TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Mechanical and Industrial Engineering

TALLINNA TEHNIKAÜLIKOOL

DEVELOPMENT OF A DIGITAL TOOL FOR PROJECT-BASED PRODUCTION MANAGEMENT

DIGITAALSE LAHENDUSE LOOMINE PROJEKTIPÕHISE TOOTMISE JUHTIMISEKS

MASTER THESIS

Student: Liisi Miller

Student code: 192501 MARM

Supervisor: Kashif Mahmood, Researcher

Tallinn 2021

AUTHOR´S DECLARATION

Hereby, I declare, that I have written this thesis independently. No academic degree has been applied for based on this material. All works, major viewpoints and data of other authors used in this thesis have been referenced.

22.05.2021

Author: ....

/ signature /

This is in accordance with terms and requirements.

“.......” 2021

Supervisor: ....

/ signature /

Accepted for defence.

“.......”.................... 2021

Chairman of thesis defence commission: ....

/ name and signature /

Non-exclusive Licence for Publication and Reproduction of Graduation Thesis*

I Liisi Miller (date of birth: 01.11.1992)
hereby

1. grant Tallinn University of Technology (TalTech) a non-exclusive licence for my thesis

Development of a digital tool for project-based production management.

supervised by Kashif Mahmood,

1.1 reproduced for the purposes of preservation and electronic publication, incl. to be entered in the digital collection of TalTech library until expiry of the term of copyright,

1.2 published via the web of TalTech, incl. to be entered in the digital collection of TalTech library until expiry of the term of copyright.

1.3 I am aware that the author also retains the rights specified in clause 1 of this license.

2. I confirm that granting the non-exclusive license does not infringe third persons' intellectual property rights, the rights arising from the Personal Data Protection Act or rights arising from other legislation

---

*Non-exclusive Licence for Publication and Reproduction of Graduation Thesis is not valid during the validity period of restriction on access, except the university`s right to reproduce the thesis only for preservation purposes.

________________ (signature)

22.05.2021

Department of Mechanical and Industrial Engineering

THESIS TASK

Student: Liisi Miller, 192501MARM

Study programme: Industrial Engineering and Management

Supervisor: Kashif Mahmood, Researcher

Thesis topic:

(in English) Development of a digital tool for project-based production management.

(in Estonian) Digitaalse lahenduse loomine projektipõhise tootmise juhtimiseks.

Thesis main objectives are to:

1. analyze, what makes project-based production environment different from other production systems,
2. analyse possible IT solutions for project-based production management,
3. build a live production schedule, visible and usable to everybody in production,
4. present live production reports and feedback system to keep track of project budgets,
5. achieve a stress-free work environment by recognizing common goals and deadlines.

Thesis task and time schedule:

No	Task description	Deadline
1.	Literature review and analysis	14.03.21
2.	Analysis of enterprise systems on the market	21.03.21
3.	Development of the digital tool for project-based production management	25.04.21
4.	Representing conclusions and results of the thesis	24.05.21

Language: English Deadline for submission of thesis: 26.05.2021

Student: Liisi Miller ……………………………“…..”…………..2021

/signature/

Supervisor: Kashif Mahmood ………………………… “…..”…………..2021

/signature/

Head of study programme: Kristo Karjust …………………… “…..”…………2021

/signature/

TABLE OF CONTENT

PREFACE 6

List of abbreviations and symbols 7

INTRODUCTION.. 8

1 PROJECT-BASED PRODUCTION – CHALLENGES OF CONTROLLING THE COMBINED ENVIRONMENT..10

1.1. Challenges of ETO production management 10

1.2. Critical success factors 12

1.3. Common solutions for project-based production management 13

2 OVERVIEW OF AVAILABLE ENTERPRISE MANAGEMENT SOFTWARE FOR PROJECT-BASED PRODUCTION COMPANIES 16

2.1 Selection criteria...17

2.2 Solution selection 18

3 METHODOLOGY 21

4 DEVELOPMENT OF A DIGITAL TOOL FOR PROJECT-BASED PRODUCTION MANAGEMENT...24

4.1. Presentation of the company under study 24

4.1.1 Manufacturing process. 25

4.1.2 Current production information system. 27

4.2. Requirements´ specification 32

4.3. System architecture 34

4.4. Implementation and further suggestions..42

SUMMARY...43

KOKKUVÕTE 44

LIST OF REFERENCES 45

Appendix 1 – As-is simulation report..49

Appendix 2 – To-be simulation report 51

Appendix 3 – To-be process flowchart...53

PREFACE

I am sincerely grateful to those, who´s encouragement led me studying industrial engineering and management in TalTech. Great thanks to my employer, colleagues and my family for patience and support on this journey.

Special thanks to my supervisor Kashif Mahmood (Researcher at Tallinn University of Technology) for his help and support in compiling the thesis.

Keywords: engineer-to-order, production planning and control, digital, master thesis.

LIST OF ABBREVIATIONS AND SYMBOLS

CAD – Computer-Aided Design

ERP – Enterprise Resource Planning

ETO – Engineer-to-order

IoT – Internet of Things

LPS – Last Planner System

MES – Manufacturing Execution System

MPC – Manufacturing Planning and Control

MRP – Material Requirements Planning

PBP – Project-Based production

WBS – Work Breakdown Structure

INTRODUCTION

Nowadays, where digital technologies offer new ways to connect and collaborate, we hear and talk more about digital transformation also in business processes and manufacturing. Industry 4.0 is the digital transformation of manufacturing and value creation processes. Many ambitious companies try to strive that direction by exchanging old technologies to smarter ones. The goal is to achieve autonomous decision-making, monitor processes in real-time, and enable connected value creation networks [1]. One example of digital transformation is deployment of digital information systems like ERP and MES, which have continuously been developed since 1960s [2].

Most studies for production planning and control describe solutions for large scale production, because most of world´s products are manufactured in massive amounts on continuous flow of production lines. However, complex products with high level of customization cannot be produced in this way. Approach called engineer-to-order (ETO) or project-based production (PBP), known also as project manufacturing has become an important challenge of manufacturing management [3].

More and more products in the postmodern society are realized through projects [4]. Classic examples would be construction projects and shipbuilding. Large construction projects are carried out in a way that all the elements that can be produced in the production units are produced into finished elements. Producing construction elements in manufacturing units helps to cut costs and increase efficiency [5]. Companies can provide better working conditions for employees and use high-tech machinery for production. All that can increase construction quality, make it possible to use weather-sensitive materials and build faster.

While many manufacturing resource management systems are provided for standard production systems like mass production or job shop production, project-based companies tend to be relatively under-served by enterprise system vendors. Aim of this thesis is to provide a digital solution for project-based production management in context of manufacturing construction elements. As a result, a company specific project manufacturing planning and control system is built. Benefits of this system to the company are to be:

1. a live and visual production schedule,
2. stress free work environment enabled by awareness of workload, common goals, and deadlines,
3. online involvement of project stakeholders (cloud-based solution), enabling remote working which turned out crucial in situation of Covid19 pandemic,
4. live project reports,
5. a step ahead towards digitalisation,
6. readiness for paper free production.

The structure of this thesis paper is divided into four sections: literature review, analysis of available solutions, methodology and case study. Literature review concentrates on the challenges of manufacturing control in project environment. Which are the bottlenecks in project production and key success factors for a functional IT solution? The analysis of available solutions compares some ready-made enterprise systems on the market, trying to find possibly best for the thesis case. Development process follows the protocol of systems analysis and design method. First, the requirements are defined, then software architecture explained and finally, suggestions for implementation and further development are provided.

The benefits of the system are proved by simulation analysis, comparing the as-is process to new to-be process, which is achieved after implementation of improved system. Although, the implementation of the system is hypothetical. For simulating the processes, Bizagi software is used, which is oriented towards business process flow visualisation and simulation.

1 PROJECT-BASED PRODUCTION – CHALLENGES OF CONTROLLING THE COMBINED ENVIRONMENT

1.1. Challenges of ETO production management

According to Langhoff [4] and Pacagnella et al [3], project-based production is characterized by unique products, high complexity, high value, many stakeholders, and dependence on many variables. For ETO, the product is produced on a one-off basis and the design and manufacturing process as well as the sequence of operations are usually different from one product to another [6].

According to Cutler [7], ETO companies build unique products designed to customer specifications. Each product requires a unique set of item numbers, bills of material, and routings. Estimates and quotations are required to win business. Products are complex with long lead times, typically months or even years. El-Mehalawi [8] brings out, that project manufacturing is to produce or assemble one unit of each unique product. Although it is a manufacturing environment, it follows the definition of the project of being temporary and unique.

Arbulu et al [9] have researched project controls and project production control. They bring out, that project controls provide project accounting and reporting function against a baseline plan, rather than effective production planning and control function. It means, that project-based production cannot be effectively planned and managed by monitoring project controls and using project management techniques. They specify, that project production control incorporates a distributed approach to planning work for execution, where those responsible for executing the work, plan their work. However, the schedule must be constantly updated, executed, and therefore controlled. This requires that project teams meet regularly to make commitments about exactly what work will be executed in the next production cycle. Achieving higher reliability and consistency requires automated control of human work. Automating control of human work requires computer described tasks.

Synchronization of engineering, manufacturing and installation is crucial for companies in the ETO environment [10]. It refers to the need of software integration as well as integration or better communication regarding managing, planning and execution. Many small and medium-sized manufacturing companies have already implemented enterprise resource planning (ERP) and manufacturing execution systems (MES). MRP and MES systems are build up on traditional BOM and routings [11]. For ETO production, the BOM and routing are every time different, so there is no help of a standard BOM. A new and more flexible solution needs to be found. System vendors are coming up with MRP systems for ETO, but the greatest challenge seems to be connection creation between manufacturing and project management.

Agility and timely propagation of business-relevant events are the top priorities for ETO manufacturers to react turbulent scenarios regarding schedules [12]. Agility refers to the ability to create and respond to changes, the ability to quickly reprioritize use of resources when requirements, technology, and knowledge shift. Agility is a fast response to market changes, it is the approach forward maximizing the business value with right-sized, just enough and just in time processes and documentation [13]. Agility and flexibility are common characterizers of engineer to order environment. Continuous reprioritizing on the other hand, means change of plans repeatedly.

Planning itself is always a continuous process [14]. Continuous planning is a lean approach to planning, where fixed plans are replaced with continually updated plans, which are modified every time a change in priorities or unexpected delay occurs [15]. Production planning process focuses on optimizing the use of applied resources for a specific time frame or control cycle (day, shift, week) and updating of production plans for that cycle [9].

Table 1.1 Characteristics of engineer to order production environment.

Publications	Challenges of ETO environment
A. C. Pacagnella, S. L. da Silva, O. Pacífico, P. S. de Arruda Ignacio, and A. L. da Silva (2019); C. Langhoff (2012)	high complexity, unique products, high value, many variables, many stakeholders
M. El-Mehalawi (2021)	temporary and unique like a project
T. R. Cutler (2006)	unique products, routings, and bills of materials
R. J. Arbulu, M. Eng, H. J. J. Choo, and M. Williams (2016)	planning work for execution, automated control, schedule updates
Erwin Rauch, Patrick Dallasega, and Dominik T. Matt (2015)	synchronization between design, manufacturing, and installation
Jorge Minguez, Sema Zor, and Peter Reimann (2011)	agility

Table 1.1 concludes the findings for the question regarding the unique environment of engineer to order. What makes this production type challenging is its temporary and complex product, that is created for one time only according to customer specifications. It sets the limits for implementing any traditional MRP software for production control, because BOM and routings are every time different. Planning of work and resources gets a totally new perspective, a perspective from project management angle.

1.2. Critical success factors

To help understand, what requirements should be met for a workable project manufacturing system, critical success factors are analysed. Pacagnella et al [3] have divided the factors into five categories: related to human resources, organization, stakeholder relationship, project management, and structural and technical aspects. Many studies indicate the importance of human factor and team synergy for successful project management. By the end of all, people are the ones who do the work. Organizational factors are related to the characteristics of the business environment. It´s also related to human resources, how the organizational culture is developed. Stakeholder relationships are one of the most important factors for project manufacturing. Effective communication has a key role in any organization, especially where human factor plays a big role. Activities related to project management have a great influence on the final success of the project. I would highlight clear objectives, clear documentation, proper planning, and constraints analysis as vital from the practitioner´s viewpoint. The last category of success factors- structure and technical aspects, refers to the helping tools for executing the project and for succeeding in previous categories.

Table 1.2 Critical success factors of project manufacturing (based on Pacagnella et al [3]).

Human resources	Empowerment	Project management factors	Clear objectives
	Project manager leadership		Clear documentation
	Project team integration		Project planning
	Project team flexibility		Management requirements
	Conflict handling		Prevention of multitasking
	Project manager experience		Analysis of critical resources
	Team experience		Analysis of limiting factors
Organization	Project manager authority		Register of lessons learned
	Organizational structure		Risk identification
	Change management		Risk analysis
	Top management support		Responses to risks
	Project management office		Reserves of time and money
Stakeholder relationships	Effective communication		Risk control
	Incentive mechanisms		Control of baselines
	Distinctive mechanisms	Structure and technical aspects	Communications infrastructure
	Integration with suppliers		Information systems for projects
	Selection of suppliers		Technical performance control
	Client engagement		Proper execution of commissioning
			Use of previous technologies

All these factors in the table, are important for project success. Some of them have shown more impact, some less. As this thesis is concerned more with information technology and digital tools, I would bring out from the research that it is important to have a system that enables to maintain data integrity and consistency, transmitting and storing such data to facilitate the processing of change requests, control mechanisms, lessons learned and configuration management. Use of these systems assists in determining lead times, delivery dates, improves information exchange, and makes the projects more efficient. “Because of interdependencies, projects often start to compete for resources, whether financial, human, or technological, and those sought most frequently become scarce. [3]” That is why it is important to visualize and see the critical resources beforehand, to level the needs and prevent overload.

From a practitioner´s perspective, I would add the importance of simplicity and integration. In the environment of constant uncertainty, we look for calming routine. A simple yet efficient system for managing the abundance of information without manual work (like typing big data from one program to another), could be a great help in achieving a healthy routine.

1.3. Common solutions for project-based production management

There are different ways and methods and tools, that project manufacturers use to control production. Tenhiälä [16] has proposed four preliminary categories for project-based production management:

◊ manual coordination,
◊ project MRP (project planning is done within the conventional MPC system),
◊ ERP systems´ project management modules,
◊ bolt-on software offered to the conventional ERP systems.

Manual coordination refers to an arrangement where information systems for project management and production management are separated from one another. The coordination is handled informally through meetings, emails, spreadsheets, or groupware solutions. Project MRP stands for the solution where BOMs and routings are used for project management purposes. This system has been considered unreasonable, because of project managements´ creative and informal nature, which is not common to rigid ERP systems. The third category – ERP systems´ project management modules would solve the problems of previous solution, but a closer look reveals that often these systems are rather aimed at the cost accounting functions than production planning. The last solution category refers to systems integration, where separate systems are used by project management and the production planners, but they are integrated through middle-ware software [16].

The importance of information transparency has been brought out in a research by Gosling et al [17]. They found that web-based project planning software were widely used in construction sector. Cloud-based solutions´ primary advantage is accessibility from everywhere. That unties workplaces from workers, and location-independent cooperation becomes available. Covid pandemic has shown us the need for that and changed our way of working for good.

From previously described literature review, it came out that lean methods are also commonly used for project-based production management. Lean Manufacturing is a philosophy of eliminating wastes - eliminating wastes from production and from processes [18]. Waste is any activity that does not add value to the customer. Lean Construction extends from the objectives of Lean Manufacturing – maximize value and minimize waste – to specific techniques and applies them in a project delivery process [19]. The core elements of lean construction are waste reduction, just-in-time delivery, information technology and joint IT tools, and off-site manufacturing of components and units [5].

The Last Planner System [20] (LPS, created in 1990s) for production planning and control is one of the lean construction methods that has been successfully implemented in construction industry to increase reliability of planning, improve production performance, and create a predictable workflow. Implementation of LPS allows for the collection of key performance indicator such as Percentage Plan Completed. It is a measure of the proportion of promises made that are delivered on time, calculated based on the weekly work plan (the number of activities planned and the number that was completed). Perez and Ghosh [21] have brought out that successful implementation of LPS requires a thorough implementation planning process, analysis of root-causes for the non-completion of tasks and a standard practice for updating the schedule. On an operational level, visual controls that indicate the condition of production process at any time, are required to provide an understanding of the necessary actions [22]. Figure 1.1 presents the planning stages in the last planner system and gives clues on the structure of possibly successful information system design.

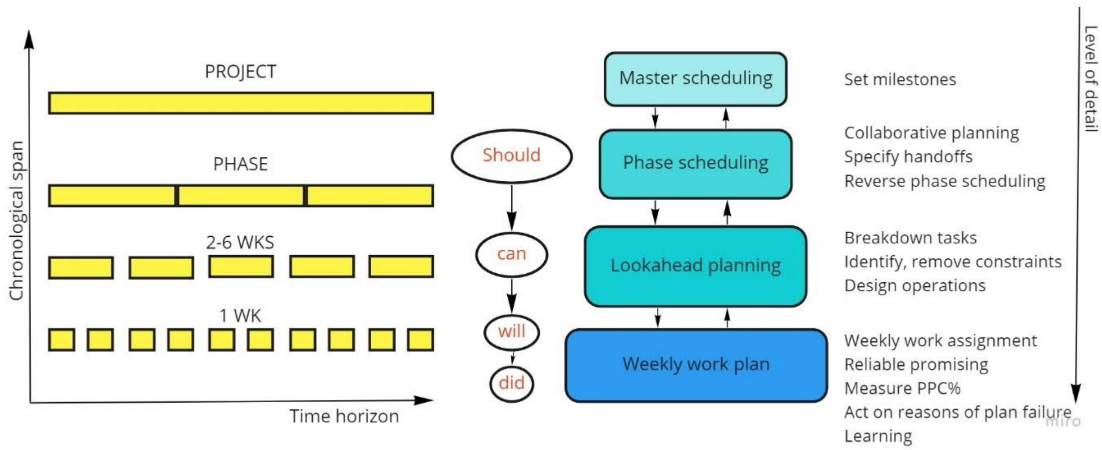


Figure 1.1 Planning stages in the Last Planner System [20].

It should be noted that the planning process should not be judged only by the outcome deliverable such as schedule. Cohn [23] has brought out, that the best results are achieved in a collaborative and democratic fashion and successful planning is expected to reduce risk, manage, and reduce uncertainty, support sound decision making, establish trust, and share information.

The key takeaways from the literature are integration, hierarchical structure of scheduling, flexibility, and collaboration. In the field of construction, cloud-based services have proved their worth.

2 OVERVIEW OF AVAILABLE ENTERPRISE MANAGEMENT SOFTWARE FOR PROJECT-BASED PRODUCTION COMPANIES

The history of ERP systems goes back to the time when computers were applied to materials planning for production, years 1960 [11], [24]. Since then, development has been significant. Nowadays, ERP systems and manufacturing management systems like many other IT systems, are turned towards cloud software systems and moved away from traditional client server-based models. Development is a continuous process. The future will be about integration of cloud ERP with Internet of Things, Augmented Reality and Virtual Reality. Only the sky is the limit.

As this thesis concentrates on manufacturing, the overview of available enterprise systems addresses production execution and production resource management. A comparative analysis against pre-set criteria is carried out. The programmes are selected based on their introductions and demo programs on the providers web pages. Software, that is specialized for other production systems than project manufacturing, is excluded.

Eziil [25] is cloud based MRPII software, developed in Estonia. Functionalities: real time overview of order status, work planning, project summary, product net price calculation and integration with multilevel BOM interface. Eziil enables project-based purchasing and warehouse management. It is a production-oriented software with some other business operations functionalities. Eziil is currently developing a new BOM software for better integration between design and manufacturing, which is oriented towards project manufacturers.

Smartsheet [26] is cloud based enterprise platform for dynamic project management. Smartsheet was launched in 2005 and it is an American software. Smartsheet is a collaborative working tool which enables to build whatever system in it. Its best qualities are expressed in project management. Smartsheet is currently used in the case study company of the thesis.

Microsoft Dynamics 365 [27] is cloud based enterprise software solution that brings ERP, customer relationship management and supporting business applications together as one streamlined product. By connecting enterprise solutions for supply chain management, Microsoft enables real-time overview of project operations, including production.

MRPEasy [28] is cloud based MRP system for small manufacturers. Although it is not developed specifically for project manufacturers, it has possibility to create project-based production orders. Compared to Microsoft, the structure is much easier to follow, interface is simpler to learn, and implementation scale is narrowly pointed to production only.

2.1 Selection criteria

After very simple and superficial introduction of available software, a more thorough analysis against important criteria is carried out. The criteria are compound of authors experience and Pacagnella et al [3] critical success factors of project manufacturing. The criteria important to project manufacturers are:

- ability to purchase materials to the project,
- ability to easily connect materials to production orders,
- ability to keep project- and the general inventory separate.
- ability to integrate engineering functions with manufacturing operations,
- enable visibility of entire project portfolio key data,
- master scheduling and short-term planning,
- machine queueing,
- enable visibility of real-time data against original estimate in terms of time and money,
- enable synchronisation of shop floor and project controls.

Often in construction production the projects are so different in nature and so are the materials. Sometimes for example aluminium profiles are custom made for this one project only. There isn´t a traditional material warehouse. That is why the manufacturing software need to enable purchasing materials directly for a project. Furthermore, it must enable connecting purchased materials to the production order to keep track when a certain production order can start. ETO production is dependent on material deliveries. Trustworthy partners are a very important asset. There are still some standard materials kept in stock in case of emergency, so to say buffer. There are cases when installation site needs extra fastenings or something like that. To keep track whether project materials are used as needed or need replenishment, project inventory should be monitored as well as buffer materials.

Time and workforce are important resources, that should not be wasted on duplicate tasks. That is why it is important to integrate manufacturing software with design software. CAD programs such as AutoCAD and SolidWorks enable to create a bill of materials based on the drawings. The software should be able to import a multilevel BOM via excel or other more direct version to avoid re-typing BOM information to the manufacturing software.

What makes project-based production different from other types of production is project orientation. Project controls like project schedule and budget are constantly monitored as well as production controls like machine utilisation and productivity. Project schedule acts like a master schedule. Short term planning and machine queueing could be done when a BOM is generated and imported to the manufacturing system.

Rauch and others [10] have brought out that synchronisation of engineering with manufacturing and installation is crucial to ETO companies. It is as important on the other way around too. To give out adequate information about production progress, delivery time and planning of next production cycle, it is essential to have feedback from production floor level. Synchronisation and easy feedback system bring more agility to the management and planning processes.

2.2 Solution selection

Comparing the available IT systems on market, based on these criteria, helps to make the most suitable selection. These criteria have been given weights from 1-5, based on the relative importance to an ETO production. Final scores are calculated by summing the scores of each system multiplied by the relative weight of the criteria:

$$F_k = \sum_i^N PS_i \, WR_i \tag{2.1}$$

where the relative weight of criteria is expressed through formula:

$$WR_i = \frac{WC_i}{\sum_i^N WC_i} \tag{2.2}$$

where: P – Solution
C – Criteria
WC – Weight of criteria [1 – 5]
WR – Relative weight of criteria
PS – Score of solution [1 – 10]
N – Number of criteria
F – Final score

The highest score indicates best suitability in terms of set criteria. Table 2.1 compares four different solutions for production control: Eziil, MRPEasy, Microsoft Dynamics 365 and Smartsheet. The criteria are synthesis on literature review and practical experience with working in a project-based production company.

Table 2.1 Comparison of different production management solutions.

Root Cause/Problem: No control over production management						
Criteria	Weight	Relative weight	Eziil	Smartsheet	Microsoft Dynamics 365	MRPEasy
Purchase materials to the project	5	0,14	8	10	4	1
Connect materials to production orders	4	0,11	10	5	9	10
Keep project- and the general inventory separate	3	0,08	7	9	2	3
Integrate engineering with manufacturing operations	5	0,14	9	9	9	9
Visualize entire project portfolio key data	4	0,11	6	10	8	1
Master scheduling and short-term planning	5	0,14	9	9	7	8
Machine queueing	4	0,11	9	7	8	9
Visualize real-time data against original estimate	2	0,06	9	6	9	9
Synchronize shop floor and project controls	4	0,11	9	7	8	6
FINAL SCORES			4,86	4,53	3,81	3,42
RANK			1	2	3	4
SELECTED [X]			x			

According to the table, Eziil has got the highest weighted score of 4,86. This means it is currently the most suitable software in terms of set criteria. The pros for Eziil were integration with multi-level BOM, simple work planning, real time overview of order status, work time accounting, and convenient user interface. Because Eziil still lacks in project management features, it would be necessary to have a project portfolio management tool next to Eziil software. A conversation with Eziil customer management revealed, that they are currently developing a new BOM software directed to project production control. Future cooperation could be mutually beneficial.

The selection compared two MRPII solutions, one ERP software and one project management platform that enables to build custom made system on it for production management. MRPII solutions are very good to solve production problems, Eziil has more potential with project production. But the weakness for both MRP solutions was at the inability to synchronize production with project portfolio management in context of great construction projects.

The ERP solution, Microsoft Dynamics 365, was very complex and was able to solve many business managing issues. Downside of ERP implementation is the same, complexity and reduce in agility. In context of a medium sized construction element manufacturing company, flexibility, simplicity, and transparency are some of many key success factors.

Smartsheet, which main objective is agile project management, is a platform, that looks like an excel, works with formulas, but has extra features like dashboard creation and reporting. Basically, it is possible to build a simplified MRP system with shop-floor feedback ability to it. And by connecting with project sheet, synchronizes information flow between production and project schedule. The difficulty about this platform is that there is no pre-built system, everything must be created from the beginning.

To conclude, there is no ready-made solution yet on the market and there will never be, that would fit perfectly to all project-based production companies. There are many vendors worldwide, providing ERP and MRP solutions to ETO companies, but one of the two choices must be made – to adapt the business to the software or adapt the software to the business. Why not build your own solution then?

3 METHODOLOGY

At the heart of the issue is real life problem, occurring in a project-based production company. Production schedules delay, plans are weak, there is no overview of production progress and no visibility of resource utilization. Workflow is uneven, causing stress and seasonal overload. To analyse and eventually solve the problem, theoretical background was investigated. Figure 3.1 illustrates the methodological concept of the thesis. Conceptual statements explored were engineer-to-order production system, planning and management, achieving visibility in non-repetitive manufacturing environment and achieving synchronization of information flow in an organization.

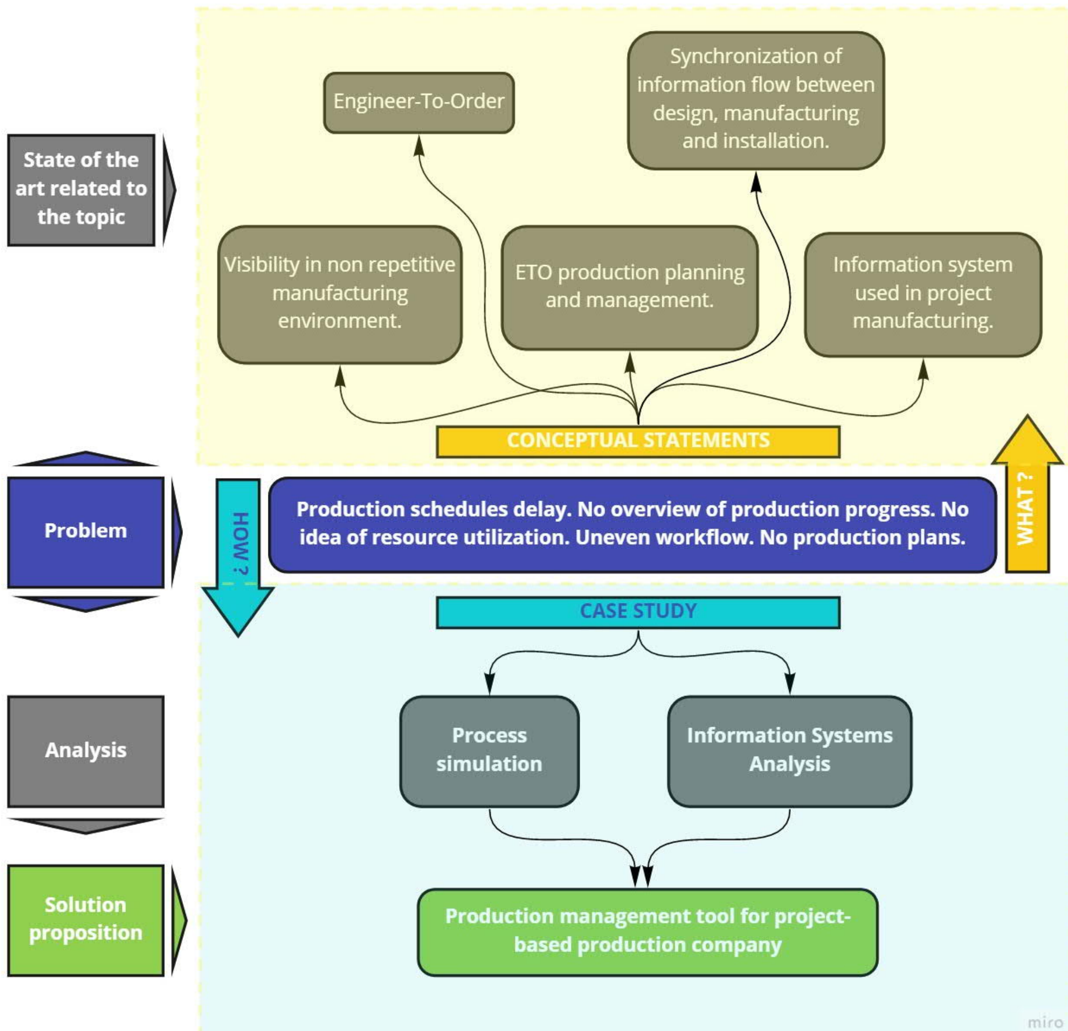


Figure 3.1 Methodological concept of the thesis.

To achieve a workable solution in context of this company, qualitative case study method was used, analysing the processes and information systems of the studied company.

Qualitative case study [29] is a research method, that helps to study a phenomenon in a specific context through various data sources. Company internal procedures are examined to understand how the context operates. The author observes the meetings and work groups to analyse the processes and conducts informal interviews (in form of e-mail and oral discussion) to ask questions regarding existing information systems from the system participants.

This thesis is an empirical analysis of project-based production in context of construction and on the example of one company. The unit of analysis in this case is production planning and control. To better understand aims of this thesis paper, author´s standing point is explained. Having been working in the case company for 2,5 years, last 1,5 years as production planner, without previous experience in manufacturing nor professional education, questions regarding planning methods and production management started to rise. Through inductive reasoning, observation and theoretical studies have led to understanding of different production systems and peculiarity of ETO production. Even though author´s subjectivity prevails, and the narrow objective is to design a smarter production management system for project-oriented company, the wider aim is to generalize research outcomes and provide ideas for other similar production businesses.

Simulation [30] is a powerful tool for business process management and operational decision making. Simulation is an imitation of a real process. Simulation promotes process analysis and detects model defects to assess their impacts on the performance of a company. Steps of simulation process are problem identification, decision variables and performance identification, simulation model construction, experiment design, running the simulation model and result evaluation.

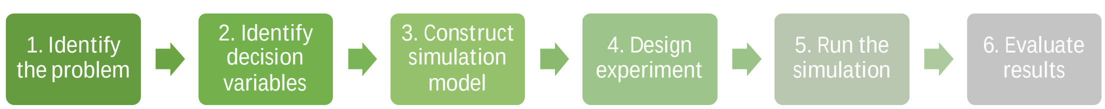


Figure 3.2 Steps of simulation process.

A simulation of as-is process model was carried out to detect the common ground of business processes and information system. Based on simulation analysis, modifications were proposed to present a to-be model of the process. Bizagi was used as simulation software. The software was selected according to its specialty. Bizagi specializes in business processes.

Systems Analysis and Design [31] is a term for describing methodologies for developing high quality Information System which combines information technology, people, and data to support business requirements. Classic systems analysis and design methodology is the waterfall model which was originally conceived for software development. The key phases of the waterfall model are the analysis and design phases, but it always includes implementation, operation, and maintenance.

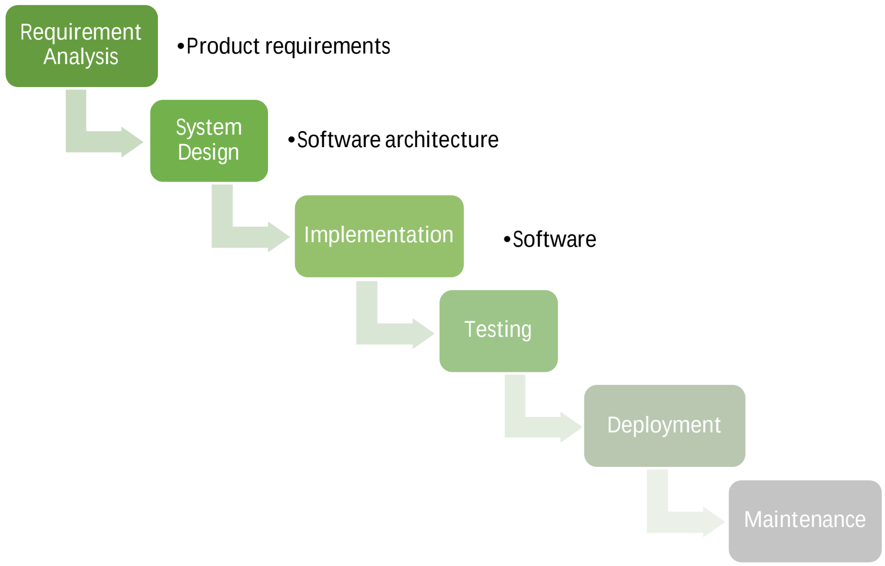


Figure 3.3 Waterfall model [32].

With this thesis the key phases of the model will be covered: system requirements analysis, system architecture and finally a demo version of possible solution will be provided. Due to time limitations, software testing, deployment, and improvements will not be described and documented within the thesis but will be carried out with future work in the company.

For ethical considerations, the name of the company under study will not be mentioned.

4 DEVELOPMENT OF A DIGITAL TOOL FOR PROJECT-BASED PRODUCTION MANAGEMENT

4.1. Presentation of the company under study

Company under study is engaged in facade elements production. It manufactures curtain walls, facade coverings, thermoprofile elements, aluminium windows and -doors. Manufacturing unit is situated in Estonia, Saaremaa. Construction projects (installation sites) are located in Finland, mostly in Helsinki.

Organisational structure is visualized on the figure below. It is a medium sized company with 85 staff and turnover 15 million euros. Company is divided into departments: sales, design, procurement, production, installation, project management and finance. The owners (marked with colour) contribute actively to company´s daily work.

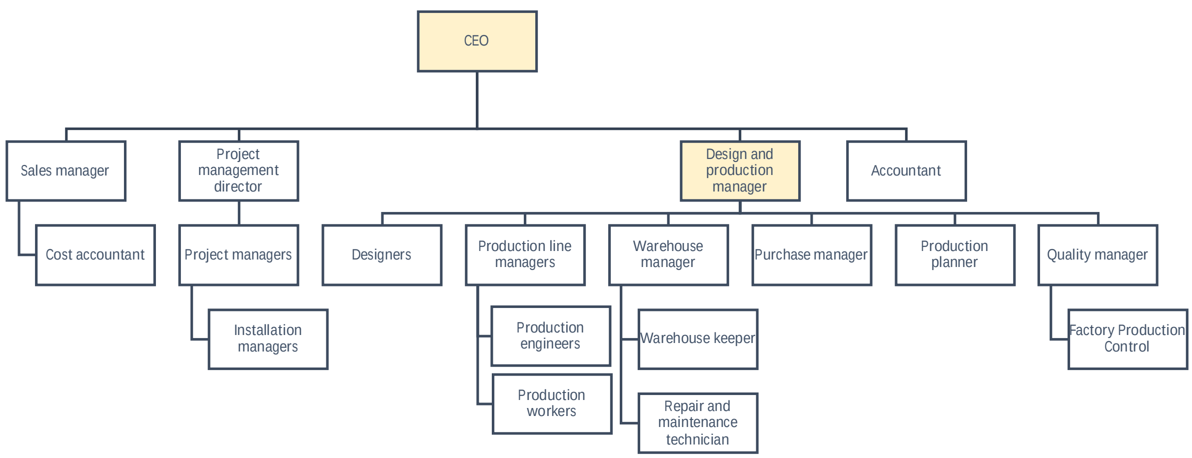


Figure 4.1 Organisational structure of company under study.

As an engineer-to-order company the process flow is project-centred. Multiple projects are in process at the same time and are all in different stages of project lifecycle.

Lifecycle of a project starts with the sales. The terms are signed in the subcontract. Then starts cooperation between designers and the architect to create a technical solution for carrying out architect´s vision. Designer team creates a model in CAD program and makes production drawings for manufacturing. Materials are ordered based on the model, for one position at the time. Typically, new projects require different materials. That is why there is no profile warehouse, and the process is very dependent on material deliveries. Key processes of a project lifecycle are shown also on figure of business process below.

When materials have arrived at the factory, production can start. Manufacturing takes place in four cells: two material processing cells and two assembly lines. The division is based on different product types and different materials.

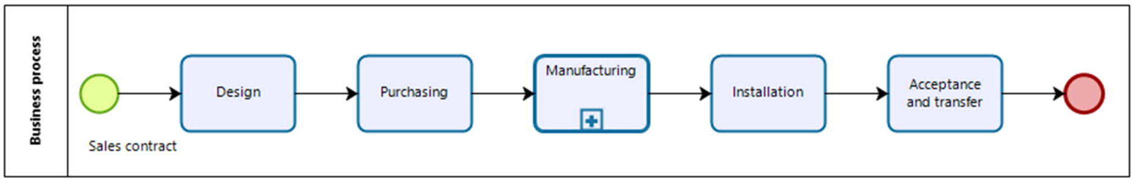


Figure 4.2 Business process.

Ready-made products are packed and delivered to construction sites, where they will be installed. After installation, acceptance process starts, and the client will be invoiced. In future, if needed, any broken element will be replaced (warranties). Due to architectural and technical solutions, it would not be very easy for another company to replace the elements.

The process is simple, and schedule is easy to follow one project at the time. When several (up to 10) projects are conducted at the same time, managing their resources and schedules gets complicated.

4.1.1 Manufacturing process.

To look closer into manufacturing phase of project lifecycle, production procedure is explained. Information system, that is supporting the procedure is explained in the next paragraphs. Manufacturing gets the input data form the project manager and the designer. Input data consists of production drawings, a list of materials to purchase and deadline for final product delivery. Next, the information lands on the table of a production engineer, who prepares it for production execution. The engineer does the optimization for materials and doublechecks whether there have been ordered enough raw materials for the product. When there is shortcoming in materials, he places an order for purchase. Engineer´s preparation is complete when a paper-printed production folder is ready to be handed over to the production line manager.

Production line manager plans production execution and confirms the production time. He orders purchased materials from the warehouse and divides work within the production team. He instructs the team and communicates deadlines and goals. After finishing production, production line manager creates a packaging list, which is uploaded to the register of ready-made products. Project manager orders the product delivery and the logistic organizes transport to the working site. Production procedure is visualized through figure 4.3, the notations are explained on below.

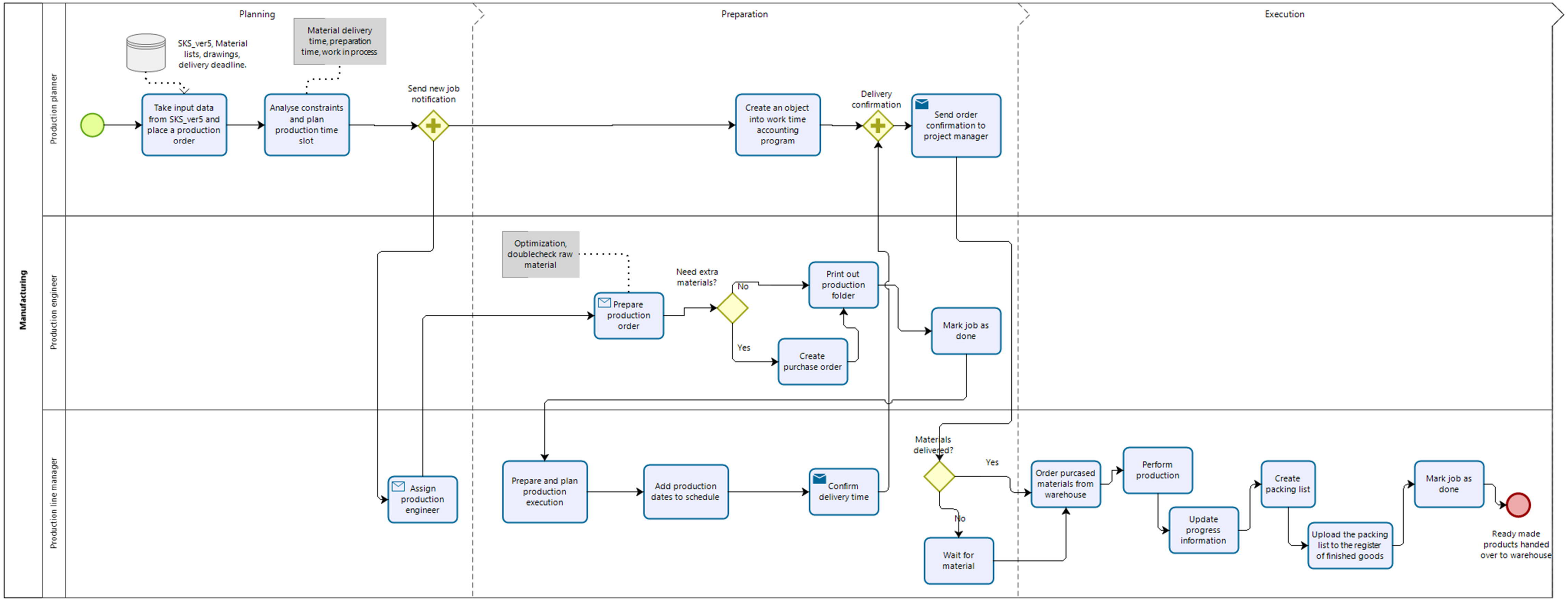


Figure 4.3 Manufacturing process.

	Start event		End event
	Parallel gateway. Several actions take place simultaneously		Gateway, a decision point that can adjust the path based on conditions
	Database	Task 1	Task/activity, performed by a person or system
	Additional information for the reader	Task 2	Receive task
	Sequence flow, showing the order of activities to be performed	Task 3	Send task

Production planner has the role of monitoring the whole process, raise questions when some data has not arrived on time and bring input data from company´s projects sheet to manufacturing worksheet. The planner coordinates delivery times with project managers, monitors factory resources and visualizes the overall production workload to spotlight moments of potential overload to prevent them. Reporting against production budget hours are also one task of the production planner.

4.1.2 Current production information system.

For project management and production management Smartsheet platform is used. As described in the chapter of solutions analysis, Smartsheet is a cloud-based enterprise platform for dynamic work. Smartsheet was taken into use about 5 years ago. Since then, the company has developed its project management and production management system. In the opinion of the author, a workable solution has not yet been reached. Therefore, the aim of this thesis work is to develop a digital management tool for the company.

When new project is sold, it is entered to the great table of the company´s projects. A project schedule is drawn up as a Gantt chart and schedules for key operations are defined. This table (see figure 4.4), named SKS_ver05, includes among other, general project information: project manager, chief designer, budgets for production and installation. It is like an excel table, but with more functionalities (collaborative usage, generation of reports and dashboards).

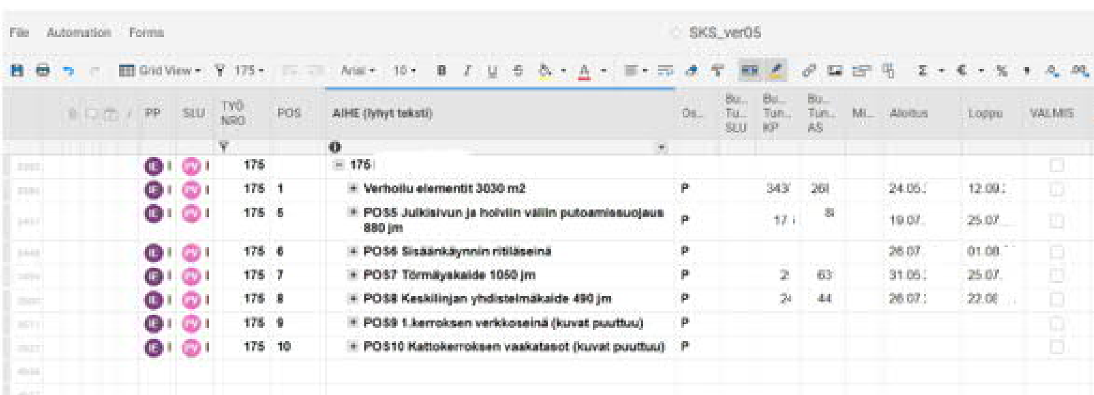
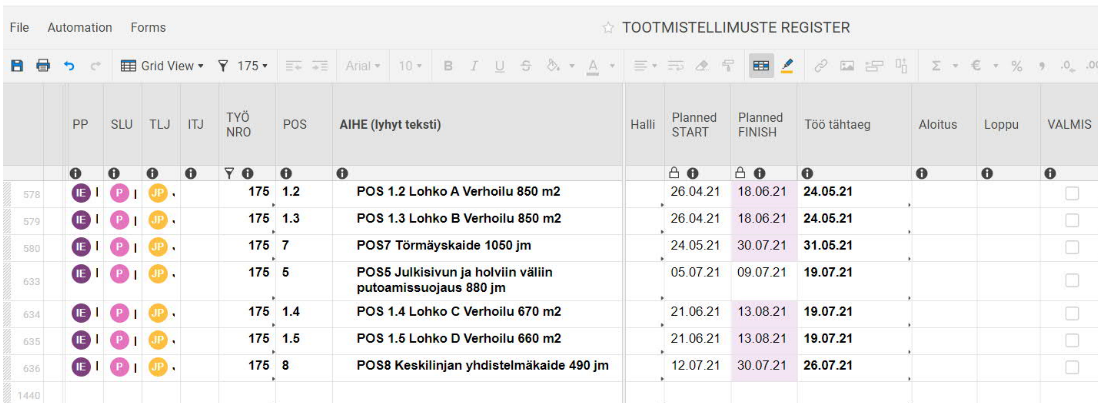


Figure 4.4 SKS_ver05.

The advantages of this table are compactness and ability to see the company´s overall projects Gantt view. Shortcomings of this table are abundance of information, complicated filling, inability to track one project, lack of standard hierarchy. Also, in history, administration of this table has been a creative group work and now in version 5, some people don´t know how it was agreed to fill. That is why, the same information is described in different ways, and it complicates data management.

Production orders get input from the main project rollout sheet (SKS_ver05). Project schedules generate a master production schedule for manufacturing. The same positions, that are described in SKS, mark orders in production schedule (Tootmistellimuste register in Estonian), see figure 4.5. There are different methods for describing the order structure. Some of the orders are described through multi-level bills of materials. Up to three levels are in use: final product, sub-assemblies, and parts. Some orders have no specified structure described at all. Production line managers use separate spreadsheets or excel tables to assign people and plan resources. Control is manual. There is very little to no visibility over production progress.


File
Automation
Forms
TOOTMISTELLIMUSTE REGISTER
Grid View
175
Arial
10

	PP	SLU	TLJ	ITJ	TYÖ NRO	POS	AIHE (lyhyt teksti)	Halli	Planned START	Planned FINISH	Töö tähtaeg	Aloitus	Loppu	VALMIS
578	IE	P	JP		175	1.2	POS 1.2 Lohko A Verhoilu 850 m2		26.04.21	18.06.21	24.05.21			
579	IE	P	JP		175	1.3	POS 1.3 Lohko B Verhoilu 850 m2		26.04.21	18.06.21	24.05.21			
580	IE	P	JP		175	7	POS7 Törmäyskaide 1050 jm		24.05.21	30.07.21	31.05.21			
633	IE	P	JP		175	5	POS5 Julkisivun ja holviin väliin putoamissuojaus 880 jm		05.07.21	09.07.21	19.07.21			
634	IE	P	JP		175	1.4	POS 1.4 Lohko C Verhoilu 670 m2		21.06.21	13.08.21	19.07.21			
635	IE	P	JP		175	1.5	POS 1.5 Lohko D Verhoilu 660 m2		21.06.21	13.08.21	19.07.21			
636	IE	P	JP		175	8	POS8 Keskilinjan yhdistelmäkaide 490 jm		12.07.21	30.07.21	26.07.21			
1440														

Figure 4.5 Production schedule.

After final assembly and packing, packaging list is made and uploaded to the register of final products. Packages are handed over to the warehouse manager, who stores them until ordered from the installation site. At least three different sheets are in use to manage one production order. All of them contain partly the same information but add some additional value to project lifecycle.

The advantage of this production orders register is general overview of all production orders in schedule, but it has several disadvantages, that hinder work and rise risk of not fulfilling client´s expectations. For production management, the general overview is too general. As Arbulu et al [9] and Hamzeh [12] have noted, production cannot be planned nor managed through project controls. Production plan needs to be taken into smaller pieces. In current table it is unable to plan machine queues or human resources. No week plans or more detailed planning could be done because of non-standard structure. It means, additional resource planning table or software is needed. Purchased materials are not associated with the parts, which makes planning of smooth production flow impossible. Deadlines are often exceeded; workers are seasonally overloaded and seasonally underloaded. Stress level is high in the whole production unit.

Table 4.1 summarizes the assessment of the system currently in use. The requirements for functionalities are presented on the left. Right side consists of keywords demonstrating the compliance against requirements.

Table 4.1 Current system analysis

Functionality requirements	Compliance of the current system
Constraint analysis	Production drawings and material lists existence is controlled manually via SKS_ver5. Material deliveries are monitored within current production orders register.
Resource management function	Human resource analysis is carried out based on mathematical calculations of production budget hours. Not associated with the nature of work or measured production times.
Monitor whole process	Poor overview of process progress, manual coordination.
Create production schedule	Possible, but inconsistent due to undefined structure.
Connection with project schedule	Manual cell linking.
Ability to prioritize	Poor.
Purchase order´s connection to production order	Connected. Errors occur when materials are ordered to many production orders at the same time.
Machine queueing	Not monitored.
Live shop-floor progress reporting	Not possible.

The development of the production management system has worked on a trial-and-error method so far, learning to use the Smartsheet platform and trying to seize the opportunities of it. Next step is to finalize the system and document it for future use and development.

A workable system should help the participants to execute their tasks and simplify decision making on setting the priorities. Due to many shortcomings in the current information system, the whole process takes more time than should. To illustrate the situation, simulation analysis is made. The full report is presented in appendix 1. Simulation variables are presented in the table below. Simulation model was presented on figure 4.3.

Table 4.2 presents process variables set for the simulation. The first column refers to the activity in process. Resource is defined by the position performer: production planner, production engineer or production line manager. Time presents the processing time it actually takes to complete the job. The time values are experiential. The company has also recently started to measure process times, which will give precise data for future analysis.

Table 4.2 Simulation variables.

Nr	Activity	Resource	Time (h)	Type
1	New production order			Start event
2	Take input data from SKS_ver5 and place a production order	Production planner	1	Task
3	Analyze constraints and plan production time slot	Production planner	1	Task
4	Send new job notification			Gateway
5	Assign production engineer	Production line manager	0,2	Task
6	Create an object into work time accounting program	Production planner	0,1	Task
7	Prepare production order	Production engineer	40	Task
8	Need extra materials?			Gateway
9	Create purchase order	Production engineer	2	Task
10	Print out production folder	Production engineer	2	Task
11	Create WBS to production schedule	Production engineer	2	Task
12	Mark job as done	Production engineer	0,1	Task
13	Prepare and plan production execution	Production line manager	3	Task
14	Add production dates to schedule	Production line manager	1	Task
15	Confirm delivery time	Production line manager	0,5	Task
16	Delivery confirmation			Gateway
17	Send order confirmation to project manager	Production planner	0,5	Task
18	Materials delivered?			Gateway
19	Wait for material	Production line manager	0	Task
20	Order purchased materials from warehouse	Production line manager	0,5	Task
21	Perform production	Production line manager	80	Task
22	Update progress information	Production line manager	1	Task
23	Create packing list	Production line manager	2	Task
24	Upload the packing list to the register of finished goods	Production line manager	0,5	Task
25	Mark job as done	Production line manager	0,5	Task
26	Ready-made products handed over to warehouse			End event

Simulation scenario lasted for 120 days. Maximum number of times to create arrivals (new production orders) was 30 and the time interval between arrivals was 2 days.

As-is process average total time is 50 days. This means, a production order fulfilment takes 50 days from the start to the very end. Most of the time goes for production execution and the activities regarding progress reporting. The shortest tasks are new production order creation and order confirmation sending. Figure 4.2 shows time spent on different activities.

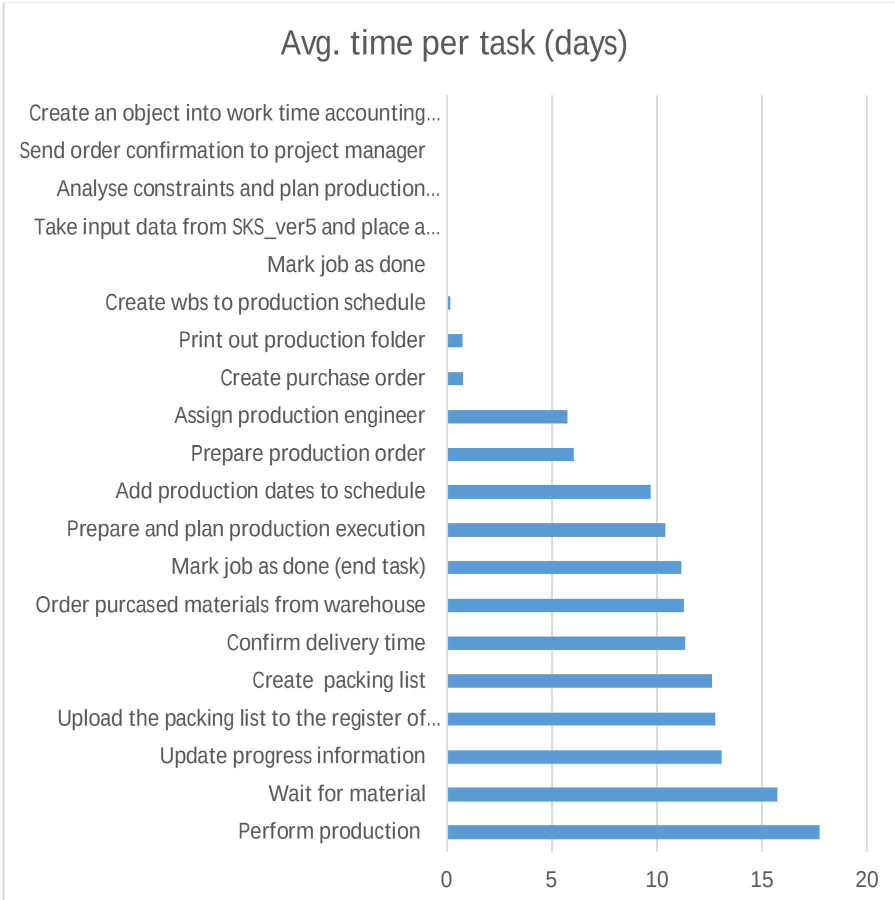


Figure 4.6 Average time per tasks (in days)

The biggest stress for production process execution is on production line manager 94,74%. Production engineer´s utilization is 43,36%, and production planner´s utilization for production process execution is 2,6%.

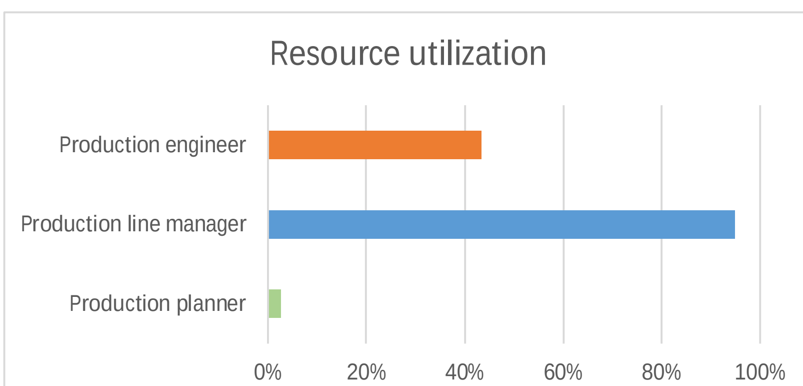


Figure 4.7 Resource utilization.

In context of value creation to the customer, there are only 17,7 days valuable time, which makes 35,4% from average total. Valuable time is the time spent on production activities (perform production). The aim of the improved production information system should be minimizing of non-value adding time in the process. How it will be achieved, is explained in the following subsections.

4.2. Requirements´ specification

System is a group of related operations that are made for a common goal [33]. Every part of the system gets input from the previous part of the system and gives output to the next participant of the system. Therefore, we need to define prerequisites for each system participant. The question is, what information is vital for the operation needed to be done and what information is vital for the next system participant to perform their task? Information to define the assumptions has been gathered through 2 years of practical work and observations in the company and it is presented in the order in which the need arises (production order life cycle), see table 4.3. So, who are the system participants (processors), what input they need and what is their contribution to the system (input->process->output)?

Table 4.3 Process inputs and outputs.

INPUT	PROCESS	OUTPUT
• Contractual requirements	Project management	• Project Work Breakdown Structure (WBS) • project schedule
• Contractual requirements • Architect´s vision • Schedule • WBS	Design	• Production drawings • Material lists for purchasing
• Material lists	Purchasing	• Material delivery time • Order confirmation
• Project WBS • Schedule • Production drawings • Material lists • Material delivery times	Production planning	• Production order • Production schedule • Production lookahead plan
• Production order • Production schedule	Production engineering	• Production WBS • Material optimization, cut lists, machining files, • Additional material orders (if needed) • Paper printed production file
• Prepared production order • Production schedule	Production	• Detailed production execution planning (action dates and performers) • Packing list
• Material lists • Material delivery times • Product packing lists	Warehouse/logistics	• Confirmed material arrivals, • Organized product transportation

Process inputs and outputs form the general requirements of the system. General requirements, meaning the fields of information to be filled, the information that is vital to the organization to function.

Technical requirements are overarching requirements on technical aspects like the platform on which the solution will operate [33]. On this use case the requirements were ease of use (familiar to the company), cloud based, and connectivity between project and production management.

Functional requirements define what a proposed solution is expected to do [33]. Hereby, a list of functional requirements is presented:

1. The system shall identify when an action is overdue and send out reminder to the assigned worker,
2. The system shall have a report function to present the order of priorities and create individual to-do lists,
3. The system shall have a Gantt view function to visualize schedules,
4. Critical path function for prioritization and resource allocation,
5. The system shall measure the time spent on a subprocesses for identifying bottlenecks and increasing process productivity,
6. Assign function for resource management,
7. Visualizing functions like check box or % complete,
8. Approval workflow function, for identifying in which stage a production order currently is.

Non-functional requirements define how the solution should operate [33]. General non-functional requirements would be reliability, security, flexibility, accessibility, and user-friendliness. Security in context of sensitive business information is one main aspect when choosing a platform or service provider. Smartsheet uses encryption to safeguard user´s data.

On the example of this use case, the non-functional requirements can also be defined as personal settings on Smartsheet platform. For example, auto-save settings, communication and notification preferences, time, and date formats. Every 1 minute, the system automatically saves all changes. Time and date formats are associated with the user region. In Estonia European date format EDATEw is used (dd.mm.yyyy). Communication and notification settings can be set by every user individually. All users can define, whether they like to get e-mails and notifications to their e-mail address or only to the Smartsheet platform (bell sign with numbers of notifications on it). Smartsheet uses encryption to safeguard user´s data. Those general non-functional requirements are provided by or pre-defined by the platform provider.

System requirements (functional and non-functional as well as product design characteristics) set the objectives for system design, see figure 5.2.

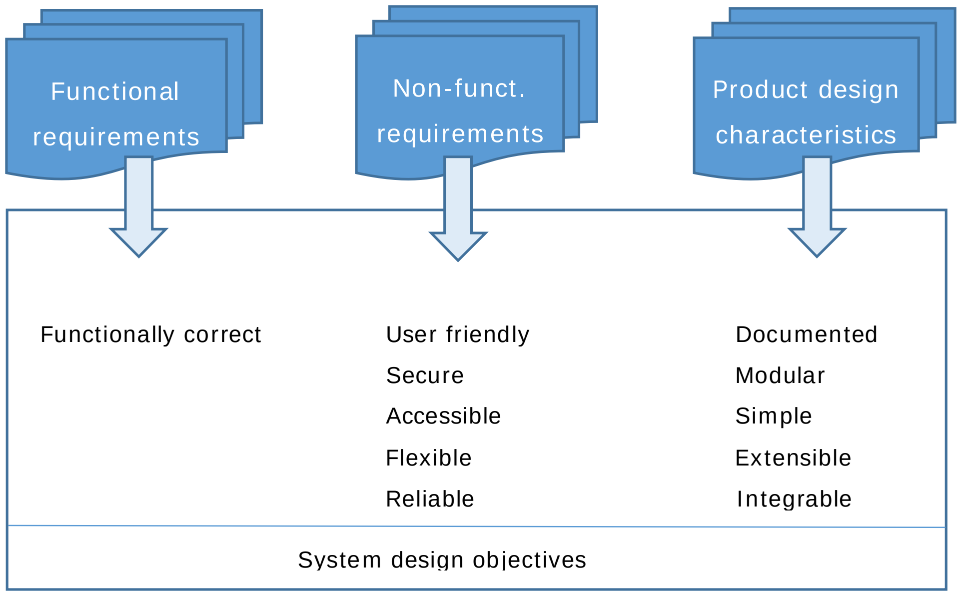


Figure 4.8 System design objectives.

System architecture and product design characteristics will be addressed in the next chapter.

4.3. System architecture

Description of system architecture is built up on a hierarchical structure, from general to individual, representing levels of management (planning) activities. General system architecture is presented on figure 4.9.

The heart of the system is the project blueprint sheet, which is the one source of truth about project progress. Project blueprint consists of work breakdown structure (positions), position budgets, project schedule, which is defined by installation deadlines and manufacturing and design schedules (using reverse planning method). Project blueprint has also project manager, chief designer, project ID and other general information in it.

Project sheets generate the project portfolio report, which is basically the CEO´s view to all projects in the company. Project portfolio gives a health overview to all projects, budget statuses and progress statuses. It is the general guidance for company resource allocation.

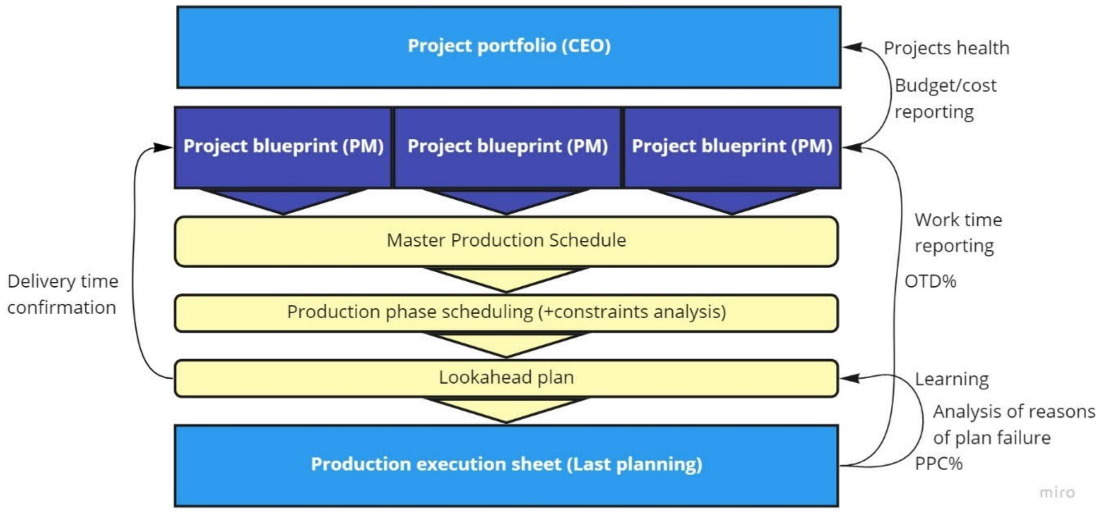


Figure 4.9 General system architecture.

Projects schedules generate the report of master production schedule. Master production schedule has contract deadlines, which exceeding may bring a contractual penalty. Phase scheduling, consisting of constraints analysis helps to bring attention to the right things on right time. The purpose of phase scheduling is prioritizing. Lookahead plan, with the scope of 2-6 weeks is to break down tasks and plan operations. The last planning is done before final production execution, where plant workers are assigned, and exact production dates are stated. The last planning enables to generate work orders (to-do lists in form of a report) for production workers weekly work plans.

Due to the mechanisms of operation of the platform, the key is the structure of project sheet. That is because sheet linking is done via row sending or copying. For that the columns on sheets (fields) must be identical. Receiving sheet can have its own additional columns. Smartsheet identifies the matching fields and places the row to the very end of receiving table. With this functionality, production orders can be submitted in order of priority. On figure 4.10 functional structure of production execution sheet is presented.

The function of production process management is to achieve real-time monitoring of production progress. Enabling production staff feedback online keeps production order information up to date and makes it independent of the production line manager. It also provides quick feedback to weekly production schedules.

Resource management incudes human and machine resources. Resources´ planning is the activity of connecting people and machinery to production orders and scheduling their tasks by dates.

Order management is the drive of factory´s all production activities. Order management includes order import, decomposition (work breakdown structure) and description of parameters. Order management creates the interface for the actual function module-production workers task list.

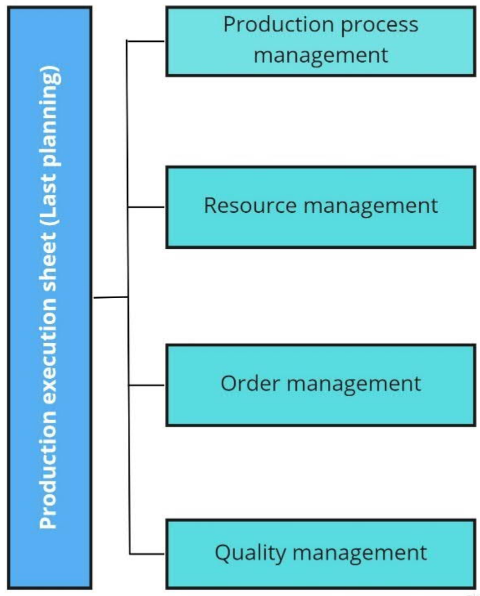


Figure 4.10 Functions of production execution sheet.

The function of quality management is to save quality control feedback – quality grades and date of quality check. Quality faults and solutions are analysed periodically by Factory Production Control to further increase product quality.

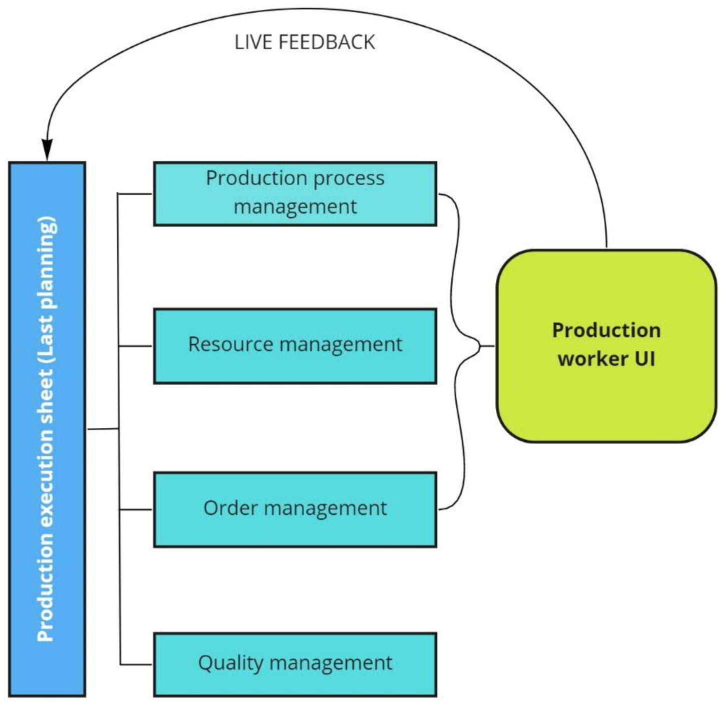


Figure 4.11 Production workers´ User Interface creation

Production execution sheet functions generate the input for plant workers´ user interface, see figure 4.11. The last level in the production order hierarchy is displayed here. Regarding Smartsheet platform, the user interface is created as a report from production execution sheet. The report filters out tasks (rows) for the exact machine or worker, that are planned to be executed in pre-defined time slot (a week for example). For better overview, screenshots of improved information system are displayed.

Firstly, the project sheet. Project sheet (schedule) is the centre of project data. It is where all project team members are defined, work breakdown structure and schedule are defined. Additional columns are created for smooth system operation. Department, as the name of the column says, defines the department, on who´s responsibility is the execution of the task. The most important information is raised to the left side of the page, and less critical information is presented at the end of the page and process measuring columns are completely hidden (these work in the background). When project work breakdown structure is created, the team members can start adding their input (drawings, material lists, material delivery information) to the project.

As material delivery time is critical information on terms of scheduling, material orders are presented each order on a separate line (under the correct position) and each order gets its own delivery date. Material orders are assigned to purchase department, enabling filtering them by setting needed conditions.

Based on predefined schedule and actual time when tasks are completed, project performance measures can be calculated, like On Time Delivery percentage (OTD%). OTD shows the percentage of tasks, that have been delivered on time or earlier. For that calculation additional columns are created to save dates for marking job as done and for calculating days between planned and actual finish dates (logic: a date is saved when Done check box is ticked; calculate days from actual finish date to planned finish date).

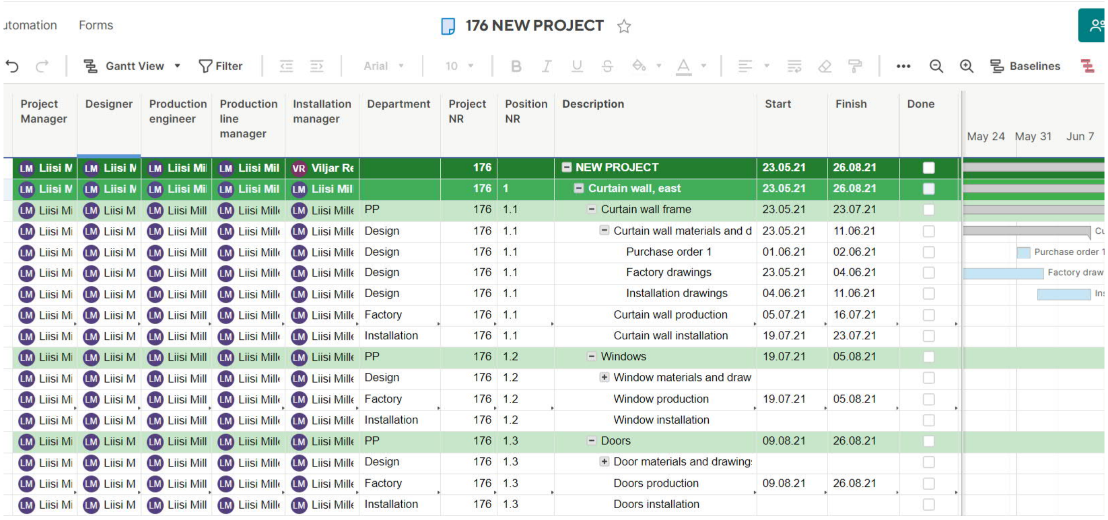


Figure 4.12 Project blueprint

When a new project sheet is generated, it can be added to the report of project portfolio. Project portfolio takes the main row from project sheet and displays only the most general information from the project: name, project manager, project designer, budget, scope, start, finish and %complete.

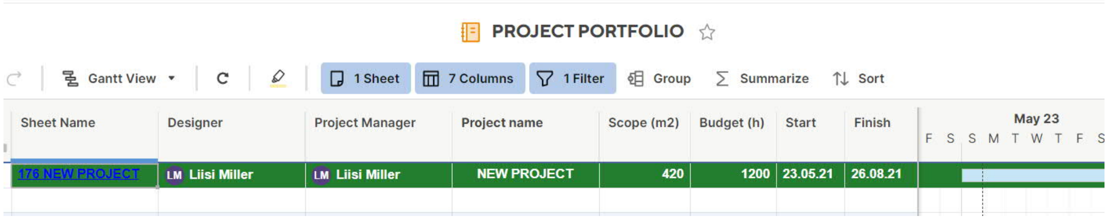
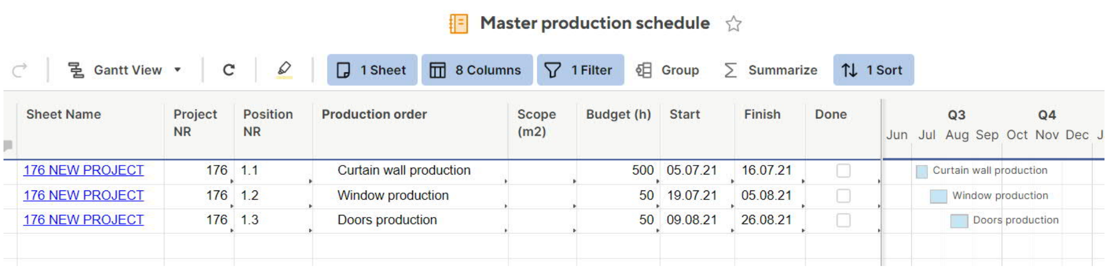


Figure 4.13 Project portfolio

Project portfolio is a CEO´s view of company´s projects. It is the bigger picture on projects health and progress, their schedule, and remaining budgets. The Gantt view of project portfolio visualizes company´s workload and the available time slot for a new project.

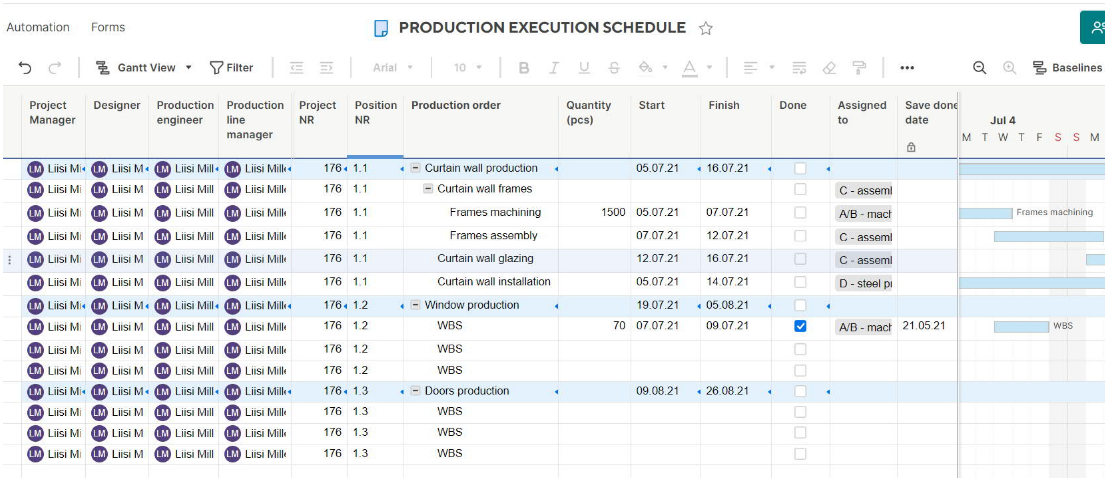
Master production schedule is also a report-based sheet, which is generated from project sheets. It is formed by filtering out only factory rows in the order of starting time. The goal for this type of schedule is to analyse factory overall resources in longer perspective and give guidance regarding priorities. In a situation of overload, the values of the cells can be changed from this view and the changes will reflect directly on projects sheets. The same type of master schedules could be created for all departments.



Sheet Name	Project NR	Position NR	Production order	Scope (m2)	Budget (h)	Start	Finish	Done
176 NEW PROJECT	176	1.1	Curtain wall production		500	05.07.21	16.07.21	☐
176 NEW PROJECT	176	1.2	Window production		50	19.07.21	05.08.21	☐
176 NEW PROJECT	176	1.3	Doors production		50	09.08.21	26.08.21	☐

Figure 4.14 Master production schedule

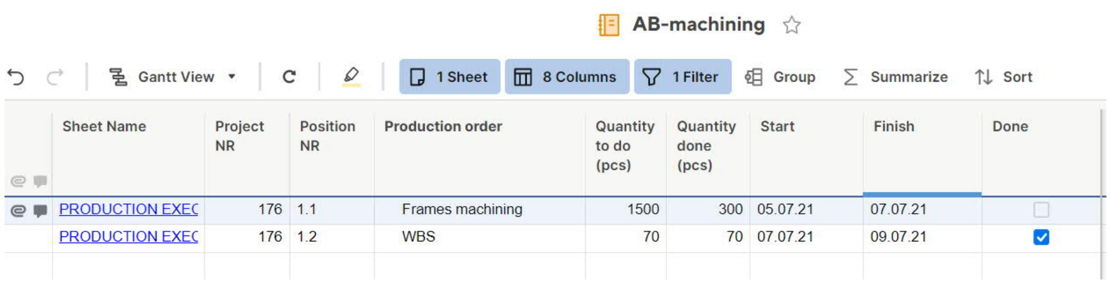
Production execution schedule is a tool for production line managers to do the fine planning. Work breakdown of every production order enables to connect workers by names or workstations to the exact task. In this example (figure 4.15), the task frames machining is connected to the workstation AB-machining.



Project Manager	Designer	Production engineer	Production line manager	Project NR	Position NR	Production order	Quantity (pcs)	Start	Finish	Done	Assigned to	Save done date
Liisi Mi	Liisi M	Liisi Mill	Liisi Mill	176	1.1	Curtain wall production		05.07.21	16.07.21	☐		
Liisi Mi	Liisi M	Liisi Mill	Liisi Mill	176	1.1	Curtain wall frames				☐	C - asseml	
Liisi Mi	Liisi M	Liisi Mill	Liisi Mill	176	1.1	Frames machining	1500	05.07.21	07.07.21	☐	A/B - mach	
Liisi Mi	Liisi M	Liisi Mill	Liisi Mill	176	1.1	Frames assembly		07.07.21	12.07.21	☐	C - asseml	
Liisi Mi	Liisi M	Liisi Mill	Liisi Mill	176	1.1	Curtain wall glazing		12.07.21	16.07.21	☐	C - asseml	
Liisi Mi	Liisi M	Liisi Mill	Liisi Mill	176	1.1	Curtain wall installation		05.07.21	14.07.21	☐	D - steel pı	
Liisi Mi	Liisi M	Liisi Mill	Liisi Mill	176	1.2	Window production		19.07.21	05.08.21	☐		
Liisi Mi	Liisi M	Liisi Mill	Liisi Mill	176	1.2	WBS	70	07.07.21	09.07.21	☑	A/B - mach	21.05.21
Liisi Mi	Liisi M	Liisi Mill	Liisi Mill	176	1.2	WBS				☐		
Liisi Mi	Liisi M	Liisi Mill	Liisi Mill	176	1.2	WBS				☐		
Liisi Mi	Liisi M	Liisi Mill	Liisi Mill	176	1.3	Doors production		09.08.21	26.08.21	☐		
Liisi Mi	Liisi M	Liisi Mill	Liisi Mill	176	1.3	WBS				☐		
Liisi Mi	Liisi M	Liisi Mill	Liisi Mill	176	1.3	WBS				☐		
Liisi Mi	Liisi M	Liisi Mill	Liisi Mill	176	1.3	WBS				☐		

Figure 4.15 Production execution schedule

When the tasks are assigned, another report-based worksheet is created – a workstation task list. As an example, AB-machining task list is presented. This report filters out tasks assigned only for AB-machining station. The worker sees his tasks sorted ascendingly by starting time. He will open documents from the attachment, does the work and when finished, checks the box "Done". Checked box will appear also in production execution sheet, letting know, when the worker has finished the job. If the work is in progress, the employee can report the number of pieces made (Quantity done), letting know the state of work progress.



AB-machining

Gantt View | 1 Sheet | 8 Columns | 1 Filter | Group | Summarize | Sort

Sheet Name	Project NR	Position NR	Production order	Quantity to do (pcs)	Quantity done (pcs)	Start	Finish	Done
PRODUCTION EXEC	176	1.1	Frames machining	1500	300	05.07.21	07.07.21	☐
PRODUCTION EXEC	176	1.2	WBS	70	70	07.07.21	09.07.21	☑

Figure 4.16 AB-machining task list

By enabling our employees to confirm themselves their completed tasks, we take some of the burden off production line managers´ shoulders. At the same time, we increase production workers motivation to complete their task on time. A list of tasks to do will have a psychological effect. When not having a list, we tend to use longer time doing the work, because it is harder to go and ask for new job. Another psychological effect is the sense of well-being from the completed task. When the list is empty by the end of the week, we know we did everything that we were expected to do.

Implementation of improved system will also make an impact on the production process flow. What changes? Production line manager will no longer assign production engineer because the engineer is pre-defined by the planner and based on the task list (schedule) of the engineer. Progress reporting is done by the production workers and production line manager must only confirm the whole order completion. To-be process simulation was carried out to analyse the changes. To-be process map is presented in appendix 3. Other process variables are left unchanged.

The results of the simulation reveal, that the average total order throughput time is decreased 5 days, from 50d to 45d. The time spent on non-value adding tasks is reduced 8,71% and the number of completed production orders increased by 2. It means, that the process is creating more value in the same time unit.

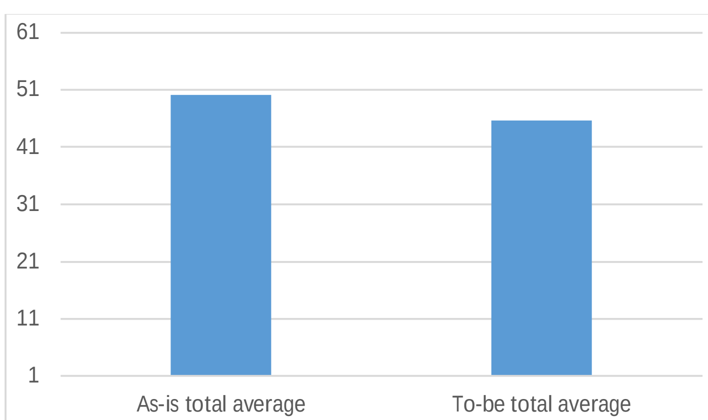


Figure 4.17 Average throughput time.

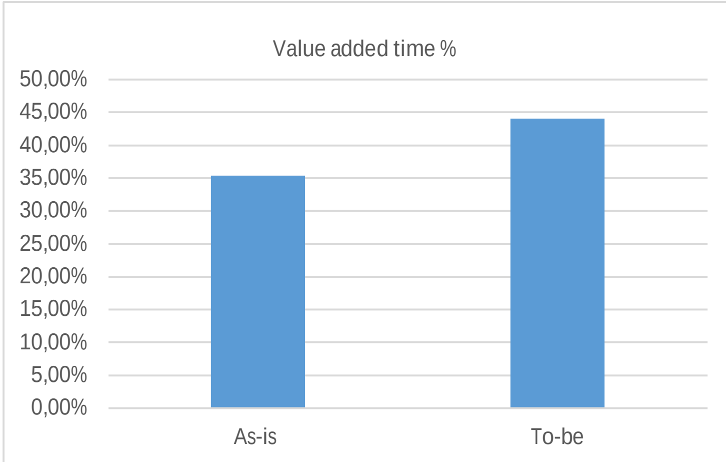


Figure 4.18 Value added time %

To conclude system design and architecture, the changes compared to the existing system and impact on the work culture of the organization are:

1. The whole system structure is changed from one general sheet to hierarchical structure, where different sheets focus on displaying specific information.
2. The sheets are linked to each other, which provides immediate information in the event of changes.
3. Manual work of copying data from one sheet to the other is reduced. It´s achieved by automated workflow function with the ability to copying rows when an event occurs.
4. Information presentation structure within a sheet is defined by hierarchy.
5. Live overview of production progress. Sheet hierarchy creates possibility to generate workstation weekly schedule, where the production worker himself marks jobs done when his´ finished.
6. Employee motivation will be increased.
7. There have been created readiness for integration with work time accounting programme (Begin). In Smartsheet it is an extra feature (Data Uploader) with additional cost, which requires extra investment from the company.
8. Visual appearance of the system has improved. The use of colours makes it easier to differentiate between orders.
9. An improved system is potentially decreasing time spent on non-value adding tasks by 8,71% and total average order throughput time by 9%.

As an additional value, the improved system decreases the time spent on decision making on priorities. Master schedule gives the opportunity to set a live list of priorities. And another value added with the system is a stress-free work environment, which is achieved by awareness of workload, common goals, and deadlines.

4.4. Implementation and further suggestions

Due to time limitations on thesis presentation, paragraph of implementation of the changed system is hypothetical.

Every change in an organization with many collaborators requires documentation and training. Documentation acts like a collective memory, identifying the last agreed version of system performance. It comes in handy when process improvements need to be done or new colleagues are taught. In short words, one must have a document on which the organization´s activities are based, and future necessary changes are identified. This document could be called an information system manual and it consists of activities and indicators that all participants in the system must follow and consider while doing their part.

Information system manual is the basis of implementation trainings (and new colleague trainings). Training is necessary for collective understanding, what is written in the handbook. Reading individually is not effective enough because of one´s background and previous experience. Individuals perceive text and context differently. Trainings could take place in groups of collaborators, where the most stress is put on the precise task, they are supposed to perform. For example, training for designers – how to fill in their boxes. Or training for production line managers – what and how should they fill in their part. There is no fully automatic production management system or enterprise management system. The system is as good as how well the system users perform the system and how consistently they work in the system.

The author suggests the company to set a coded system for document names. Currently, production drawings and material lists are named almost randomly. Every designer has his own script for naming the files. Faceted codes are recommended to relate projects and positions with their drawings and material lists. The reason system designers use faceted codes is because they are intrinsically meaningful to users of the code [33]. Coding enables to create a related database of project and it´s documentation. On the example on this use case, uniform codes would keep the project sheet clear and visually easy to follow.

For further improvement, the author suggests cooperation with Estonian IT developers, for example Eziil (new BOM software development), which could reduce non-value adding activities by providing even better integration between design and manufacturing.

SUMMARY

The aim of this master's thesis was to develop a digital production planning and management tool for a company producing facade elements, which would enable real-time production progress to be monitored in a complex system such as project-based production, and integration with the project schedule. Project-based production is complicated because of the product that is made and the fact that these products are different for each new project. Production planning software itself is no longer a novel idea. Manufacturing software solutions have their roots in the 1960s. However, the bottleneck, which prevents the integration of the real-time production overview with the project schedule, has not been satisfactorily solved so far.

The main methods for solving a similar situation are manual management, project planning in classical production software, project module of ERP systems or project management software integrated into a classical ERP system. The main bottlenecks in existing systems are the excessive complexity for small or medium-sized enterprises or the precondition that the use of a standard BOM is required.

On the example of the company studied in the master's thesis, the task was solved by changing the structure of the existing system. This avoids the time and efficiency loss associated with implementing new software. The Smartsheet platform, which is already in use, makes it possible to achieve the desired goals to a large extent. The next step in the company's development ladder could be to create your own software.

According to the author, the goals set in the master's thesis have found a good solution, laying a solid foundation for creating the company's production planning principles. Time constraints are those that always create obstacles to achieving the desired thoroughness, so the implementation of the created system is beyond the scope of the master's thesis.

Further work will continue with the implementation of the system in this company. Before implementing the system, it is important to document all development work in detail and prepare instructional material. Then the whole team is trained. Further development work in the advanced system is necessary for the integration of warehouse. Due to time constraints, the master's thesis has not sufficiently solved the purchase-warehouse-production workflow, which is also very important for the smooth organization of production. However, the hierarchical structure of the created system allows it to be extended for project warehouse integration.

KOKKUVÕTE

Käesoleva magistritöö eesmärgiks oli arendada fassaadielemente tootvale ettevõttele digitaalne tootmise planeerimise ja juhtimise tööriist, mis võimaldaks keerukas süsteemis nagu projektipõhine tootmine jälgida tootmise reaalajas edenemist ning samas oleks integreeritud projekti graafikuga. Projektipõhise tootmise muudab keerukaks just toode, mida valmistatakse, ja fakt, et need tooted on iga uue projekti puhul erinevad. Tootmise planeerimise tarkvara iseenesest ei ole enam uudne idee. Tootmist abistavate tarkvaralahenduste juured ulatuvad juba 1960sse aastatesse. Küll aga ei ole seni rahuldavalt lahendatud kitsaskohta, mis takistab tootmise reaalülevaate integreerimist projekti graafikuga.

Peamised meetodid sarnase olukorra lahendamiseks on manuaalne juhtimine, projekti planeerimine klassikalises tootmistarkvaras, ERP süsteemide projekti mooduli kasutamine või ERP süsteemile integreeritud projektijuhtimise tarkvara kasutamine. Peamised kitsaskohad olemasolevate süsteemide puhul on liigne keerukus väikese ja keskmise suurusega ettevõtete jaoks või eeltingimus, mis sätestab standardse materjaliandmiku kasutamise.

Magistritöös uuritud ettevõtte näitel lahendati ülesanne olemasoleva süsteemi ülesehituse muutmise teel. Selliselt hoitakse ära uue tarkvara juurutamisega kaasnev ajaline kulu ja efektiivsuse langus. Juba kasutusel olev platvorm Smartsheet võimaldab soovitud eesmärgid suurel määral saavutada. Järgmine samm ettevõtte arenguredelil võiks olla juba oma tarkvara loomine.

Autori hinnangul on magistritööga seatud eesmärgid leidnud hea lahenduse, pannes tugeva aluse ettevõtte tootmise planeerimise põhimõtete loomiseks. Ajalised piirangud on need, mis seavad alati takistusi soovitud põhjalikkuse saavutamisel, mistõttu loodud süsteemi rakendamine jääb magistritöö piiridest välja.

Edasine töö jätkub magistritöö näite aluseks olevas ettevõttes loodud süsteemi ellu viimisega. Enne süsteemi rakendamist on oluline kogu arendustöö detailne dokumenteerimine ja juhendmaterjali koostamine. Seejärel toimub kogu kollektiivi koolitamine. Edasine arendustöö loodud süsteemis on vajalik laomajanduse integreerimiseks. Magistritööga ei ole ajalise piiritletusse tõttu piisaval määral lahendatud ost-ladu-tootmine töövoogu, mis sujuvaks tootmise korraldamiseks on samuti väga oluline. Küll aga võimaldab loodud süsteemi hierarhiline struktuur selle laiendamist ka lao integreerimiseks.

LIST OF REFERENCES

[1] "Industry 4.0: fourth industrial revolution guide to Industrie 4.0." https://www.i-scoop.eu/industry-4-0/ (accessed May 22, 2021).

[2] P. Rondeau and L. A. Litteral, "The evolution of manufacturing planning and control systems: From reorder point to enterprise resource planning.," 2001. Accessed: May 22, 2021. [Online]. Available: http://digitalcommons.butler.edu/cob_papers/41.

[3] A. C. Pacagnella, S. L. da Silva, O. Pacífico, P. S. de Arruda Ignacio, and A. L. da Silva, "Critical Success Factors for Project Manufacturing Environments," Project Management Journal, vol. 50, no. 2, pp. 243–258, Apr. 2019, doi: 10.1177/8756972819827670.

[4] C. Langhoff, "Understanding Project Based Production through Socio-technical Modularity," APA, Paper presented at The Academy of Management 2012 Annual Meeting, Boston, MA, United States., 2012.

[5] P. E. Eriksson, "Improving construction supply chain collaboration and performance: A lean construction pilot project," Supply Chain Management, vol. 15, no. 5, pp. 394–403, 2010, doi: 10.1108/13598541011068323.

[6] A. Rahman Abdul Rahim and M. Shariff Nabi Baksh, "The need for a new product development framework for engineer-to-order products," European Journal of Innovation Management, vol. 6, no. 3, pp. 182–196, Sep. 2003, doi: 10.1108/14601060310486253.

[7] T. R. Cutler, "Engineer-to-Order Manufacturers Find Little Global Competition," World Trade, pp. 62–67, 2006.

[8] M. El-Mehalawi, "Scheduling and Controls of Project Manufacturing." Accessed: Feb. 21, 2021. [Online]. Available: https://www.fgould.com/media/resources/files/Project%20Manufacturing%20-%20Full%20Paper.pdf.

[9] R. J. Arbulu, M. Eng, H. J. J. Choo, and M. Williams, "Contrasting Project Production Control with Project Controls," 2016. Accessed: Feb. 21, 2021. [Online]. Available: https://projectproduction.org/wp-content/uploads/2017/11/Contrasting-Project-Production-Control-With-Project-Controls.pdf.

[10] Erwin Rauch, Patrick Dallasega, and Dominik T. Matt, "Synchronization of Engineering, Manufacturing, and on-site Installation in Lean ETO-Enterprises," in Procedia CIRP 37, 2015, pp. 128–133, Accessed: Apr. 21, 2021. [Online]. Available: https://reader.elsevier.com/reader/sd/pii/S2212827115009002?token=5C6FC8C1AB2B7502DB18F3C5581635315F0457D719AA1A9CE5E4B8F6C1DC3F9B9BACB52C5C7B640804A1666A1FD1596C&originRegion=eu-west-1&originCreation=20210421074723.

[11] F. Robert Jacobs and F. C. "Ted" Weston, "Enterprise resource planning (ERP)-A brief history," Journal of Operations Management, vol. 25, no. 2, pp. 357–363, Mar. 2007, doi: 10.1016/j.jom.2006.11.005.

[12] Jorge Minguez, Sema Zor, and Peter Reimann, "Event-driven Business Process Management in Engineer-to-Order Supply Chains," in 15th International Conference on Computer Supported Cooperative Work in Design, 2011, pp. 624–631, Accessed: Apr. 21, 2021. [Online]. Available: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5960183.

[13] C. G. Cobb, Making Sense of Agile Project Management: Balancing Control and Agility. John Wiley & Sons, Incorporated, 2011.

[14] Z. Vuksanović-Macura, M. Gvozdic, and V. Macura, "Continuous Planning: Innovations from Practice in Stavanger (Norway) and Belgrade (Serbia)," Planning Theory and Practice, vol. 21, no. 5, pp. 727–747, 2020, doi: 10.1080/14649357.2020.1849776.

[15] T. Suomalainen, "Defining continuous planning through a multiple-case study," in Springer International Publishing Switzerland, 2015, vol. 9459, pp. 288–294, doi: 10.1007/978-3-319-26844-6_21.

[16] A. Tenhiälä, "Solutions for project-based manufacturing [004-0136] Research agenda." Accessed: Feb. 21, 2021. [Online]. Available: https://www.pomsmeetings.org/confpapers/004/004-0136.pdf.

[17] J. Gosling, D. R. Towill, M. M. Naim, and A. R. J. Dainty, "Principles for the design and operation of engineer-to-order supply chains in the construction sector," Production Planning and Control, vol. 26, no. 3, pp. 203–218, Feb. 2015, doi: 10.1080/09537287.2014.880816.

[18] John X. Wang, Lean Manufacturing: Business Bottom-Line Based. Taylor & Francis Group, 2010.

[19] “Lean Construction defined,” Lean Construction Institute. https://www.leanconstruction.org/uploads/wp/2016/02/TDC-CH04.pdf (accessed May 13, 2021).

[20] Hamzeh Farook and Bergstrom Erik, “The Lean Transformation: A Framework for Successful Implementation of the Last Planner TM System in Construction,” 2010. https://www.researchgate.net/publication/242112169_The_Lean_Transformation_A_Framework_for_Successful_Implementation_of_the_Last_Planner_TM_System_in_Construction (accessed May 10, 2021).

[21] A. M. Perez and S. Ghosh, “Barriers faced by new-adopter of Last Planner System®: a case study,” Engineering, Construction and Architectural Management, vol. 25, no. 9, pp. 1110–1126, 2018, doi: 10.1108/ECAM-08-2017-0162.

[22] G. Ballard and I. Tommelein, “Current Process Benchmark for the Last Planner System,” 2016. Accessed: May 11, 2021. [Online]. Available: http://p2sl.berkeley.edu/wp-content/uploads/2016/10/Ballard_Tommelein-2016-Current-Process-Benchmark-for-the-Last-Planner-System.pdf.

[23] M. Cohn, Agile Estimating and Planning. Addison-Wesley, 2006.

[24] M. D. Okrent and R. J. Vokurka, “Process mapping in successful ERP implementations,” Industrial Management & Data Systems, vol. 104, no. 8, pp. 637–643, 2004, doi: 10.1108/02635570410561618.

[25] “Eziil pilvepõhine tootmistarkvara.” https://eziil.com/eng (accessed May 02, 2021).

[26] “Dynamic Work & Collaboration Software | Smartsheet a Platform for Enterprise Achievement.” https://www.smartsheet.com/ (accessed May 02, 2021).

[27] “Microsoft Dynamics 365 for Project-based manufacturing industry.” https://www.saglobal.com/int/industry/manufacturing/microsoft-dynamics-365-for-project-based-manufacturing.html (accessed May 03, 2021).

[28] “ERP/MRP süsteem, tootmistarkvara - MRPeasy.” https://www.mrpeasy.com/et/ (accessed May 04, 2021).

[29] P. Baxter and S. Jack, “Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers,” The Qualitative Report, vol. 13, no. 4, pp. 544–559, Jan. 2015, doi: 10.46743/2160-3715/2008.1573.

[30] K. Mehdouani, N. Missaoui, and S. A. Ghannouchi, “An approach for Business Process Improvement Based on Simulation Technique,” in Procedia Computer Science, 2019, vol. 164, pp. 225–232, doi: 10.1016/j.procs.2019.12.176.

[31] Ramakrishnan S, “System Analysis and Design,” Journal of Information Technology and Software Engineering, vol. 8, pp. 1–2, 2012, doi: 10.4172/2165-7866.S8-e001.

[32] W. W. Royce, “Managing the development of large software systems,” in IEEE WESCON, 1970, pp. 1–9, Accessed: Apr. 23, 2021. [Online]. Available: http://www-scf.usc.edu/~csci201/lectures/Lecture11/royce1970.pdf.

[33] James Cadle et al., Developing Information Systems: Practical guidance for IT professionals. BCS Learning & Development Limited, 2014.

Appendix 1

Simulation Results AS-IS

Resources

Resource	Utilization	Total fixed cost	Total unit cost	Total cost
Production planner	2,60 %	0	0	0
Production line manager	94,74 %	0	0	0
Production engineer	43,36 %	0	0	0
	Total	0	0	0

Manufacturing

Name	Type	Instances completed	Instances started	Min. time	Max. time	Avg. time	Total time	Min. time waiting resource	Max. time waiting resource
Manufacturing	Process	4	30	22d 8h 55m	71d 9h 45m	50d 5h 15m	2234d 19h 10m		
New production order	Start event	30							
Take input data from SKS_ver5 and place a production order	Task	30	30	1h	1h	1h	1d 6h	0	0
Print out production folder	Task	30	30	2h	5d 3h 50m	17h 51m 30s	22d 7h 45m	0	5d 1h 50m
Order purcased materials from warehouse	Task	16	16	1d 30m	24d 10m	11d 6h 51m 33s	180d 13h 45m	0	22d 23h 40m
Perform production	Task	13	15	10d	36d 8h 10m	17d 17h 53m 4s	230d 16h 30m	0	26d 8h 10m
Create packing list	Task	8	8	5h	27d 7h	12d 14h 21m 15s	100d 18h 50m	3h	27d 5h
Upload the packing list to the register of finished goods	Task	6	6	2h	25d 14h 30m	12d 18h 56m 40s	76d 17h 40m	1h 30m	25d 14h
Create an object into work time accounting program	Task	30	30	5m	1h 5m	7m	3h 30m	0	1h
Confirm delivery time	Task	25	25	30m	25d 14h	11d 8h 17m 36s	283d 15h 20m	0	25d 13h 30m
Analyse constraints and plan production time slot	Task	30	30	1h	1h	1h	1d 6h	0	0
Send order confirmation to project manager	Task	25	25	30m	1h 50m	48m 24s	20h 10m	0	1h 20m
Need extra materials?	Gateway	30	30						
Mark job as done	Task	30	30	5m	6h 5m	1h 8m 50s	1d 10h 25m	0	6h
Create purchase order	Task	12	12	2h	3d 2h 50m	19h	9d 12h	0	3d 50m
Materials delivered?	Gateway	25	25						
Mark job as done	Task	4	4	1d 11h 30m	23d 10m	11d 3h 27m 30s	44d 13h 50m	1d 11h	22d 23h 40m
Ready made products handed over to warehouse	End event	4							
Add production dates to schedule	Task	27	27	1h	27d 5h 40m	9d 16h 44m 4s	261d 19h 50m	0	27d 4h 40m
Wait for material	Task	13	13	5d 1h	27d 17h 20m	15d 17h 40m 23s	204d 13h 45m	1h	22d 17h 20m
Prepare and plan production execution	Task	30	30	3h	33d 15h 25m	10d 9h 51m 10s	312d 7h 35m	0	33d 12h 25m
Assign production engineer	Task	30	30	10m	22d 7h 25m	5d 17h 44m 20s	172d 4h 10m	0	22d 7h 15m
Prepare production order	Task	30	30	5d	10d 2h 40m	6d 1h 14m 40s	181d 13h 20m	0	5d 2h 40m
Send new job notification	Gateway	30	30						
Delivery confirmation	Gateway	25	30						
Update progress information	Task	11	11	13h 40m	27d 17h 20m	13d 1h 24m 32s	143d 15h 30m	9h 40m	27d 13h 20m
Create wbs to production schedule	Task	30	30	2h	8h	3h 58m 30s	4d 23h 15m	0	6h

Appendix 2

Resources

Resource	Utilization	Total fixed cost	Total unit cost	Total cost
Production planner	2,52 %	0	0	0
Production line manager	94,70 %	0	0	0
Production engineer	43,43 %	0	0	0
	Total	0	0	0

Manufacturing

Name	Type	Instances completed	Instances started	Min. time	Max. time	Avg. time	Total time	Min. time waiting resource	Max. time waiting resource
Manufacturing	Process	6	30	17d 13h 20m	67d 15h 5m	45d 15h 30m	1944d 18h 30m		
New production order	Start event	30							
Take input data from SKS_ver5 and place a production order	Task	30	30	1h	1h	1h	1d 6h	0	0
Print out production folder	Task	30	30	2h	2h	2h	2d 12h	0	0
Order purcased materials from warehouse	Task	20	20	1d 30m	28d 1h 30m	13d 15h 28m 30s	272d 21h 30m	0	27d 1h
Perform production	Task	15	17	10d	36d 15h 30m	20d 2h 41m	301d 16h 15m	0	26d 15h 30m
Create packing list	Task	12	12	14h	26d 12h 30m	11d 1h 53m 45s	132d 22h 45m	12h	26d 10h 30m
Upload the packing list to the register of finished goods	Task	8	8	4h 30m	27d 22h 15m	12d 19h 54m 22s	102d 15h 15m	4h	27d 21h 45m
Create an object into work time accounting program	Task	30	30	0	0	0	0	0	0
Confirm delivery time	Task	25	25	30m	26d 12h	9d 23h 9m	249d 2h 45m	0	26d 11h 30m
Analyse constraints and plan production time slot	Task	30	30	1h	1h	1h	1d 6h	0	0
Send order confirmation to project manager	Task	25	25	30m	30m	30m	12h 30m	0	0
Need extra materials?	Gateway	30	30						
Mark job as done	Task	30	30	5m	5m	5m	2h 30m	0	0
Create purchase order	Task	15	15	2h	2h	2h	1d 6h	0	0
Materials delivered?	Gateway	25	25						
Mark job as done	Task	6	6	5h 15m	18d 11h 15m	7d 18h 47m 30s	46d 16h 45m	5h	18d 11h
Ready made products handed over to warehouse	End event	6							
Add production dates to schedule	Task	30	30	1h	27d 23h 45m	11d 6h 13m 30s	337d 18h 45m	0	27d 22h 45m
Wait for material	Task	7	7	6d 4h	29d	14d 47m 8s	98d 5h 30m	1d 4h	24d
Prepare and plan production execution	Task	30	30	3h	18d 12h	8d 2h 44m	243d 10h	0	18d 9h
Prepare production order	Task	30	30	5d	5d	5d	150d	0	0
Send new job notification	Gateway	30	30						
Delivery confirmation	Gateway	25	30						
Create wbs to production schedule	Task	30	30	2h	2h	2h	2d 12h	0	0

Appendix 3 – To-be process flowchart