tools that are suitable for manufacturing process planning and optimization. Since the 1980s, there has been an increase in the availability of simulation tools. The programs vary in terms of their features, user interfaces, capabilities, as well as performance metrics. Some are more focused on specific industries or types of simulations, while others offer broader application areas. Additionally, differences are visible in terms of pricing models and customer support. Presently, the count has surpassed 200 tools, indicating an expansion in the options available for simulation *(Dias, Vieira, Pereira, & Oliveira, 2016)*. In general, the selection process of the most suitable tool for a specific company has proven to be highly resource demanding. Often high costs and a long decision-making process which usually can take up to one year are negative side effects of this selection *(Zakri, Guan, Shao, Riaz, & Hameed, 2011)*. Although the available literature is filled with numerous papers regarding simulation modeling tools, the majority focuses on the listing of evaluation criteria instead of techniques for the decision of simulation models. That's why an evaluation technique is essential *(Fumagalli et al., 2019).*

The literature presents a couple of recommendations and suggestions. For instance, two researchers created a database that serves as a tool for an unbiased decision-making process. SimSelect enhances the effectiveness of the selection of specific simulation modeling tools for companies. SimSelect supports the users in selecting simulation software by using a database that relates to a designed interface. The system tries to match user-specified requirements with suitable simulation packages and offers alternative recommendations. It also allows us to prioritize the requirements based on levels of importance. However, it is not without its limitations. The integration of user comments, feedback, and additional factors could improve SimSelect. Another recommendation focuses on a structured two-phase approach aimed at efficiently narrowing down options to identify the most suitable solutions for the needs and requirements of a company. In the initial phase, the emphasis is placed on narrowing the extensive number of available options down to a condensed list. This stage involves a rapid assessment of various packages based on predetermined criteria and essential requirements. The criteria focus on the general application area, the license models, and the overall range of functions. Once the short-list is established, the focus lies more on the examination of the features of the packages about the specific demands of the company. This detailed assessment ensures that the chosen simulation package aligns closely with the unique operational requirements, functionality preferences, and strategic objectives of the organization. In general, this two-phase process can facilitate a comprehensive and well-informed decision-making process, leading to the selection of a simulation package that optimally supports the objectives of the manufacturer. The structured two-phase approach may lack in terms of time issues. The rapid assessment in the initial phase can lead to overlooking critical details in the available simulation packages. While the detailed assessment in the second phase will consume considerable time and resources. Overall, the approach offers a structured framework, however, it is essential to understand the concern regarding the timing concerns.

Central to these considerations is the need to comprehensively review all available simulation tools to ensure great knowledge of the existing platforms. A more detailed investigation is recommended to fully understand the features of each simulation program and compare it with the needs the specific organization emphasizes. To name some details, this includes the conduction of a detailed investigation to understand the features offered by each simulation program. Key points to consider in this evaluation include the compatibility with existing systems, the ease of usage, the learning curve, as well as the customization options. This procedure is strongly connected with the funnel principle which progressively narrows down the options based on predefined criteria. It represents a suitable and effective strategy for filtering choices to optimize the decision process. Additionally, the conduct of pre-selection surveys to receive insights from potential users or stakeholders is possible. This procedure addresses a broader audience for an intensive assessment. However, there might be the risk of bias and prioritization based on the organization or type of stakeholder. Another possibility can be seen in using a 30-day free trial of each product. Consequently, it would allow full-on exploration and evaluation before committing to an expensive purchase. This trial period provides an opportunity to assess the usability, functionality, and performance of different simulation tools in real-world scenarios which allows for a more detailed comparison of features and capabilities. However, while demo versions or free trials offer an opportunity for investigation, companies must balance out the benefits against the time and cost constraints. Another finding from the literature review suggests a framework with distinct stages to point out the most appropriate tool for the application area. Central to this proposed framework is the understanding of the problem the simulation tool should solve. By understanding the details of the problem, organizations can ensure that the chosen tool closely aligns with their specific needs and objectives. Furthermore, the significance of defining key goals and the application domain where the simulation tool will be utilized is highlighted. This focuses on the main objectives and desired outcomes of the simulation project as well as identifying the specific industry in which the tool will be applied. By prioritizing the application area and ensuring that the selected tool effectively addresses the requirements and challenges specific to that field, users of simulation programs can significantly improve the relevance and effectiveness of their simulation modeling attempts. A broad stage framework is recommended to emphasize the application area of the simulation programs. This approach supports organizations to thoroughly assess their own unique application area and operational context. This means that the organization will consider factors such as industry-specific processes, regulatory requirements, and performance objectives. By doing so, organizations can base decisions on well-informed selection processes to ensure that the simulation tool aligns closely with their specific needs and objectives. It might improve the accuracy and reliability of simulation modeling outcomes and contribute to the overall success of the decision.

The decision for the selection of the simulation programs combined the approach suggested above with a structured four-step procedure. As explained in detail within the methodology chapter, it began with the first step to list all programs mentioned in the literature, in a table format. The second step focused on categorizing the programs based on their focus on DES, ABS, or SD. This classification allowed a clearer understanding of the primary modeling focus of the different programs. Then, the purpose of each simulation program was identified. The main consideration included the types of projects and industries for which the programs are commonly used. To name some examples, manufacturing processes, operator ergonomics, manual assembly, and robotics were some fields. This step enabled a detailed evaluation of the suitability for specific applications of each program. The last step focused on the analysis which included comments on presented case studies where these programs were used. This offered insights into their real-world applications and performance. Overall, this approach combines the structured methodology discussed by the literature with a focus on the application area. The following *Table 7* illustrates an extract to provide an impression of how the analysis was conducted analysis. The list is already filtered based on DES.

Table 7: Comparison of DES Programs (own illustration, based on literature review)

Program	Typical Applications	Primary Markets and Industries
AnyLogic	Focus on complex systems, but used as a tool for ABS, DES, and SD	Supply Chains; Logistics; Warehousing; Manufacturing; Transportation; Healthcare
ARENA	Model verification; analysis of input and output data regarding material flows	Supply Chains; Logistics; Packaging; Food and Beverage; Manufacturing
3D Experience – DELMIA	Simulating and optimizing complex processes	Manufacturing; Production Processes
FlexSim	Creation of realistic scenarios; flow of materials	Logistics; Transportation; Manufacturing
SIMUL8	Reducing waiting times; optimizing resource allocation	Healthcare; Logistics; Service Industries
Tecnomatix Plant Simuation	Optimize processes and design to increase efficiency	Machinery; Electronics Manufacturing; Automotive
Visual Components	Optimizing production processes; Increasing KPIs	Production Processes; Manufacturing; Robotics
WITNESS	Planning, scheduling, and optimizing logistical flows	Logistics; Service Industries; Manufacturing

In the presented thesis, the simulation programs need to match the case study of company A. The focus lies on the analysis of a particular semi-automated production process. The main tasks of the simulation modeling for this specific process are defined in the analysis and the potential optimization of the current production process. The selection process is based on the application area approach. Based on *Table 7*, two simulation modeling programs emerged: *3D Experience – DELMIA* provided by Dassault Systèmes, and the Finnish simulation program, *Visual Components*. Coming back to the second research question, the decision for both tools can be argued as follows. Both options were evaluated with a primary focus on their application within the context of manufacturing process planning and optimization. In comparison to other available simulation modeling programs, those fulfill the overall criteria in terms of the DES focus area. Furthermore, both programs are the most suitable ones for the overall application based on the case study which will form the foundation for the analysis and comparison of the programs. In addition, the decision to use the simulation modeling program DELMIA was also influenced by its pre-existing usage within the case company B. On one hand, the familiarity with DELMIA enabled knowledge from experts which the author of the thesis could profit from. Despite this, the interest of company B in another simulation program existed due to some of the program's limitations which didn't match the expectation of company B. Consequently, the choice for DELMIA was based on the application area in the context of manufacturing and production processes as well as the investigation whether other programs can fulfil the list of requirements to a higher extent. Regarding Visual Components, similar reasons led to the selection process. The decision to use the simulation program Visual Components was driven by a combination of factors. Primarily, the focus of the program matched the application area entirely as it is depicted in *Table 7*. This alignment ensured that the program's capabilities were directly usable to the investigation needs which promised a high degree of relevance. Additionally, the author's pre-existing familiarity with Visual Components played a critical role in the selection process. This familiarity enabled a potential for a faster learning curve, because the author's foundational knowledge of the software could be utilized to improve the integration and starting phases. The existing expertise not only minimized the training requirements but also facilitated a faster adaptation to the interface environment. In the end, DELMIA and Visual Components are suitable choices for manufacturing process planning and optimization of specific production processes and will be analyzed in this thesis.

4.3. Benchmarking Criteria Development

The development of benchmarking criteria is significant for this master thesis because it addresses gaps in the existing literature and state-of-the-art methodologies. The current evaluation methods, such as yes and no checklists, lack on providing a detailed understanding of the program's capabilities and focus only on surface analysis of the criteria. That's why the presented chapter and development of benchmarking criteria are crucial for the overall outcome of the decision matrix for the comparison of the simulation modeling programs. Moreover, the third research question will be addressed within this section, which focuses on identifying key criteria and features essential for simulation software in manufacturing process planning and optimization. The entire benchmarking criteria development process is split into three data collection methods. The literature review builds the foundation, while the conducted interviews provide insight into realistic industry cases and perspectives. To conclude the process and prepare the final analysis, the results of the questionnaire will be considered. The latter supports the evaluation of the criteria's importance level. It forms the basis for the weighting of the selected criteria and the fourth research question. To begin with a structured analysis of the literature content, it was important to distinguish between papers that focus only on criteria groups and those that consider individual criteria factors. The review of recent literature and research articles was conducted to identify common criteria groups and sub-criteria that are frequently used in previous studies. This process involves collecting criteria from a wide field of articles that specifically address the comparison of simulation modeling programs. Afterward, all mentioned criteria groups were listed based on the authors in one Excel list, while another Excel list included the individual criteria factors. This procedure supports a holistic perspective and a structured analysis that tries to focus on identifying the most common criteria and overlaps between similar terms. The goal was to identify the criteria that are consistently cited or used frequently in the context of simulation modeling programs.

Table 8 shows the mapping of similar criteria groups. A detailed comparison of the criteria cited by 23 authors over several decades is depicted. The headline of each column tries to generalize the topic area. All of them were defined by the author of this thesis. To name some examples and point out aspects of the list below, it is obvious that different authors refer to similar benchmarking criteria. The most common criteria groups focused on the integration of data as well as the modeling capabilities. As it is shown in the *Table 8*, in total 18 out of 23 authors mentioned aspects regarding both topic areas. The column with general aspects also contains more than 50%. In comparison to the costs, support, and performance less than half of the authors mentioned those factors within in their articles. The findings are particularly interesting because they highlight the importance of data integration and modeling capabilities in simulation modeling programs. This leads to the conclusion that both topic areas present the main purpose of these software programs. Furthermore, it seems more important to focus on the modeling capabilities of a program than considering the costs. However, it is surprising that the group regarding the support functions didn't receive a high response rate. Customer support usually presents crucial for the success rate of programs in general. Another notable aspect of the findings is the consistent use of similar terms by most authors to describe key areas in simulation modeling programs. This uniformity promotes a shared understanding of the essential components required for useful programs. This common terminology supports the consensus on what presents as critical functionality in simulation tools. This consistency also increases reliability and supports the selection of these criteria factors. Overall, the structured analysis reveals a comprehensive set of criteria that include technical features, cost considerations, support, integration capabilities, performance, and modeling functionalities. This enables the possibility of creating more general criteria groups based on the provided literature. In *Appendix VII* to *Appendix XII*, the Excel list with the sub-criteria collection is attached. The mapping was conducted in a similar way to the mapping for the criteria groups. The goal also consisted of identifying connections between various researchers and their academic contributions.

Table 8: Comparison Criteria Groups - Results of Literature Review

Author	Year	General	Costs	Support	Integration	Performance	Modeling
Law & Haider	1989	General Features	-	Customer Support	Statistical Capabilities Output Reports	-	Animation Material modules
Holder	1990	-	Commercial	-	-	Functionality	-
Banks et al.	1991	Basic Features	Cost	-	-	-	-
Banks	1991	-	Cost	-	Input Output	-	Processing
Law & Kelton	1991	General Features	-	Customer Support	Statistical Capabilities Output Results	-	Animation
Mackulak et al.	1994	General	-	Documentation	Data acquisition Output analysis	Validation & Verification	Simulation data Model execution & development
Davis & Williams	1994	Comprehensiveness of the system Ease of use Hardware and Installation	Cost	Documentation Training	Integration with other systems	-	-
Banks et al.	1996	-	-	-	Input features Output features	Processing features	-
Kuljis	1996	Main system characteristics	-	Printed Manuals Online User Assistance	Data Input Simulation Results	-	Simulation Experiment Model Specification
Hlupic	1997	General Features	Financial & Technical Features	-	Statistical Facilities Input / Output Software Compatibility	Efficiency Testability	Visual Aspects Coding Aspects Modeling Assistance Experimental Facilities
Banks	1998	-	Cost	-	Input Output	-	Processing
Nikoukaran et al.	1998	-	-	-	Input Output	Testing Efficiency	Model Execution Animation
Tewoldeberhan	2002	-	-	-	Input Modes Output	Testing Efficiency	Model Development Execution
Sahay	2003	Technology	Cost and Pricing	Support & Service	-	-	Features
Hlupic	2007	Hardware Considerations Software Considerations	-	-	Input Issues Output Issues	-	Modeling Capabilities Simulation Capabilities
Alvarez, Rincón, Pérez, Hernández	2008	Functionality Usability Ease of Use Easy of Understanding & Learning	-	-	-	Efficiency	Graphic Interface Operability Execution Performance
Azadeh, Shirkouhi	2009	-	-	-	Input Output Execution	Testing Efficiency Development	Model Animation
Jadhav, Sonar	2011	Functional Technical	Cost & Benefit Opinion	-	Output	-	Simulation Capabilities
Mourtzis	2014	Hardware and Software General Features	-	Modeling Assistance	Input / Output	-	Simulation Capabilities
Jadric	2015	-	-	Modeling Support	Output Analysis	-	Modeling Process Simulation
Pezzotta, Rondini, Pirola, Pinto	2016	-	-	-	Input Execution Outputs	Testing Efficiency	Model Animation
Fumagalli	2019	Technical Characteristics General Characteristics	-	User Support	Implementation Input Implementation Output	Efficiency	Visual Aspects Programming Aspects Testing Experimentation

The interviews were conducted with a focus on different stakeholders to find insights into their preferences and identify additional criteria supportive for comparison. The results of the interviews are attached to *Appendix XIV* to *Appendix XVIII*. Expert A, a production developer, highlighted detailed functionalities crucial for constant projects such as error debugging and the options of statistical features. Furthermore, the emphasis lies on customer support due to potential struggles that might occur more often with more complex projects. Expert B, who is involved in changing projects, mentioned the importance of general features. The user-friendliness and the learning curve are important based on the interview with this expert. As a sales consultant, Expert C focused on the significance of meeting customer needs and marketing purposes. To connect it with simulation modeling programs, it includes animation options. Moreover, it is crucial that the models and their simulations are representative. Even though the manager of the consultancy company, Expert D, covered many different areas, the cost considerations, the employee training possibilities, and the ease of the program adoption were highlighted. Expert E, a project manager, also highlighted several factors. The benchmarking criteria for simulation modeling programs were defined by combining findings from the literature review with insights from the conducted interviews. This approach led to the identification of six key criteria groups which are listed below. The findings of *Table 8* presented the foundation for the final development. The mentioned criteria groups were cross-checked with the answers of the interviews to match the academic with the industrial perspective. This process ensured that the evaluation process addresses both the functional and practical requirements of simulation modeling programs.

1. General Features
2. Financial considerations
3. Customer support
4. Input & output functionality
5. Performance
6. Modeling capabilities

To give a short description of each criterion, the general features cover fundamental functionalities and the user-friendliness of the programs. The economic perspective and the financial constraints will be discussed in the second group. While customer support evaluates the availability and quality of support services, the input & output functionality addresses the system's capabilities in handling data inputs and outputs as well as the integration with external programs. The performance refers to the efficiency of the program, while the modeling capabilities focus on the overall modeling possibilities and visualization.

The following *Table 9* shows the criteria groups with their respective sub-criteria. A detailed explanation of the criteria is attached to *Appendix XIII*. The development of the sub-criteria was oriented on the identified key groups, the findings from the literature, and the insights from industrial interviews. Each criterion group was analyzed to identify specific factors that contribute to its evaluation. This process involved breaking down the broad categories into more detailed components. The integration of both academic and industrial perspectives ensured that the resulting sub-criteria addressed not only theoretical considerations but also practical requirements.

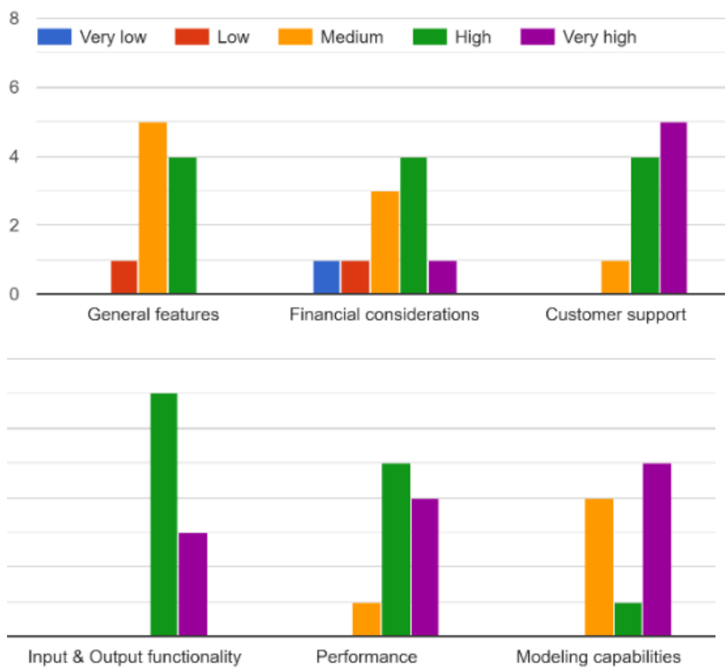
Table 9: Criteria Groups and Sub-Criteria

General Features	Financial Considerations	Customer Support
Ease of Installation and Updates	Initial Costs	Quality of Documentation, Tutorials, Training
Learning Curve	Additional Costs	Direct Customer Support
User Friendliness	Price of Training Course	Quality of Community Support

Performance	Input & Output Functionality	Modeling Capabilities
CPU Utilization	Ease of Data Integration and Saving Options	Options of Templates and Libraries
Quality of Error Messages	Options of Statistical Features and Functions	Animation and Simulation Options
Programming Features	Integration with Add-Ons and Software Programs	Representativeness of Models and Animation

The questionnaire aimed to identify the importance level of predefined benchmarking criteria for the analysis of simulation modeling programs. The overall goal consisted of providing valid and especially industry-relevant feedback. Its purpose also covered the definition of weight rankings for these criteria which will be used for the development of the general decision matrix, which will provide the answer to the fourth research question. The questionnaire was sent to the five experts and interview partners from the case study company B. Moreover, other professionals in production development or with an understanding of simulation modeling programs were questioned. It ensured various perspectives, including different angles and importance levels regarding the benchmarking criteria. In total, ten experts participated in the questionnaire. The number of participants was restricted because of the limited resources who had experience with simulation modeling programs in general. The overall focus lies on industry-related opinions and perspectives. The following *Figure 6* illustrates the results from the questionnaire in terms of the importance of the general criteria groups.

Figure 6: Results of Questionnaire for Criteria Groups



All the criteria groups were ranked based on five different categories, from *very low* to *very high*. As shown in the bar chart, the groups regarding customer support as well as the modeling capabilities contain the highest outcome of the category *very high*. Even though the *very high* value of the groups, performance, and input & output functionality, is lower than the former, both groups performed well in the category *high*. While the general features were mainly placed in the *medium* and *high* sections, the financial considerations received rankings for all levels of importance with the category *high* as the most crucial one. The evaluation of the criteria groups will be conducted at a later stage of this chapter. Meanwhile, the fulfillment of the fourth research question stands in the center of the overall importance generation and evaluation.

To show more examples of the questionnaire results, the sub-criteria of customer support as well as the modeling capabilities are illustrated in the *Figure 7* and *Figure 8*. The wording of the questions in the questionnaire was chosen to be clear and consistent to keep the focus on the main topic. In addition, the questions covered a broad range of relevant topics. The procedure aimed to focus on specific and meaningful responses from participants to enable a detailed assessment of simulation modeling programs.

Figure 7: Results of Questionnaire for Customer Support

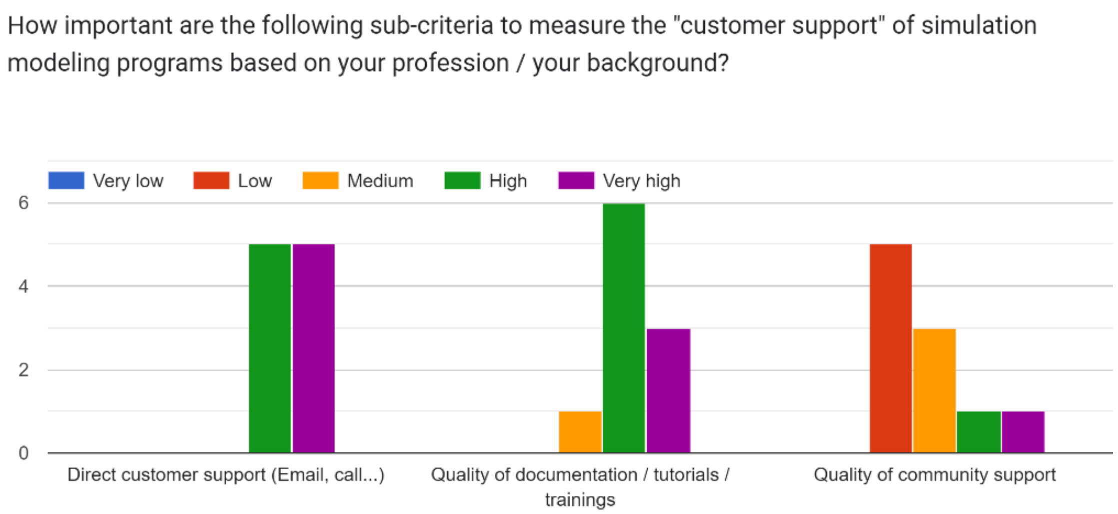
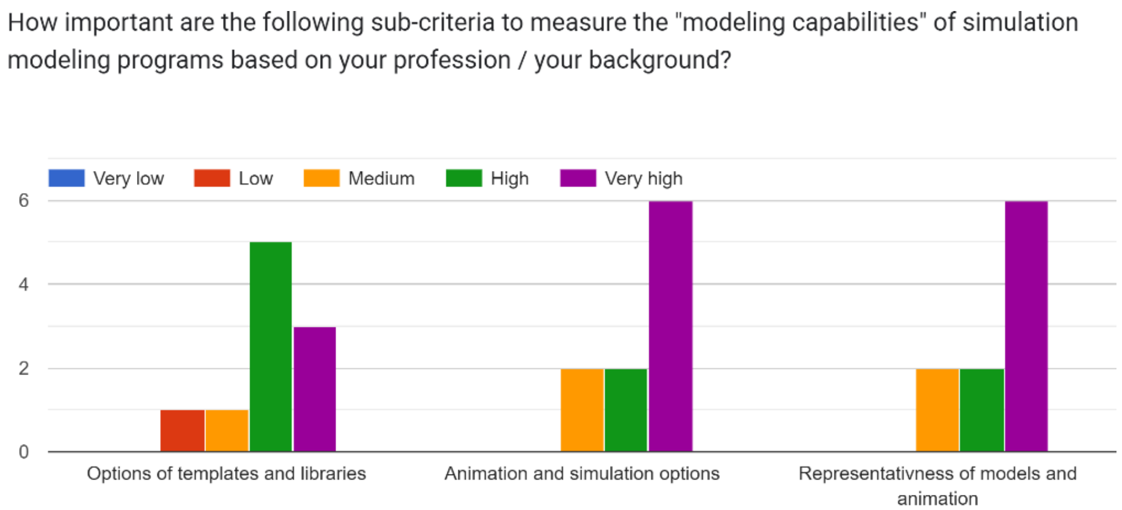


Figure 8: Results of Questionnaire for Modeling Capabilities



It is crucial to mention that for customer support, the direct support, as well as the quality of documentation / tutorials / training, were ranked at a high importance level. Meanwhile, community support isn't presently as important in comparison to the former. For the modeling capabilities, the animation and simulation options and the representativeness of models and animation are highly important based on the opinions of the questioned experts. The options of templates and libraries can be classified on a high importance level as well, while some answers cover the *low* and *medium* sections. Consequently, this results in a mixed importance level for the last sub-criterion. The results of the remaining criteria groups are attached to *Appendix XIX*.

Finally, the results of the questionnaire contribute mainly to the development of the weight for each criterion and allowed an answer to the fourth research question. First, some explanations of the procedure of the questionnaire are required. Evaluating the general categories and sub-criteria individually enabled the identification of areas for improvement and potential areas of innovation within each criterion. The goal of evaluating both general categories and subcategories individually was to ensure that the criteria groups did not influence the assessment of the sub-criteria. By separating the evaluation into distinct levels, the questionnaire focused on a higher objectivity. The importance levels for the criteria groups and sub-criteria were determined through a systematic process that aimed to reflect both the frequency of responses and the perceived significance of each factor. Initially, the number of answers received for each criterion was multiplied by the level of importance assigned to it within the questionnaire. This multiplication provided a quantitative measure of the relative importance of each criterion based on the input of the participants. Finally, the average of the data was calculated for each sub-criterion individually, using the results from the questionnaire. Following the development of sub-criteria weights, the ranking for the criteria groups was calculated by averaging the weights of their respective sub-criteria. This process enabled a direct connection between the ranked importance level of the criteria groups and the underlying sub-criteria. Moreover, it ensured alignment and consistency in the entire evaluation. As a result, the importance levels assigned to each criterion group were informed by the aggregated importance of its constituent sub-criteria. The following calculation in *Table 10* reflects how the process was conducted. The numbers marked in blue represent the category, while the green color focuses on the number of answers within this level of importance.

Table 10: Calculation Example of Questionnaire Results

General Features	**(2,9 + 3,9 + 4,3) / 3 = 3,7**
Ease of Installation and Updates	((0*1) + (4*2) + (4*3) + (1*4) + (1*5)) / 10 = 2,9
Learning Curve	((0*1) + (0*2) + (3*3) + (5*4) + (2*5)) / 10 = 3,9
User Friendliness	((0*1) + (0*2) + (0*3) + (7*4) + (3*5)) / 10 = 4,3

The results of the importance evaluation are depicted in *Table 11*. As illustrated in the questionnaire results, the input and output functionality as well as the modeling capabilities received the highest grades. General features, performance, and customer support are in the second most position, while financial considerations are at the lowest ranking. At the end of the analysis, the weight evaluation will form one foundational part of the following final decision matrix to answer the fourth research question.

Table 11: Weight Generation of Criteria Groups and Sub-Criteria

Criteria	Weight
General Features	**3,7**
Ease of Installation and Updates	2,9
Learning Curve	3,9
User Friendliness	4,3
Financial Considerations	**3,3**
Initial Costs	3,7
Additional Costs	3,1
Price of Training Course	3,0
Customer Support	**3,8**
Direct Customer Support	4,5
Quality of Documentation, Tutorials, Training	4,2
Quality of Community Support	2,8
Input & Output Functionality	**4,1**
Ease of Data Integration and Saving Options	4,2
Options of Statistical Features and Functions	4,5
Integration with Add-Ons and Software Programs	3,5
Performance	**3,7**
CPU Utilization	3,3
Quality of Error Messages	4,5
Programming Features	3,3
Modeling Capabilities	**4,3**
Options of Templates and Libraries	4,0
Animation and Simulation Options	4,4
Representativeness of Models and Animation	4,4

5. Analysis

The analysis chapter represents the most important section of the master thesis. It takes all research questions into account and focuses on the comparison between the selected simulation modeling programs based on the previously defined criteria. The development of the general decision matrix will conclude this chapter.

5.1. Approach Description

The approach to the analysis and comparison of the selected simulation modeling programs will be explained in the following. To avoid bias in the evaluation, the set of criteria was used as the foundation for the comparison. In addition, evaluations were conducted independently, and regular cross-checks with supervisors were performed to increase the validity level. Overall, the simulation modeling programs Visual Components and DELMIA are juxtaposed. The comparison is based on the criteria groups as well as the sub-criteria which were defined in the earlier process steps of this master thesis. The consideration of the criteria ensures consistency of the analysis and guides the entire evaluation process. Furthermore, the foundation of the comparison must refer to the same factors to maintain objectivity and reliability. Therefore, the description of the analysis is also structured and divided into the criteria groups with their relative sub-criteria underneath. The conduction of simulation based on the case study of company A represents the center of the analysis. It facilitates the analysis of the capabilities of the programs in realistic manufacturing scenarios. However, the investigation and benchmarking of the two programs based on the case study example remain the goal of the conducted project. Besides the case study with the conducted time studies and observations as data collection methods, the programs' platforms provide the author with the necessary information and data. This includes access to training materials, documentation, and additional information provided on the programs' web pages. This allows a deeper understanding and broader perspective of the functionality of the programs. Moreover, figures, tables, and screenshots will be included in the analysis chapter. It will provide increased clarity, interpretation, and comprehension of the findings. Screenshots of the interfaces and the simulation models allow concrete examples of the programs' features and enable a higher tangibility for the reader and a potential user. The figures will support the transparency of the entire analysis between both simulation modeling programs. Overall, the guidance provided based on the criteria groups and sub-criteria enables a structured and systematic comparison of Visual Components and DELMIA. Consequently, it will lead to the development of the general decision matrix as well as the formulation of the suggested procedure for manufacturing companies. This part will answer the fourth research question which focuses on the creation of a general decision matrix as a support tool for organizations.

5.2. General Features

Starting with the general features, this criteria group combines aspects concerning the overall program with the software requirements. Besides the ease of installation, the perceived learning curve as well as the accessibility, usability, and user-friendliness of the selected programs will be discussed.

5.2.1. Ease of Installation and Updates

The installation process of the simulation modeling program Visual Components appears uncomplicated based on available information. The downloads for the various license models and products are available on the webpage of the Finnish company which makes it accessible and easy to find. A product and license key are required for the download of the desired programs. In addition to the installation page, Visual Components provides the potential customer with the requirements of the system. These clearly outline the demands for software and hardware. The information is divided into the minimum and recommended specifications. It guides the user and shows transparency. Furthermore, it ensures that the hardware aligns with the requirements and needs of the software program, which avoids inconsiderate decisions. In general, the installation process follows typical steps such as the download of the file, activating the license, and the start of the program usage. Besides the initial download of the program, frequent updates are crucial to maintain the performance level of the software. To ensure that users have access to the recent features and improved functionality, Visual Components releases updates once or twice a year. The updates are also accessible from the company's webpage. Each update is accompanied by documentation that includes not only the instructions for the update installation process but also the release notes with the basic information about this specific update. It allows the upgrade to the newest version of the purchased software program and increases comprehensibility. Subscription licenses come with free updates, which means that the user has the right to update the license for free once a new update is released. In general, the provided data, background information, as well as the actual installation process are easily accessible and systematically structured to provide a guided provision of the products.

In general, the installation process of the simulation modeling program DELMIA also follows the usual and standardized steps required to access software. Nevertheless, the platform of Dassault Systèmes offers plenty of possibilities, options, and solutions that might be a little bit overwhelming for first-time usage. Locating the correct license options and contracts can complicate the process because the user might have difficulties keeping the overview of the entire webpage. Based on the conducted process, it is suggested to identify the needs and the necessary program aspects beforehand. The choice of the correct product suitable for the potential user requires a detailed investigation. Based on the latter, the decision for a certain product can be made. Without an in-depth analysis of which program will be suitable, the incorrect licenses will be purchased. Once the initial steps are overcome, the installation and activation of the license follows a standard procedure. Regarding the updates, Dassault Systèmes provides updates at least once a year and presents the availability of the updates as pop-up messages in the program itself. It creates the awareness of the user and increases the convenience of the software upgrade. Users are also provided with a document regarding the terms and conditions for updates which contains the essential information about the upgrade. Depending on the hardware capacity, the update process itself may be time-consuming due to the significant amount of data updated. A temporary slowdown usually follows an update because the entire platform needs to adjust. However, the platform typically stabilizes after a day and functions normally. Some features and functions are adjusted without further notifications, which leads to an initial, complicated navigation after the update.

5.2.2. Learning Curve

The learning curve was assessed based on how the proficiency with the program developed over time. The evaluation focused on the performance of completion time, user confidence, the accuracy of simulation outcomes, as well as error rates.

In general, Visual Components present a quick learning curve. Based on the creation of the model, the understanding of the user interface as well as the utilization of Visual Components for the manufacturing simulation purpose doesn't require extensive prior knowledge in either coding or software experience. The main approach of the program can be described as a plug-and-play version of a programming language. This enables a quick understanding and intuitiveness. Besides the user-friendly and intuitive structure, fundamental knowledge will be taught with the provided tutorials, documentation, and learning equipment. Therefore, it enables the possibility that the software can be used in different user groups, including users without coding or software knowledge. After a certain point, however, background knowledge in those fields might be beneficial and essential to increase the representation of the models. Furthermore, the success of the simulation will always depend on the effort and practice the user puts into the learning and achievements. Taking the case study into account, the initial implementation of the basic 3D layout, the main process flow, and the basic operations were easily conducted. The editing of the operations according to the given time studies is already more difficult. Overall, the learning curve for the usage of Visual Components leads to the conclusion that the program is potentially useable in a fast development.

In comparison to Visual Components, the learning curve of DELMIA presents a slower development mainly because of inconsistency and the overwhelming number of features. The initial usage phase requires a lot of effort to understand the interface, the basic functionality, and the procedure of the program. Therefore, a familiarity between DELMIA and its daughter programs SolidWorks and CATIA is visible. It might be beneficial for the user to have some background knowledge of those programs. The learning progress and overall success will be fastened due to similarities in the interface, structure, and underlying logic of the program. Background knowledge in other DES simulation modeling programs can also support overcoming the initial learning phase. Without prior knowledge, the users must rely on the provided educational videos or an additional training course. In opposite to Visual Components, the tutorials provided will not fully prepare a beginner to apply for the program in realistic scenarios. Based on the educational videos, there was no possibility of rebuilding the Packautomation process. Participation in a training course was indispensable for gaining a fundamental understanding of DELMIA's functionality. To name further examples to support the statements, the huge number of features and functions can overwhelm users even though some of them are not usable however shown. A screenshot with the marked functions is attached to *Appendix XX*. The inconsistent confirmation of all process steps limits the learning curve as well. Even experts of DELMIA list the description and shortcuts of functions and features in several documents to keep track of the huge number of possibilities. In conclusion, it is important to mention that the learning curve of DELMIA will be a slower development compared to Visual Components. Especially for beginners the initial learning process requires more effort. Once, however, this phase is overcome, the learning depends equally on the effort and practice of the user.

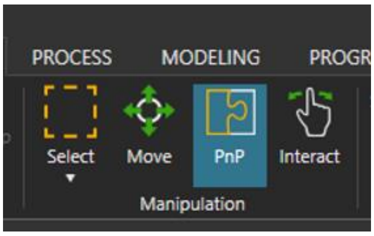
5.2.3. User Friendliness

The user friendliness focuses mainly on the ease of usage of the simulation program. Visual Components simulation modeling program provides user-friendly software. The interface is structured with high clarity and designed for easy usage. The menu tabs include an eCatalog for the provided components and free libraries, panels for the tree graph, the output, and the properties, as well as the selection area. The key functionalities of the program are structured in distinct sections. While the home section focuses on the creation of the 3D layouts, the process tab provides the user with features for the flow and process design. The modeling and programming sections focus on the application of robotic scenarios and enable possibilities for offline programming. In general, the structure of the entire program seems to be inspired by common software structures such as Microsoft applications. *Figure 9* below shows the described interface.

Figure 9: Menu tabs of Visual Components

The same presentation and layout are consistently adopted for the entire platform. This means that the webpage of Visual Components including the commercial pages, the educational tutorials, as well as the community support adopted a similar interface. Therefore, users benefit from this high consistency which focuses on a structured and logical design and navigation options. The simulation modeling program itself uses common and intuitive commands which are also more inspired by standard applications such as Windows applications rather than complex software programs. For instance, the usage of the mouse in the 3D world of Visual Components equals to the usage in standard applications. The interaction with components in the 3D world layout creation focuses on drag-and-drop object placement. It allows the user to interact with the components intuitively. In total, the program provides four manipulation features that have slightly different functionalities. *Figure 10* below shows an extracted screenshot of those.

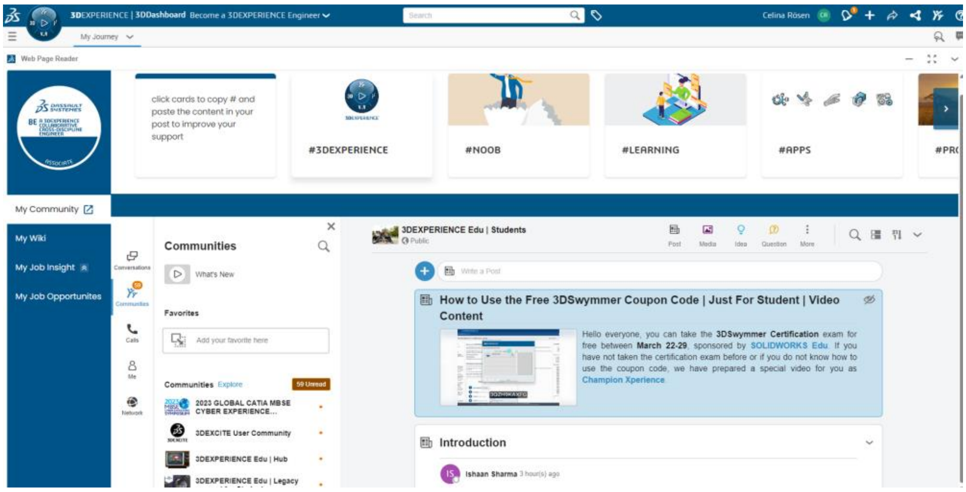
Figure 10: Manipulation features of Visual Components



Additionally, Visual Components incorporates high intelligence and logic in its programs. This means that the provided components and features for simulation modeling contain a pre-defined and pre-coded intelligence from the start. To give an example, the components are usable without any major changes and additions. The user is not required to build their logic for the program, but rather focus on their objectives regarding the simulation modeling. This high level of intelligence supports a user-friendly approach and usage even more. Overall, Visual Components focuses on an intuitive program that can easily be used by beginners.

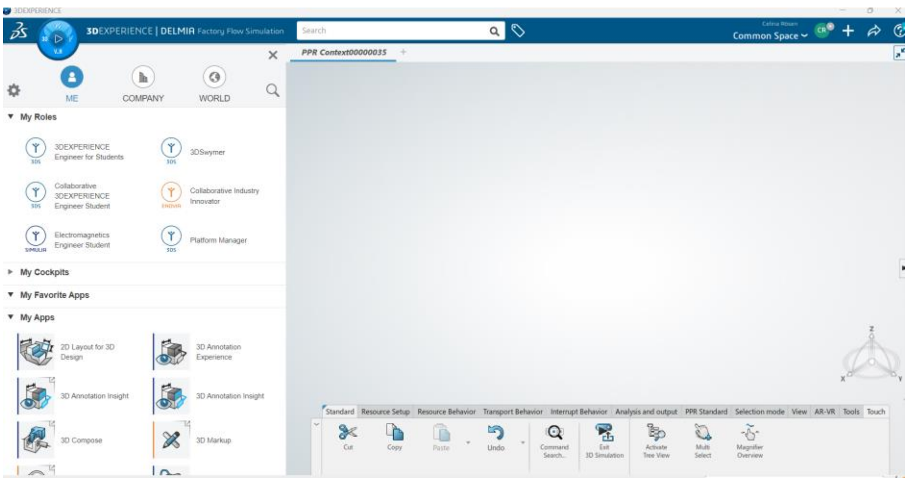
The user-friendliness of DELMIA presents a mixed picture. As part of the 3D Experience platform provided by Dassault Systèmes misses the consistency that Visual Components can provide. While the webpage of the provider uses a highly commercial approach, the simulation modeling program itself is only accessible through the online 3D Experience Dashboard. The latter allows the user to personalize their dashboards combined with access to online community support and the vast number of software programs provided by the company. The 3D Experience Dashboard is presented in the following *Figure 11*.

Figure 11: Dassault Systèmes' 3D Experience Dashboard



By choosing the desired program with the navigation compass, the installation process starts and leads the user to an external platform. This platform represents the actual program in which the simulation modeling can be performed. The user-friendliness in connection with this procedure can be harmed due to the confusing change of platform and the access through the online dashboard. Several steps are required before the user can enter the simulation modeling program. The interface of DELMIA is designed by the 3D Experience platform. *Figure 12* below depicts the interface. The panel on the left side allows the user to change the programs as desired. The tabs at the bottom provide a huge number of features that are potentially usable for the creation of the 3D layouts. In comparison, this program is more inspired by typical software applications rather than the common Office packages which can make it more difficult for beginners.

Figure 12: Interface of 3D Experience, example DELMIA



In addition to the general interface, DELMIA doesn't equip the user with the same drag-and-drop functionality as in Visual Components. Especially the usage of new files and components is based on uploading and importing instead of dragging them into the layout. Furthermore, the intelligence level of the components is low. Usually, the components are simple CAD files without any logic behind them. The user is responsible for assigning the preferred logic and intelligence to the components. This means that the components can't be used immediately, rather they need to know "what" they are. So, a 3D model of a conveyor is just a CAD file unless the user assigns it with resource logic. In conclusion, DELMIA provides the user with a huge number of features while the user-friendliness and intuitiveness of the program remain low.

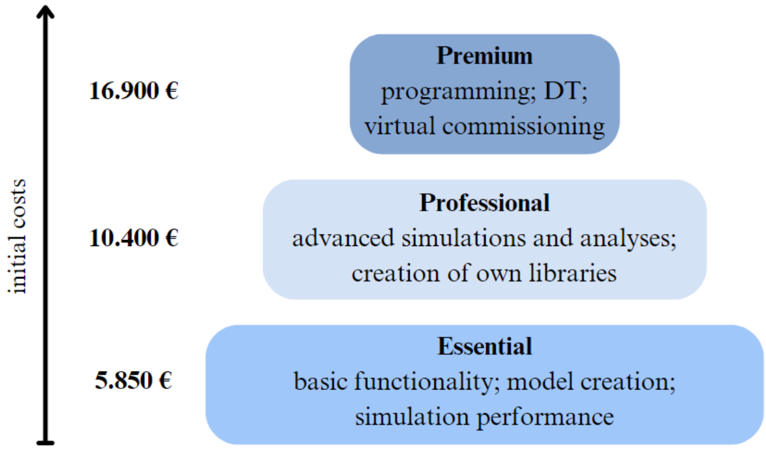
5.3. Financial Considerations

Financial considerations are an important part of software programs in general, including simulation modeling programs. This criteria group is split into the initial costs, the additional costs, as well as the financial expenses for available training courses.

5.3.1. Initial Costs

The initial costs refer to the expenses which are needed to purchase the program and the associated license. Regarding Visual Components, it is important to highlight that the company provides two main licensing concepts. One focuses on offline programming (OLP) and robotics which is mainly utilized for highly robotic and automated production areas. The other considers the manufacturing simulation which enables manufacturers to design, analyze, and improve processes and entire factories. Since the case study focuses on a semi-automated manufacturing process, the attention will lie on the manufacturing simulation license models. Within this category, the users can choose from three different models: Essentials, Professional, and Premium. Each of the license models offers varying levels of functionality and a range of features. The higher the category, the more functions are available. This means that the Essential version of the manufacturing simulation category includes the basic functionalities required for building factories, performing simulations, and analyzing the statistical results. The Professional version includes further features such as the possibility to create the own libraries, while the most advanced model is defined as Premium. The latter considers robotic programming, virtual commissioning options, and the possibility of creating DT scenarios. The following *Figure 13* illustrates the costs that are required for purchasing the different license models of the manufacturing simulation category. So far, Visual Components only offers annual subscriptions as floating licenses of their products.

Figure 13: Initial Cost Structure - Visual Components



Dassault Systèmes offers a similar license and cost structure compared to Visual Components. DELMIA is placed within the 3D Experience platform and is divided into several models with distinct options available. For instance, DELMIA Ortems and Quintiq specialize in supply chain planning and optimization while DELMIA 3D Lean focuses on process improvement and efficient teamwork. According to the presented case study, the planning, analysis, and optimization of manufacturing processes lie at the center. DELMIA Industrial Engineering – Virtual Factory aligns mainly with this field. The option includes virtual factory simulation and offers capabilities for optimizing manufacturing processes and layouts. Besides the content of the different models, quarterly and yearly subscriptions are supported. The programs can be purchased as floating licenses. The initial costs for DELMIA Industrial Engineering – Virtual Factory lie around 100.000 SEK per year. This covers the license and enables the users to use the simulation modeling program for their purposes.

5.3.2. Additional Costs

In terms of additional costs, Visual Components generally doesn't charge users extra costs except the initial license fee. Educational resources such as documentation, tutorials, webinars, and lessons are included in the initial purchase. The access is provided on the webpage of Visual Components which enables the users to receive learning materials without incurring additional costs. Depending on the requirements, certain add-on software or features don't result in additional expenses. However, this doesn't belong to the actual simulation modeling program of Visual Components. In terms of discounts, the Finish company provides free-trial versions. It allows potential customers to gain knowledge about the suitability of the program beforehand. Furthermore, commercial discounts are primarily applied based on the time and volume commitment. Companies can benefit from longer-term licenses in a range of two to five years and for a volume of three or more licenses. Educational and research discounts are available; however, this analysis focuses on the commercial usage of simulation modeling programs.

Regarding the additional costs of DELMIA, access to the online learning portal, Edu Space, is not free of charge. Within the platform, educational tutorials, documentation, and other lessons are provided. Depending on the learning content or the role required, the price differs. The training for gaining knowledge as a plant layout designer or a process flow simulator request around 5.000 SEK per year. Furthermore, additional costs can arise based on the need for specific modules. Those can be added to the initial program. While Visual Components offers most of their add-ons without extra expenses, the one-time prices for modules in DELMIA range from 20.000 SEK to 300.000 SEK. These costs can fluctuate depending on the modules selected. In general, discounts are mainly provided for educational purposes or under specific circumstances with commercial organizations. Demo versions are accessible as well.

5.3.3. Price of Training Course

Visual Components offers training courses depending on the purchased license models. Typically, these courses cover three days and are priced at 1.400 € per day. The number of participants will not be taken into consideration. The structure of the training program focuses on different skill levels. The first and second days of training cover the most basic functions and are suitable for users of the Essential license model. The fundamental features, functions, and workflows represent the content of the first two days of the training course. Based on the solid understanding of using the simulation modeling program, the third day covers more advanced functions and provides the participants with detailed knowledge for performing simulations and analyses.

DELMIA offers training courses to support the users with the initial start and learning of the simulation modeling programs. One option regarding the manufacturing simulation purpose focuses on onsite training with an expert in simulation modeling. At the beginning, the training course covers the fundamental functions of the program. As a step-by-step approach, the understanding of the essential features and the usability of the program will be explained. The instructor provides the possibility to guide the users while questions can be addressed constantly. Overall, the training for the role of a plant factory designer and process flow simulator is priced at 1.500 SEK per hour and participant. Besides the expenses, it will be beneficial to gain knowledge about the usage of the simulation modeling program.

5.4. Customer Support

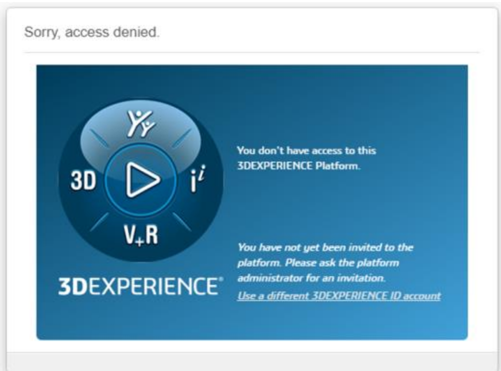
Customer support represents an essential criteria group because it directly affects the user experience and the success of the projects. In terms of simulation modeling programs, assistance, and guidance might be crucial to solve technical issues effectively and ensure that the simulations will increase the productivity of the real-case scenarios. The focus of this section will lie on direct customer support, the availability, and quality of the educational options, as well as community support.

5.4.1. Direct Customer Support

The main customer support of Visual Components works through online options and email contact. Compared to other software providers, the automated or AI-generated support function on the webpage of Visual Components works normally. It is based on algorithms and guides the customer through specific questions to identify the problem or the question. For the current case study, the automated support function couldn't provide the necessary information but delivered directions and the contact details of responsible people to question. Technical problems or issues with modeling are difficult to solve via the automated support function. For instance, in the model of the Packautomation process, the operators neglected obstacles and walked through fences and fixed components. The support function on the webpage of Visual Components referred directly to community support and email contacts instead of providing a solution. Consequently, this tool works more as a guidance rather than a support function. Even though the company doesn't offer technical support via phone calls, their email support can be considered useful. Due to the small size of the company, there are only ten simulation programming experts working constantly with questions of the users and issues they face with their modeling. Visual Components ensures that email requests regarding technical support will be addressed immediately, and the users will receive a tailored response within two days. Coming back to the problem of the operator example, the technical support first provided common solutions that didn't work in the presented case. However, the second reach-out enabled a direct personal conversation which provided customized solutions to fix the problem. This personal approach ensured an effective problem-solving process.

In comparison, Dassault Systèmes is a collaborative company with more than 20.000 employees. Personal and direct customer support is difficult to receive. The main customer support for DELMIA as part of the 3D Experience platform works through email contact. Phone numbers are presented on the webpage; however, they are not assigned. For the current case study, a similar request was made to the central help desk email address. The automated response lacked customization which was needed to answer the technical modeling questions. In the provided example, the response didn't fully match the problem described. A further request didn't change the situation. The possibility of receiving personal contacts and therefore tailored responses for simulation questions is difficult. Moreover, it represents a timely procedure without the required information provided at the end. Within the automatically generated email response of direct customer support, a request ticket link was attached. Usually, it allows the customer to follow the stage of the support request. In the presented example, access was denied even though the correct license was available. The following *Figure 14* shows the result of the search request.

Figure 14: Customer Request of 3D Experience Support Function



To conclude, the 3D Experience platform with DELMIA as a part of it offers support through email communication. However, the reliance on automated responses and missing customization options makes it difficult for the user to receive the support needed for technical modeling assistance.

5.4.2. Quality of Documentation, Tutorials, Training Courses

The academy platform of Visual Components is accessible online. It offers a wide range of documentation, tutorials, and educational videos which provide various learning resources. Access to the academy platform doesn't require a purchased license. In general, users can find specific courses focusing on topics such as Python programming or process modeling statements. In addition, the software provider complied with four pre-structured learning paths to achieve specific goals. Those consist of the essential tutorials, modules, and lessons required to achieve a specific performance goal and to provide structured guidance. In the case of the application focus of the Packautomation case study process, the learning path designed for *Manufacturing Design and Planning* is the most suitable version. It is divided into eleven distinct modules, which focus on different topics in chronological order. The combination of videos and documentation is balanced equally. This path provided the knowledge foundation for the modeling and simulation of the case study example. Without any background, it is feasible to gain enough knowledge through this learning path to create and simulate the main structure of the Packautomation process. The following *Table 12* illustrates the modules within the presented learning path, their titles, and the knowledge that was gained for the case study modeling.

Table 12: Content of Learning Path "Manufacturing Design and Planning"

Module Title	Learning for Packautomation case study
Introduction	Purpose of simulation modeling; visualization, analysis, and optimization of manufacturing processes
Layout Basics	General features regarding the program; content about functions such as navigation, manipulation, selection, visualization
Importing Layout Data	Integration with input and output data; importing of the provided 2D Packautomation layout
eCatalog and Component Libraries	Usage of the available libraries; re-creation of the entire Packautomation line as a 3D model according to the 2D layout
Modeling Custom Components	Additional knowledge about customized components
Creating Products and Assemblies	Knowledge of product creation; replication of the pallet types produced and assembled in the Packautomation process
Creating Manufacturing Flow	Connection and creation of the main process flow within the Packautomation line
Simulation Resources	Knowledge about the functionality of resources; focus on humans, forklifts, and robots due to the given case study example
Process Modeling Statements	Manipulation of process statements according to the conducted time studies and observations
Statistics and System Analysis	Analysis of the current scenario of the Packautomation line; focus on statistics and KPIs
Sharing Results	Creation of recordings and 2D layout files based on the 3D model

In general, the content of the tutorials differed depending on the instructor of the course. The overall quality covered the most important functions and aspects necessary to understand how the program is structured, to build a 3D model based on a realistic scenario, and to simulate the processes involved. On some occasions, it would be helpful to get more input regarding the rationale behind certain steps or actions. Especially for beginners, the procedure is sometimes difficult to understand due to the missing practice and routine with the program. However, the approach is structured, provides useful documentation, and facilitates a step-by-step learning process. In addition to the academy, educational tutorials are offered through alternative sources such as a YouTube channel, webinars, or channels provided by Visual Components simulation experts. Besides content and course-related tutorials, customer case studies are shared which offer insight into the usage of this simulation modeling program in realistic scenarios. In conclusion, the provided documentation and tutorials are structured and provide sufficient information to understand and use the simulation modeling program. A training course which is offered as a three-day format, while the first two days focus on the basic aspects of the program and the third day covers more specific topics, might offer additional insights but is not urgently needed for a basic usage of the simulation modeling in Visual Components.

The 3D Experience platform provides a range of documentation and tutorials that are structured based on the program and the professional role requested. In the case of DELMIA and the application area of the case study example, the learning preference covers the content of the role of plant layout designer as well as factory flow simulator. The resources offer step-by-step tutorials, including quizzes to check the knowledge, additional theoretical explanations, and offer some explanations. The educational videos start from the basics and progress with more advanced topics. The content is presented easily. However, the entire learning content is restructured to the Edu Space online learning platform which requires a purchased license. Moreover, the use of a computer-generated voice in the provided tutorials distracts from the learning experience and reduces the personal level. The tutorials lack depth and flexibility. Only the most basic functions and features of the program are explained. The understanding of why certain steps and actions are conducted is not to be taught. Furthermore, the provided information is limited to gain enough knowledge for performing simulation modeling tasks. The content of 2,5 hours is not sufficient to be able for the replication of the Packautomation process as a simulation in the program. To receive more knowledge that enables a sufficient understanding for beginners, a training course provided by an instructor is necessary. The training course covers essential functions more in detail which makes it possible to navigate through the huge number of features and functions provided in DELMIA. Valuable shortcuts and additional explanations of why certain steps, actions, or confirmations are required will be explained within the three-day training course. In general, the focus of the course depends on the preferences. The case study covered topics regarding Plant Layout Design and Process Simulation Flow. Due to the high complexity and the endless number of features of DELMIA, the training course is indispensable for beginners in simulation modeling. The available tutorials via the Edu Space online learning platform didn't provide enough content to navigate and therefore replicate the Packautomation process of the case study in the simulation program.

5.4.3. Quality of Community Support

Visual Components offers the opportunity for community support through a forum platform available through the webpage. Users can access the forum without a license, but with a sign-up requirement which prevents advertisements and requests not related to simulation modeling problems. The community forum is structured based on categories for filtering topics or creating new discussions. Often, the questions are answered by technical experts at Visual Components. In general, the support received for the case study was helpful. For instance, the question regarding the shuttle conveyor used for the Packautomation process led to the educational tutorial suitable for answering the question. In this case, however, the search was successful and provided the support requested, the quality of the community support varies a lot depending on the questions and experts responding. Answer times differ a lot and might not lead to the expected results. Overall, the structure of the community support is systematic and offers the exchange of discussions related to simulation modeling.

Community support for DELMIA is provided online via the 3D Experience Dashboard. Around 60 different communities focus on various aspects of the platform, including DELMIA as a simulation modeling program. User assistance is offered within these communities based on shared knowledge from other customers and users. Questions can be asked, and comments made. It offers a vast range of options which lead to the navigation challenge and a time-consuming process. The search function within the communities remains indispensable to finding the content required for the requests. Even though access to the communities is possible through the online dashboard of the 3D Experience platform, some videos, tutorials, or files to download remain inaccessible. Some disruptions happen occasionally due to lost access to the online dashboard or announcements which equal more advertisements than technical support of the programs. Overall, the community support of the 3D Experience platform provides access to a vast number of communities that offer valuable content accessible and available via the search function.

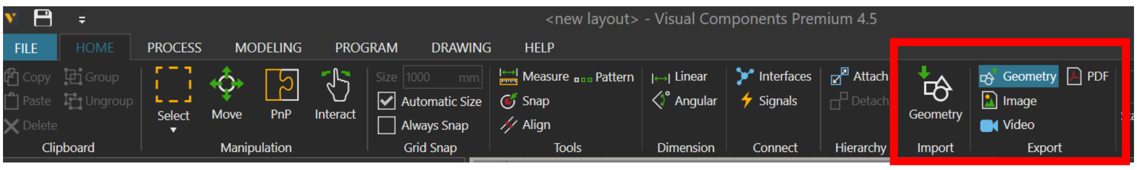
5.5. Input & Output Functionalities

The criteria group regarding the input and output functionality concerns the data exchange and integration with add-ons in simulation modeling programs. Furthermore, the statistical features and functions available and the ease of saving options will be presented. This criteria group takes specific examples from the Packautomation process into consideration.

5.5.1. Ease of Data Integration and Saving Options

Visual Components offers a wide range of input and output functions to enable data integration. The import and export of files can easily be accessed on the Home tab. Both functions are logically structured and straightforward. In *Figure 15* below, those functions are marked with a red rectangle.

Figure 15: Input and Output Functions in Visual Components



Several different geometry files are supported by Visual Components. The most common input files include .dwg such as 2D layouts, .step, or .csv formats. Furthermore, 3D models are covered by .3dxml formats and are often used as well. The following *Table 13* lists all supported import and export file formats with their name, versions, and extensions. All of them can be uploaded while only a few formats, mainly the 2D layout formats, are suitable for export.

Table 13: Supported Import and Export Files in Visual Components

Name	Version	Extension	Import	Export
3D Manufacturing Format	1.2.3	.3mf	yes	yes
3D Studio	All	.3ds	yes	yes
ACIS	Up to 2023	.sat / .sab	yes	no
ASCII Point Cloud file	All	.xyz / .pts / .xyzrgb	yes	no
Autodesk FBX	FBX ASCII: from 7100 to 7500. Binary: all.	.fbx	yes	no
Autodesk Inventor	Up to 2024	.ipt / .iam	yes	no
Autodesk Navisworks	from 2012 to 2024	.nwd / .nwf / .nwc	yes	no
Autodesk RealDWG	AutoCAD 2000-2019	.dwg / .dxf	yes	yes
Binary point cloud file	All	.bxyz	yes	no
CATIA V4	Up to 4.2.5	.session / .dlv / .exp	yes	no
CATIA V5	Up to V5_6R2023	.CATDrawing /.CATPart /.CATShape / .cgr	yes	no
CATIA V6	Up to V5-6 2019	.3dxml	yes	no
COLLADA	Any	.dae	yes	no
Creo	Pro/Engineer 19.0 to Creo 10.0	.asm / .neu / .prt / .xas /.xpr	yes	no
GL Transmission Format	2.0 only	.gltf / .glb	yes	no
Ideas	Up to 13.x (NX5) and NX I-deas 6	.mf1 / .arc / .unv / .pkg	yes	no
IFC2x	2 to 4	.ifc / .ifczip	yes	no
IGES	5.1 to 5.3	.igs / .iges	yes	no
Igrip/Quest/VNC	All	.pdb	yes	yes
JT	Up to v10.6	.jt	yes	yes
Parasolid	Up to v35.1	.x_b / .x_t / .xmt / .xmt_txt	yes	no
PRC	All	.prc	yes	yes
Revit	2015 to 2023	.rvt	yes	no
Robface	All	.rf	yes	no
Rhino	from 4 to 7	.3dm	yes	no
Solid Edge	V19-20, ST-ST10, 2023	.asm / .par / .pwd / .psm	yes	no
SolidWorks	from 97 up to 2023	.sldasm / .sldprt	yes	no
STEP*	Up to AP 203 E1/E2, AP 214 and AP 242	.stp / .step	yes	yes
Stereo Lithography (ASCII and Binary)	All	.stl	yes	yes
U3D	ECMA-363 1st, 2nd and 3rd editions	.u3d	yes	yes
Unigraphics (Siemens PLM Software NX)	V11.0 to v18,NX to NX12.0, and NX1847 Series to NX2212	.u3d	yes	yes
VDA-FS	1.0 and 2.0	.vda	yes	no
VRML	1.0 and 2.0	.wrl / .vrml	yes	yes
Wavefront	All	.obj	yes	yes

Depending on the hardware capacity, the loading of certain files such as the ones of 3D models requires some time. However, Visual Components allows users to customize and adjust the properties of the files according to their requirements. This can reduce the capacity needed and shorten the entire process. Regarding the output options, the animations can be recorded, and the videos downloaded in different file formats, for instance, .avi, .mp4, or .mov. This creates dynamic presentations of the simulations. In addition, there are image rending options available to increase the ability to produce high-quality images and videos. Specifically for these purposes, there are plenty of add-ons compatible with the simulation modeling program to improve the outcomes. Besides the standard input and output files, connectivity to Virtual Reality and Augmented Reality is possible as well. Both are accessible through the Visual Components Experience environment which enables users to visualize the simulations interactively. There is no additional license or extra costs required. This software addition is available on the company's website. In general, the input and output functions focus on a structured approach and the adjustment of properties increases the customization level. However, the input of large amounts of data such as Excel spreadsheets can cause some complications. Some programming experience might be necessary to include the required data within the simulation. This can be seen as a critical and difficult aspect when it comes to complex scenarios. In the case of the Packautomation process, the adjustment of the processes and their times was done manually. The knowledge was not sufficient to enable the integration of large data files. That's why the accuracy of the simulated process might be lower compared to one scenario when the correct data can be imported directly. In terms of data storage and saving options, the processes are like the standard Windows file management. The files can be saved locally in a .vcmx format and accessed in the same way. Depending on the complexity of the simulations, the data storage capacity can differ. In the case of the pack automation process, the files required around 2-3 MB of data storage.

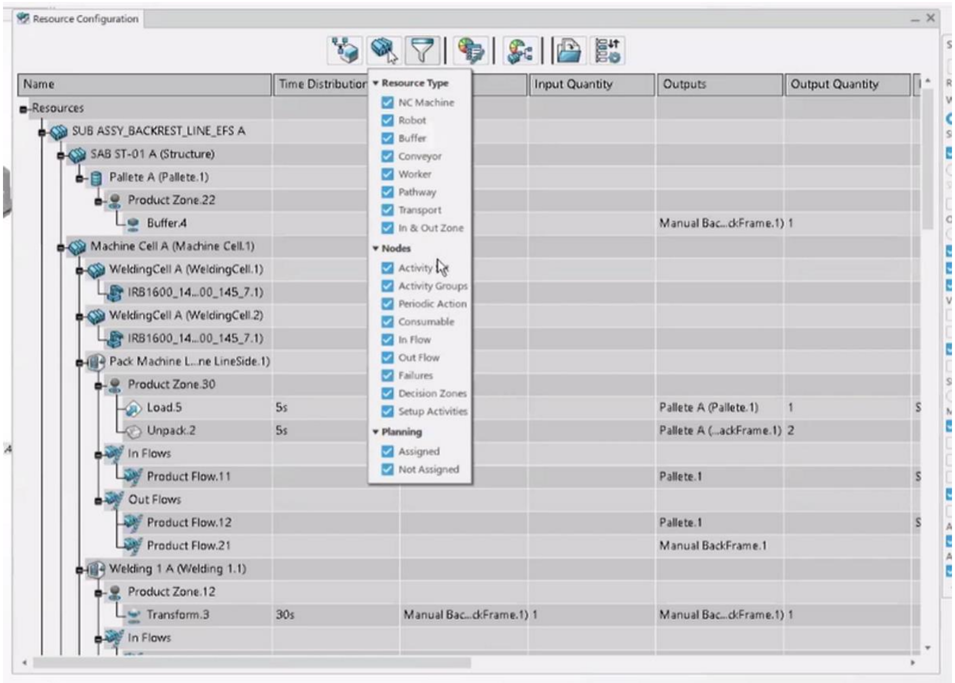
In comparison, DELMIA also offers a range of import and export possibilities. The following *Table 14* lists the supported import files regarding their names and extensions.

Table 14: Supported Input Files in DELMIA

Name	Extension	Import
3DXML for review	.3dxml	yes
3DMXL with authoring	.3dxml	yes
Abaqus/CFD	.inp	yes
Abaqus_materials	.inp	yes
Allegro	.bdf	yes
DWG2D	.dwg	yes
DXF2D	.dxf	yes
EMN	.emn	yes
ITEM	.icem	yes
IDF	.idf	yes
IDX	.idx	yes
IFC	.ifc / .ifcZIP	yes
IDES2D	.ig2	yes
IDES3D	.igs	yes
Mean_Stream_Correction	.msc	yes
Mentor_Graphics	.brd	yes
Power_Spectral_Density	.psd	yes
STEP	.stp / .step / .stpZ / .stpa / .stpx / .stpxZ	yes
STL_FOR_REVIEW	.stl	yes
Signal_Data	.amc / .asc / .dac / .pch / .rsp / .sbf / .sbr / .sm / .tab / .txt	yes
Sine_Sweep	.SineSweep	yes
SolidWorks	.asm / .prt / .sldasm / .sldprt	yes
SolidWorks Materials	.sldmat	yes
Stress Spectrum	.spectrum	yes
Substructures	.fbi / .sim	yes
Surface Finish Properties	.sfprop	yes
VRML	.wrl	yes

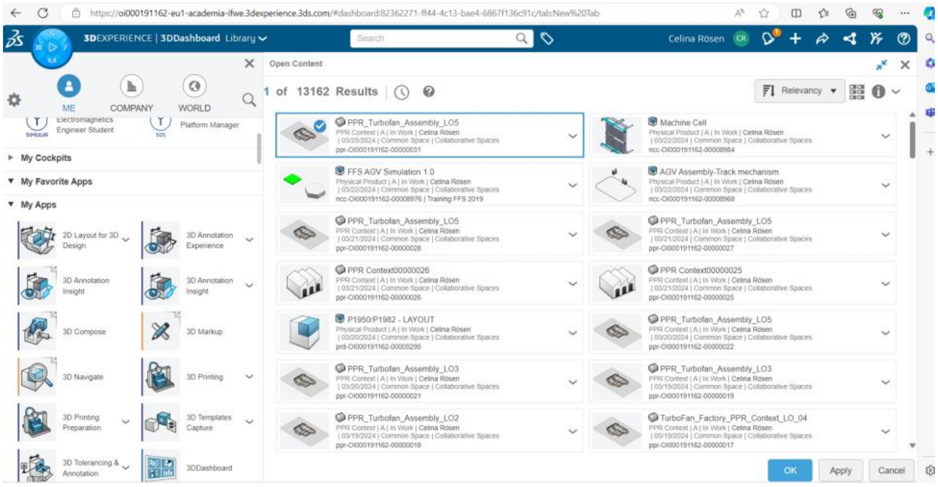
The importing of the files requires several steps; therefore, it will not reach the high intuitiveness compared to Visual Components. However, DELMIA aligns more with an output in form of a table which provides the functionality to import extensive data files based on spreadsheets. This remains easier which leads to higher accuracy in the simulations such as the Packautomation process. It depends a little on the focus and the complexity of the scenarios. The more data is needed, the easier it is to import data files. *Figure 16* below shows how DELMIA handles the import of the data based on a DES-style format.

Figure 16: Import of Data in DELMIA



The loading times for importing files also highly depend on the hardware capabilities. Regarding the output options, the program supports file formats such as .csl or .html to export the requested data. However, exporting videos based on the animations can cause some challenges. External software programs such as Camtasia are needed to show the simulations as separate videos. It was not possible to record and then download the recordings directly. In addition to the input and output options, integration with VR and AR is available. Even though the intuitiveness is lower compared to Visual Components, the possibility is given which enables future development potentials. For the case study example, both didn’t matter but the availability of them presents crucial for the general comparison. Coming to the saving options, this presents quite complicated. Due to the nature of the program as an online version, the files are saved online as well. There is no intuitive option for saving the simulation models locally. The following *Figure 17* depicts the online saving options in DELMIA. The saved files can only be accessed online via the 3D Experience Dashboard. Two specific applications within the dashboard provide the list of files saved. However, it is crucial to remember the complete file name of the simulations. Otherwise, it might be impossible to find the files again. In summary, DELMIA offers several options regarding data integration. The import of huge data files presents easier and ensures higher accuracy compared to Visual Components. However, some functions such as the recording of videos or the general saving options are complicated and decrease the intuitiveness of the program.

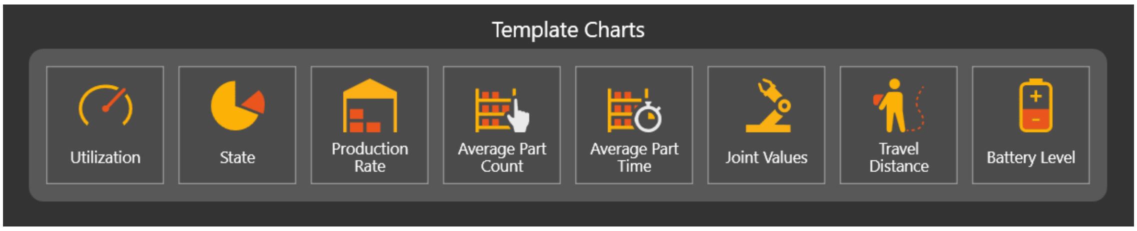
Figure 17: Online Saving Options in DELMIA



5.5.2. Options of Statistical Features and Functions

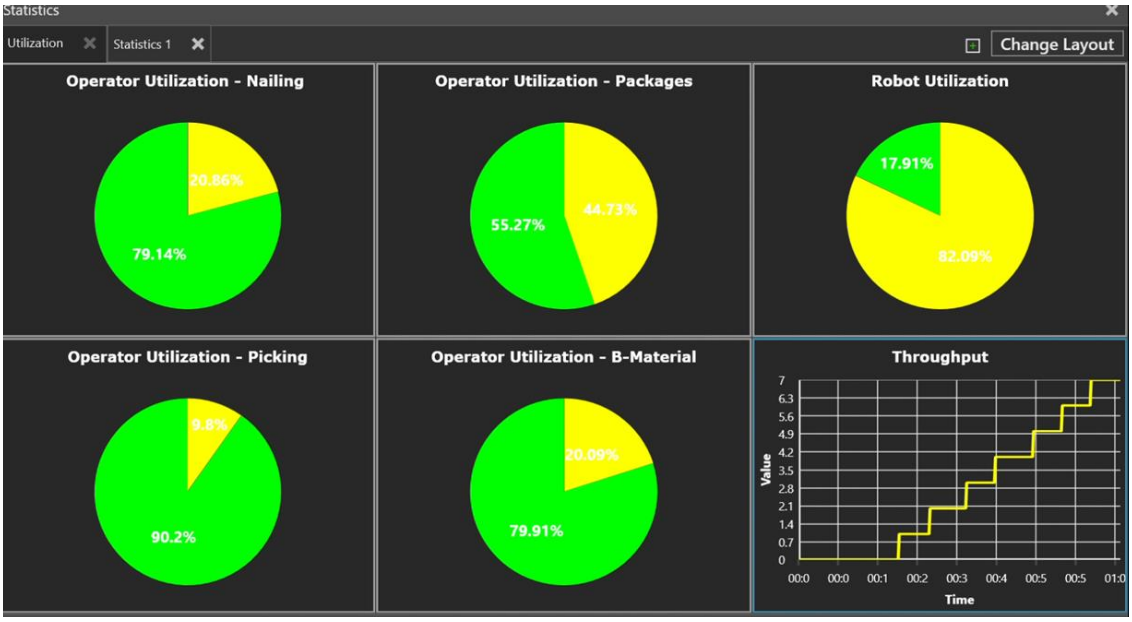
The statistical features of simulation modeling programs are crucial for the final analysis of the models. It provides the user with the tools required for the identification of critical KPIs such as throughput, bottlenecks, or utilization level of resources. In the case of Visual Components, it provides a wide range of statistical features and functions. Due to the high consistency of this program, the identification as well as the usage of those is intuitive. The access takes place via the Home tab. As already mentioned in the previous chapter, the software offers the option of downloading the statistics as Excel files or .csv format. The generation of the statistical outputs can be split into several steps. First, the object or component to be analyzed will be selected, followed by the format and layout of the output and the type of statistics requested. The standard statistics cover line, area, bar, and pie charts. Besides standard statistical graphs, the program provides the user with template charts that enable pre-set versions and defined properties. An extract of those is illustrated in *Figure 18* below. While the utilization level refers to any kind of resource, the joint values focus mainly on robots and the battery level of general vehicles. The templates offer a quick and easy assessment of the statistical parameters required. It supports the users with the analysis of their simulations.

Figure 18: Template Charts of Visual Components



Besides the charts, other statistical features are possible to be directly included within the 3D simulation model. To name some examples, a light tower, a beacon, or an inventory tracking point can be attached to machines to indicate the performance level visually. Those will mainly be used to increase the reality and representativeness of the simulated model. A combination of those components with the statistics and charts is possible. In general, users can open several tabs to compare different sets of statistics at the same time. Furthermore, the program allows users to simultaneously display the statistics while the animation is running. This supports a real-time decision-making approach. The customization level of the statistics is high. For each component, resource, or machine the analysis of a wide range of features is possible. However, Visual Components doesn't provide a specific bottleneck analysis. Within the program, there is no function available that indicates the bottlenecks of the model and the simulation. To identify bottlenecks, a manual inspection of the utilization and throughput is required. An alternative is the usage of certain add-ons which mainly focus on the identification of bottleneck scenarios. Although it might be easier with a direct bottleneck function, the analysis of the performance is possible. To focus on the case study example, several features of the Packautomation process were analyzed. The main aspect lies in the analysis of the overall utilization and performance level of the production line. For instance, it was interesting to investigate how much robots are utilized to compare the figures with the other program. The performance of simulated human resources was analyzed as well. To avoid ethical issues, the names of the original operators were not mentioned in the evaluation. In this case, the comparison between the stations was crucial to identify the bottleneck of the entire process. The following *Figure 19* shows one potential outcome of the statistics based on the Packautomation process. The example illustrates the utilization level of the operators as well as the robot utilization. Overall, the list of statistical features is long and can be adjusted based on the needs and requirements.

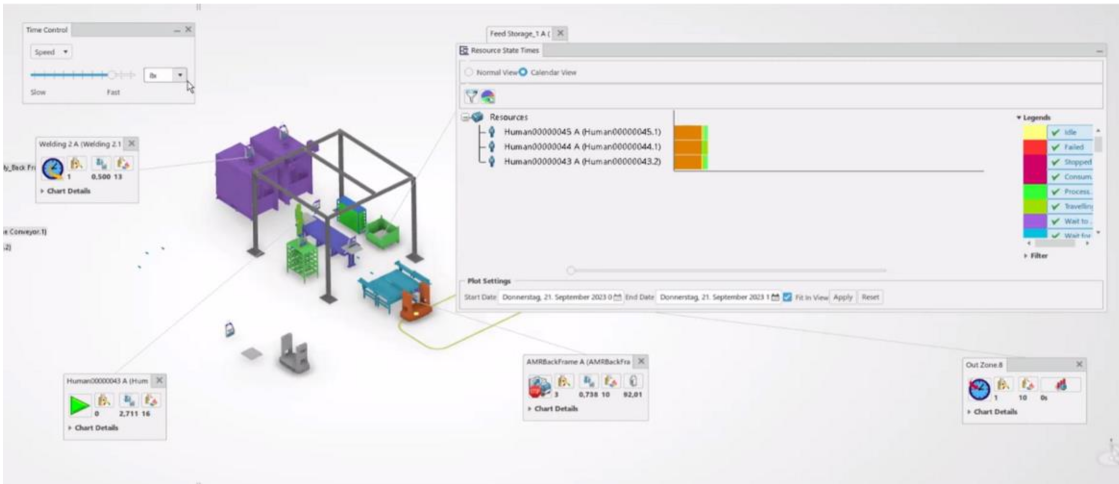
Figure 19: Utilization Level - Potential Statistical Outcome in Visual Components



In summary, Visual Components offers a wide range of statistical features and functions that enable the user to analyze the simulation and model in detail. The high customization level increases the flexibility within the analysis. Moreover, the templates already offer pre-set charts to support the user with a quick assessment of the model. The missing bottleneck function decreases the direct identification of problems, but the evaluation of performance or utilization levels are still supportive features for identifying bottlenecks manually.

DELMIA also provides a wide range of features and functions used for analyzing the outcomes of the simulations. In comparison to the previous simulation modeling program, the statistical aspects are already integrated with each component possible to show while running the simulations. If the object or component is defined as a resource, the statistics can be evaluated by activating the statistics. In general, KPIs such as throughput, utilization level, and processing time can be analyzed which offer insights for the process optimization at a later stage. Besides the standard parameters, DELMIA provides a direct bottleneck analysis function. It allows the identification of the inefficiencies in the processes immediately and supports the general evaluation. In addition, the program focuses on a color-coded approach. While the simulation is running, the used resources change their color according to the status and performance level they are. Consequently, a high level of visualization is possible, and users can quickly identify the status of the machines, components, or human resources. The following *Figure 20* depicts an extract of how the statistical features as well as the color-coded resources in DELMIA look like while the simulation is running.

Figure 20: Statistical Features in DELMIA



To bring the Packautomation process into account, the following aspects focus on both the strengths and the limitations in terms of the statistical features of the entire simulation modeling program. The color-coded approach enabled a quick identification of the status of the resources and components. Based on the yellow color code, it was identified that the robot of the case study process is mainly in an idle status. Furthermore, the green color of the human resources of workstations three and four led to the conclusion that both are working consistently. Consequently, the utilization level of the robot is extremely low while the bottleneck stations might be the last two stations of the process. The bottleneck analysis function was used to prove this assumption. Even though the statistical features of DELMIA provided a comprehensive analysis of the Packautomation performance and utilization level, the clarity of the evaluation is low. The reason for this is the huge number of possibilities available. While analyzing the case study example, it was challenging to focus only on the aspects required and not on each feature provided. The same counts for the generation of the Excel files or output data. The following *Figure 21* shows what the outcome of the statistical data taken from one part of the Packautomation process looked like. As depicted in the figure, the entire data available from the simulations is presented in the output files. DELMIA doesn't provide intuitive filter functions which would support a higher clarity of the information. This presents a challenge when it comes to a quick assessment and analysis of the required data.

Figure 21: Outcome of Statistical Data in DELMIA

Productions

Run	Products								State Times (Second)				Average Processing Time (Second)	Average Requirement Time (Second)	Reference Waiting Times (Second)			Reference Waiting Counts			Average Bottlenecks			Utilization (%)
	Input	Produced	Consumed	Output	Assembled / Packed	Rejected	Reworked	Scrapped	Processing	Wait for Input (s)	Wait to Output (s)	Failed			Min	Max	Avg	Min	Max	Avg	Time (Second)	%	Confidence Interval	
1	6	0	0	11	0	0	0	0	60	72,743	44,389	20	5,714	5,196	0	0	0	0	0	0			0	30,437

Products

Product	Waiting Time (Second)			Initial	Input	Consumed	Produced	Assembled / Packed	Scrapped	Output
	Min	Max	Avg							
Pallete A (Pallete.1) [Pallete.1]	10	21,141	15,57	0	2	0	0	0	0	2
Manual BackFrame A (Manual BackFrame.1) [Manual BackFrame.1]	39,317	39,317	6,553	0	0	0	0	0	0	6
Pallete A (Pallete.1) [Pallete.1]	20	20	20	0	2	0	0	0	0	1
Pallete A (Pallete.2) [Pallete.2]	10	10	10	0	1	0	0	0	0	1
Pallete A (Pallete.3) [Pallete.3]	13,931	13,931	13,931	0	1	0	0	0	0	1

Operations

Operation	Count	Rejected	Reworked	Processing Time (Second)			Requirement Time (Second)		
				Min	Max	Avg	Min	Max	Avg
Load.5	6	0	0	5	5	5	1,719	37,107	12,124
Unpack.2	6	0	0	5	5	5	0	0	0

Failures

Repairs	Count	Repair Time (Second)			Requirement Time (Second)		
		Min	Max	Avg	Min	Max	Avg
Repair.1	2	10	10	10	0	0	0

Cycle Time

Count	Cycle Time (Second)		
	Min	Max	Avg
6	11,719	47,107	25,457

5.5.3. Integration with Add-Ons and Software Programs

Visual Components offers a wide range of integration capabilities with add-ons and other software programs. Python serves as the main programming language which means that the coding of add-ons is based on this language. On the community forum, several categories focus only on add-on possibilities. Users can explore and access the existing add-ons via the community forum, while the development of add-ons depends on the users' knowledge and understanding of programming. Some explanations and tutorials are also provided on the community forum which supports users with the integration of add-ons and other software programs. In addition, Visual Components provides a specific course on the creation of add-ons. This approach offers the possibility to gain a basic understanding of how those add-ons will be created as well as combined with the original simulation modeling program. In general, there are plenty of opportunities to integrate add-ons and external software programs. One way is to access available ones via the community forum or develop own ones which depends on the programming skills. The tutorials and courses provided by Visual Components guide the users with the usage of these add-ons.

On the other hand, DELMIA presents a part of the entire Dassault Systèmes platform. Consequently, there are plenty of add-ons or additional software features available. These cover not only the product design and certain product simulations but also rendering and animation add-ons. However, it is important to mention that every feature or add-on requests an additional purchase. Due to the nature of this huge system, the availability of the add-ons is provided but the users must stick with the options based on this platform. The availability of add-ons can be discovered through the website of Dassault Systèmes, which also gives a brief overview of the functionalities and features of the specific add-ons. The same procedure applies to the integration with additional software programs. A purchase is needed to get access and combine the simulation modeling program with those additional features. This ensures the commitment to the Dassault Systèmes platform but increases the additional costs for the users.

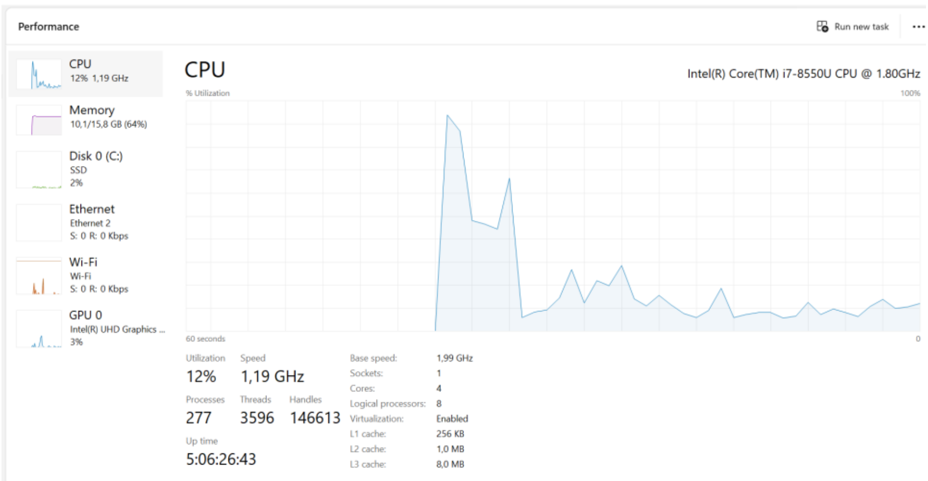
5.6. Performance

The performance of simulation modeling programs is crucial for evaluating the efficiency and usability of the tools. Quality error messages and ease of debugging are helpful features to solve issues quickly and enhance simulation accuracy. While monitoring CPU utilization provides insights into system resource management, the programming features cover coding accessibility and programming languages.

5.6.1. CPU Utilization

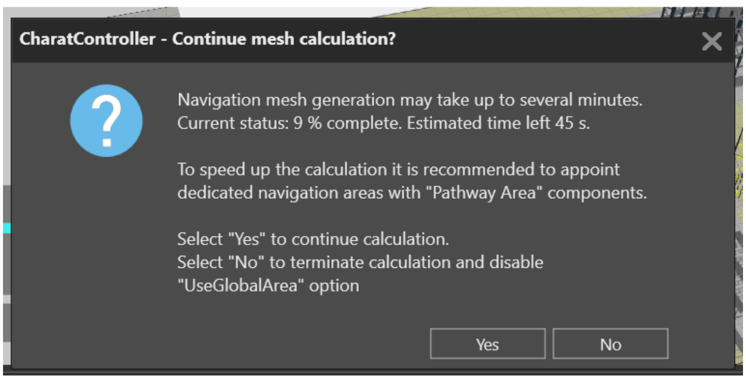
CPU utilization is a critical performance factor when using simulation modeling programs. Based on the website of Visual Components, users can gain knowledge about the hardware requirements and potential recommendations for the needed system. An Intel i7-8 processor, a graphic card with 4GB dedicated memory, and 8GB overall memory are recommended. To give some examples of how much CPU utilization Visual Components consumes, the following *Figure 22* illustrates the level while opening a simulation file in the program. It shows a high peak within the CPU utilization while it will be balanced out after the initial peak.

Figure 22: CPU Utilization while Opening Files in Visual Components



Furthermore, starting simulations often requires a high-performance level of the program. It requires several minutes before the program runs smoothly. While initializing, notifications like *Figure 23* often appear which indicate a slowdown of the loading.

Figure 23: Notification while Loading Simulations in Visual Components



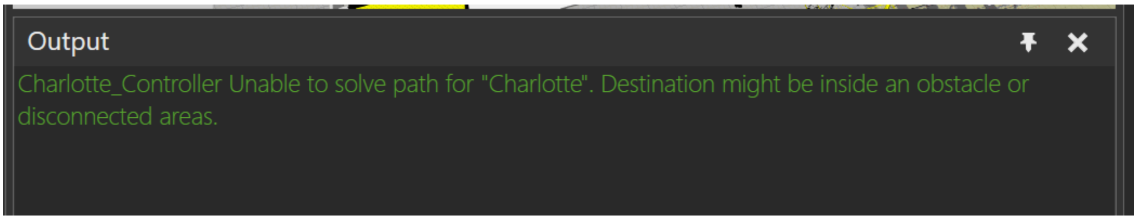
In general, the performance of the simulations depends a lot on the processor of the hardware. Therefore, it is crucial to match the system with the requirements of the simulation modeling program.

To assist users in managing CPU utilization, Dassault Systèmes provides the details of the hardware requirements on their website. This overview allows users to filter manufacturers and identify the hardware resources needed for the usage of DELMIA. Preparation is recommended to increase the success of the simulation modeling projects. A high CPU level is essential for complex simulations. For the simulation of the Packautomation process, it was advised to turn off the animation. It decreased CPU utilization but raised questions about the necessity of using a simulation program for its animation purposes. Depending on the hardware conditions, the loading of the 3D Experience platform and DELMIA applications can be time-consuming and take several minutes to complete. Even on high-performance laptops, the loading of the 2D layouts of the Packautomation process took more than five minutes while the CPU utilization reached a high level during this process. Moreover, the opening process of the 3D models as well as the importing of additional files consumed a considerable amount of time and CPU resources. Users should be aware that simulation modeling programs consume a high level of CPU. The disabling of animations during long-term simulations and the choice of correct hardware can improve the overall performance. In the case of DELMIA, access to the program takes place through the online platform. This leads to the fact that the online version as well as the external platform request a high CPU utilization at the same time. This needs to be considered.

5.6.2. Quality of Error Messages

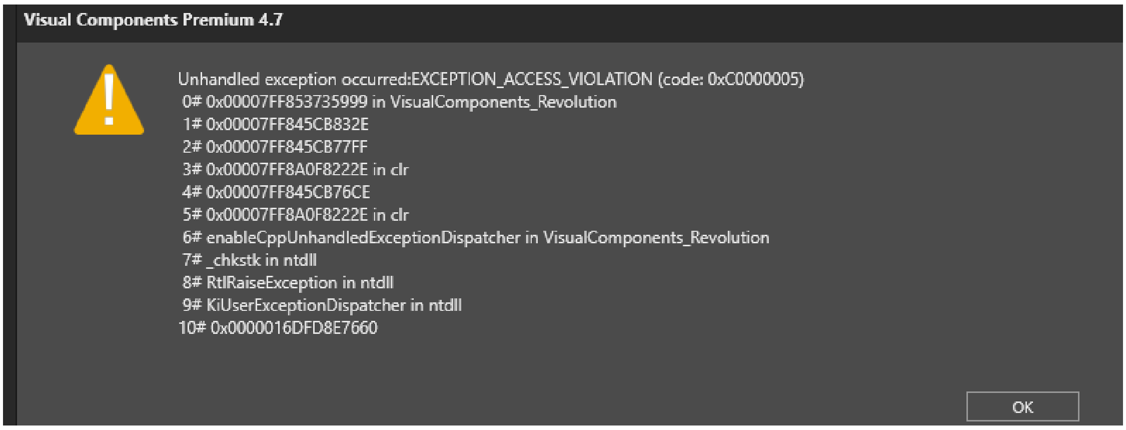
The quality of error messages affects the ease of debugging and consequently the success of simulation modeling as well. Visual Components provides a diverse mix of debugging possibilities. The error messages are displayed in a separate tab linked directly to the screen and therefore not overwhelming on the entire screen. The user can observe the error messages in this output panel. While running the simulations, the messages indicate which problems occur and which mistakes were made during the modeling so that the process flow is not functioning as it should. In the best cases, the user gets the opportunity to identify the errors based on the provided information within the output panel. However, the quality of the notifications is low. First, the number of messages is limited which makes it already difficult to receive a lot of information through the output panel. But even though a message appears, the interpretation of those messages is challenging. Existing experience in coding and general software knowledge might help in understanding the error statements. In general, the messages provide only short information which doesn't support error identification and elimination. Potential add-ons might help to improve the ease of debugging. However, some basic knowledge in programming is recommended to integrate those add-ons for improving the quality of error messages and the successful elimination of bugs in the simulations. To name some examples regarding the Packautomation simulation process, the simulated operators neglected obstacles and walked through fences or other objects. Even though an error message appeared in the output panel, the quality of the statement was low. The following *Figure 24* shows a screenshot of this output message. Based on this information, there is no possibility of identifying the original cause of the problem. Especially for beginners, it leads to a trial-and-error approach which might end in frustration and endless debugging without success.

Figure 24: Example of Error Message in Visual Components



Besides those short error statements, the simulation program stops occasionally without any reason. An additional message panel shows up which contains the information that an unhandled exception occurred. Those critical errors lead to the shutdown of the entire program without any explanatory feedback. The following *Figure 25* illustrates one of those errors that happened during the simulation of the Packautomation process.

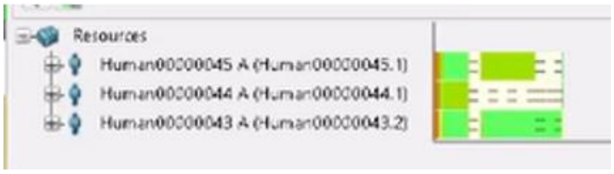
Figure 25: Unhandled Exception Occurred in Visual Components



Overall, the quality of the error messages needs to be improved to increase the general ease of debugging. Otherwise, the trial-and-error approach will continue for identifying and solving issues in the simulations.

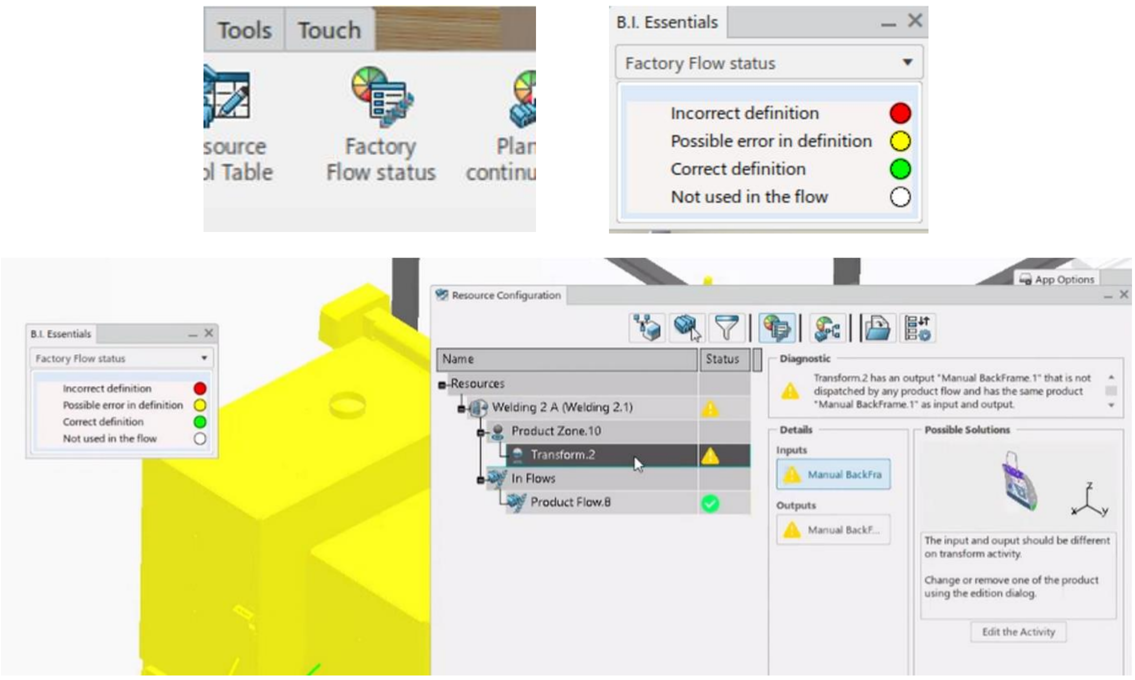
The debugging within DELMIA also presents a significant challenge for the users. Often, errors occur without any clear reasons which leads to a trial-and-error approach based on missing solutions. Even with the guidance of the instructor of the training course, the understanding of why certain errors appeared remains difficult and unclear. The lack of clarity and consistency might contribute to a high level of frustration and a low success rate in simulating. The quality of error statements is often low based on missing and meaningful insights into the root causes of issues. Users are left with the existence of errors but without any reason. This shortage of error messages seems to be a common challenge across simulation programs, DELMIA doesn't present an exception. To exemplify the lack of error statements, all operators in the Packautomation process were assigned to a shift schedule. However, without any notification or reason, only one human followed the correct shift. The following *Figure 26* shows the screenshot of the three operators while the green bar stands for working and the yellowish bar for a break. As it is visible in the screenshot, all of them are different while the first one is the correct version of the schedule. Although an error occurred, DELMIA didn't provide any notification about it, not to mention the reason for it.

Figure 26: Shift Schedule Error in DELMIA



Despite these challenges, DELMIA offers some positive features regarding the debugging topic. There is a function called Factory Flow Status Analysis which enables users to validate the model configurations before conducting the simulations. It indicates the status of defined actions, processes, and flows as incorrect, possible error, correct, or not used statements. This feature provides proactive error detection and is helpful in the creation of the pack automation simulation procedure. The following *Figure 27* illustrates the function and its statements.

Figure 27: Factory Flow Status Analysis in DELMIA

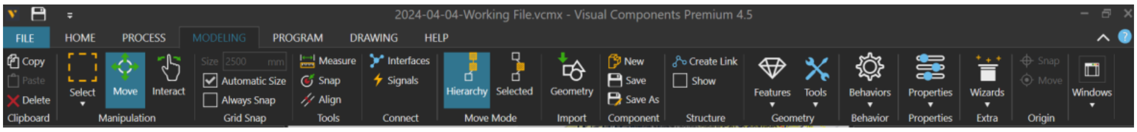


Frankly speaking, the quality of error messages within DELMIA involves some challenges that lead to a trial-and-error procedure for identifying issues. The ease of debugging requires some improvements to increase the efficiency in solving problems.

5.6.3. Programming Features

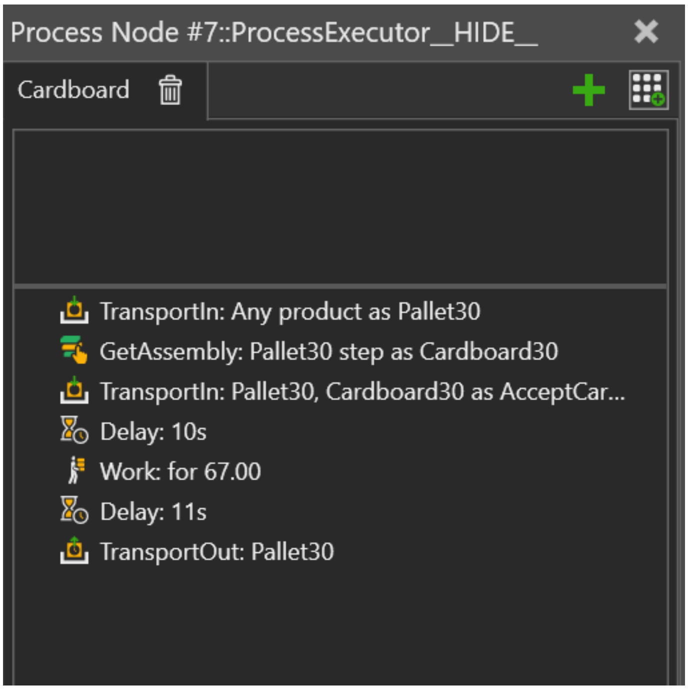
The programming features address the possibility of interacting with the code behind the program. Visual Components offers users certain options to access and adjust the program based on the coding background. The primary languages used are Python and .NET (in particular C#). Due to its simple and object-oriented nature, Python can be understood quickly and is easy to use. Moreover, it facilitates the creation of a modular code and a high modularity. In general, access to the source code and its manipulation is available within the Professional license of the program. Consequently, users can program robots directly within the program tab and use the modeling tab to adjust the code of certain components. The following *Figure 28* shows the available features within the modeling tab.

Figure 28: Programming Features in the Modeling Tab of Visual Components



As already mentioned, the design of Visual Components is highly focused on a plug-and-play approach that regards the programming features as well. Processes within the simulations can easily be adjusted based on the provided statements. The high level of logic and intelligence of the modification options allows users without programming experience to adjust and manipulate the coded processes on a basic level. The *Figure 29* below illustrates an adjusted process of the Packautomation case study example.

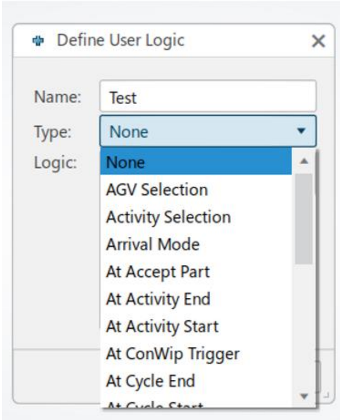
Figure 29: Adjusted Process with Statements



Overall, the programming capabilities of Visual Components are based on a sophisticated level of logic and intelligence which presents the main approach of this simulation program. Pre-built functionalities and plug-and-play options allow beginners to access and manipulate certain coding aspects. Additional add-ons unlock further programming options and increase the customization of the simulations.

The programming features within DELMIA are limited. Depending on the general platform of Dassault Systèmes, several coding languages such as C#, C++, Java, or Python are supported. However, the access and manipulation of the code within DELMIA remain difficult. Some actions and processes are hard-coded and cannot be modified such as the loading of automated vehicles. Other functions require the purchase of additional features. For instance, the programming of robots is not supported within DELMIA. It complicates the process and makes it less intuitive for users to modify the program based on their requirements and needs. The Create Logic function remains the only one that goes in the direction of programming features. Users are enabled to develop a customized logic for certain simulation tasks. As *Figure 30* below shows, the original code cannot be modified but instead, a list of options that can be added to a specific process is provided.

Figure 30: Create Logic Function in DELMIA



Despite the missing code accessibility and the lack of functionalities within DELMIA, the absence of guidance and tutorials for learning how to use the available features hinders the programming generally.

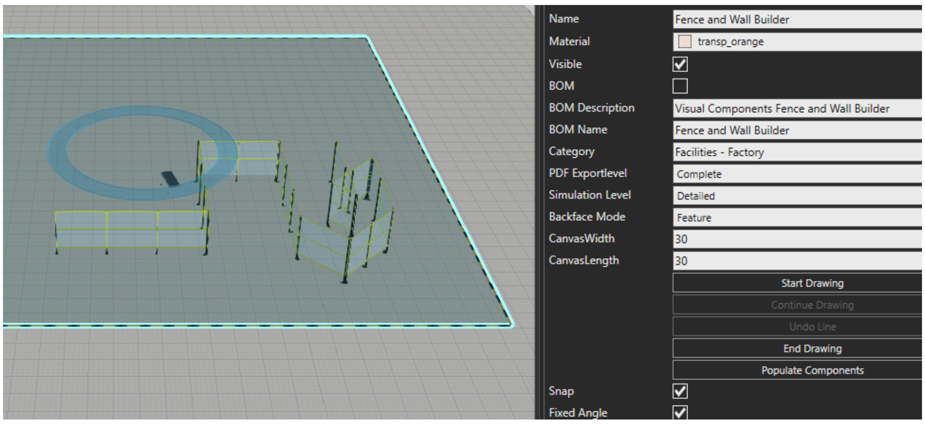
5.7. Modeling Capabilities

Modeling capabilities in simulation programs are highly crucial for the effectiveness and efficiency of the model creation. The key criteria include the availability of free templates and libraries that serve as a foundation for greenfield projects. Furthermore, the animation and simulation options will be covered to prove the customization of the program. Concrete examples of the Packautomation process will be taken into account.

5.7.1. Options of Templates and Libraries

In general, Visual Components provides the user with an intuitive and consistent simulation modeling program. Referring to the learning curve, especially at the beginning, the process is going fast which means that users gain knowledge quickly. Besides the intuitive program, the provided features contribute to the ease of modeling as well. One aspect is represented by the broad library of templates and components within the so-called eCatalog. The access is offered through the Essential license. The eCatalog is clustered into a wide range of objects and components, categorized both by manufacturers and types. Due to one focus area of Visual Components on Robotics, the library contains a huge number of robots, automation, and related components. Besides smaller suppliers like a factory, the library includes products of manufacturers like ABB or Kuka. Even though there is a huge number of robotic components available, the library contains other components as well which support the possibility to create an entire factory and layout on its own without using external CAD files. To name some examples and draw a connection to the Packautomation process, eCatalog offers several resources such as human resources but also forklifts and automated guided vehicles (AGV). Regarding the automation aspect, conveyors and machines in different varieties and adjustable properties are available. The interior of the factory can be represented by fences, warehouse components, pathways, and several standard products which are usually found in factory settings. In the case study example, the entire process was built with those available components of the eCatalog. The 2D layout presented the foundation of the replication. On top of the layout, the conveyor, the fences, the robot, and the warehouse objects were placed according to the layout requirements and measurements. Furthermore, four human resources and one forklift were applied at each workstation. In conclusion, the entire Packautomation process was replicated from scratch without using pre-existing CAD files. For that kind of greenfield project, Visual Components offers one key advantage compared to other simulation modeling programs. The existing components within the eCatalog are equipped with a high level of intelligence and logic. This means that users can immediately use these objects for the simulations without the need to define additional intelligence. Details and properties such as length, weight, and materials can be adjusted according to the requirements, but the main tasks, movements, and functionality are already pre-defined. Consequently, this enables rapid development and simulation modeling. Due to the plug-and-play functionality as well as the ability to adjust the properties of the used components, the program increases user-friendliness. To give one concrete example of an intuitive, user-friendly, and easily usable component, Visual Components provides a fence and wall builder. *Figure 31* below shows an extract of this feature in usage. It simplifies the creation process of fences and walls, due to its functionality of drawing physical barriers directly in the virtual environment. With a high level of intuitiveness, the fence and wall builder improves efficiency and enables a quick factory creation based on a 2D layout as a reference.

Figure 31: Fence and Wall Builder in Visual Components

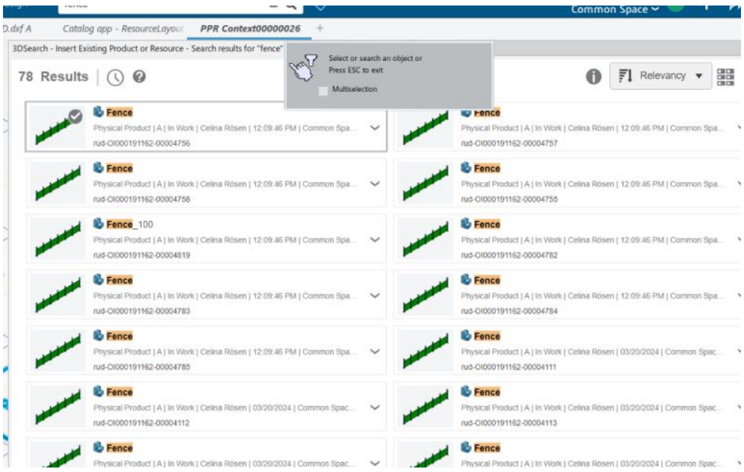


Besides specific components and intelligent objects, Visual Components equips the user with various templates of smaller processes but also entire factory layouts. Even though the purpose of those templates might not be fully applicable to the examples, they can be changed and adjusted. This supports the rapid model building. Overall, the availability of a wide range of components, objects, and templates provides an intuitive model creation and simulation process. Consequently, simulation modeling is possible and suitable for different user levels.

In comparison to Visual Components, DELMIA provides a slightly different approach for model building and its simulations. The process focuses on the usage of pre-existing

CAD files which leads to the fact that the program is more suitable for brownfield projects rather than greenfield ones. Even though it is possible to access free libraries, catalogs, or download CAD files from external websites, the general procedure is stiff, the options are limited, and the customization is small. An explanation of the available libraries is required to mention some details. Due to the program's existence within the entire Dassault Systèmes platform, the connection between DELMIA and progams such as SolidWorks or CATIA is close. Consequently, the simulation modeling program refers to the usage of the CAD files provided by the mentioned sub-systems. While there are some free libraries and catalogs available, they are limited in scope and customization options. The following *Figure 32* shows an example of the component library in DELMIA. The search was based on a fence required for the replication of the Packautomation process. As it is depicted in the figure, the search resulted in almost 80 hits. The availability of those results can be seen as a positive aspect. However, the number of results seems overwhelming even though the fence is based on a CAD file which means that the customization and adjustment of the properties represent a challenge.

Figure 32: Example of Component Library in DELMIA

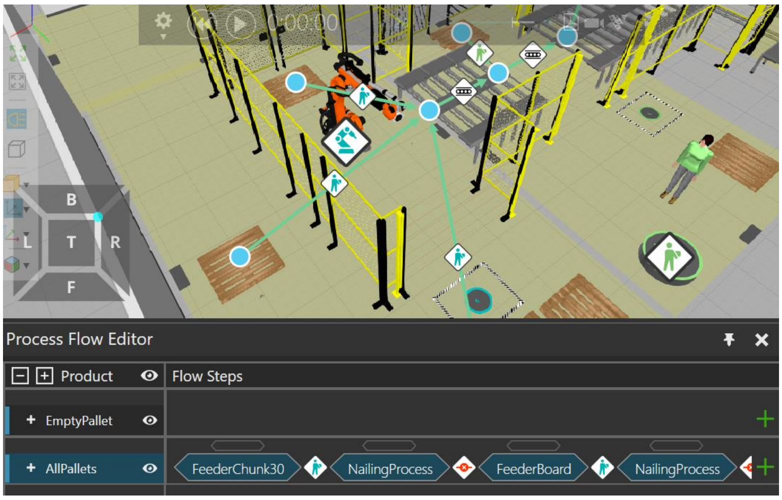


Furthermore, the lack of intelligence among these objects and components requires additional effort to define the specific logic, functions, and tasks of those. That's why users find it easier to upload their own CAD files instead of relying on the provided libraries. In the case study example of the Packautomation process, it was possible to get access to the 3D CAD files of all workstations as well as the connected automation system. The import was manageable which quickly enabled the replication of the 3D model within the simulation program. However, the objects and components lack the intelligence level. This results in the manual definition of logic and intelligence for each component before it can be used effectively. For the Packautomation process, every object, product, machine, or resource required a concrete definition of the purpose and the functionality, although 3D CAD files were available and provided. This draws the conclusion that the program is not organized and designed for using the components accessible in the free libraries. Users find it easier to upload their own CAD files, which are designed based on the factory or processes to be analyzed. However, transforming the components into resources and equipping them with intelligence and logic can be challenging. In summary, brownfield projects for which the CAD files are already available can be realized more easily than the simulation of projects that are not based on pre-existing models. Without provided CAD data, the replication, simulation, as well as adjustment of the process to be simulated can be challenging due to the rigid libraries and low level of customization options.

5.7.2. Animation and Simulation Options

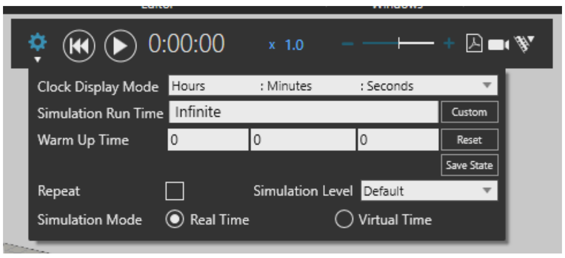
Besides the replication of the real-case scenarios within the programs, the animation and simulation options available are important for the success of the modeling projects. This criterion addresses the simulation speed, realism, accuracy, and customization in terms of the playback of the animations. In terms of the general modeling aspects, the process begins with the creation of the layout using the components from the eCatalog as well as imported CAD files. Then, the users have the possibility to define the processes according to the factory requirements. The process tab focuses mainly on the definition of those steps and flows for preparing the model for running the simulations and viewing the statistics. The general flow creation is intuitive and based on the plug-and-play concept of the entire program. The following *Figure 33* depicts an extract of how the processes and flows can be created and defined. For the case study example, the conducted observations built the foundation of this generation. Based on the observed process, the flows were designed by connecting the processes. In general, the approach of this flow definition is logical and intuitive. Once the model of the Packautomation process was prepared, the simulations and analysis were conducted.

Figure 33: Flow Creation in Visual Components



Visual Components offers several animation options to provide the users with the tools to create realistic and dynamic simulations. The following *Figure 34* shows the options available in Visual Components regarding the simulation and animation playback.

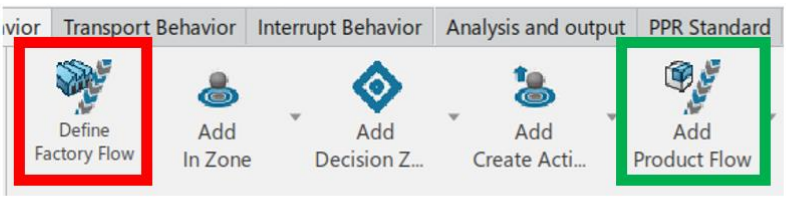
Figure 34: Simulation and Animation Options in Visual Components



As it is illustrated above, the simulation run time, the warm-up time, as well as specific settings regarding reality can be adjusted. Within those settings, the recording of the simulations and the ability to export them are also available. However, there are some limitations to consider which are crucial to be mentioned. Currently, the simulation program doesn't provide features like shifts, schedules, and breaks. This limits the ability to accurately represent real-world scenarios and processes. In most cases, manufacturing processes are conducted in working shifts. For instance, the Packautomation process takes one dayshift into account which starts at 7 am and ends at 4 pm with several breaks in between. To replicate the reality of it within the simulations, some creativity would be needed. This means that an operator can be forced to conduct a break of 16 hours to imitate the period from the end of one shift to the beginning of the next day's shift. Even though this might be possible, it requires higher programming skills and doesn't accurately reflect the reality of the Packautomation process. Another limitation in terms of the simulation and animation features regards the simulation of batch experiments. Under this term, the execution of numerous successive runs can be understood which enables the user to explore certain parameters on each run. The optimization of the process based on the parameters is the goal of those batch experiments. So far, Visual Components doesn't provide this functionality. Consequently, the exploration of specific parameters needs to be conducted step-by-step rather than simultaneously. Overall, Visual Components equipped the program with the basic features and functions regarding the simulation and animation functionality. However, specific functionalities are missing which would increase the accuracy and subsequent analysis of the model.

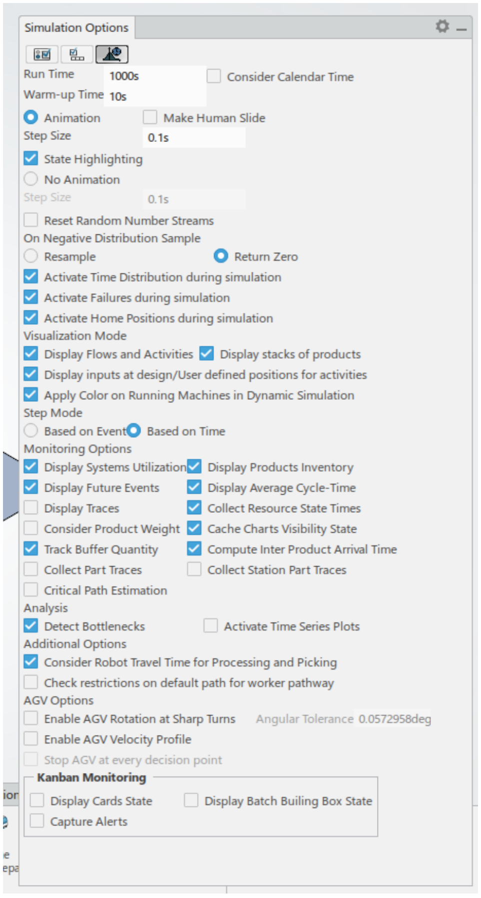
The preparation for the simulations and animation is based on the development of processes and flows. The creation of DELMIA can be done in two different ways. One approach focuses more on automated flow creation, while the other one only includes a manual definition. In comparison, the automatic approach in DELMIA resembles the procedure used in Visual Components, while the manual version requires a lot more data input and modeling knowledge of the program. The following *Figure 35* shows the two possibilities while the red frame refers to the automatic and the green frame to the manual approach. For the case study example, the automatic version was used to decrease the complexity.

Figure 35: Flow Creation in DELMIA



One of the key strengths of DELMIA is represented by the simulation and animation features. Although the huge range of options available might be overwhelming to navigate and select the most relevant ones, especially while learning the program, the functions make sure that the accuracy and realism of the simulations and animations are high. Moreover, the flexibility of adjusting and adapting the settings according to the real-case scenario enables various possibilities. *Figure 36* depicts a screenshot of the simulation and animation options available in DELMIA. Referring to the case study example, it was possible to adjust the simulation speed and runtime. Moreover, the precise working shifts and breaks were incorporated into the simulations to reflect reality as accurately as possible. DELMIA also supports simulation playback based on a predefined calendar schedule. This feature enabled the possibility of following the real-world production environment and including public holidays or other downtime days within the simulations. Besides the shift function which increases the accuracy of the models, the functionality of the batch experiment is available in DELMIA. Consequently, the simulations and the analyses can be based on specific parameters to be conducted simultaneously. This offers a quick assessment and decreases the complexity of subsequent analyses.

Figure 36: Simulation and Animation Options in DELMIA



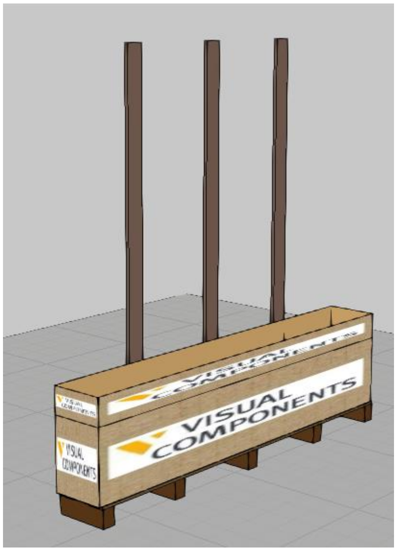
In conclusion, the simulation and animation options available in DELMIA offer users the possibility to design, simulate, and analyze processes on a high accuracy level. The shift option enables a highly realistic focus, while the function of the batch experiments allows detailed analyses.

5.7.3. Representativeness of Models and Animation

The representativeness of models and animation refers to the graphics and visualization aspects of the simulations. Furthermore, it evaluates the level of reality and detail in the models generated. Before analyzing and comparing both programs with each other, it is crucial to point out that Visual Components relies mainly on the usage of the components available, while the approach of DELMIA focuses on pre-existing CAD files. Therefore, the representativeness of the models and animation is influenced by those slightly different concepts.

In general, Visual Components offers a wide range of features that contribute to the representativeness of the models and animations. The availability of templates and libraries strengthens users to create layouts and processes based on their needs. Especially for greenfield projects, the program provides several options. Even though original CAD files are not used, the expressiveness and quality of the graphics are high. The long list of manufacturers and available types of components gives the user the freedom to create and replicate the processes required. In case one specific supplier is not listed in the catalog, other manufacturers with similar components are available. This allows plenty of options to represent the scenarios according to the realistic case. Besides the adjustment of properties and features of the components, a high level of customization is available to ensure that layouts accurately reflect realistic scenarios. One feature was used for the case study example. The main product of the Packautomation process is represented by a special pallet size which includes a cardboard box filled with posts and other materials. Because the product was not available as a 3D CAD file, the assembly feature of Visual Components was utilized to create this pallet. The result of this replication is shown in *Figure 37*. It enabled the possibility to get closer to reality and show a realistic product. Consequently, even though no CAD files are provided for a given scenario, there is a high potential for a realistic representation of the process, the products, and the factory. However, this level of detail can lead to increased CPU usage and capacity requirements. Especially for the simulation of complex scenarios and bigger projects, a reduction in the level of detail is recommended which requires a balance between realism and performance.

Figure 37: Replicated Pallet in Visual Components



The animation settings of Visual Components are configurable. Detailed statistics enable the users to analyze simulations and identify potential issues or optimization potentials. While errors and downtime can be included in the simulations, they are typically planned on a specific percentage rather than spontaneously happening. However, this presents a typical issue within simulation modeling programs and a trade-off between realism and the need for coding experience. To name other aspects which were apparent during the creation of the pack automation process, it is challenging to incorporate shifts and real-case settings. This results in the situation that operators don't follow normal working schedules or routines. In addition, the collision between components often seems unrealistic. In terms of human resources, the operators often walk through fences or AGVs and fail to follow the defined pathways even though collision detections are enabled. Despite these challenges, Visual Components offers a high level of expressiveness and graphics quality. Even without using original CAD files, the program generates realistic simulations, animations, and representative analyses.

DELMIA provides a wide range of simulation options which were explained in the section above. Regarding the representativeness of the models, there are positive and negative aspects crucial to be mentioned. The program uses simple graphics which don't require a high level of CPU capacity or performance. Even though a high degree of detail can't be illustrated, simplicity is supportive for logistical projects or complex scenarios. Furthermore, the simplicity of the components and the process is mainly expressed by the status of machines and resources visualized in different colors. While the graphics of those simulations are simple and lack a high visualization, they fulfill the purpose of a quick identification of the status and utilization level. *Figure 38* depicts the color-coded representation of processes in DELMIA. While the color coding of machines supports the following analysis, it doesn't reflect reality and needs to be switched off in certain contexts to reduce the capacity level.

Figure 38: Color-coded Representation of Processes in DELMIA

Besides those graphical limitations, the flow of products is depicted simplistically as well. For the Packautomation example, the abstraction level of the process flows was high. The products seemed to jump or appear and disappear rather than continuously moving through the entire process. The lack of a continuous flow of products and production affected realism, contributing to a high abstraction level. The representation of product flow was not the most accurate. Often, it seemed stiff and discontinuous. This abstraction requires that users rely more on imagination to interpret the simulations. Another contributing factor can be connected to human resources. Without defined pathways, the operators walk through objects and follow the shortest ways rather than focusing on realistic scenarios. Even though it is a common issue with those programs, it decreases the level of realism. In addition to these aspects, DELMIA relies on the usage of pre-existing CAD files rather than the availability of an extensive library and high customization options. Consequently, simulation projects, which are not based on existing data, might be challenging to conduct and to meet a high realism. However, the program from Dassault Systèmes provides users with more realistic scenarios due to the possibility of following working shifts, breaks, and calendar schedules. In conclusion, DELMIA offers the possibility to enable complex scenarios and larger intra-logistic projects due to its lower level of detail. While the color-coded concept and the discontinuous flow of products reduce the realism, the analysis of the simulations might be supported by those functions.

5.8. Development of General Decision Matrix

The development of a general decision matrix presents the answer to the fourth research question and a part of the main outcome of the entire thesis. While the first three research questions provided the guidance and the foundation for this development, the whole matrix can be seen as a structured framework that compares and evaluates the two presented simulation modeling programs. It presents a potential and general approach on how the analysis and comparison of the key criteria and features support the selection process of simulation modeling programs. The matrix is based on an objective assessment of both programs and their suitability for the manufacturing process example of the case study in company A. The development of the general decision matrix focused on a structured procedure to ensure relevance and objectivity to the Packautomation process. The criteria were defined through a literature review and conducted interviews with experts from the industry. The first three criteria groups, including the general features, the financial considerations, as well as the customer support, represent more general comparison aspects. The last three criteria groups, which consist of the input and output functionalities, the performance, and the modeling capabilities, can be applied directly to the case study example of the Packautomation process. Consequently, the last three criteria groups are more relevant for the case study example due to the close link. That's why the following decision matrix in this chapter focuses on the last three criteria groups. The more general aspects of the matrix can be found in the *Appendix XXI*. The final step for the development of the general decision matrix combined the weight of the criteria groups and sub-criteria with the ranking of both programs based on the previous analysis. Through this procedure, the decision matrix included the direct opinions and perspectives of the questioned experts from the industry as well as the direct link to the analyzed Packautomation process.

The following paragraph provides the explanation of the ranking of each criteria group and sub-criteria in detail. The development of the general decision matrix followed a systematic approach, which focused on an objective ranking of the mentioned criteria. First, the detailed analysis and comparison of both programs from the previous chapters were conducted to establish a foundation for the ranking process. This analysis provided the necessary insights into each criterion's performance. The ranking process followed the analysis of the programs. To enable a higher understanding of the ranking and where the numbers come from, the following *Table 15* shows the basic criteria for each grade.

Table 15: Rating Explanation

Explanation	Grades
The program shows mainly limitations	1
The program shows more limitations than strengths	2
The program shows strengths and limitations in an equal balance	3
The program shows mainly strengths, but there is a limitation	4
The program shows only strengths	5

As it is shown in the table above, five grades from 1 to 5, with 5 representing the highest performance and 1 the lowest, can be assigned for the performance of each program. The ranking process began with the evaluation of the sub-criteria, where each sub-criterion was individually assessed and assigned a grade. Following this, the focus shifted to the criteria groups. Here, the overall ranking for each group was deducted by considering the performance scores of the associated sub-criteria. This ensured that the broader categories reflected the detailed evaluations conducted earlier. To calculate the weighted scores for each criterion, the weight which came from the questionnaire results and the conducted rating based on the previous analysis were multiplied with each other. Consequently, for both programs two different weighted scores were developed. Finally, the total score was evaluated as the sum of the weighted scores. The differentiation between the sub-criteria and the criteria groups was also used in the total score to keep the structure.

The final decision matrix is illustrated in the following *Table 16.* The explanation of the given rankings will follow in the next paragraph. The more general criteria of the decision matrix can be found in the *Appendix XXI.*

Table 16: General Decision Matrix

Criteria	Weight	Visual Components		3D Experience DELMIA	
		Rating	Weighted Score	Rating	Weighted Score
Input & Output Functionality	**4,1**	**4**	**16,4**	**3**	**12,3**
Ease of Data Integration and Saving Options	4,2	3	12,6	3	12,6
Options of Statistical Features and Functions	4,5	5	22,5	4	18
Integration with Add-Ons and Software Programs	3,5	4	14	2	7
			0		0
Performance	**3,7**	**4**	**14,8**	**3**	**11,1**
CPU Utilization	3,3	3	9,9	3	9,9
Quality of Error Messages	4,5	2	9	3	13,5
Programming Features	3,3	5	16,5	2	6,6
Modeling Capabilitites	**4,3**	**4**	**17,2**	**4**	**17,2**
Options of Templates and Libraries	4,0	5	20	2	8
Animation and Simulation Options	4,4	2	8,8	5	22
Representativeness of Models and Animation	4,4	5	22	3	13,2
Total Score - Sub-Criteria	-	-	**135,3**	-	**110,8**
Total Score - Criteria Groups	-	-	**48,4**	-	**40,6**

Regarding the input and output functionality, Visual Components exceeded in the available options of statistical features and functions as well as the integration with add-ons and software programs due to the high number of features, the ease of functionality, and the customization level. While the saving of files presents an understandable and simple procedure with local saving options, the data integration can cause some challenges. Especially the direct input of huge files based on complex scenarios are challenging to be performed properly. In comparison to DELMIA, the latter is easier to conduct. The focus of this program lies more on a typical DES which focuses mainly on the integration of a lot of data. Meanwhile, the files can only be saved online, which causes some difficulties with the relocation. DELMIA also provides a long list of useful statistical features, however, the presentation of the data is overwhelming due to missing filter options. The integration of additional add-ons and software programs is possible but causes additional costs. Coming to the performance group, both programs are in the low to medium level regarding the CPU utilization and quality of error messages. Particularly the latter is crucial for the general success of the simulations and analysis. However, both programs don't exceed in this category due to the lack of error messages. Just one feature of DELMIA, which enables a pre-liminary evaluation of the process steps and the identification of potential errors can be supportive in certain situations. Regarding the programming features, Visual Components receives a high ranking due to the ease of statement adjustments and the number of pre-existing add-ons accessible through the forum. The already existing intelligence and logic behind the program enables a quick learning curve in every context including the programming possibilities. On the other hand, the simulation modeling program from Dassault Systèmes offers only limited options in terms of the programming. Many functions are hard coded without any adjustments possible. The customization level of the only available programming function is low because the users can only choose from a list of options provided. The last criteria group regards the modeling capabilities. Due to the large library of free templates and components, Visual Components received a high ranking for this criterion. It is also related to the representativeness of the models and animations because greenfield projects which don't provide any CAD files can easily be replicated and simulated as well. Those aspects represent one of the main strengths of this program. Even though the animation and simulations are possible to be generated, recorded, as well as analyzed, the lack of batch experiments and a working shift function present some downsides which weigh heavily on the ranking. In comparison, the latter are available in DELMIA besides a long list of other animation options. Nevertheless, the representativeness of the models and animations is lower due to the discontinuous flow of products and the missing possibilities for greenfield projects. This also concerns the ranking for the availability of templates and libraries. DELMIA focuses on the usage of pre-existing CAD files from the users directly. Therefore, it might be difficult to perform projects without any available data or pre-developed 3D models. Both programs provide the users with positive and negative aspects while Visual Components exceeds the total score based on the analysis and the ranking above.

DELMIA, integrated into the Dassault Systèmes platform, provides diverse solutions for various industries. It operates within the 3D Experience platform and serves as a business and innovation tool. Moreover, the program promotes real-time collaboration and connectivity. With its focus on combining the virtual and real worlds, DELMIA addresses manufacturing challenges across supply chains, logistics, and service. However, its main objective is to develop virtual twins of real-world scenarios, particularly in the manufacturing industry. Therefore, the French program offers the possibility to optimize manufacturing operations, provides visibility and illustration, as well as analyzes operational bottlenecks. It might be particularly suited for large companies with a large amount of Computer-Aided Design (CAD) data. So far, the automotive industry presents a relevant area for the usage of DELMIA. In general, simulation experts might be crucial for consistent and successful usage. The main projects highlight logistical, supply chain, and material flow optimization within manufacturing environments. Simulating details of manufacturing processes does not represent the main purpose of the program. Moreover, DELMIA doesn't focus a lot on robotics. The program offers a sequence of features that align specifically with the needs of the presented case study. Its capabilities allow the modeling of production environments, including factors such as machine interactions, material flow, and resource utilization. For the presented case, the level of detail covers a normal degree. This also includes the topic of robotics due to the low utilization level of the Kuka-robot within the case study process.

There are various areas for utilizing Visual Components simulation modeling across different processes and industries. It focuses on two primary focus groups: robotics and offline programming (OLP), as well as manufacturing simulation and optimization projects. These enable a wide range of applications, from automation processes to production workflows. Customer case examples include companies such as Kuka, Nike, CAT, Kone, Mitsubishi, Flexlink, and Beckhoff. Typical projects involve the exploration of automation possibilities, the integration of various automation systems, and the optimization of workstations and production processes while combining automated tasks with manual handling. Additionally, Visual Components enables virtual commissioning and DT to provide options for the future of Industry 5.0. The ergonomics of workers cannot be included in projects. Overall, the software is used for addressing diverse simulation needs across different industries. Visual Components offers accessible libraries to the users to visualize dynamic and interactive representations of manufacturing workflows whereby stakeholders can analyze statistics and simulation results. This simple usage provides a potential for the application area of the case study process.

5.9. Verification of the Results

The verification of the results presents a crucial step for validating the ranking and the conclusions of the decision matrix. It also offers the possibility to ensure the validation of the fourth research question which aimed for supporting the selection process of simulation modeling programs. The discussions and the gathering of feedback from the experts of the conducted interviews were in the focus for the verification of the results. Especially the production developers who are actively involved in the creation of simulations provided the possibility of validation for the developed decision matrix. The following paragraph contains a detailed explanation of the conducted steps.

1. During the analysis and development of the decision matrix, regular meetings and discussions with the production developers from the conducted interviews were performed. It supported the focus on objectivity and enabled the inclusion of expert opinions already included in the criteria definition.

2. After the first attempt of the decision matrix was finalized, an interview with the two production developers was conducted regarding a first verification of the matrix. In this interview, the results were presented, and questions asked specifically towards certain criteria groups and the decided rankings. The interview was held as an unstructured interview to increase the discussion proportion.
3. The feedback of the interview supported the critical reflection of the given rankings for both programs equally. All the criteria groups and sub-criteria were discussed, which enabled the review of every aspect of the decision matrix. Based on the comments and the outcome of the interview, the rankings were adjusted slightly.
4. The last step focused on the development of the final decision matrix. After the completion, the matrix was sent to the two production developers another time. This final verification of the ranking and the entire decision matrix allowed the concluding validation of the results.

In summary, feedback was collected during the development phase in the form of regular meetings, interviews, and discussions. Confirmation and critical aspects were exchanged to ensure a clear direction with the ranking of both programs. These validation steps were also used to avoid bias in the development of the ranking in any direction.

6. Discussion

The discussion chapter contains a critical reflection on the conducted study. The focus is divided into the theoretical framework, the methodology, the findings, as well as the analysis sections. Besides the critical reflection, the potential adjustment and expansion of the decision matrix will be explained.

6.1. Focus: Theoretical Framework

The theoretical framework of the presented master thesis focused on several, interrelated topics. To connect the theory with the findings and the analysis of the thesis, certain areas will be used as discussion points. First, the main areas of Industry 5.0 include resilience, sustainability, as well as human-centricity *(Raiche, 2022)*. Starting with resilience, simulation modeling programs are suitable for customization, flexibility, and responsiveness to changes in the requirements and conditions of manufacturing processes. Simulations can be adjusted based on changes. However, even though several scenarios can be simulated with those programs, the simulation is resource demanding. Continuous and fast changes require an immediate reaction within simulations, which might be difficult due to resource limitations. Consequently, the dynamic changes in production processes might outpace the capabilities of simulation modeling programs. Regarding the sustainability focus of industry 5.0, both advantages and limitations are discovered as well. Due to this approach, simulations can be used for experimenting with different scenarios before implementing them. This reduces the amount of resources such as cost constraints of machines or production lines which were not required to be used before the final implementation decision. However, the holistic approach to sustainability also includes environmental and social aspects. Those are not completely fulfilled by simulation modeling programs. The analysis of the two programs showed that there is still a gap in the focus of the environmental factors. Neither of the chosen programs offered specific environmental features or enabled the users to analyze those aspects. Also, only few authors mentioned sustainability in connection with simulation modeling programs which leads to the conclusion that there is still potential *(Chen et al., 2023)*. The last area focuses on the connection with human-centricity. It is possible to analyze human-machine interactions with simulation modeling programs. Different scenarios can be simulated and tested to identify the most suitable configurations to bring the human resource in the center of production processes. On the other hand, it is challenging to fully capture and simulate all elements which are crucial for humans such as empathy or decision-making processes. In this sense, ABS might be more suitable compared to DES *(Siebers, Macal, Garnett, Buxton, & Pidd, 2010)*. Overall, simulation modeling programs offer a moderate connection and fulfillment of the characteristics of Industry 5.0 in terms of customization and sustainability. However, there are also critical gaps which can limit how simulations support the core principles of human-centricity, resilience, and sustainability. As mentioned, and explained in the theoretical chapter, Industry 5.0 is closely connected with DTs *(Sahal et al., 2021)*. In general, simulation modeling such as the programs analyzed and compared are the foundation for virtual replications which represents the final goal for both programs. The collection of statistical data can be supportive for mirroring the performance of manufacturing processes which need to be analyzed. Although the goal of simulation modeling might be the creation of DTs, modeling such as DES traditionally uses data of predefined scenarios. This was visible in the analysis of the two programs, especially in the section which focused on the input and output functionalities. Consequently, the connection to the real-time data is getting lost due to the more static framework of simulation modeling programs. To ensure real-time integration, it must incorporate more dynamic capabilities to fully realize the potential of DTs assigned to simulation modeling programs.

6.2. Focus: Methodology

The reflection on the methodology refers to the data collection methods applied within this thesis. The conducted literature review enabled a connection and relationship between previous studies and the outcome of this master thesis. Especially the comparison of the benchmarking criteria allowed the discovery of similarities between different authors. It supported the argumentation line for the identification of the crucial criteria groups and factors. Moreover, it formed the theoretical foundation for the decision-making process of the selection of simulation modeling programs. While conducting the literature review, it was evident that Jerry Banks and Vlatka Hlupic can be identified as the key authors of simulation modeling research. Throughout the studied articles and research documents, the work of the researchers was cited and used as a base for later studies. There are only a few authors who can be defined as the founders of simulation modeling. It is interesting that most of the articles go back to those authors which means they formed the keystone for later research. But it might also be the case that the number of new inputs and perspectives based on new technological advancements is limited as well. Overall, the literature review was useful in building the foundation for both topic areas *(Säfsten, Gustavsson, & Ehnsiö, 2020)*. When comparing the conducted literature review with other articles, similarities as well as differences are visible. First, the presented master thesis focused on literature from the last three decades starting in the year 1989. While some research articles focus more on the most relevant studies *(Mourtzis, Doukas, Vlachou, et al., 2014)*, most of the identified literature also included findings from early stages *(Fumagalli, Polenghi, Negri, & Roda, 2019)*. For the presented master thesis, the focus laid on the broad development and evaluation of benchmarking criteria to identify the most often mentioned and relevant factors. Other papers aim more for the selection of the criteria which have been used in the latest years. Therefore, it is logical that the time frame of the research differs. Regarding the structure of the conducted literature review, it followed a step-by-step approach to ensure constant logic throughout the findings while other researchers presented the findings directly *(Nikoukaran & Paul, 1997)*. In summary, the conducted literature review of this master thesis provides some similarities as well as differences with other research articles.

The conducted interviews presented a valid alternative to include insights from an industrial perspective in relation to academic research. This data collection method aimed for the identification of additional criteria factors which are important to be considered for the comparison of simulation modeling programs *(Williamson, 2002)*. In total, five interviews with experts from different positions supported a broad perspective within this field. It enabled focus and insights from distinct angles. While the production developers focused mainly on the modeling factors and the sales consultant represented the connection with customers, the project leader as well as the manager aimed for holistic viewpoints. Even though the addressed issue was the same, it was interesting to identify that all stakeholders had different expectations towards the benchmarking criteria of simulation modeling programs. Furthermore, it turned out that the different opinions of all interview participants presented difficult to combine. A balance was required to equally focus on all factors. On the other hand, the thesis aimed for addressing a broad range of key criteria rather than specializing on the features a certain stakeholder group preferred. Consequently, the conducted approach was reasonable for this master thesis. But it seems crucial to align the procedure with the purpose the research wants to achieve. Finally, the combination of the literature review and the interviews formed a good mixture of the academic and practical sides.

The distribution of the questionnaire with subsequent analysis of the results supported the ranking of the criteria importance level. The questionnaire represented a valid method for objectivity, anonymity, as well as confidentiality of the opinions and perspectives of the participants. Moreover, the analysis of the results was easy to conduct due to color-coded charts and statistics. Due to the time constraints, it was difficult to locate participants who have worked with simulation modeling or present a connection with those programs. This limitation could have impacted the depth and specificity of the collected insights. The more positions and therefore perspectives of the participants are available, the broader will be the view on the importance level of the selected benchmarking criteria *(Williamson, 2002)*. In conclusion, the use of questionnaires was effective but could have benefited from a longer evaluation period for gathering more opinions and perspectives of relevant outcomes.

The case study presents the last method to be discussed in this section. The company provided a semi-automated manufacturing process as foundation and industrial context for the conducted analysis. Besides the practical relevance to a manufacturing company, the case study enabled an illustrative example with a high degree of transferability to other organizations. Due to the close relation to the industry, the findings can possibly be applied to manufacturers in similar contexts. This approach was often identified as the main framework for evaluating and comparing simulation programs *(Pekarcikova et al., 2021)*. Most of the studies used a practical example in form of a case study as the foundation *(Yaser et al., 2021)*. In addition, the data collection regarding the case study was divided into observations and time studies. While the observations supported the understanding level of the entire flow, the time studies aimed for a detailed investigation of the steps performed at each workstation. They also formed the foundation of later simulations and the related analysis. Consequently, this enabled a close connection to the industry. The provided case example connected several flows and a long list of steps with each other. It would have been interesting to reduce the number of details within the case study and focus on a more limited number of aspects as some researchers have done in their studies *(Pekarcikova et al., 2021).*

6.3. Focus: Research Questions

The research questions enabled guidance throughout the entire master thesis. In the following paragraphs, the main statements of each question will be summarized.

RQ1: What are the most relevant application areas for simulation modeling programs?

Simulation modeling is divided into three main types. While Systems Dynamics focuses on the analysis of dynamics *(Sterman, 2000)*, the creation of models and interacting agents builds the center of interest for the Agent-Based Simulation *(Nicolae & Wagner, 2011)*. The third type, Discrete-Event Simulation, has been developed as a simulation method used in various industries to illustrate, analyze, and optimize complex scenarios, processes, and systems *(Vieira, Dias, Santos, Pereira, & Oliveira, 2018)*. In general, the application areas of simulation modeling are broad. Besides educational and training purposes, it is also represented in mathematical and scientific environments. Especially ABS is used to study human behavior and daily situations *(Siebers, Macal, Garnett, Buxton, & Pidd, 2010).* However, engineering and manufacturing are by far the most common application areas of simulation modeling. DES plays an important role in those fields. The focus lies on the simulation, analysis, and subsequent optimization of production processes. The improvement of certain KPIs such as the throughput and utilization of resources are crucial. Moreover, the bottleneck analysis always presents a significant aspect of these simulations. However, DES can be used in various scenarios such as to analyze supply chains, logistical and transportational aspects, manufacturing processes, or robotic scenarios *(Borshchev & Grigoryev, 2013)*. Overall, simulation modeling is applied to various purposes and its application areas are growing due to technological advancements and the high demand for productivity improvement.

RQ2: Which simulation program is suitable for the purpose of manufacturing process planning and optimization and what are the reasons for this suitability?

The second research question focused on the selection process of suitable simulation modeling programs for analysis and comparison. The focus lay on a semi-automated production process in the manufacturing context which was strengthened by the case study example. That's why the most common programs were collected and listed with regards to their typical application areas and primary markets and industries. The *Table 17* shows the most important aspects of the analysis whereby it was depicted in the discussion.

Table 17: Comparison of DES Programs (based on literature review)

Program	Typical Applications	Primary Markets and Industries
AnyLogic	Focus on complex systems, but used as a tool for ABS, DES, and also SD	Supply Chains; Logistics; Warehousing; Manufacturing; Transportation; Healthcare
ARENA	Model verification; analysis of input and output data regarding material flows	Supply Chains; Logistics; Packaging; Food and Beverage; Manufacturing
DELMIA	Simulating and optimizing complex processes	Manufacturing; Production Processes
FlexSim	Creation of realistic scenarios; flow of materials	Logistics; Transportation; Manufacturing
SIMUL8	Reducing waiting times; optimizing resource allocation	Healthcare; Logistics; Service Industries
Tecnomatix Plant Simuation	Optimize processes and design to increase efficiency	Machinery; Electronics Manufacturing; Automotive
Visual Components	Optimizing production processes; Increasing KPIs	Production Processes; Manufacturing; Robotics
WITNESS	Planning, scheduling, and optimizing logistical flows	Logistics; Service Industries; Manufacturing

The selection process was primarily based on the application area approach, with *Table 17* highlighting two suitable programs: *3D Experience – DELMIA* and the program *Visual Components*. Both tools were evaluated based on their relevance to manufacturing process planning and optimization. The choice of DELMIA was also partly influenced by its pre-existing usage within case company B. This offered the benefit of existing knowledge which was supportive for the procedure and the structure of the analysis. However, due to the need for improved capabilities and other limitations, the goal consisted in the investigation of other programs to meet the company's requirements more effectively. Similarly, Visual Components was selected for its alignment with the application area. In addition, the author's pre-experience with the software enabled a faster learning curve and integration. Consequently, a combination of reasons led to the decision of the selected programs. Both DELMIA and Visual Components were suitable for the manufacturing process planning and optimization tasks which formed the basis for further analysis and comparison in this master thesis. But at the same time, the pre-existing knowledge and expertise directed the decision-making process as well.

RQ3: What are the key criteria and features required from simulation software to contribute to manufacturing process planning and optimization?

The last research question formed the foundation for the comparison and analysis of the chosen simulation modeling programs. The findings of the literature review combined with the analysis of the conducted interviews enabled the synthesis of the most important key criteria and features in terms of simulation modeling programs. While the literature review focused on the research perspective, the interviews allowed insights into industrial and realistic processes. The conducted interviews brought practical insights into consideration and highlighted how the theoretical criteria can be applied in real-world settings. By incorporating views from industry professionals, the gap between theory and practice was closed. The following *Table 18* summarizes the main statements shortly.

Table 18: Criteria Groups and Sub-Criteria

General Features	Financial Considerations	Customer Support
Ease of Installation and Updates	Initial Costs	Quality of Documentation, Tutorials, Training
Learning Curve	Additional Costs	Direct Customer Support
User Friendliness	Price of Training Course	Quality of Community Support

Performance	Input & Output Functionality	Modeling Capabilities
CPU Utilization	Ease of Data Integration and Saving Options	Options of Templates and Libraries
Quality of Error Messages	Options of Statistical Features and Functions	Animation and Simulation Options
Programming Features	Integration with Add-Ons and Software Programs	Representativeness of Models and Animation

When critically reflecting on simulation modeling programs, several strengths and limitations among the key criteria must be acknowledged. Even though each criteria group contains three sub-criteria, some of them are still considered as broad terms. For instance, the programming features within the performance group are often perceived as one entire analysis itself instead of being one small aspect beside several others. This can also be seen in the animation and simulation options. Underneath this criterion there are more options and details which can be analyzed in depth. In addition to the broad spectrum of the terms, some of the criteria mainly focus on a qualitative description. Except for the financial considerations, it was difficult to capture the outcomes of the comparison in quantitative statements or aspects. The complexities of factors such as ease of installation, user-friendliness, and quality of documentation often challenge numerical measurement. Instead, these criteria are often evaluated through assessments, user feedback, and qualitative observations. This approach made it challenging to receive the outcomes of comparisons. Despite these difficulties, qualitative evaluations play an important role in providing insights and understanding of the user experience. In conclusion, it would have been interesting to compare the two programs only on quantitative criteria or on a limited but more detailed number of factors to narrow it down even further. However, the thesis aimed for a broader evaluation and wider range of criteria to compare all features relevant for diverse stakeholder groups.

RQ4: How can the key criteria and features be used for supporting organizations with the selection of simulation modeling programs?

The fourth research question focuses on the development of a potential tool which supports the selection of simulation modeling programs. Developed as a decision matrix, these criteria enable the possibility to compare and evaluate the two analyzed simulation modeling programs. The decision matrix provides a structured procedure to ensure relevance and objectivity in the selection process. While the initial criteria groups, such as general features, financial considerations, and customer support, offer broad comparison aspects, the subsequent groups, including input and output functionalities, performance, and modeling capabilities, focused on the case study example of the Packautomation process. The final decision matrix includes both the weighted importance of each criteria group based on the questionnaire results and the ranking of the programs based on the conducted analysis with direct relevance to the Packautomation process. The following *Table 19* shows the final decision matrix.

Table 19: Final Decision Matrix

Criteria	Weight	Visual Components		3D Experience DELMIA	
		Rating	Weighted Score	Rating	Weighted Score
Input & Output Functionality	**4,1**	**4**	**16,4**	**3**	**12,3**
Ease of Data Integration and Saving Options	4,2	3	12,6	3	12,6
Options of Statistical Features and Functions	4,5	5	22,5	4	18
Integration with Add-Ons and Software Programs	3,5	4	14	2	7
			0		0
Performance	**3,7**	**4**	**14,8**	**3**	**11,1**
CPU Utilization	3,3	3	9,9	3	9,9
Quality of Error Messages	4,5	2	9	3	13,5
Programming Features	3,3	5	16,5	2	6,6
Modeling Capabilitites	**4,3**	**4**	**17,2**	**4**	**17,2**
Options of Templates and Libraries	4,0	5	20	2	8
Animation and Simulation Options	4,4	2	8,8	5	22
Representativeness of Models and Animation	4,4	5	22	3	13,2
Total Score - Sub-Criteria	-	-	**135,3**	-	**110,8**
Total Score - Criteria Groups	-	-	**48,4**	-	**40,6**

Now it is the question, how the matrix can be modified so that companies can use it as a flexible tool. To increase its flexibility and modularity, different adjustments could be considered. Firstly, the inclusion of additional criteria would allow a broader focus on new areas and perspectives. Extra criteria groups or sub-criteria can easily be added. Secondly, the weighting system for the criteria is based on the distributed questionnaire and its results. In case an organization would prefer a more customized weight ranking, it might be an option to distribute a survey to gain feedback about the internal importance levels. The ranking of the two programs could remain the same so that the focus lies more on the level of importance and therefore the weight creation of the specific criteria groups and sub-criteria. Another modification possibility focuses on the integration of further simulation modeling programs. Even though the initial development of the matrix included two specific simulation modeling programs, the inclusion of other programs is possible as well. By integrating additional programs, the decision matrix might become a more comprehensive tool for a broader analysis. The weight of the criteria groups and the sub-criteria will remain while the new program will be analyzed in the same way as the previous programs were. It is crucial to keep the focus on the manufacturing process to use the matrix as it is structured. By incorporating further simulation modeling programs, the decision matrix becomes a more dynamic resource for organizations which request support in their software selection processes. However, it is crucial to work accurately and consistently. The procedure needs to be adjusted on a similar approach compared to the initial decision matrix. Additionally, while integrating further simulation modeling programs expands the applicability of the matrix, it also increases the complexity of comparisons and evaluations. Maintaining the focus on the manufacturing process is crucial for ensuring the relevance and effectiveness. In conclusion, the modification of the developed decision matrix is possible. It can support organizations in further integrating and focusing on additional criteria or simulation programs. But it is essential to understand that it can also introduce challenges that must carefully be addressed to ensure the continuous effectiveness in supporting the selection process of simulation programs.

6.4. Focus: Analysis

The focus on the analysis regards the overall reasons why and how the study contributes to the general research. As already mentioned in the problem formulation, there is a lack of evaluation techniques regarding the selection process of simulation modeling programs. A lot of research articles address the identification of relevant benchmarking criteria while the actual comparison process of specific simulation programs is not conducted. Usually, only few programs are usually subject to the investigations and comparison, while others miss out. Furthermore, the research mainly provides yes and no checklists and doesn’t give deep insights regarding the understanding of the programs. Consequently, the lack of standard evaluation techniques combined with the focus on the selected simulation modeling programs represent the main reasons why this study was conducted. It enabled a more holistic and general perspective on this topic and contributed additional insights into both programs. In the following tables, the main statements of the analysis are listed. The *Table 20* focuses only on Visual Components. To reflect on the findings of the analysis in a critical way, the following paragraph highlights some aspects. Visual Components is a user-friendly simulation modeling program characterized by a fast-learning curve and an intuitive interface mainly due to the logical structure of its components and processes. The analysis of this program was based on the pre-defined criteria to provide a comprehensive overview of the strengths and limitations of the program. The inclusion of the case study process was considered a practical example and enabled the transferability to the industrial perspective. However, the analysis could have investigated deeper into some limitations. The integration of quantitative data and more direct user feedback would have increased the degree of details. Additionally, a comparative analysis with even more simulation programs would have improved a broader understanding of further programs. But time constraints limited the analysis in terms of the depth.

Table 20: Main Statements of Visual Components

Module Title	Strengths	Limitations
General Features	- Fast learning curve based on high user friendliness - Intuitive program due to the logic/intelligence level of the components / overall processes/statements	
Financial Considerations	- Different license types with reasonable levels and included features - No additional costs for learning / tutorials - Several participants allowed for training courses	- Considerable initial costs - Only an annual subscription possible
Customer Support	- Direct customer support from 10 dedicated teams working with customer problems - Learning of the program possible just based on the tutorials/documents - Learning paths summarize the main tutorials / documents required	- Customer forum doesn't always support
Input & Output Functionalities	- Ease of file saving - Long list of statistical features available - Customization of statistics and flexibility in output - Integration with add-ons and additional software possible - Pre-existing add-ons	- Input of huge data files is challenging, depending on the programming skills
Performance	- Ease of programming due to logic/intelligence of the general program/features	- High CPU utilization - Capacity issues and unpredictable bugs happening - Low-quality of error messages which don't support solving the issues
Modeling Capabilities	- Huge library with available templates and components - Components are equipped with logic/intelligence which makes the modeling fast, and easy for all user levels - Recording options for the simulations and animations - High representativeness of models and components, even though there are no CAD files already existing	- Missing working shift function - Batch experiments are currently not possible - Use of CAD files / models can cause a high utilization level - Direct bottleneck analysis not available, only manually possible

Table 21 takes DELMIA into consideration.

Table 21: Main Statements of DELMIA

Module Title	Strengths	Limitations
General Features	- Pop-up updates offer immediate reaction	- Longer learning curve due to lower user friendliness - Low intuitiveness level, especially challenging for beginners
Financial Considerations	- Plenty of license types and roles available - Monthly/quarterly / annual subscriptions possible	- Considerable initial costs - Every add-on or additional software causes extra costs - Learning platform is not included in the initial costs
Customer Support	- Training course provides users with a good overview of the usage and functions	- Automated / AI-generated customer support - Quality of the learning platform is low which resulted in difficulties in understanding and using the program - Only with a training course it is possible to learn the program quickly
Input & Output Functionalities	- Batch experiments possible - Integration of large data files possible due to the high focus on DES style	- Low customization and filter options for output files - Only online saving options, difficult to find - Integration with additional software and add-ons causes extra costs
Performance	- Localization of error possible before performing the simulations based on the feature: factory flow analysis	- High utilization level - Problems/bugs occur without any reason - Low-quality of error messages which don't support solving the issues - Limited programming flexibility and possibilities
Modeling Capabilities	- Availability of working shift options apart from a long list of simulation possibilities - Batch experiments possible - Direct bottleneck analysis	- Discontinuous flow of products reduces animation representativeness - High representativeness of processes only possible with pre-existing 3D models - Limited number of libraries and templates available

One limitation concerns the challenge of exploring certain sub-criteria, especially those related to programming or coding aspects. The complexity of these criteria made it difficult to draw conclusions just based on the conducted analysis. Technical and license limitations are also part of the constraints of the analysis. A significant challenge realized during the analysis was the mix of stakeholders, interests, and focus areas. This highlights the importance of maintaining clarity, and consistency in defining evaluation criteria and ensuring alignment with the objectives of the study. While the thesis focused on a broad comparison, it would have been interesting to focus only on the examination of modeling capabilities. This aspect will be discussed in the outlook section.

7. Conclusion

The conclusion combines the general reflection of the entire master thesis as well as an outlook for future research potential. It can be seen as a summary of the main statements and findings of the presented thesis.

7.1. Reflection

In conclusion, the presented master thesis contributes to the overall literature due to several aspects. Firstly, the comparison and analysis of the selected simulation modeling programs have not been conducted in previous studies. This fills a gap in the existing research. Secondly, the chosen benchmarking criteria are relevant aspects based on the literature review and the conducted interviews. It focuses on the features, capabilities, and applications of simulation modeling programs. Thirdly, the case study approach enables practical relevance and offers insights that are transferable to other companies with similar focus areas. Regarding the connection to the field of production systems, this thesis contributes to the investigation of innovative technologies. The importance of simulation modeling is growing due to the contribution to Industry 5.0 and particularly Digital Twins. Consequently, the conducted thesis provides valuable insights into the landscape of industrial automation and the potential interaction between the physical and virtual production environments. The thesis offers insights with practical implications for industry. In summary, the presented master thesis contributes to literature by addressing critical gaps identified within existing research. Particularly the decision-making methodologies for evaluating simulation modeling programs can be supported. Often, the lack of a commonly accepted list for the comparison is evident. While previous studies have used case studies to explore simulation programs, a systematic method for conducting these evaluations was not developed. Furthermore, the lists provided within the research often focus on yes and no assessments. Details of an analysis are often neglected. By addressing these shortcomings and developing a decision matrix, the thesis enables a structured framework for supporting organizations in the selection of simulation modeling programs. The application area lies in the context of manufacturing processes. Due to the connection to a realistic, industrial case, the transferability of the analysis and the decision matrix is established.

While the presented master thesis has addressed several complexities within the literature and research perspective, it is important to acknowledge some limitations. Diverse perspectives and interests of various stakeholders increased the complexity of the outcome as well as the purpose of the master thesis. Even though the attention was based on the analysis of the selected simulation programs, it was essential to keep the focus area based on chosen criteria. Regarding the benchmarking criteria, the thesis took several aspects into account which broadened the investigation area. Therefore, the analysis focused more on the fulfillment of every criterion instead of analyzing the details of one criteria group. Additionally, time constraints can also be seen as a significant challenge throughout the research process. The decision to focus on two modeling programs or the limited number of interviews could have been broadened without the time constraints in the background. However, it was still possible to conduct the analysis as planned.

7.2. Outlook

The outlook for future research offers some possibilities to build on the findings of the conducted master thesis. One potential direction involves the conduction of another case study example to investigate more insights based on the selected and defined criteria groups and sub-criteria. It would allow the focus on another, slightly different application area. Both Visual Components and DELMIA can be examined from this shifted angle while the criteria factors remain the same.

Moreover, a comparison can be expanded beyond the selected simulation programs. It would be possible to include another program such as the Tecnomatix Plant Simulation from Siemens in the evaluation and benchmarking. This enables the broadening of the analysis as well as the decision matrix. By expanding the scope of comparison, additional criteria for evaluating simulation programs can be identified and the selection of the most appropriate program for the application in the context of manufacturing processes can be conducted. This holistic approach might improve a deeper understanding of the programs and enable another level of knowledge needed to manage the complexities of the program selection effectively.

In addition to the mentioned potentials, the comparison between DELMIA and its daughter platforms, such as SolidWorks or CATIA, would have been interesting due to the connectivity within the same system. By comparing DELMIA with these related platforms, the studies can focus on strengths and limitations within the same system. This might enable an understanding of how different programs are dealt with on a platform offered by only one provider.

Furthermore, the incorporation of perspectives of students, production developers, or researchers through a survey or other methods might offer a valuable opportunity to assess new user perceptions and preferences. Gaining feedback from individuals with diverse backgrounds and levels of familiarity with the programs enables insights into usability, functionality, and overall user experience. While this approach extends beyond the scope of a master's thesis, it presents a potential opportunity for future research. Moreover, this approach would increase the validity of the analysis which ensures the correctness of the data and identified findings.

In conclusion, there is potential to build on the findings of the conducted master thesis. The analysis can be expanded and elaborated into different areas.

References

Abar, S., Theodoropoulos, G. K., Lemarinier, P., & O'Hare, G. M. P. (2017). Agent-Based Modelling and Simulation tools: A review of the state-of-art software. In *Computer Science Review* (Vol. 24, pp. 13–33). Elsevier Ireland Ltd. https://doi.org/10.1016/j.cosrev.2017.03.001

Abdulnour, S., Baril, C., Abdulnour, G., & Gamache, S. (2022). Implementation of Industry 4.0 Principles and Tools: Simulation and Case Study in a Manufacturing SME. *Sustainability (Switzerland)*, *14*(10). https://doi.org/10.3390/su14106336

Alcácer, V., & Cruz-Machado, V. (2019). Scanning the Industry 4.0: A Literature Review on Technologies for Manufacturing Systems. In *Engineering Science and Technology, an International Journal* (Vol. 22, Issue 3, pp. 899–919). Elsevier B.V. https://doi.org/10.1016/j.jestch.2019.01.006

AnyLogic. (2015). *Simulation Software Comparison.* AnyLogic.

Attaran, M., & Celik, B. G. (2023). Digital Twin: Benefits, use cases, challenges, and opportunities. *Decision Analytics Journal*, *6*. https://doi.org/10.1016/j.dajour.2023.100165

Aurich, P., Stonis, M., & Nyhuis, P. (2018, March). Entwicklung einer Methode zur quantiativen, mehrdimensionalen Fabriklayoutplanung. *ZWF Zeitschrift für Wirtfschaftlichen Fabrikbetrieb*, pp. 117-120. doi:https://doi.org/10.3139/104.111872

Axelent Solutions. (n.d.).

Abar, S., Theodoropoulos, G. K., Lemarinier, P., & O'Hare, G. M. P. (2017). Agent Based Modelling and Simulation tools: A review of the state-of-art software. In *Computer Science Review* (Vol. 24, pp. 13–33). Elsevier Ireland Ltd. https://doi.org/10.1016/j.cosrev.2017.03.001

Abdulnour, S., Baril, C., Abdulnour, G., & Gamache, S. (2022). Implementation of Industry 4.0 Principles and Tools: Simulation and Case Study in a Manufacturing SME. *Sustainability (Switzerland)*, *14*(10). https://doi.org/10.3390/su14106336

Alcácer, V., & Cruz-Machado, V. (2019). Scanning the Industry 4.0: A Literature Review on Technologies for Manufacturing Systems. In *Engineering Science and Technology, an International Journal* (Vol. 22, Issue 3, pp. 899–919). Elsevier B.V. https://doi.org/10.1016/j.jestch.2019.01.006

An, L., Grimm, V., & Ii, B. L. T. (n.d.). Editorial: Meeting Grand Challenges in Agent-Based Models. In *Journal of Artificial Societies and Social Simulation*.

Attaran, M., & Celik, B. G. (2023). Digital Twin: Benefits, use cases, challenges, and opportunities. *Decision Analytics Journal*, *6*. https://doi.org/10.1016/j.dajour.2023.100165

Axelrod, R. (1997). *Advancing the Art of Simulation in the Social Sciences Obtaining, analyzing, and sharing results of computer models* (Vol. 3, Issue 2). John Wiley & Sons, Inc.

Azizi, A., Vatankhah, R., & Editors, B. (n.d.). *Emerging Trends in Mechatronics Technologies, Applications, and Challenges Industry 4.0*.

Bag, S., & Pretorius, J. H. C. (2022). Relationships between industry 4.0, sustainable manufacturing and circular economy: proposal of a research framework. In *International Journal of Organizational Analysis* (Vol. 30, Issue 4, pp. 864–898). Emerald Group Holdings Ltd. https://doi.org/10.1108/IJOA-04-2020-2120

Bangsowmi, As. (2020). Tecnomatix Plant Simulation Modeling and Programming by Means of Examples, Second Edition. In *Tecnomatix Plant Simulation Modeling and Programming by Means of Examples, Second Edition*. Springer International Publishing. https://doi.org/10.1007/978-3-030-41544-0

Barbati, M., Bruno, G., & Genovese, A. (2012). Applications of agent-based models for optimization problems: A literature review. *Expert Systems with Applications*, *39*(5), 6020–6028. https://doi.org/10.1016/j.eswa.2011.12.015

Baudin, M., & Netland, T. (2022). Introduction to Manufacturing. In *Introduction to Manufacturing*. Routledge. https://doi.org/10.4324/9781351110310

Berisha, B., Mëziu, E., & Shabani, I. (2022). Big data analytics in Cloud computing: an overview. *Journal of Cloud Computing*, *11*(1). https://doi.org/10.1186/s13677-022-00301-w

Besbes, M., Zolghadri, M., Costa Affonso, R., Masmoudi, F., & Haddar, M. (2021). 3D facility layout problem. *Journal of Intelligent Manufacturing*, *32*(4), 1065–1090. https://doi.org/10.1007/s10845-020-01603-z

Biffl, S., Gerhard, D., & Lüder, A. (2017). Multi-disciplinary engineering for cyber-physical production systems: Data models and software solutions for handling complex engineering projects. In *Multi-Disciplinary Engineering for Cyber-Physical Production Systems: Data Models and Software Solutions for Handling Complex Engineering Projects*. Springer International Publishing. https://doi.org/10.1007/978-3-319-56345-9

Borshchev, A., & Filippov, A. (n.d.). *A. Borshchev and A. Filippov. From System Dynamics and Discrete Event to Practical Agent Based From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools*. www.xjtek.com

Breque, Maija., De Nul, Lars., Petridis, Athanasios., & European Commission. Directorate-General for Research and Innovation. (n.d.). *Industry 5.0 : towards a sustainable, human-centric and resilient European industry.*

Bundy, A., Chater, N., & Muggleton, S. (2023). Introduction to "Cognitive artificial intelligence." In *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* (Vol. 381, Issue 2251). Royal Society Publishing. https://doi.org/10.1098/rsta.2022.0051

Caggiano, A., Caiazzo, F., & Teti, R. (2015). Digital factory approach for flexible and efficient manufacturing systems in the aerospace industry. *Procedia CIRP*, *37*, 122–127. https://doi.org/10.1016/j.procir.2015.08.015

Chauhan, C., Parida, V., & Dhir, A. (2022). Linking circular economy and digitalisation technologies: A systematic literature review of past achievements and future promises. *Technological Forecasting and Social Change*, *177*. https://doi.org/10.1016/j.techfore.2022.121508

Chen, L., Chen, Z., Zhang, Y., Liu, Y., Osman, A. I., Farghali, M., Hua, J., Al-Fatesh, A., Ihara, I., Rooney, D. W., & Yap, P. S. (2023). Artificial intelligence-based solutions for climate change: a review. In *Environmental Chemistry Letters* (Vol. 21, Issue 5, pp. 2525–2557). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s10311-023-01617-y

Chung, C. A. (2004). *Simulation modeling handbook : a practical approach*. CRC Press.

Cimino, C., Negri, E., & Fumagalli, L. (2019a). Review of digital twin applications in manufacturing. *Computers in Industry*, *113*. https://doi.org/10.1016/j.compind.2019.103130

Cimino, C., Negri, E., & Fumagalli, L. (2019b). Review of digital twin applications in manufacturing. *Computers in Industry*, *113*. https://doi.org/10.1016/j.compind.2019.103130

D'Addona, D. M., Ullah, A. M. M. S., & Matarazzo, D. (2017). Tool-wear prediction and pattern-recognition using artificial neural network and DNA-based computing. *Journal of Intelligent Manufacturing*, *28*(6), 1285–1301. https://doi.org/10.1007/s10845-015-1155-0

Daneshjo, N., & Malega, P. (2021). Proposal of the Reworking Station Model using Plant Simulation. *TEM Journal*, *10*(1), 197–203. https://doi.org/10.18421/TEM101-25

De Felice, F., Travaglioni, M., & Petrillo, A. (2021). Innovation trajectories for a society 5.0. In *Data* (Vol. 6, Issue 11). MDPI. https://doi.org/10.3390/data6110115

Demir, K. A., Döven, G., & Sezen, B. (2019). Industry 5.0 and Human-Robot Co-working. *Procedia Computer Science*, *158*, 688–695. https://doi.org/10.1016/j.procs.2019.09.104

Ebni, M., Bamakan, S. M. H., & Qu, Q. (2023). Digital Twin based Smart Manufacturing; From Design to Simulation and Optimization Schema. *Procedia Computer Science*, *221*, 1216–1225. https://doi.org/10.1016/j.procs.2023.08.109

Enang, E., Bashiri, M., & Jarvis, D. (2023). Exploring the transition from techno centric industry 4.0 towards value centric industry 5.0: a systematic literature review. In *International Journal of Production Research* (Vol. 61, Issue 22, pp. 7866–7902). Taylor and Francis Ltd. https://doi.org/10.1080/00207543.2023.2221344

Esmaeilian, B., Behdad, S., & Wang, B. (2016). The evolution and future of manufacturing: A review. In *Journal of Manufacturing Systems* (Vol. 39, pp. 79–100). Elsevier B.V. https://doi.org/10.1016/j.jmsy.2016.03.001

Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics*, *210*, 15–26. https://doi.org/10.1016/j.ijpe.2019.01.004

Fumagalli, L., Polenghi, A., Negri, E., & Roda, I. (2019). Framework for simulation software selection. *Journal of Simulation*, *13*(4), 286–303. https://doi.org/10.1080/17477778.2019.1598782

Galvão Scheidegger, A. P., Fernandes Pereira, T., Moura de Oliveira, M. L., Banerjee, A., & Barra Montevechi, J. A. (2018). An introductory guide for hybrid simulation modelers on the primary simulation methods in industrial engineering identified through a systematic review of the literature. *Computers and Industrial Engineering*, *124*, 474–492. https://doi.org/10.1016/j.cie.2018.07.046

Hayat, A., Shahare, V., Sharma, A. K., & Arora, N. (2023). Introduction to Industry 4.0. In *Studies in Big Data* (Vol. 119, pp. 29–59). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/978-981-19-8730-4_2

Höse, K., Amaral, A., Götze, U., & Peças, P. (2023). Manufacturing Flexibility through Industry 4.0 Technological Concepts—Impact and Assessment. *Global Journal of Flexible Systems Management*, *24*(2), 271–289. https://doi.org/10.1007/s40171-023-00339-y

Hu, W., Zhang, T., Deng, X., Liu, Z., & Tan, J. (2021). Digital twin: a state-of-the-art review of its enabling technologies, applications and challenges. *Journal of Intelligent Manufacturing and Special Equipment*, *2*(1), 1–34. https://doi.org/10.1108/jimse-12-2020-010

Hughes, H. P. N., Clegg, C. W., Robinson, M. A., & Crowder, R. M. (2012). Agent-based modelling and simulation: The potential contribution to organizational psychology. *Journal of Occupational and Organizational Psychology*, *85*(3), 487–502. https://doi.org/10.1111/j.2044-8325.2012.02053.x

Inkulu, A. K., Bahubalendruni, M. V. A. R., Dara, A., & SankaranarayanaSamy, K. (2022). Challenges and opportunities in human robot collaboration context of Industry 4.0 - a state of the art review. In *Industrial Robot* (Vol. 49, Issue 2, pp. 226–239). Emerald Group Holdings Ltd. https://doi.org/10.1108/IR-04-2021-0077

Ivanov, D. (2023). The Industry 5.0 framework: viability-based integration of the resilience, sustainability, and human-centricity perspectives. *International Journal of Production Research*, *61*(5), 1683–1695. https://doi.org/10.1080/00207543.2022.2118892

Jacob, F., Grosse, E. H., Morana, S., & König, C. J. (2023). Picking with a robot colleague: A systematic literature review and evaluation of technology acceptance in human–robot collaborative warehouses. *Computers and Industrial Engineering*, *180*. https://doi.org/10.1016/j.cie.2023.109262

Jerin Leno, I., Saravanasankar, S., & Ponnambalam, S. G. (2012). Layout design for efficient material flow path. *Procedia Engineering*, *38*, 872–879. https://doi.org/10.1016/j.proeng.2012.06.110

Kaewunruen, S., & Lian, Q. (2019). Digital twin aided sustainability-based lifecycle management for railway turnout systems. *Journal of Cleaner Production*, *228*, 1537–1551. https://doi.org/10.1016/j.jclepro.2019.04.156

Kliment, M., Pekarcikova, M., Trojan, J., & Kronova, J. (2022). Use of the FlexSim simulation tool for creating simulation models. *Acta Simulatio*, *8*(1), 1–8. https://doi.org/10.22306/asim.v6i1.56

Klingstam, P., & Gullander¨, G. (1999). Overview of simulation tools for computer-aided production engineering. In *Computers in Industry* (Vol. 38).

Kovbasiuk, K., Židek, K., Balog, M., & Dobrovolska, L. (2021). ANALYSIS OF THE SELECTED SIMULATION SOFTWARE PACKAGES: A STUDY. *Acta Tecnología*, *7*(4), 111–120. https://doi.org/10.22306/atec.v7i4.120

Kraus, S., Jones, P., Kailer, N., Weinmann, A., Chaparro-Banegas, N., & Roig-Tierno, N. (2021). Digital Transformation: An Overview of the Current State of the Art of Research. *SAGE Open*, *11*(3). https://doi.org/10.1177/21582440211047576

Kritzinger, W., Karner, M., Traar, G., Henjes, J., & Sihn, W. (2018). Digital Twin in manufacturing: A categorical literature review and classification. *IFAC-PapersOnLine*, *51*(11), 1016–1022. https://doi.org/10.1016/j.ifacol.2018.08.474

Kusiak, A. (2018). Smart manufacturing. *International Journal of Production Research*, *56*(1–2), 508–517. https://doi.org/10.1080/00207543.2017.1351644

Leng, J., Sha, W., Wang, B., Zheng, P., Zhuang, C., Liu, Q., Wuest, T., Mourtzis, D., & Wang, L. (2022). Industry 5.0: Prospect and retrospect. *Journal of Manufacturing Systems*, *65*, 279–295. https://doi.org/10.1016/j.jmsy.2022.09.017

Leng, J., Zhong, Y., Lin, Z., Xu, K., Mourtzis, D., Zhou, X., Zheng, P., Liu, Q., Zhao, J. L., & Shen, W. (2023). Towards resilience in Industry 5.0: A decentralized autonomous manufacturing paradigm. In *Journal of Manufacturing Systems* (Vol. 71, pp. 95–114). Elsevier B.V. https://doi.org/10.1016/j.jmsy.2023.08.023

Lu, Y., Liu, C., Wang, K. I. K., Huang, H., & Xu, X. (2020). Digital Twin-driven smart manufacturing: Connotation, reference model, applications and research issues. In *Robotics and Computer-Integrated Manufacturing* (Vol. 61). Elsevier Ltd. https://doi.org/10.1016/j.rcim.2019.101837

Lv, Z., & Fersman, E. (2022). Digital Twins: Basics and Applications. In *Digital Twins: Basics and Applications*. Springer International Publishing. https://doi.org/10.1007/978-3-031-11401-4

Machado, C. F., & Davim, J. P. (2023). Industry 5.0: Creative and Innovative Organizations. In *Industry 5.0: Creative and Innovative Organizations*. Springer International Publishing. https://doi.org/10.1007/978-3-031-26232-6

Mäkitie, T., Hanson, J., Damman, S., & Wardeberg, M. (2023). Digital innovation's contribution to sustainability transitions. *Technology in Society*, *73*. https://doi.org/10.1016/j.techsoc.2023.102255

Malec, E. (2018). The benefits of using computer simulation models to support decision-making. *Lecture Notes in Mechanical Engineering*, *0*, 205–214. https://doi.org/10.1007/978-3-319-68619-6_20

Melcher, D., Kuster, B., & Overmeyer, L. (2020). Automated data acquisition and processing for factory layout planning. *IEEE International Conference on Industrial Engineering and Engineering Management*, *2020-December*, 91–95. https://doi.org/10.1109/IEEM45057.2020.9309902

Mourtzis, D. (2020). Simulation in the design and operation of manufacturing systems: state of the art and new trends. *International Journal of Production Research*, *58*(7), 1927–1949. https://doi.org/10.1080/00207543.2019.1636321

Mourtzis, D., Doukas, M., & Bernidaki, D. (2014). Simulation in manufacturing: Review and challenges. *Procedia CIRP*, *25*(C), 213–229. https://doi.org/10.1016/j.procir.2014.10.032

Mourtzis, D., Doukas, M., Vlachou, A., & Xanthopoulos, N. (2014). Machine availability monitoring for adaptive holistic scheduling: A conceptual framework for mass customization. *Procedia CIRP*, *25*(C), 406–413. https://doi.org/10.1016/j.procir.2014.10.056

Müller, Julian., & European Commission. Directorate-General for Research and Innovation. (n.d.). *Enabling Technologies for Industry 5.0 : results of a workshop with Europe's technology leaders.*

Murphy, A., Taylor, C., Acheson, C., Butterfield, J., Jin, Y., Higgins, P., Collins, R., & Higgins, C. (2020). Representing financial data streams in digital simulations to support data flow design for a future Digital Twin. *Robotics and Computer-Integrated Manufacturing*, *61*. https://doi.org/10.1016/j.rcim.2019.101853

Nafors, D., Johansson, B., Gullander, P., & Erixon, S. (2020). Simulation in Hybrid Digital Twins for Factory Layout Planning. *Proceedings - Winter Simulation Conference*, *2020-December*, 1619–1630. https://doi.org/10.1109/WSC48552.2020.9384075

Nahavandi, S. (2019). Industry 5.0-a human-centric solution. *Sustainability (Switzerland)*, *11*(16). https://doi.org/10.3390/su11164371

Nee, A. Y. C., & Ong, S. K. (n.d.). *Digital Twins in Industry*. www.mdpi.com/journal/applsci

Pekarcikova, M., Trebuna, P., Kliment, M., & Dic, M. (2021). Solution of bottlenecks in the logistics flow by applying the kanban module in the tecnomatix plant simulation software. *Sustainability (Switzerland)*, *13*(14). https://doi.org/10.3390/su13147989

Pourhassan, M. R., & Raissi, S. (2017). An integrated simulation-based optimization technique for multi-objective dynamic facility layout problem. *Journal of Industrial Information Integration*, *8*, 49–58. https://doi.org/10.1016/j.jii.2017.06.001

Qi, Q., Tao, F., Hu, T., Anwer, N., Liu, A., Wei, Y., Wang, L., & Nee, A. Y. C. (2021). Enabling technologies and tools for digital twin. *Journal of Manufacturing Systems*, *58*, 3–21. https://doi.org/10.1016/j.jmsy.2019.10.001

Rebentisch, E., Conforto, E. C., Schuh, G., Riesener, M., Kantelberg, J., Amaral, D. C., & Januszek, S. (2018). Agility factors and their impact on product development performance. *Proceedings of International Design Conference, DESIGN*, *1*, 893–904. https://doi.org/10.21278/idc.2018.0236

Robinson, S. (2020). Conceptual modelling for simulation: Progress and grand challenges. *Journal of Simulation*, *14*(1), 1–20. https://doi.org/10.1080/17477778.2019.1604466

Romero, D., Stahre, J., & Taisch, M. (2020). The Operator 4.0: Towards socially sustainable factories of the future. In *Computers and Industrial Engineering* (Vol. 139). Elsevier Ltd. https://doi.org/10.1016/j.cie.2019.106128

Rosen, R., Von Wichert, G., Lo, G., & Bettenhausen, K. D. (2015). About the importance of autonomy and digital twins for the future of manufacturing. *IFAC-PapersOnLine*, *28*(3), 567–572. https://doi.org/10.1016/j.ifacol.2015.06.141

Russkikh, P. A., & Kapulin, D. V. (2020). Simulation modeling for optimal production planning using Tecnomatix software. *Journal of Physics: Conference Series*, *1661*(1). https://doi.org/10.1088/1742-6596/1661/1/012188

Saeed, S., Altamimi, S. A., Alkayyal, N. A., Alshehri, E., & Alabbad, D. A. (2023). Digital Transformation and Cybersecurity Challenges for Businesses Resilience: Issues and Recommendations. In *Sensors* (Vol. 23, Issue 15). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/s23156666

Sahal, R., Alsamhi, S. H., Breslin, J. G., Brown, K. N., & Ali, M. I. (2021). Digital twins collaboration for automatic erratic operational data detection in industry 4.0. *Applied Sciences (Switzerland)*, *11*(7). https://doi.org/10.3390/app11073186

Sahu, A., Agrawal, S., & Kumar, G. (2023). Triple bottom line performance of manufacturing Industry: A value engineering approach. *Sustainable Energy Technologies and Assessments*, *56*. https://doi.org/10.1016/j.seta.2023.103029

Sakr, A. H., Aboelhassan, A., Yacout, S., & Bassetto, S. (2021). Building Discrete-Event Simulation for Digital Twin Applications in Production Systems. *IEEE International Conference on Emerging Technologies and Factory Automation, ETFA*, *2021-September*. https://doi.org/10.1109/ETFA45728.2021.9613425

SIDERSKA, J. (2016). APPLICATION OF TECNOMATIX PLANT SIMULATION FOR MODELING PRODUCTION AND LOGISTICS PROCESSES. *Business, Management and Education*, *14*(1), 64–73. https://doi.org/10.3846/bme.2016.316

Sterman, John. (2000). *Business dynamics : systems thinking and modeling for a complex world*. Irwin/McGraw-Hill.

Süße, M., & Putz, M. (2021). Generative design in factory layout planning. *Procedia CIRP*, *99*, 9–14. https://doi.org/10.1016/j.procir.2021.03.002

Taylor, S. J. E., Khan, A., Morse, K. L., Tolk, A., Yilmaz, L., Zander, J., & Mosterman, P. J. (2015). Grand challenges for modeling and simulation: Simulation everywhere—from cyberinfrastructure to clouds to citizens. *SIMULATION*, *91*(7), 648–665. https://doi.org/10.1177/0037549715590594

Tram, N. T. B. (2022). Simulation modeling - An effective method in doing business and management research. *HO CHI MINH CITY OPEN UNIVERSITY JOURNAL OF SCIENCE - ECONOMICS AND BUSINESS ADMINISTRATION*, *12*(1), 108–124. https://doi.org/10.46223/hcmcoujs.econ.en.12.1.1916.2022

Uhlemann, T. H. J., Schock, C., Lehmann, C., Freiberger, S., & Steinhilper, R. (2017). The Digital Twin: Demonstrating the Potential of Real Time Data Acquisition in Production Systems. *Procedia Manufacturing*, *9*, 113–120. https://doi.org/10.1016/j.promfg.2017.04.043

Unold, J. (n.d.). *The Strategic Role of Marketing Information Systems in Modern Business*.

van Dyck, M., Lüttgens, D., Piller, F. T., & Brenk, S. (2023). Interconnected digital twins and the future of digital manufacturing: Insights from a Delphi study. *Journal of Product Innovation Management*, *40*(4), 475–505. https://doi.org/10.1111/jpim.12685

Winkelhaus, S., & Grosse, E. H. (2020). Logistics 4.0: a systematic review towards a new logistics system. In *International Journal of Production Research* (Vol. 58, Issue 1, pp. 18–43). Taylor and Francis Ltd. https://doi.org/10.1080/00207543.2019.1612964

Xu, Y., Elgh, F., Erkoyuncu, J. A., Bankole, O., Goh, Y., Cheung, W. M., Baguley, P., Wang, Q., Arundachawat, P., Shehab, E., Newnes, L., & Roy, R. (2012). Cost engineering for manufacturing: Current and future research. *International Journal of Computer Integrated Manufacturing*, *25*(4–5), 300–314. https://doi.org/10.1080/0951192X.2010.542183

Yaser, S., Abdelatif, N., Fahim, I., Emad, Y., Saleh, A., & Kassem, S. S. (2021). FlexSim Simulation to Enhance Productivity of a Production Cell : A Case Study. *NILES 2021 - 3rd*

Novel Intelligent and Leading Emerging Sciences Conference, Proceedings, 312–317. https://doi.org/10.1109/NILES53778.2021.9600545

Yin, C., & McKay, A. (2018). *Introduction to Modeling and Simulation Techniques*. https://eprints.whiterose.ac.uk/135646/

Yli-Huumo, J., Ko, D., Choi, S., Park, S., & Smolander, K. (2016). Where is current research on Blockchain technology? - A systematic review. *PLoS ONE*, *11*(10). https://doi.org/10.1371/journal.pone.0163477

Zhang, R., Lv, Q., Li, J., Bao, J., Liu, T., & Liu, S. (2022). A reinforcement learning method for human-robot collaboration in assembly tasks. *Robotics and Computer-Integrated Manufacturing*, *73*. https://doi.org/10.1016/j.rcim.2021.102227

Appendices

Appendix I: Extra Tasks of the Packautomation Process

Station	Resource	Operation	Tools
Pallet Building	Operator	Refill nails	Nailing gun (1)
	Operator	Stamp wood	Stamper
Box Building	Operator	Refill nails	Nailing gun (2)
	Operator	Refill nails	Nailing gun (3)
	Operator	Refill nails	Nailing gun (4)
Picking Long Poles	Operator	Remove empty pallet of poles, get a new one	-
Picking Extra Material	Operator	Refill nails	Nailing gun (5)
	Operator	Bring metal clips back to station 1	-

Appendix II: Tasks of Supervisor from the Packautomation Process

Tasks of Supervisor			
Station	**Resource**	**Operation**	**Tools**
Pallet Building	Operator	Fix robot	Robot
	Operator	Exchange nails in robot	Robot
	Operator	Fixing / exchanging tools	Nailing guns
	Operator	Order new wood for pallet making (many types)	Computer
Box Building	Operator	Order new wood for pallet making	Computer
	Operator	Fixing / exchanging tools	Nailing guns
	Operator	Removing empty pallets from Exit spot and move them where needed	Forklift
Picking Long Poles	Operator	Order new poles (only standard versions)	Computer
Picking Extra Material	Operator	Order new material (keep many different in mind)	Computer
	Operator	Order new wood for pallet making	Computer
	Operator	Clear buffer stations	Forklift
Whole system	Operator	Problems with sensors, system, machines	-

Appendix III: Time Studies of Pallet Size 30

Station	Resource	No.	Operation	Tools	Comment	Measurements																				
						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Average
	Operator	1	Get order, check order type	Computer	-	5,1	3,06	10,2	11,21	3,66	4,6	4,53	7,36	6,55	3,52	5,21	5,16	8,01	2,62	2,32	5,2	5,38	2,65	4,3	3,9	**5,23**
	Operator	2	Get 5 chunks and place them	-	-	17,75	15,05	26,13	14,99	20,73	18,34	21,81	21,75	19,12	21,32	20,5	26,11	22,01	22,99	19,68	21,5	20,69	22,51	17,8	15,29	**20,30**
	Operator	3	Get 2-4 basis-boards and place them	-	-	19,91	20,33	28,13	17,5	21,06	19,14	27,15	21,22	20,96	17,67	17,2	19,7	25	21,24	21,5	16,48	19,74	18,63	28,44	18,67	**20,98**
	Operator	4	Press *Reset* and *Start* buttons (2 times)	Computer	-	4,31	6,38	12,3	6,4	5,42	3,63	6,1	4,2	3,43	3,34	2,94	3,34	4,68	4,21	3,78	4,87	6,49	6,35	12,97	3,8	**5,45**
Pallet Building	Robot	5	Nailing process	-	-	22,01	21,96	20,73	22,49	20,16	20,45	21,6	20,9	22,8	21,27	21,57	20,77	21,23	21,31	21,4	22,32	20,24	20,5	20,5	21,25	**21,27**
	Operator	6	Get 3 back-boards	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Operator	7	Nail back-boards to chunks	Nailing gun (1)	-	24,77	28,28	33,13	31,79	28,63	29,84	35,35	42,51	36,65	43,73	36,99	38,8	47,72	50,12	36,61	44,43	90,5	58,68	34,94	32,8	**40,31**
	Operator	8	Press *Reset* and *Start* buttons	Computer	-	14,34	13,2	12,8	13,07	11,22	13,62	12,38	14,19	13,97	12,8	13,82	12,7	10,8	13,2	15,8	11,34	13,9	11,9	12,6	11,53	**12,96**
	Conveyor	9	Transportation	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Conveyor	10	Transportation	-	-	12,81	14,7	14,92	15,07	14,5	13,7	13,41	13,98	15,02	13,8	14,5	15,1	13,6	14,02	13,68	14,54	14,31	13,22	14,6	13,6	**14,15**
	Operator	11	Check order	Computer	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Operator	12	Press *Reset* and *Start* buttons	Computer	Only if not confirmed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Conveyor	13	Transportation	-	Only if not confirmed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Operator	14	Get 2 cardboard sheets	-	-	14,03	16,8	17,1	14,6	15,67	22,2	21,71	21,57	20,04	24,45	46,5	25,85	21,4	16,26	20,59	21,7	20,44	16,8	26,83	22,48	**21,35**
	Operator	15	Place cardboard sheets on pallet and fold	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
Box Building	Operator	16	Nail cardboard and order sheet on pallet	Nailing gun (2)	-	31,25	28,04	35,39	27,65	32,38	33,19	28,76	29,07	37,68	44,64	41,45	33,16	31,49	45,51	39,21	35,51	36,51	32,67	30,21	38,01	**34,59**
	Operator	17	Get 2 metal clips, fold cardboard and clip them	-	-	7,66	9,87	7,76	14,62	11,5	8,19	8,19	7,6	9,15	12,66	12,61	12,72	16,66	7,84	9,58	13,43	6,97	6,17	9,7	9,93	**10,14**
	Operator	18	Nail cardboard together	Nailing gun (4)	-	14,3	12,95	14,31	13,43	14,06	20,41	11,82	12,19	20,75	17,83	19,5	16,32	14,8	18,88	18,83	16,14	14,21	21,41	18,5	15,77	**16,32**
	Operator	19	Get label, control and place it	-	-	7,91	8,3	9,3	7,54	10,48	8,44	8,66	9,76	15,42	12,56	18,65	11,94	14,37	10,74	11,2	18,73	9,38	8,29	10,38	12,41	**11,22**
	Operator	20	Press *Reset* and *Start* buttons	Computer	-	24,3	25,01	23,5	23,9	24,5	24,9	24,5	23,3	25,76	23,4	25,54	24,75	25,02	50,4	28,3	27,41	23,4	24,5	28,07	26,4	**26,34**
	Conveyor	21	Transportation	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**66,40**
	Conveyor	22	Transportation	-	-	36,42	35,2	32,55	45,11	35,53	39,29	39,39	42,82	37,43	38,47	41,2	42,82	36,7	35,8	38,9	38,89	38,75	40,8	41,57	39,5	**38,86**
	Operator	23	Press *Reset* and *Start* buttons	Computer	Only if not confirmed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Conveyor	24	Transportation	-	Only if not confirmed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Operator	25	Check order	Computer	-	4,3	5,6	8,73	5,7	4,6	9,1	6,7	5,6	7,4	5,4	6,8	5,8	5,7	4,9	4,2	4,6	4,46	6,7	4,6	4,6	**5,77**
Picking Poles	Operator	26	Pick poles	-	Repeat x-times (1 to 50)	133,6	108,4	67,5	65,7	95,3	105,4	85,4	42,46	133,5	154,2	63,8	118,8	185,2	105,6	90,2	48,74	38,82	35,78	65,4	106,5	**92,52**
	Operator	27	Put paper layer for protection	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Operator	28	Confirm picked items	Computer	-	8,16	4,06	14,22	8,4	3,17	5,4	4,13	4,76	4,56	7,09	33,6	11,97	10,3	6,7	4,95	29,09	6,67	5,4	6,8	4,89	**9,22**
	Operator	29	Press *Reset* and *Start* buttons	Computer	-	37	38,44	34,56	36,5	40,7	38,6	36,19	38,4	34,5	35,4	36,4	38,6	36,3	35,48	40,5	37,4	39,67	35,67	34,6	34,6	**36,98**
	Conveyor	30	Transportation	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**105,00**
	Conveyor	31	Transportation	-	-	50,1	49,44	51,49	45,8	54,39	43,19	44,8	42,67	49,3	54,28	46,16	44,55	47,8	46,67	45,6	53,17	46,12	48,7	45,1	49,4	**47,94**
	Operator	32	Check and scan station	Handscanner	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Conveyor	33	Turn button & transportation	Computer	-	7,8	10,6	12,4	8,7	7,14	9,1	9,85	10,42	11,53	12,75	11,6	8,9	9,7	9,33	18,24	10,92	10,4	11,9	8,98	10,5	**10,54**
	Operator	34	Scan order and confirm	Computer	-	5,4	8,9	10,6	9,4	10,92	8,9	18,26	15,26	20,01	8,9	10,8	12,5	10,5	20,99	21,68	9,51	22,98	11,61	15,38	11,2	**13,19**
	Operator	35	Search, get and scan requested material	Handscanner	Repeat x-times	158,6	270,6	36,67	83,6	33,73	235,6	179,8	18,94	86,4	126,3	255,6	77,6	70,5	0	203,4	249,5	49,42	21,5	163,5	0	**116,06**
	Operator	36	Place new material in cardboard	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	**-**
	Operator	37	Put paper layer / material for protection	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	**-**
Picking Extra Material	Operator	38	Cut, fold and adjust cardboard box	Cutter	-	51,17	77,8	133,6	137,5	121,7	170,9	98,4	118,9	128,6	166,6	155,9	157,4	85,3	61,3	99,5	870	108	115,1	79,3	134,5	**153,57**
	Operator	39	Get 3 chunks and 1 little board	-	-	27,67	21,48	13,38	36,82	54,4	33,22	41,78	22,88	31,21	49,35	42,39	36,96	26,4	16,93	28,75	45,85	41,4	21,95	27,87	17,32	**31,90**
	Operator	40	Take metal clips away	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Operator	41	Place chunks	-	-	17,28	41,87	57,72	25,11	47,14	45,31	9,03	10,4	14,71	22,34	33,64	9,23	7,6	6,5	12,99	26,5	16,31	10,96	12,01	16,52	**22,16**
	Operator	42	Nail chunks to pallet	Nailing gun (5)	-	30,99	36,5	41,08	34,25	39,97	60,2	33,65	50,6	42,13	48,81	38,15	40,6	31,4	61,3	39,81	176,5	31,23	64,2	32,86	41,16	**48,77**
	Operator	43	Nail little board to chunks and pallet	Nailing gun (5)	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Operator	44	Confirm order, turn button and press *Reset* button	Computer	-	8,81	8,93	13,16	14,26	8,14	12,11	10,6	21,3	18,56	23,16	7,86	9,2	11,8	6,8	7,61	14,67	12,76	7,71	9,87	18,99	**12,32**
	Conveyor	45	Transportation to Exit / buffer	-	-	29,48	38,75	37,8	39,4	48,5	41,5	42,3	34,6	36,5	37,4	46,12	39,12	45,85	29,31	35,8	35,95	31,41	47,71	37,28	30,72	**38,28**

Appendix IV: Time Studies of Pallet Size 45

						Measurements																				
Station	**Resource**	**No.**	**Operation**	**Tools**	**Special Procedure**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**Average**
Pallet Building	Operator	1	Get order, check order type	Computer	-	4,6	3,33	3,56	4,5	3,78	4,1	4,18	5,48	3,6	4,53	5,1	4,6	5,28	2,74	2,44	3,5	3,4	9,16	4,1	5,75	**4,39**
	Operator	2	Get 5 chunks and place them	-	-	20,2	16,32	15,79	17,45	15,98	20,69	18,43	20,04	17,73	20,81	17,44	22,46	23,04	22,28	18,25	21,47	21,83	25,42	22,13	26,01	**20,19**
	Operator	3	Get 2-4 basis-boards and place them	-	-	36,8	45,16	24,87	26,35	15,98	24,56	24,92	24,49	20,33	24,07	28,33	30,02	38,37	36,45	27	29,99	23,38	28,84	17,76	33,4	**28,05**
	Operator	4	Press *Reset* and *Start* buttons (2 times)	Computer	-	2,3	3,1	2,7	2,35	2,5	4,2	3,71	3,65	2,94	3,99	2,77	4,51	3,22	5,38	2,6	3,06	5,5	5,75	3,99	12,89	**4,06**
	Robot	5	Nailing process	-	-	28,5	28,77	27	26,4	26,3	26,1	27,17	27,01	27,4	25,76	27,12	26,06	26,35	25,77	26,01	26,01	26,31	25,82	25,54	26,8	**26,61**
	Operator	6	Get 3 back-boards	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	7	Nail back-boards to chunks	Nailing gun (1)	-	27,33	30,89	22,01	34,95	38,32	32,19	30,48	41,97	38,06	39,89	30,6	40,19	80,5	48,4	38,5	42,2	37,77	52,94	41,8	32,67	**39,08**
	Operator	8	Press *Reset* and *Start* buttons	Computer	-	12,1	13,5	12,4	13,89	12,1	14,54	12,74	11,8	13,5	11,4	12,84	12,85	11,9	14,85	13,27	12,94	13,01	14,35	14,37	12,5	**13,04**
	Conveyor	9	Transportation	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Box Building	Conveyor	10	Transportation	-	-	12,68	13,5	14,8	13,81	14,45	15,02	14,1	14,3	15,63	13,35	13,02	14,2	14,01	13,6	14,4	13,2	13,9	14,05	13,5	13,04	**13,93**
	Operator	11	Check order	Computer	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	12	Press *Reset* and *Start* buttons	Computer	Only if not confirmed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Conveyor	13	Transportation	-	Only if not confirmed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	14	Get 2 cardboard sheets	-	-	27,52	23,55	20,79	22,4	24,5	23,6	27,1	21,4	23,33	25,43	21,27	24,5	27,24	32,4	36,5	28,5	19,8	21,51	35,8	35,41	**26,13**
	Operator	15	Place cardboard sheets on pallet and fold	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	16	Nail cardboard and order sheet on pallet	Nailing gun (2)	-	24,6	23,12	25,21	27,3	23,69	24,66	23,4	26,8	29,44	28,75	30,1	58,2	44,96	51,2	38,6	27,96	45,54	42,3	38,48	40,58	**33,74**
	Operator	17	Get 2 metal clips, fold cardboard and clip them	-	-	9,03	14,07	8,91	9,98	7,34	7,49	13,36	9,7	10,7	9,08	8,96	10,6	12,88	14,11	8,99	9,33	11,2	13,06	10,84	12,63	**10,61**
	Operator	18	Nail cardboard together	Nailing gun (4)	-	14,53	12,45	11	16,74	13,55	13,4	13,14	15,49	16,09	15,64	16,44	35,8	23,26	16,99	47,88	13,95	20,3	17,55	57,95	25,86	**20,90**
	Operator	19	Get label, control and place it	-	-	8,98	9,74	8,56	12,78	7,22	8,64	10,3	12,92	8,71	7,93	11,13	16,32	15,45	13,16	8,93	10,32	11,84	9,72	10,63	14,63	**10,90**
	Operator	20	Press *Reset* and *Start* buttons	Computer	-	24,8	25,1	24,6	26,11	23,4	25,1	24,1	24,8	23,6	24,5	26,3	24,03	21,76	25,1	24,8	26,64	25,9	27,6	26,33	26,16	**25,04**
	Conveyor	21	Transportation	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**66,40**
Picking Poles	Conveyor	22	Transportation	-	-	35,4	42,05	36,19	35,4	43,81	44,3	34,63	40,01	42,02	39,69	39,53	38,3	41,1	37,82	36,4	35,7	36,8	39,9	41,3	38,7	**38,95**
	Operator	23	Press *Reset* and *Start* buttons	Computer	Only if not confirmed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Conveyor	24	Transportation	-	Only if not confirmed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	25	Check order	Computer	-	5,4	6,7	4,8	5,2	6,5	4,2	5,4	4,8	3,5	4,2	3,6	4,1	4,6	5,1	7,83	4,95	5,6	5,4	4,8	6,1	**5,14**
	Operator	26	Pick poles	-	Repeat x-times (1 to 50)	293,6	354,6	512,3	390,2	253,6	73,8	25,66	95,6	119,6	73,6	368,2	565,3	342,6	195,2	220,1	375,3	242,1	159,7	255,3	445,8	**268,11**
	Operator	27	Put paper layer for protection	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	28	Confirm picked items	Computer	-	16,3	13,51	84,5	10,2	4,7	5,76	7,5	6,4	5,8	4,6	6,39	5,9	3,98	8,4	5,1	6,34	3,65	6,4	4,9	6,1	**10,82**
	Operator	29	Press *Reset* and *Start* buttons	Computer	-	33,1	41,2	37,4	35,94	34,1	36,2	35,4	34,6	37,5	105,2	35,1	79,6	36,35	40,41	42,72	39,5	38,5	39,12	36,82	37,98	**42,84**
	Conveyor	30	Transportation	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**105,00**
Picking Extra Material	Conveyor	31	Transportation	-	-	44,2	49,1	50,44	45,49	51,8	43,39	46,19	48,54	51,95	44,85	47,5	46,5	48,9	46,78	45,98	46,5	53,19	47,8	49,5	46,5	**47,76**
	Operator	32	Check and scan station	Handscanner	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Conveyor	33	Turn button & transportation	Computer	-	8,54	9,77	8,9	9,91	8,6	12,09	9,5	35,25	12,69	11,72	8,7	8,6	9,4	8,9	10,65	10,86	8,7	6,62	9,04	21,55	**11,50**
	Operator	34	Scan order and confirm	Computer	-	5,58	9,66	10,2	11,62	10,4	84,5	11,4	18,02	5,4	7,5	6,9	17,05	12,1	16,7	10,8	12,26	10,4	13,38	13,55	30,7	**15,91**
	Operator	35	Search, get and scan requested material	Handscanner	Repeat x-times	147,8	172,8	0	136,5	140,5	454,8	205,8	325,6	0	0	195,3	34,38	0	1800	375,2	0	396,1	248,1	42,09	35,18	**235,51**
	Operator	36	Place new material in cardboard	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	37	Put paper layer / material for protection	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	38	Cut, fold and adjust cardboard box	Cutter	-	33,66	68,9	85,5	105,8	34,1	203,9	63,4	101,8	90,4	65,3	43,08	61,2	34,53	20,6	10,6	103,4	105,6	4,88	116,4	125,6	**73,93**
	Operator	39	Get 3 chunks and 1 little board	-	-	26,38	13,55	17,07	34,75	25,4	33,85	6,4	43,42	22,1	25,36	19,81	24,94	10,1	21,6	27,36	27,76	13,31	10,02	13,5	15,4	**21,60**
	Operator	40	Take metal clips away	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	41	Place chunks	-	-	9,45	8,01	7,24	82,7	20,4	10,73	18,4	17,36	12,4	13,4	20,17	9,7	11,61	15,8	10,49	13,8	12,96	8,74	15,17	14,2	**16,64**
	Operator	42	Nail chunks to pallet	Nailing gun (5)	-	37,58	40,24	40,64	49,47	30,6	48,87	41,52	46,06	38,5	31,91	34,14	26,3	27,01	45,1	93,3	38,75	33,78	36,9	54,87	68,5	**43,20**
	Operator	43	Nail little board to chunks and pallet	Nailing gun (5)	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	44	Confirm order, turn button and press *Reset* button	Computer	-	8,3	9,17	12,36	8,19	7,68	11,27	12,81	17,76	10,8	9,8	7,89	7,66	7,36	9,1	6,59	12,16	5,9	7,14	6,77	13,06	**9,59**
	Conveyor	45	Transportation to Exit / buffer	-	-	35,66	42,1	36,5	38,7	65,3	28,68	30,74	32,36	29,77	31,51	47,81	30,77	32,32	43,49	34,8	35,47	48,5	41,5	42,3	34,6	**38,14**

Appendix V: Time Studies of Pallet Size 60

						Measurements																				
Station	**Resource**	**No.**	**Operation**	**Tools**	**Special Procedure**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**Average**
Pallet Building	Operator	1	Get order, check order type	Computer	-	5,6	7,8	10,34	4,55	7,12	3,61	14,88	5,87	5,9	3,24	4,3	5,4	5,52	12,8	6,05	7,99	4,5	3,9	4,6	5,6	**6,48**
	Operator	2	Get 5 chunks and place them	-	-	20,44	23,5	21,75	26,08	19,25	21,96	24,17	31,81	27,5	25,81	23,52	20,13	24,24	29,75	30,25	22,88	29,7	24,54	26,7	22,11	**24,80**
	Operator	3	Get 2-4 basis-boards and place them	-	-	30,24	41,42	52,21	37,05	42,2	46,94	36,02	45,26	54,98	41,58	53,48	38,57	33,31	32,76	54,8	48,9	32,6	31,27	29,76	23,75	**40,36**
	Operator	4	Press *Reset* and *Start* buttons (2 times)	Computer	-	2,2	4,5	4,98	2,5	3,84	5,87	4,03	2,94	4,26	5,68	7,32	3,77	3,46	4,2	3,39	4,5	8,73	4,03	3,44	6,36	**4,50**
	Robot	5	Nailing process	-	-	34,09	33,5	31,95	33	32,6	32,4	31,5	32,3	32,4	31,96	32,18	32,6	32,05	32,49	32,03	32,4	32,5	31,82	32,99	31,85	**32,43**
	Operator	6	Get 3 back-boards	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	7	Nail back-boards to chunks	Nailing gun (1)	-	23,1	48,13	51,2	30,78	34,5	31,34	30,5	44,8	41,2	36,73	41,11	38,31	30,88	37,41	135,2	46,7	31,33	73,5	40,9	34,99	**44,13**
	Operator	8	Press *Reset* and *Start* buttons	Computer	-	14,64	13,3	12,7	13,22	12,4	13,4	12,83	12,27	13,9	12,53	12,6	12,4	10,79	11,2	12,4	13,1	12,81	11,8	10,57	13,59	**12,62**
	Conveyor	9	Transportation	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Box Building	Conveyor	10	Transportation	-	-	15,65	16,3	14,63	14,35	15,02	14,8	14,55	13,8	14,5	15,1	13,6	14,99	14,2	14,3	13,7	14,5	13,4	14,95	14,23	13,3	**14,49**
	Operator	11	Check order	Computer	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	12	Press *Reset* and *Start* buttons	Computer	Only if not confirmed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Conveyor	13	Transportation	-	Only if not confirmed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	14	Get 2 cardboard sheets	-	-	42,5	39,1	28,42	27,31	27,12	40,03	22,66	26,73	27,23	26,02	36,44	27,91	40,01	28,03	29,7	35,94	37,59	46,65	54,4	50,3	**34,70**
	Operator	15	Place cardboard sheets on pallet and fold	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	16	Nail cardboard and order sheet on pallet	Nailing gun (2)	-	48,28	48,73	28,1	27,12	29,23	50,6	39,51	44,29	46,96	52,65	24,49	58,49	97,3	52,45	29,71	42,5	55,6	58,37	36,16	31,9	**45,12**
	Operator	17	Get 2 metal clips, fold cardboard and clip them	-	-	10,21	11,02	9,1	7,79	7,4	10,48	11,19	12,11	12,55	15,51	8,91	18,7	15,26	12,78	11,54	10,9	18,13	16,5	13,4	13,85	**12,37**
	Operator	18	Nail cardboard together	Nailing gun (4)	-	22,34	20,73	14,23	17,12	13,11	20,09	20,12	19,45	16,62	17,73	13,87	32,84	32,84	34,08	15,2	17,5	25,6	21,4	22,31	25,6	**21,14**
	Operator	19	Get label, control and place it	-	-	11,52	10,51	8,78	8,68	9,65	12,44	15,6	12,84	10,01	12,66	9,25	17,73	19,97	10,8	7,93	11,16	12,6	18,37	15,6	11,69	**12,39**
	Operator	20	Press *Reset* and *Start* buttons	Computer	-	23,34	23,56	24,1	90,5	24,55	25,76	24,8	24,1	25,57	24,25	25,76	25,11	25,94	24,9	24,64	24,1	24,6	24,3	24,56	23,98	**27,92**
	Conveyor	21	Transportation	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**66,40**
Picking Poles	Conveyor	22	Transportation	-	-	38,5	43,24	35,16	40,2	39,67	37,53	38,29	41,39	43,82	36,4	35,9	38,5	49,5	38,5	42,1	41,5	39,78	38,9	42,72	45,44	**40,35**
	Operator	23	Press *Reset* and *Start* buttons	Computer	Only if not confirmed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Conveyor	24	Transportation	-	Only if not confirmed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	25	Check order	Computer	-	3,5	6,4	4,8	4,56	5,8	5,3	7,33	6,4	4,6	5,1	3,6	4,2	6,7	5,4	4,2	3,9	4,5	5,6	4,9	3,9	**5,03**
	Operator	26	Pick poles	-	Repeat x-times (1 to 50)	480,3	294,6	475,3	280,9	465,3	487,5	256,8	495,2	500,3	248,6	273,5	443,2	424,7	544,2	390,2	560,3	503,6	307,5	359,1	298,1	**404,46**
	Operator	27	Put paper layer for protection	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	28	Confirm picked items	Computer	-	5,23	9,8	4,68	5,6	10,57	9,06	8,09	6,5	8,5	5,2	7,3	4,6	6,7	5,2	4,46	5,8	6,7	4,7	4,5	2,87	**6,30**
	Operator	29	Press *Reset* and *Start* buttons	Computer	-	41,2	34,46	32,4	37,8	36,5	34,5	38,6	34,6	33,82	38,35	36,8	37,39	34,56	35,2	34,5	34,8	35,4	36,7	34,9	41,75	**36,21**
	Conveyor	30	Transportation	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**105,00**
Picking Extra Material	Conveyor	31	Transportation	-	-	54,94	46,49	50,8	45,39	47,19	46,54	51,85	47,85	47,5	48,8	46,45	49,6	54,17	50,2	48,65	61,2	47,5	57,57	49,5	47,65	**49,99**
	Operator	32	Check and scan station	Handscanner	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Conveyor	33	Turn button & transportation	Computer	-	11,2	9,8	10,6	12,4	10,5	8,24	8,7	17,89	12,79	10,32	10,68	12,42	51,83	10,8	11,22	11,25	12,39	13,14	16,9	10,2	**13,66**
	Operator	34	Scan order and confirm	Computer	-	12,4	12,3	15,6	23,17	12,04	11,21	11,65	15,07	19,4	17,01	98,4	18,13	10,3	17,5	16,42	13,81	8,9	22,41	18,5	11,89	**19,31**
	Operator	35	Search, get and scan requested material	Handscanner	Repeat x-times	20,49	195,6	440,5	0	358,2	459,7	830,4	301,5	0	246,7	283,4	107,5	158,6	68,9	0	80,2	1200	226,3	123,4	110,2	**260,58**
	Operator	36	Place new material in cardboard	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	37	Put paper layer / material for protection	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	38	Cut, fold and adjust cardboard box	Cutter	-	49,5	18,04	6,3	8,23	42,77	54,4	44,35	40,7	109,9	125,8	34,54	38,63	28,6	127,4	72,6	62,4	27,55	106,4	201,4	73,6	**63,66**
	Operator	39	Get 3 chunks and 1 little board	-	-	23,8	18,97	22,68	20,94	26,34	23,4	20,96	26,45	25,16	27,96	34,62	27,49	6,22	33,05	35,36	17,4	13,05	31,85	24,36	28,11	**24,41**
	Operator	40	Take metal clips away	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	41	Place chunks	-	-	11,88	2,1	6,03	6,23	14,52	13,45	75,6	17,19	13,46	8,49	27,02	11,47	13,71	17,5	9,83	10,3	32,52	30,96	15,24	14,64	**17,61**
	Operator	42	Nail chunks to pallet	Nailing gun (5)	-	37,5	27,43	31,34	29,37	37,63	48,12	35,05	73,9	40,75	34,42	45,2	44,64	61,09	50,8	30,66	40,86	31,26	47,5	48,7	35,74	**41,60**
	Operator	43	Nail little board to chunks and pallet	Nailing gun (5)	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Operator	44	Confirm order, turn button and press *Reset* button	Computer	-	7,69	8,69	14,88	8,5	12,33	11,88	8,44	15,65	9,56	17,59	14,06	12,3	12,74	8,29	10,92	7,76	7,41	18,58	14,87	11,6	**11,69**
	Conveyor	45	Transportation to Exit / buffer	-	-	39,52	56,3	41,2	33,93	29,06	32,4	31,5	39,3	30,72	33,2	28,68	39,24	45,58	36,9	35,95	35,07	31,83	28,75	77,5	33,92	**38,03**

Appendix VI: Time Studies of Empty Pallet

						Measurements										
Station	**Resource**	**No.**	**Operation**	**Tools**	**Comment**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Average**
Box Building	Conveyor	10	Transportation	-	-	13,4	12,8	14,6	12,3	12,9	13,7	13,4	14,5	13,65	13,89	**13,51**
	Operator	11	Check order	Computer	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-
	Operator	12	Press *Reset* and *Start* buttons	Computer	Only if not confirmed	-	-	-	-	-	-	-	-	-	-	-
	Conveyor	13	Transportation	-	Only if not confirmed	-	-	-	-	-	-	-	-	-	-	-
	Operator	14	Get order sheet and extra board	-	Times combined in following step	-	-	-	-	-	-	-	-	-	-	-
	Operator	15	Nail order sheet	Nailing gun (2)	-	26,3	15,4	8,98	11,6	25,42	25,77	21,51	14,36	17,4	11,98	**17,87**
	Operator	16	Change tube for tools	-	-	12,4	16,34	5,4	8,9	9,29	6,15	6,45	9,8	11,3	7,4	**9,34**
	Operator	17	Nail board	Nailing gun (3)	-	15,83	9,1	8,25	14,5	17,26	15,05	24,86	20,9	17,1	15,25	**15,81**
	Operator	18	Get label, control and place it	-	-	16,7	12,1	8,8	11,3	21,84	13,06	13,19	10,27	11,1	12,8	**13,12**
	Operator	19	Press *Reset* and *Start* buttons	Computer	-	26,04	25,6	24,5	25,2	24,04	25,6	24,26	23,08	24,6	23,5	**24,64**
	Conveyor	20	Transportation	-	Times combined in previous step	-	-	-	-	-	-	-	-	-	-	-
	Conveyor	21	Transportation to Exit	-	-	42,1	42,59	41,9	42,3	41,88	42,6	42,7	41,75	42,6	42,54	**42,30**

Appendix VII: Sub-Criteria of "General Features"

1991 Banks	1998 Banks	1999 Hlupic	2002 Tewoldeberhan	2007 Hlupic	2014 Mourtzis	2015 Jadric	2019 Fumagalli
Ease of use Ease of learning	Ease of use Ease of learning	Ease of installation Hardware requirements Types of contracts available Frequency of update Ease of using User friendliness Ease of conceptualisation of simulation logic Ease of learning Experience required for software use Versions of software for different operating systems	Package application area Flow oriented modeling approach	Frequency and comprehensiveness of update Portability Experience and education required for software use Ease of learning User friendliness	Purpose Experience required Ease of use	-	Hardware compatibility Trial version Software compatibility Simulation type Hierarchical model Operations integration User-friendly interface Multi-screen configuration

Appendix VIII: Sub-Criteria of "Financial Considerations"

1991 Banks	1998 Banks	1999 Hlupic	2002 Tewoldeberhan	2007 Hlupic	2014 Mourtzis	2015 Jadric	2019 Fumagalli
Initial cost Additional cost	General costs	Installation costs Free software trials Free technical support Educational discount Price of training course	-	Pricing and total cost of ownership	-	-	-

Appendix IX: Sub-Criteria of "Customer Support"

1991	1998	1999	2002	2007	2014	2015	2019
Banks	Banks	Hlupic	Tewoldeberhan	Hlupic	Mourtzis	Jadric	Fumagalli
On-line help	Quality of documentation	Quality of documentation	Maintenance support	Documentation and tutorial	On-line help	Number and types of templates	Documentation
On-line tutorial		Glossary	Documentation	Consultancy	User support	Level of details during modeling	Tutorial
Customer support		Discussion groups on the Internet		Training course		Intuitiveness of objects	
Quality of documentation		Tutorial / Training course		Package maintenance		Automatic tracking of basic model performance	
		Custom tailored training course		Demo models, libraries		Automatic tracking of a larger number of experiments	
		Demo models		Documentation notes		On-line help	
		Help-line		On-line help			
		Consultancy					
		Package maintenance					

Appendix X: Sub-Criteria of "Input and Output Functionalities"

1991	1998	1999	2002	2007	2014	2015	2019
Banks	Banks	Hlupic	Tewoldeberhan	Hlupic	Mourtzis	Jadric	Fumagalli
Interface to other software	Point-and-Click Capability	Integration with CAD software	Statistical distribution	Warm-up period	Software compatibility	Importing resources into a model	Statistical Analysis
Input data analysis capability	CAD Translation	Integration with statistical packages	Input from text files	Breakpoints	Input / output capabilities	Importing data into a model	Re-starting
Portability	Importing a file	Integration with spreadsheet packages (Excel)	Input from spreadsheets	Speed adjustments	Manufacturing capabilities	Importing and choosing probability distribution	Automatic multi-run
Syntax	Exporting a file	Model input	Interactive input mode	Austomatic determination of run length	Analysis capabilities	Dynamic display of statistical data	Import from other packages
Input flexibility	Syntax	Static graphical output	Random number generators	Automatic batch run		Report's format	Memorise in the database
Interactive debugger	Interactive Run Controller	Dynamic graphical output	Report customization	Theoretical statistical distributions		Possibility to clearly understand reports	Specific output
Modeling flexibility	Interface to other language	Quality & understandability of output reports	Feature for exporting data to spreadsheets	User-defined distributions		Output's statistical analysis	Export to other packages
Modeling conciseness	Input data analysis capability	Availability of results before end of simulation	Feature for exporting data to text files or word processors	Random number streams			Precision
Standardized reports	Standardized reports	Independent replications of experiements		Output data analysis			Simple Graphics
Customized reports	Customized reports	Speed adjustments		Quality of data analysis facility			Transfer to other packages
Confidence intervals	Business graphics	Quality of experimental design facility		Distribution fitting			
Business graphics	Database maintenance	Output data analysis		Confidence intervals			
File creation	Collection of mathematical expressions desired	Quality of data analysis facility		Input data reading from files			
Tracing capability	Custom performance measures			Quality and understandability of output reports			
Data base maintenance	Write to a file			User defined output			
				Periodic output of simulation results			
				What-if-analysis			
				Conclusion making support			
				Optimization			
				Integration with spreadsheet packages			
				Integration with statistical packages			
				Integration with DBMS			
				Integration with legacy applications, ERP			
				Integration with WFM systems, BAM systems			

Appendix XI: Sub-Criteria of "Performance"

1991	1998	1999	2002	2007	2014	2015	2019
Banks	Banks	Hlupic	Tewoldeberhan	Hlupic	Mourtzis	Jadric	Fumagalli
Programming	Stability	Level of detail	-	Robustness	Coding aspects	-	Modularity
Conditional routing	Programming	Robustness		Level of detail	Efficiency		Code manipulation
	Portability	Automatic saving		Model reusability	Testability		Flexibility
		Model execution time		Model reliability			User-defined functions
		Ease of model editing		Time scale for model building			Union of different models
		Time scale for model building		Model chaining: linking outputs from different models			Quick response
		Automatic model building		Queuing policies			Level of detail
		Merging of models		Logic checks			Error Message Quality
		Quality of error messages		Error messages			Attribute access
		Ease of debugging		Ease of debugging			
		Facility for immediate user actions		Trace files			
		Step function (event to event jumping)		Step function (event to event jumping)			
		Trace files (showing events and entity status)		Dynamic display of eelemtns			
		Rejection of illegal inputs		Display of the workflow path			
		Programming flexibility		Programming flexibility			
		Access to source code		Access to source code			
		Support of programming concepts		Global variables			
		Comprehensiveness of added code		Built-in functions			
				Support of programming concepts			

Appendix XII: Sub-Criteria of "Modeling Capabilities"

1991	1998	1999	2002	2007	2014	2015	2019
Banks	Banks	Hlupic	Tewoldeberhan	Hlupic	Mourtzis	Jadric	Fumagalli
Execution speed	Powerful construct	Libraries and templates of simulation objects	Graphical model building	Representativeness of models	Library and templates	Model animation	-
Model size	Speed	Warning messages for model currently developed	Multiple runs	Formal logic	Comprehensiveness of promting	Adaptability to model changes	
Material handling	Run-time flexibility	Quality of on-line help	Warm-up period	Simulation modelling approach	Visual aspects	Reliability (animation)	
Random variate generators	Random variate generator	Undo / redo commands	Reset capability	Modularity	Experimentation facilities	Speed of executing the simulation	
Reset	Reset	Automatic connection between elements	Speed control	Model and data separation	Statistcal data	Dynamic objects of the model	
Independent replications	Independent replications	Search facilities within help	Animation on / off feature	Animation		Performance display	
Attributes	Attributes and global variables	Type of graphical display		Type of animation		Using the tool	
Global variables	Animation capability	3D graphics		Animation with visual clock		Procedure of model building	
Animation capability	Run-only version	Animation layout development		Expressiveness and quality of graphics		Studying how to use the tool	
		Importing graphics and multimedia elements		Graphic library		Model verification	
		Virtual reality features				Adding and editing model data	
		Ease of using screen editor					
		Quality of data storage, retrieval and manipulation facilities					
		Modelling transparency					
		Representativeness of models					

Appendix XIII: Explanation of Criteria Groups and Sub-Criteria

Criteria Definiton and Explanation

1. General Features

The criteria group *General Features* evaluates several aspects that are related to the hardware and software requirements of the simulation modeling program. Besides the ease of installation and updates, the user-friendliness and learning curve will be covered. The criteria group will be referred to in the case study example. However, it will also cover the overall perception without addressing the presented manufacturing process.

1.1. Ease of Installation and Updates

The *Ease of Installation and Updates* refers to the steps required for the installation process. It focuses on the complexity of the approach and the availability of information for providing customer support. The criterion also covers the frequency of updates.

1.2. Learning Curve

The *Learning Curve* criterion addresses the time and effort needed to understand the usage and the procedure of the simulation modeling. It considers the ease of learning as well as the experience required for the specific program.

1.3. User Friendliness

The *User Friendliness* refers to the accessibility across the program and the ease of use in general. The navigation, the consistency, the interface clarity, as well as the intuitiveness are factors to be considered.

2. Financial Considerations

The *Financial Considerations* are an important part of software programs in general, including simulation modeling programs. This criteria group is split into the initial costs, the additional costs, as well as the financial expenses for available training courses.

2.1. Initial Costs

The *Initial Costs* criterion focuses on the expenses involved in the purchase of the simulation modeling program. It considers factors such as the license models and gives insights into the financial investment needed to obtain the program.

2.2. Additional Costs

The *Additional Costs* criterion for simulation modeling programs examines potential extra expenses such as educational training or add-ons. It provides insights into the financial considerations which are added to the initial expenses.

2.3. Price of Training Course

The *Price of Training Course* covers a short description of the content as well as the structure of the training courses available. Furthermore, it considers the monetary investment required to participate in these courses.

3. Customer Support

The *Customer Support* represents an essential criteria group because it directly affects the user experience and the success of the projects. In terms of simulation modeling programs, assistance, and guidance might be crucial to solve technical issues effectively and ensure that the simulations will increase the productivity of the real-case scenarios. The focus of this section will lie on the direct customer support, the availability, and quality of the educational options, as well as the community support.

3.1. Direct Customer Support

The *Direct Customer Support* addresses the accessibility and quality of support services. It considers the available options such as email contact or online help. Furthermore, the quality of direct customer support will be analyzed.

3.2. Quality of Documentation, Tutorials, Training Course

The criterion referring to the *Quality of Documentation, Tutorials, Training Course* evaluates the possibilities provided to gain knowledge about simulation modeling and the program in general. It covers the clarity, accuracy, relevance, and outcome of the educational support.

3.3. Community Support

The *Quality of Community Support* criterion assesses the availability and relevance of support accessible via forums and communities. It evaluates the helpfulness of the assistance for simulation modeling programs.

4. Input & Output Functionality

The criteria group regarding the *Input and Output Functionality* concerns the data exchange and integration with add-ons in simulation modeling programs. Furthermore, the statistical features and functions available and the ease of saving options will be presented. This criteria group takes specific examples from the Packautomation process into consideration.

4.1. Ease of Data Integration and Saving Options

The *Ease of Data Integration and Saving Options* refers to the available possibilities to upload and download data, files, or other documents. Besides the ease of data integration, the potential saving options and the accessibility will be discussed.

4.2. Options of Statistical Features and Functions

The criterion regarding the *Options of Statistical Features and Functions* addresses the presence and effectiveness of statistical tools within the programs. It considers aspects such as the analysis of bottlenecks, the performance evaluation, and the range of analysis options available.

4.3. Integration with Add-Ons and Software Programs

The *Integration with Add-Ons and Software Programs* evaluates the compatibility of the selected simulation modeling programs with additional tools and programs. The availability will be covered as well as the ease of integration while the focus lies on the case study example.

5. Performance

The *Performance* of simulation modeling programs is crucial for evaluating the efficiency and usability of the tools. Quality error messages and ease of debugging are helpful features to solve issues quickly and enhance simulation accuracy. While monitoring CPU utilization provides insights into system resource management, the programming features cover coding accessibility and programming languages.

5.1. CPU Utilization

The criterion concerning *CPU Utilization* addresses the efficiency of simulation modeling programs in utilizing the capacity resources. It is crucial to measure the program performance based on specific examples such as initialization, opening files, or running the simulations.

5.2. Quality of Error Messages

Debugging and error-solving are critical aspects of successfully creating, simulating, and analyzing models based on real-case scenarios. The criterion regarding the *Quality of Error Messages* considers whether error messages focus on identifying and addressing specific errors and whether they provide supportive guidance for solving issues. The simplicity of the debugging process and the time required will be considered.

5.3. Programming Features

Besides the criteria concerning the general features and functionality of the programs, the *Programming Features* address the possibility of interacting with the code behind the program. When evaluating simulation modeling programs from a coding perspective, the access and manipulation of the source code, the supported programming languages, and the ease and flexibility will be analyzed.

6. Modeling Capabilities

Modeling capabilities in simulation programs are highly crucial for the effectiveness and efficiency of the model creation. The key criteria include the availability of free templates and libraries that serve as a foundation for greenfield projects. Furthermore, the animation and simulation options will be covered to prove the customization of the program. Concrete examples of the Packautomation process will be taken into account.

6.1. Availability of free Templates and Libraries

Depending on the type of project, the *Availability of free Templates and Libraries* might be highly crucial for simulation modeling of processes and factories. It considers the variety and creativity of available resources, the flexibility in adapting the components, the degree of customization, as well as the intelligence level of the components. This criterion considers the accessibility for users to a wide range of resources within the program.

6.2. Animation and Simulation Options

Besides the replication of the real-case scenarios within the programs, the *Animation and Simulation Options* available are important for the success of the modeling projects. This criterion addresses the simulation speed, realism, accuracy, and customization in terms of the playback of the animations.

6.3. Representativeness of Models and Animation

The *Representativeness of Models and Animation* refers to the graphics and visualization aspects of the simulations. Furthermore, it evaluates the level of reality and detail in the models generated. It answers the question of whether and to what extent can the created model and simulated processes represent reality.

Appendix XIV: Interview Expert A - Production Developer

Questions & Answers

Question 1: Can you explain shortly your role in terms of responsibilities, tasks, and main projects conducted?

Answer: As a production planner, the responsibilities lie on management of the manufacturing processes and ensuring that products are produced efficiently and delivered on time. It can involve forecasting demand, the creation of production schedules, coordination with suppliers and optimizing the production processes to increase the efficiency, reduce costs, and improve the quality of the products. As a production planer in a consultancy, the customers face a problem within their manufacturing / production context and would like to solve this issue. Mainly, the productivity or efficiency need to improve. Overall, production planners in consultancy firms play an important role in helping clients optimize their manufacturing operations, improve efficiency, and drive business growth through strategic planning, technology integration, and continuous improvement initiatives. Right now, the focus lies more on one specific company so there is much more detail required for the project.

Question 2: What specific role do simulation modeling programs play in your position?

Answer: These programs allow production planners of a consultancy to create virtual representations of manufacturing processes. They enable them to analyze and optimize various aspects of production without disrupting actual operations. Simulation modeling focuses on process optimization, capacity planning, and different scenarios analysis. It is a great tool to show customers in an illustrative way how the production can be optimized or how a company can look like in a future scenario.

Question 3: Can you name an example of when you used simulation modeling program for a project?

Answer: There was a big project with Stena Recycling which included a lot of simulations. Stena Recycling wanted to expand their production / loading of trucks to the double volume than the current case. First, the simulation of the current scenario was created. In the next step, different scenarios were created in order to show what kind of changes they might have and face such as including more trucks into the layout. This enabled the possibility to compare the different scenarios and increase the efficiency. But on the other hand, it was helpful to show the illustrations to the managers in order to identify the problems and get an illustrative impression how the company could look like.

Question 4: How do simulation modeling programs help in analyzing and optimizing manufacturing processes compared to other methods? Based on your projects / view

Answer: The combination of statistics and visualization is the main benefit of the simulation modeling programs. On one hand, the statistics are important because they show the numbers and the improvements in quantitative figures. But on the other hand, the visualization supports the understanding. A manager / CEO would like to see the problems visualized which can confirm the quantitative data. Especially for a consultancy, it is helpful to show the results as a simulation. At the end, it depends on the project and the outcome. For some customers, numbers might be fine while for others, the simulation / visualization part is the most crucial one.

Question 5: What specific features or capabilities are essential for you in simulation modeling software for manufacturing processes?

Answer: **Important aspects are the following:** Statistic features / Excel spreadsheets at the end to share and compare the quantitative data; function for time distribution so that for each days different times can be adjusted; error debugging in order to understand and solve the problems; basic functions with not too high level of detail

Question 6: What are the key factors you consider when evaluating different simulation modeling program options for your specific project / work focus?

Answer: **Important aspects are the following:** High quality of error messages to understand what the problems are; personal guide / customer support to focus on individual problems; good and easily accessible customer support without waiting times; free and basic templates and libraries to use; more plug-and-play functions for a faster learning process and usability; more intuitive program with fewer functions

Question 7: Can you discuss any major challenges or limitations you have faced when using simulation modeling software in manufacturing contexts?

Answer: 1. First, the error debugging and the quality of the error messages is weak. Even though there is the function of showing the factory flow status with some information about the errors and correct connections between the process steps, the error messages are not detailed and informative. Sometimes, there is a problem but the reason can't be identified.

2. Also, there is no step-by-step debugging function. It would be supportive to use this in order to identify the issues in the code.

3. The customer support requires long waiting times and doesn't provide a high level of individualism and adaptability. There are help functions, but they cover mainly the general problems. If there is a specific problem, it is hard to solve just with the documentation and the tutorials / videos.

4. The initial and additional costs for the license and the usage of the educational videos are high. The company using those programs have to be really sure about the usage in order to make profit at the end.

5. In general, the program needs a high amount of practice in order to make it work. The learning process starts with using the program frequently. There is no possibility to gain the knowledge from the tutorials and educational videos.

6. The flexibility of the program is low. In case of a specific function, Delmia has to create this function first before it might be available for the users. One example, the creation of the Excel functions for a specific customer case.

Question 8: What level of training was needed so that you were capable of using the simulation modeling program?

Answer: Overall, the training provided will never give that much knowledge to learn the program entirely. There are some tutorials, documents, educational videos, and help-functions available. However, those cover just the basic aspects of the program. Furthermore, they don't explain why those steps are taken. They just show what to do and the user follows the steps without understanding the purpose of those. Delmia is not an intuitive program. For the first and basic usage, there are way too many functions which are not relevant for the job and the purpose. Furthermore, the functions used are also not fully utilized because the knowledge about them is missing.

Question 9: What advancements or developments do you expect from simulation modeling programs that would further benefit your tasks / projects / focus?

Answer: **Important aspects to consider:** improved debugging and higher quality of error messages; individual support and educational training programs; more intuitiveness

Question 10: Looking forward, how do you see the role of simulation modeling developing in the future of production development, and what are your expectations for advancements in this field?

Answer: Simulation modeling will become more and more important for the future. Especially for the usage of consultancies, it might be highly supportive because of the visualization aspects. However, having coding as a background might be helpful for a quicker learning curve and better utilization of those programs. It also depends on the purpose of the projects and the expected outcome.

Appendix XV: Interview Expert B - Production Developer

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Questions & Answers

Question 1: Can you explain shortly your role in terms of responsibilities, tasks, and main projects conducted?

Answer: As a production planner in a consultancy, the coordination of the production processes for client projects presents the main responsibility. The projects mainly focus on the continuous improvement efforts and the optimization of workflows. Performance measurements, analysis, and planning are also part of the main tasks as a production developer.

Question 2: What specific role do simulation modeling programs play in your position?

Answer: Certain clients and customer projects focus on simulation modeling in order to understand where bottlenecks might be located. Furthermore, it represents a helpful tool to visualize the manufacturing area and gain some statistical outcomes from it. In the past, some customer projects requested simulations as an outcome.

Question 3: Can you name an example of when you used simulation modeling program for a project?

Answer: The main customer was within the Stena project. They requested a simulation to visualize their production / loading of the trucks with a focus on a future scenario with double the size of the current situation. The simulation

Question 4: How do simulation modeling programs help in analyzing and optimizing manufacturing processes compared to other methods? Based on your projects / view

Answer: The main benefit from simulation modeling programs is the visualization aspect. Even though calculations help for an improvement and optimization of the production / manufacturing / processes in general, simulations offer the possibility to visualize what is happening. Especially for future scenarios, visualizations are supportive because they increase the understanding level and are also based on statistical background. So it is a good combination between quantitative data and visualization aspects.

Question 5:	What specific features or capabilities are essential for you in simulation modeling software for manufacturing processes?
Answer:	The most crucial factor is the user friendliness and the customer support. In most projects, the time and the delivery are significant, especially in a consultancy. That's why the program should offer qualitative good customer support. The functionalities don't have to be too sophisticated and complex. Simple features which offer the usage of visualization and the generation of statistical outcomes are the most crucial ones. The projects (at least in this company / consultancy) focus mainly on smaller companies and clients. So that's why a simple and user friendly program is important.

Question 6:	What are the key factors you consider when evaluating different simulation modeling program options for your specific project / work focus?
Answer:	The key factors might be definitely the ease of use and the learning curve. It doesn't make sense to spend too much time in learning a new program which is also hard to control and handle. Furthermore, available training courses and educational videos are necessary. The availability of free videos or tutorials supports the learning of the program or in case of issues / struggles. In these terms, the simulation modeling company should also provide good customer support and personal contact.

Question 7:	Can you discuss any major challenges or limitations you have faced when using simulation modeling software in manufacturing contexts?
Answer:	The major issue with the current program is the high complexity of the program. It is not intuitive, and the usage is not easy to learn. Without a proper training program, there is no possibility to understand how the program and the platform work. Furthermore, the provided educational videos are weak. There are no free tutorials or YouTube videos available which can be used for training and support in certain programs. The current program does not have a good manual or documentation in order to learn the basic functions of the system. So, in general the learning curve is really slow and the complexity of the program makes it harder to understand and to use it. When it came to the actual simulations, the files of the program were huge. This means that long loading / waiting times came along with the usage of the simulations. One slight change in the program required several minutes of waiting until the change could be seen in action. Especially for the smaller customers / organizations, there is too much data requested which need to be implemented into the program for showing the reality or match with the real case. However, often the data can't be provided which makes the simulations weak regarding the reality perspective.

Question 8: What level of training was needed so that you were capable of using the simulation modeling program?

Answer: Without knowledge in simulation modeling in general, it is always more difficult to understand latest programs. In general, a qualitative documentation, customer support, training courses are required to learn a new program. In the current case, a full training course was needed to understand the basic functions and usage of the program. The learning curve was slow and the program is not intuitive.

Question 9: What advancements or developments do you expect from simulation modeling programs that would further benefit your tasks / projects / focus?

Answer: The more tutorials, videos, customer support, and documentation is available, the better the learning curve and the easier the understanding of those programs. Personal contact is always helpful to get because it offers the possibility to answer questions directly.

Question 10: Looking forward, how do you see the role of simulation modeling developing in the future of production development, and what are your expectations for advancements in this field?

Answer: Looking forward, the role of simulation modeling in production development will increase in significance. However, companies must undergo a preliminary journey before simulation modeling can be applied. The access and generation to data and detailed information are highly crucial. Without providing data, simulation modeling might be useless because it will never show the full reality. That is important before considering the effort of simulating processes.

Others / Comments

Thoughts from the customer perspective, what might be important

1. Overview of the material flow / production flow
2. Visualization of how everything works together
3. Statistics are important
4. Optimization and identification of issues as a combination between statistics and visualization

Appendix XVI: Interview Expert C - Sales Consultant

Questions & Answers

Question 1: Can you explain shortly your role in terms of responsibilities, tasks, and main projects conducted?

Answer: The main responsibilities as a sales consultant are the understanding and fulfilling of the customer needs. Usually, the process starts with the analysis of the processes, manufacturing, and production area of the customer. Most of the projects focus on the increase or improvements of certain KPI's, the performance, or productivity level. After analyzing the current situation, improvement and optimization possibilities are suggested so that the customer can expand or increase the business. In general, the main responsibilities lie into customer relationships, the entire sales process, and marketing.

Question 2: What specific role do simulation modeling programs play in your position?

Answer: As a sales consultant, simulation modeling programs usually offer the possibility of a better marketing strategy. It shows a high level of visualization which customers often like to see and might be fancy about. So, it is a lot about marketing in the first step. In the second step, they would like to gain also the statistical parts out of it which makes it possible to observe the improvement possibilities.

Question 3: Can you share examples of how simulation modeling has been utilized to optimize sales forecasting or demand planning in manufacturing contexts?

Answer: The most important project was conducted with Stena, a Swedish recycling and warehouse company. The organization wanted to double the outcome and requested the simulation for visualizing the material flows. The statistics gave them the possibility to see what might be possible for a future scenario.

Question 4: How do you see simulation modeling programs supporting sales and customer-focused strategies in manufacturing businesses?

Answer: Simulation modeling programs can attract new customers because of the high level of visualization and graphics. In general, the customers are always keen to see 3D simulations in comparison to the 2D layouts. It is easier to understand and to visualize in the first step. However, the programs also need to offer the possibility of generating statistics or quantitative data in order to see benefits for possible improvements and optimization aspects.

Question 5:	How high is the demand from the customer perspective to get a simulated manufacturing flow?
Answer:	It depends a lot on the customer and the needs. It makes sense in some cases, but in other cases it would not generate a benefit for neither of them. So, it is important to understand what the customer needs and wants. Sometimes it doesn't make sense to sell the simulation modeling to the customer because other tools will be more supportive. At the end, it is a balancing act and depends on the customer and the project.
Question 6:	What specific features or capabilities are essential in simulation modeling software for your projects / sales focus?
Answer:	To name some examples: the visualization to catch the customer at first; the outcome and statistical parts in the second step; how can the simulation program support the improvement possibilities
Question 7:	What are the key factors you would consider when evaluating different simulation modeling program options for your specific project / work focus?
Answer:	Always a combination between the visualization and the data quality.
Question 8:	Can you discuss any major challenges or limitations you have faced when showing simulations to customers or within projects?
Answer:	Difficult education; missing educational support; slow learning curve; getting the correct access and license; many license types; weak customer support; high financial considerations; high complexity of the usage; big platform
Question 9:	How do you assess the return on investment when incorporating simulation modeling into sales? Does it bring the expected results?
Answer:	Yes, so far simulation modeling offered a possibility to improve the marketing and to address more customers. It has potential to support the sales by first addressing the customers. In the second step, it might be helpful to get the needed data and statistics out of it.

Question 10: Looking ahead, how do you expect simulation modeling developing to better support sales and customer-centric strategies in the manufacturing industry, and what opportunities or challenges do you think might come?

Answer: There is an increasing need of customers interested in simulation modeling. It will always depend on the projects, the size of the customers, and the benefit which simulation modeling can have in comparison to other tools. However, Digital Twins are getting more important as well. If there is more need of the simulation modeling, then it will be crucial to get a program which is easy to learn, easy to adapt and offers both, the visualization and the statistical outcomes.

Others / Comments

For a better understanding of the customer projects and the processes behind:

1. Usually the aim of the projects are
    a. Increasing the OEE level
    b. Major improvements
    c. Increase their output
    d. Increase of the performance, facilities
    e. Logistical projects and manufacturing processes
2. Process
    a. Current state analysis (time studies; frequency studies; OEE studies)
    b. Defining the goal of improvement and increase
    c. Strategic improvements
3. Types of customers
    a. No typical type of customers
    b. From small to big businesses
    c. Logistical problems, production processes
    d. Sector: industry & manufacturing
    e. Main goal: improvement, optimization, expansion, increase, performance

Appendix XVII: Interview Expert D - Manager

Questions & Answers

Question 1: Can you explain shortly your role in terms of responsibilities, tasks, and main projects conducted?

Answer: Responsibilities include overseeing the day-to-day operations, managing a team of consultants, and ensuring the satisfaction of customers. Tasks involve project delegation, resource allocation, and providing guidance and support to consultants. The focus lies on the customer acquisition as well as the employee coordination and creation of a positive work culture.

Question 2: What specific role do simulation modeling programs play in your position?

Answer: Within the role, simulation modeling programs don't play the biggest role in terms of the user perspective. In general from the consultancy perspective, it is crucial that the customers get the possibility of simulations so the sales increase. Additionally, the employee / colleague perspective is an important aspect as well.

Question 3: Can you share examples of how you see the functionality of simulation modeling from your organizational perspective?

Answer: Potential for an increased sales and customer marketing; unique selling point to customers; different focus in manufacturing processes regarding visualization and optimization aspects (bottleneck, profitability)

Question 4: What drove your company to adopt simulation modeling program for manufacturing processes / customer projects as a key service offering?

Answer: It started with a close collaboration with Dassault Systemes, which is the provider of Delmia. Joel was the first person using the simulation program due to this collaboration. Now, the contract ended and there is potential to explore in new programs. However, the main reason for providing simulation modeling to customers are the possibilities as in visualization and insights in the statistics / quantitative data.

Question 5: What are the key factors you would consider when evaluating different simulation modeling program options for the use of your company?

Answer: Fast learning curve; possibility for education (tutorials, documentation, videos); low financial considerations; high qualitative outcome / result and good quantaitvie data for improvement possibilities; visualization is important, but the statistics are more important → tool should help the consultant to access improvement possibilities for the customer

Question 6: Can you discuss any major challenges or limitations you / your employees have faced or could see when using simulation modeling programs?

Answer: Difficult access; weak customer support; too little educational tutorials / material; complex program; hard to gain knowledge; long learning curve; many license options; high costs

Question 7: What kind of training do you provide for your employees so they can use the simulation modeling programs efficiently?

Answer: The training is mainly based on the options available from the program provider. It covers educational videos, tutorials, documentation and customer support.

Question 8: Looking ahead, what trends or advancements do you expect from simulation modeling software that will further benefit manufacturing processes, and how is your consultancy preparing for them?

Answer: The importance of Digital Twins and simulation modeling programs is growing. It is important to be ready for this development. Especially as a small consultancy, it is crucial to have a unique selling point. Right now, there is no other competitor focusing on simulation modeling programs which offers the possibility to gain more knowledge in this area / field. It doesn't make sense to compete with bigger companies which already use simulations programs within their own manufacturing area. It is better to focus on the smaller companies.

Others / Comments

Needs for the new simulation program

1. Quite easy to learn
2. Fast learning curve, 2 to 3 weeks to learn the program
3. How to get the knowledge
   a. Educational videos
   b. Tutorials
   c. Customer support
4. How high is the quality of the material
5. Export and import of the data
6. How smart is the program
   a. Which data is coming out
   b. How accurate is the data
   c. Is the program smart to show the problems
   d. To extract the data and analyze it
   e. Does the program show in colors where to focus on
7. Financial considerations to compare it
8. Focus of the programs
   a. Which types of projects
   b. Manufacturing
   c. Logistical
   d. Customer sizes
9. Time of the modeling
10. Computer performance
    a. How smart and efficient the program is
    b. CPU level
11. Graphics & visualization
    a. It is important to have a high level

Appendix XVIII: Interview Expert E - Project Leader

Questions & Answers

Question 1: Can you explain shortly your role in terms of responsibilities, tasks, and main projects conducted?

Answer: As a mechanical project leader, the role involves managing the planning, execution, and completion of mechanical engineering projects. The responsibilities include coordinating with cross-functional teams, managing resources, and ensuring that projects are delivered on time based on the budget and other specificiations. Tasks include creating project plans, assigning tasks to team members, monitoring progress, and resolving issues or conflicts that arise during the project lifecycle. Additionally, risk management, quality assurance, and the communication to stakeholders is important to ensure successful project outcomes.

Question 2: What specific role do simulation modeling programs play in your position?

Answer: In the position as a mechanical project leader, simulation modeling programs will not be a task performed. However, it might be included within a project and especially team members (mainly production planner / developer) will use this program in order to simulate, analyze, and improve the manufacturing processes.

Question 3: Can you share examples of how simulation modeling has been utilized or would be utilized in your position / tasks / projects?

Answer: It depends a lot on the project. But for getting new customers, it would be supportive to show a simulation case and get an understand for how the programs will be used for. Then the customer could decide whether they also would like to have this program for the visualization of their manufacturing area. But depending on the project, simulation modeling can be used to visualization and then identifying issues in order to optimize the manufacturing areas.

Question 4: How do you see simulation modeling programs supporting mechanical design projects?

Answer: There is a possibility of using simulation modeling programs for risk reduction and the prediction of performance within the manufacturing process. The main purpose will be the identification of optimization aspects and improvement of productivity. This can be applied to diverse set of projects which also include mechanical design projects.

Question 5: What specific features or capabilities are essential in simulation modeling software for your projects / mechanical design focus?

Answer: For the projects, the main focus lies on the illustration / reality level. The simulation should match or reflect the reality entirely in order to gain knowledge out of it. Besides this aspect, it is important to gain some outcomes and optimization possibilities out of the simulation. The level of detail is not that important as long as the statistical parts, KPIs, and performance criteria at the end show what is required.

Question 6: What are the key factors you would consider when evaluating different simulation modeling program options for your specific project / work focus?

Answer: Overall, the program requires a high ease of user friendliness. The simulation will be performed by the production and simulations engineer, however, they are the group members. So in order to conduct a successful project, the team members have to perform which means the program needs a level of intuitivism so it can be used easily. Obviously, some level of visualization is key. Otherwise, a 3D simulation modeling program is not needed. But, there must be a balance between the visualization / degree of detail and the performance analysis in terms of outcomes and statistics. The focus still lies on the comparison between the current status and the optimized, future status of a manufacturing process. In some projects, it might be supportive and required to get access to available libraries. This gives a level of freedom and customization possibility. Also, in "greenfield" projects it might be necessary to create new products, objects, basic production items. For bigger / "brownfield" projects or bigger companies, this might not be needed because they have already all 3D model and CAD files which can be used for the simulations.

The evaluation process of new simulation programs can focus on trial versions. The production planners can use trial versions in order to identify which program might be the most suitable ones. Based on their opinion, a decision has to be made.

Question 7: Can you discuss any major challenges or limitations you have faced or could see when using simulations for your projects / showing it to team members?

Answer: One possible aspect might be the level of frustration. It is important to keep the team members motivated, so they can perform as required. However, if a simulation modeling program is hard to use and issues occur all the time, it will not be beneficial for the overall outcome. That's why the program needs to have a good user friendliness keeping the motivation level high.

Question 8:	How important is it for the simulation modeling programs to integrate with other tools or systems used in mechanical projects?
Answer:	Depending on the project and the customer. The bigger the customer is, the more important it might be because of already existing systems and data (such as CAD files). It will be crucial that the program can interact with those programs so that the already available data can be used further. On the other hand, the smaller the company is, the more important might be free libraries and templates to use in order to use the level of creativity.
Question 9:	Looking ahead, what advancements or developments do you expect from simulation modeling programs that would benefit mechanical project leading in the manufacturing contexts?
Answer:	High level of user friendliness; showing the reality; good level of statistical output for improvement possibilities; visualization level until a certain degree

Others / Comments

For a better understanding of project management, the following will describe the project process which project leaders should follow.

Project process

1. Define specific & measurable goals (such as statistics and performance)
2. Form the group and settle group members
3. Planning (define the responsibilities and tasks)
4. Communication (how to communicate with the different members)
5. Risk analysis (identify and manage the risks)
6. Implementation (regular checkups to control the status)
7. Results & analysis (improvements, what changed)
8. Lessons learned & documentation

Main responsibilities of a project leader

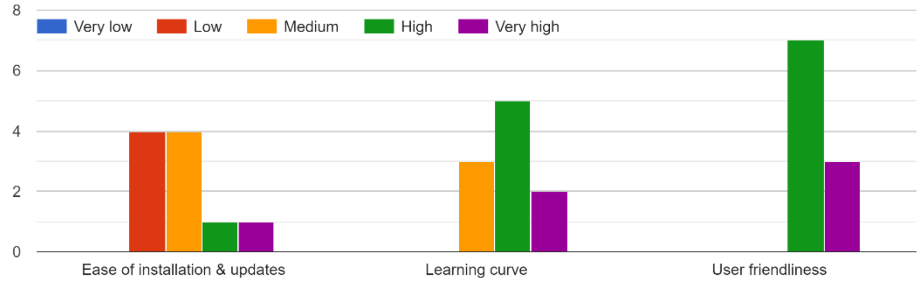
1. Management
2. Create a good atmosphere among the project members
3. General perspective on different team members

Summary

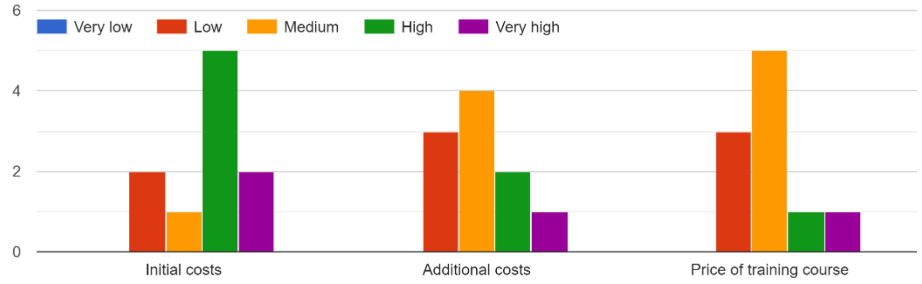
1. What is important
    a. Reality reflection
    b. Statistical analysis and outcomes for improvement and optimization
    c. User friendliness and fast learning curve
    d. A basic level of visualization (depending on the project, focus group)
    e. Availability of free libraries and templates (depending on the company, project type)
2. What is not important
    a. Too high level of graphics / visualization is not required

Appendix XIX: Questionnaire Results

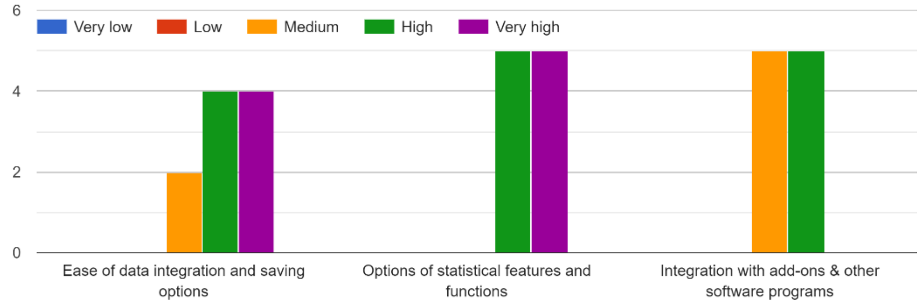
How important are the following sub-criteria to measure the "general features" of simulation modeling programs based on your profession / your background?



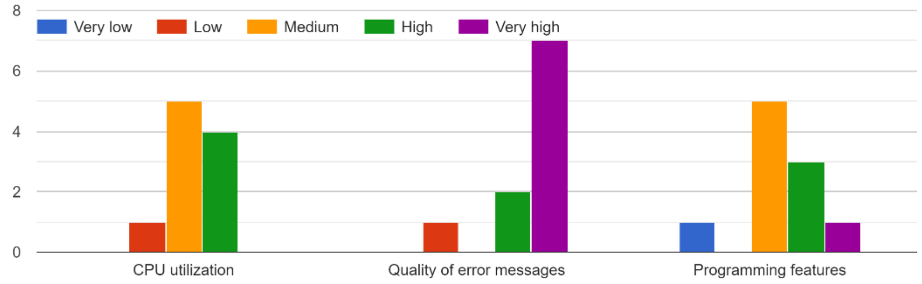
How important are the following sub-criteria to measure the "financial considerations" of simulation modeling programs based on your profession / your background?



How important are the following sub-criteria to measure the "input / output functionality" of simulation modeling programs based on your profession / your background?



How important are the following sub-criteria to measure the "performance" of simulation modeling programs based on your profession / your background?



Appendix XX: Dysfunctional Features of DELMIA

Appendix XXI: Part of Decision Matrix

Criteria	Weight	Visual Components		3D Experience DELMIA	
		Rating	Weighted Score	Rating	Weighted Score
General Features	**3,7**	**5**	**18,5**	**3**	**11,1**
Ease of Installation and Updates	2,9	4	11,6	4	11,6
Learning Curve	3,9	5	19,5	3	11,7
User Friendliness	4,3	5	21,5	2	8,6
Financial Considerations	**3,3**	**4**	**13,2**	**3**	**9,9**
Initial Costs	3,7	3	11,1	3	11,1
Additional Costs	3,1	5	15,5	3	9,3
Price of Training Course	3,0	3	9	3	9
Customer Support	**3,8**	**4**	**15,2**	**3**	**11,4**
Direct Customer Support	4,5	4	18	2	9
Quality of Documentation, Tutorials, Trainings	4,2	5	21	3	12,6
Quality of Community Support	2,8	4	11,2	3	8,4
Total Score - Sub-Criteria	-	-	**138,4**	-	**91,3**
Total Score - Criteria Groups	-	-	**46,9**	-	**32,4**