WELL-DEFINED DATA IN A PRODUCTION PLANNING CONTEXT

Bachelor Thesis

CIREX

A Signicast Company

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12 July 2019

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Preface

Dear reader,

I hereby present you the thesis that I wrote to finalize my graduation for the Bachelor Industrial Management & Engineering: '*Well-defined data in a production planning context*'. I was happy that I could carry out this assignment for my host company CIREX. Although it was only for a short period, I was quickly used to the pleasant working environment, thanks in part to my supervisor Daan van Rossum. The employees at CIREX showed interest and were helpful when I needed information or feedback. Altogether, I enjoyed my time at CIREX and I especially want to thank my supervisor for his support and advice.

Thanks also to my supervisor at the University of Twente, Adina Aldea, who helped me with writing the report and provided me with critical feedback to ensure that doing the research would really contribute to my learning progress. Finally, I want to thank my second supervisor Maria Iacob for taking the time to read my report as well.

I wish you much pleasure with reading!

Maxime Snaterse

Abstract

CIREX is a company specialized in Investment Casting ('lost wax'). It develops and manufactures complex steel components for the international industry. CIREX is limited in expanding its production facility (maximum capacity reached). Furthermore, they expect their main sales market (automotive industry, 75%) to change in the future. Changes in the automotive industry could lead to lower demands, forcing the company to look for other opportunities. Within this context, several problems prevailed. The research aimed at solving two core problems: for the first core problem, the aim was to define the data that is related to the production resources by means of a method. This pre-described framework aims at ensuring a consistent and realistic use of data for production planning. The second core problem refers to the situation in which there is not enough knowledge on how to use data to make a long term capacity planning. This makes it difficult to anticipate on the consequences of future change in demand. Considering these two core problems, the following main research question was formulated:

How can CIREX use well-defined and realistic data to obtain a capacity planning tool that provides insights that can improve decision making regarding production?

Several sub-questions derived from this main question, with as a result four deliverables: a business process model of CIREX production process, a standard set of definitions for the relevant production data and a step-by-step description how to apply these definitions, a planning tool/dashboard that shows the impact of change in demand on resource utilization, and recommendations on how the results of the research give insights that can be useful for long term capacity planning and decision making.

From the results of the research, it was concluded that some parts of CIREX's production process are highly complex, which indicates a high level of product variety. It is important for the company to adopt a strategy that enables to manage this product variety, especially when change in demand would cause even more product variety. Furthermore, the method appeared to be a first step for the company towards integrating accurate data, and ensuring that decisions are not solely based on expertise, but on this well-defined, realistic data. The planning tool/dashboard resulted in an increase of knowledge for CIREX on how to use data to obtain insights that can be used for decisions regarding long-term capacity planning. The dashboard prevails amongst others bottlenecks and makes it possible to determine what changes in capacity would be needed to meet demand.

Recommendations for further research include exploring if similar problems often occur at companies, and looking more closely at the relationship between change in demand and resource utilization. Next step for CIREX: implement the results from this research in practice and use the new insights for decision making.

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Reading Guide

This report starts with an *introduction* in which amongst others the problem statement, research questions and approach are described. The second chapter is the *theoretical framework*, in which an answer is formulated on the knowledge questions. Chapter three, four and five cover the remaining sub-questions. Chapter three includes the visualization of the company's *production process* as well as an interpretation of this model supported by the literature. Chapter four presents the *method* for defining and implementing the resource data; it provides a solution for the first core problem. Chapter five describes the design of the *dashboard* together with all the relevant information (KPIs, requirements, data model, etc.); a solution for the second core problem is presented. In chapter six, the results from the *evaluation* can be found. Finally, the *conclusion, discussion, and recommendations* are presented. Additional information can be found in the *appendices*.

1. Introduction

The Company

CIREX is a company specialized in Investment Casting ('lost wax'). It develops and manufactures complex steel components for the international industry. Different products are produced for a variety of markets, including amongst others the car industry, tools, hoisting and transportation, and the medical industry. The automotive industry is their core sales market. With the automated production process, 'Near Net Shape' components are develop and produced. CIREX does not solely manufacture the products, but works together with the client and participates in the process from idea to implementation. This is in line with their mission as stated on the website (CIREX Mission & Vision, n.d.): CIREX completely unburdens the customer by being the best development partner and producer of complex high-grade steel components.

Although lost-wax casting can be seen as an ancient process, the decision of CIREX to use this method of manufacturing was conscious made. Lost-wax casting has several benefits, such as the high degree of dimensioning precision, high surface quality and significant freedom of shape and design. Due to the high-tech production process and continuous improvement, the company was able to grow significantly the past few years and with the recent acquisition by Signicast, a Form Technologies company, they aim at continuing this trend. With the results of the research, I aimed at contributing to the mission of CIREX by providing them with useful insights regarding production: smoother decision making thanks to the availability of valuable insights could enable them to more easily meet the requirements of their customers.

The Problem

CIREX Foundry NL is limited in expanding its production facility (maximum capacity reached). During the years, new parts have already been added to the main building in The Netherlands to increase production capacity and meet the growing demands. In the situation in which expanding is not an option, CIREX has to make the most of the capacity it currently has. Furthermore, they expect their main sales market (automotive industry, 75%) to change in the future. Changes in the automotive industry could lead to lower demands, forcing the company to look for other opportunities. Luckily, there is increasing demand for complex steel components in other industries, such as industries that focus on tools, industrial components, and fluid technology. This opens up new possibilities for the future. With these circumstances in mind, the questions raise whether the current production is efficient enough, whether capacity is utilized optimally and planned realistically, and whether the strategy at this moment would lead to similar results in the future.

From the problem context, the action problems derived. These action problems represent the principals' main concerns. However, the action problems are a result of other problems that occur at the company. By determining the causes and consequences, two core problems prevailed. The overview of problems are presented in a problem cluster, *Figure 1*. It was decided to tackle both core problems during this research. This decision was made, because both core problems are related to data usage. Furthermore, it was not expected that solving these two core problems would result for example in time shortage, since both core problems involve the same type of data: the same production data would have to be analysed. Thus, solving the second core problem would not mean 'starting from scratch'.

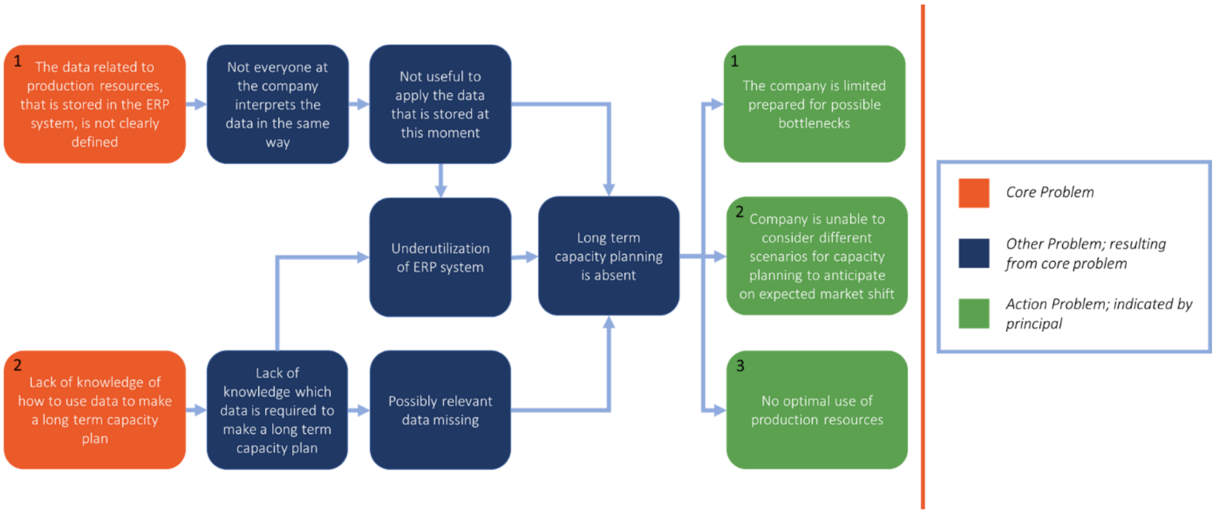

Figure 1 – Problem Cluster

The two core problems show a discrepancy between reality and norm. The norm refers to the desired situation and the reality to the current situation in which something should change to reach the norm (Heerkens & Van Winden, 2012). For the first core problem, the aim was to define the data that is related to the production resources, so that a 'standard' exists which can be used to store data in the ERP system that corresponds with reality. This would fill the gap between the real situation, in which the ERP system contains unclear and inconsistent data for each of the production steps. The second core problem refers to the reality that there is not enough knowledge on how to use data to make a long term capacity planning. The norm is the situation in which it is known what has to be done with the data to obtain insights that are necessary to make a long term capacity planning.

Solving these core problems is a prerequisite to solve the action problems: First of all, a long term capacity plan, that helps to prepare for bottlenecks, that would result in a better utilization of resources, and that also has the option to show what happens if the market shifts, can only be created when it is known which data is needed and how to implement this data. Secondly, such a long term capacity planning tool is only useful when the input data is realistic and consistent, because if the data is not gathered and interpreted in a similar way and is not based on accurate and actual measurements, it would give a misleading outcome. This research will present a method that enables to define, gather, interpret and implement relevant production data in a consistent way, and will show with a planning tool and dashboard how the production data can be used for long term capacity planning. The tool will give useful insights that enable to anticipate on market shifts, discover bottlenecks and show how production resources could be better utilized. Thus, a contribution will be made to solving the action problems. As a result of this reasoning, the following main research question derived:

How can CIREX use well-defined and realistic data to obtain a capacity planning tool that provides insights that can improve decision making regarding production?

To make the research more specific, sub-questions were formulated. These questions resulted in a set of deliverables (see also *Scope & Deliverables*) with the aim of answering the main question, solving the core problems, and, consequently, contributing to a solution for the action problems.

Problem Solving Approach

The research was approached as a descriptive case study, since the specific organization is central to the research. Besides that, the research was less related to the explanation why certain events occur (explanatory) or to exploring new knowledge (exploratory), which explains the choice of a descriptive study. The research population involved the employees of CIREX. Furthermore, the research was approached as a design science research. This type of research creates and evaluates IT artifacts, such as models and methods, intended to solve identified organizational problems (Peffers, Tuunanen, Rothenberger & Chatterjee, 2007). Since the main part of the research involved the design of models and a dashboard to solve the previous described core problems, the Design Science Research Methodology was chosen as the guiding method. See *Figure 2* for an overview of this methodology.

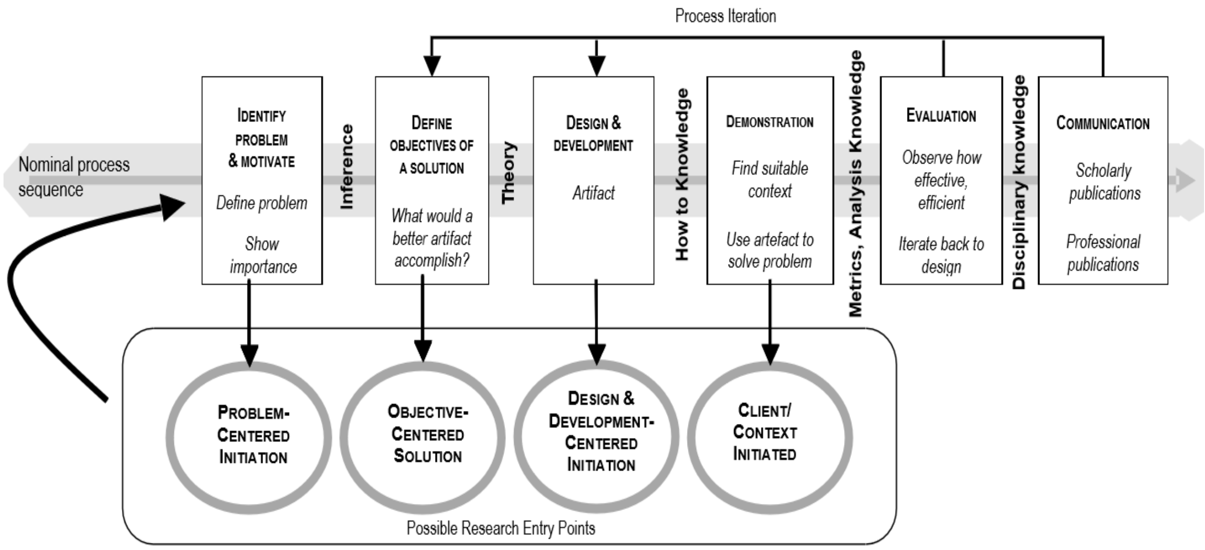

*Figure 2 – Design Science Research Methodology (DSRM) Process Model**

*Adapted from "A Design Science Research Methodology for Information Systems Research," by Peffers et al., 2007, *Journal of Management Information Systems, 24*(3), pp. 45-78.

Steps 1 and 2 are covered in the project plan and the first chapter of this report. These two steps are comparable to the first steps of the Managerial Problem Solving Method (MPSM), a method that aims at finding and comparing several alternative solutions (Heerkens & Van Winden, 2012) and finally results in a best solution for the particular problem. Since the UT recommends IEM-students to use the MPSM as a research-guide, and since it is applicable for identifying the problem and defining a problem solving approach, it replaced the first two steps of the (DSRM). For the phases that emphasize on the design of the solution (step 3-6), the DSRM was followed, because for this part of the research MPSM was less suitable: although there exist different ways to solve the core problems, the nature of the problems made it less relevant to emphasize on different solutions, which is what the MPSM does.

The theoretical part will be presented in chapter two of this report. Chapter three, four and five cover the Design & Development phase, and the Demonstration phase: data is gathered, the models and dashboard (artifacts) are created, and these artifacts are applied to the context. Chapter six represents the Evaluation phase: the results from the Design & Development phase and the Demonstration phase are discussed with the principals in the form of a presentation and discussion. Communication, last phase, is done by means of this research report.

Data Gathering/Processing Methods & Research Questions

A variety of qualitative methods were used to obtain relevant data, namely literature studies, secondary data reviews, semi-structured interviews and discussions. Below, for each of the sub-questions, a more specific description is given of the methods used and the contribution to answering the main question.

Question 1: *What are the requirements for a business process model?*

Before being able to make the business process model of the production process (question two), knowledge was required on how to do so. For this, literature was used. Based on the literature, decisions were made on amongst others the most suitable language to model the process. A list of requirements form the answer to this question and can be found in the *Theoretical Framework*.

Question 2: *How can a business process model be made of CIREX's production process?*

Before anything could be said about for instance relevant data, production performance, and use of resources, there had to be a clear idea of the production process. Secondary sources (i.e. ERP-system) provided the information regarding the production process. For additional information, the operations manager and production floor manager were interviewed (semi-structured). To visualize the production process, a business process model was created. An interpretation of the model is given to provide CIREX with insights on the flow of the products, levels of complexity and consequences for capacity planning. See *Chapter 3* for the results.

Question 3: *What is the impact of product variety on manufacturing and (capacity) planning?*

After the creation of the business process model, the complexity of the production process could be determined: the more flows between the production steps, the higher the product variety. A literature study was conducted to get an idea of the impact of product variety on manufacturing and (capacity) planning. The answer on this question can be found in the *Theoretical Framework.*

Question 4: *How can the data related to the production steps be best defined so that it ensures a consistent and more realistic application when implemented in the ERP system and used for planning?*

To get an impression whether the resource data that is currently stored in the ERP system is rather an estimation based on expertise than that it corresponds with reality in a consistent way, some samples were obtained by observing a selection of resource steps in the factory (quantitative method applied). Based on these findings and the results from the group discussions with the principal and other employees that were involved, a method was developed that suggests how to apply definitions to the data and how to make the data ready to be implemented in the ERP system for consistent future use. The approach ensures that the data that is stored in the ERP system is obtained by following a pre-described framework. Consequently, the problems that planning is unrealistic because of use of undefined data, or that not everyone interprets the data in a similar way, are tackled. Thus, this section of the research contributed to solving the first core problem, see *Chapter 4*.

Question 5: *Which KPIs are typically used to provide insights in production performance?*

Key performance indicators (KPIs) were selected that can provide the knowledge requested by the company. Literature was reviewed to determine which KPIs are typically used in a production context. This information served as a starting point for the selection of the KPIs that would be included in the dashboard. See *Theoretical Framework* for the results.

Question 6: *What are requirements for a production dashboard (including simulation option)?*

Prior to the actual design of the dashboard, knowledge was needed on the requirements for making such a dashboard. In this particular case, the production dashboard should have the option to compare the current situation with a situation in which demand has changed (i.e. features similar to simulation). In this way, the impact of the expected changing market could be analysed and it would become visible if the change of demand influences the KPIs. Literature was reviewed to find out what would be needed to make a dashboard within this particular context; see *Theoretical Framework*.

Question 7: *How to make a production dashboard that provides CIREX with insights that can be used for capacity planning?*

In this phase, the gathered knowledge from previous steps was implemented in a dashboard/tool. The dashboard shows the selected KPIs. Current data from the ERP-system was used as input. The method as presented in *Chapter 4* was applied as far as possible. However, if some data could not be obtained, estimations were made. The dashboard is meant to give useful insights regarding the production process, which then can be used for long term capacity planning. Also a tool was included that allows for adjustment of certain input data, so that different scenarios can be analysed. Thus, answering this research question contributed directly to solving the second core problem. The outcomes of the KPIs indicate what the bottlenecks are in the process and which aspects require extra attention, in case of the current situation and a fictional situation. To make sure that the dashboard fulfils the needs of the organization as much as possible, the final requirements were discussed with the principal before designing it (interview). The final dashboard was evaluated with a selected group of CIREX employees by means of a presentation and group discussion. See *Chapter 5* for the answer on this research question, and *Chapter 6* for the results of the evaluation.

Scope & Deliverables

To ensure the feasibility of the research, the scope had to be considered. The boundary conditions include the time limit of 10 weeks in which the research had to be completed, and the criteria for the bachelor thesis. Within the research, the focus was on CIREX: it did not have the main aim of generalizing the findings, although suggestions for wider application would be addressed when suitable. Furthermore, not all the data that turned out to be missing after formulating the definitions and after determining the relevance for capacity planning was gathered: this required many measurements and observations, which was not feasible within the time frame. Consequently, not all the data used for the dashboard was up-to-date and accurate. Further limitations will be discussed in *Chapter 7*.

Altogether, the aim of the research was to solve the company's core problems by providing the following deliverables, as a result from answering the research questions:

- A BPMN model that represents the current production process, including an indication of possible consequences for capacity planning.
- A standard set of definitions for the relevant production data and a step-by-step description how to apply these definitions to ensure that the data corresponds with reality, and that it can be used in a consistent way.
- A planning tool, presented in the form of a dashboard, that gives an overview of the selected KPI's that are related to production performance and capacity planning. This includes the comparison between the current situation and possible scenarios in which demand has changed.
- An advice on how the results of the research give insights that can be useful for long term capacity planning and strategic decision making.

Relevance

Besides personal relevance (doing the research at a company with a fascinating production process, and an international focus, gives the experience of participating in a real working environment) and the connection with the IEM bachelor (focus on production processes and resource planning), conducting the research was especially important for the organization: it provides CIREX with new insights and possibly leads to an implementation of the results in practice. Although the research was specifically meant for this company, it can be seen as scientifically relevant as well, in the sense that it shows how companies in a similar situation could approach a comparable problem: all the steps that are done in the research are explained in such a way that they could be repeated by another company.

This study did not directly augment or extend previous research in the field, but because it was highly relevant for the particular company, conducting the research added value nevertheless.

2. Theoretical Framework

This theoretical framework has the main aim of answering the different knowledge questions with the use of literature. This also includes defining several key terms that played a role within the research. Below, the answers on questions 1, 3, 5, and 6 as described in the *Introduction* are presented.

Key Terms

For a list of definitions of the main terms that are used within this report, see Appendix A. Important terms are amongst others *Production Process, Product Variety, Complexity, Realistic Data, Resource Steps*, and *Capacity Planning*. Some of these key concepts will be addressed below as well.

Requirements for a Business Process Model

In this part of the Theoretical Framework, the answer on the first research question, *'What are the requirements for a business process model?'* is formulated.

Business process modelling (BPM) refers to the creation of a model of a business process in order to better understand that process (business process modelling, n.d.). With a business process, a series of logically related activities or tasks performed together to produce a defined set of results (business process, n.d.), is meant. There exist different types of business processes, such as operational processes and supporting processes. Production processes belong to the operational processes; the process of interest during this research project.

Before creating a business process model, a decision has to be made which technique/tool will be used. As Aguilar-Savén (2004) states, using the right model involves taking into account the purpose of the analysis and having knowledge of the available process modelling techniques and tools. Aguilar-Savén (2004) described the main process modelling techniques, and proposed a framework for classifying business process-modelling techniques according to their purpose. Aldin & De Cesare (2009) did something similar: the article presents a comparative analysis of some popular business process modelling techniques. Aldin & De Cesare (2009) based the comparative framework on five criteria: flexibility, ease of use, understandability, simulation support and scope. Hommes & Van Reijswould (2000) add to this by presenting a framework that enables to assess the quality of business process modelling techniques. The framework defines the elements that constitute a modelling technique and presents a number of quality properties as well as ways to operationalize them (Hommes & Van Reijswould, 2000).

From these three articles by Aguilar-Savén (2004), Aldin & De Cesare (2009), and Hommes & Van Reijswould (2000), a list of criteria for selecting a business process modelling technique has been obtained. The table below shows the criteria. In some cases, the authors use different terms for a similar criterium. Therefore, for a particular criterium, the different terms that are used by the authors are presented in the same row.

Criteria	Aguilar-Savén (2004)	Aldin & De Cesare (2009)	Hommes & Van Reijswould (2000)
1	Fit with purpose of the model	Scope	Suitability
2	Model change permissiveness	Flexibility	Arbitrariness
3		Ease of use	Comprehensibility
4		Understandability	
5		Simulation	
6			Coherence
7			Expressiveness

Table 1 – Criteria for a BPM obtained from Literature

Translating these criteria into requirements that are specifically important for the BPM that had to be created during this research, resulted in the following three main requirements:

Requirement 1	The BPM technique should be flexible enough, meaning that it is possible to change a model without replacing it completely (Aldin & De Cesare, 2009). It should be active, allowing for changes (Aguilar-Savén, 2004).
Requirement 2	The BPM technique should be easy to use, being able to be readily applied by business users (Aldin & De Cesare, 2009). In addition, the way of working and the way of modelling should be easily understood by the participants (Hommes & Van Reijswould, 2000).
Requirement 3	The BPM technique should be suitable for fulfilling the purpose of the model. It should include the process modelling elements (process, activity, service & product, role, goal, event, rule) as presented by (Aldin & De Cesare, 2009), and should enable to learn about the process and possibly make decisions on the process (Aguilar-Savén, 2004).

Table 2 – Requirements of a Business Process Model

The techniques that were presented in the articles written by Aguilar-Savén (2004) and Aldin & De Cesare (2009) were compared, since these included the most frequently used techniques. Based on the requirements from *Table 2*, the following BPM technique has been selected: The Business Process Modelling Notation (BPMN). Thus, after comparing the different BPM techniques, the BPMN technique appeared to be most suitable for this research, since it meets all of the requirements. Some other techniques, such as Data Flow Diagram (DFD) and Role Activity Diagram (RAD) met the requirements as well. Nevertheless, it was expected that the characteristics of the BPMN technique (see *Appendix B)* would be most convenient for fulfilling the purpose of the model. Thus, the BPMN technique was used during the research to visualize and present CIREX's production process (see *Chapter 3* for application of the technique).

The Impact of Product Variety

Below, the answer on research question three, '*What is the impact of product variety on manufacturing and (capacity) planning?*', is presented.

Several definitions of product variety exist in the literature. Park, Velicheti, Kim & Kim (2004) give some examples: Ulrich & Randall (2001) defined product variety as the number of different versions of a product offered by a firm at a single point in time. Fisher & Ittner (1999) stated that product variety can be defined in two dimensions: the breadth of the products that a firm offers at a given time and the rate at which the firm replaces existing products with new products. Martin, Hausman & Ishii (1998) defined two types of variety: spatial variety and generational variety, where spatial variety indicates the variety that a company offers the marketplace at a point in time, and generational variety means variety across future generations of products. Within this research, the definition by Ulrich & Randall (2001) is chosen, since the rate of replacing products and the generational variety as mentioned by Fisher & Ittner (1999) and Martin et al. (1998) are less relevant.

At CIREX, a variety of products is offered. Not only products are made for one particular industry, but different products are manufactured for different markets. Besides that, the company also develops products together with the customer, which leads to even more product variety. Product variety can have consequences for the business, both positive and negative. Main benefits that are mentioned in the literature include the potential to expand markets, increase sales volumes and revenues (Elmaraghy et al., 2013), satisfy customers more, resulting in enhanced competitiveness and more market share in the market (Park et al., 2004), and increase firm performance (Wan, Evers & Dresner, 2012).

Although these possible benefits might seem attractive, product variety can have serious consequences that should be considered. According to Wan et al. (2012), beyond a certain level, increased product variety actually results in lower sales. Thus, the range of product variety should be carefully considered to ensure it has a beneficial impact for the company. Namely, more product variety may increase the manufacturing costs and complexity (Park et al., 2004). Furthermore, offering more product variants incurs expenses from product design to production, inventory, selling and service (Elmaraghy et al., 2013). Thus, as Ramdas (2003) states: how firms choose to create variety in their product offerings, and how the firm's functions and its supply chain are managed to implement variety, are key determinants of the success of this strategy.

Looking more closely at the manufacturing department, it becomes clear that product variety has a direct impact. According to Alford, Sackett & Nelder (2000), increasing product variety increases the costs and complexity in manufacturing. In the article by Park et al. (2004) it is mentioned that management has an important role in making the entire production system flexible both by insuring that production scheduling, equipment setup, and maintenance policies support the effective utilization of flexible tooling, and by training workers in multiple skills so they can handle the demands of higher variety. Thus, many aspects have to be considered when a company wants to take on a high level of product variety: increasing product variety does not simply result in increased profits.

Less literature is available on the impact of product variety on planning. However, it can be imagined that in order to manufacture different products, planning becomes more complex. The article by Elmaraghy et al. (2013) confirms this: product variety increases the complexity of planning in general and requires well-designed strategies and models to handle it. Furthermore, higher product variety also evokes the complexity of demand forecasting and matching of supply with demand in the supply chain (Park et al., 2004). With increase in variety, assembly line task balancing becomes problematic, and parts planning and production-scheduling systems becomes complex (Fisher, MacDuffie & Sethuraman, 1996). Thus, as Elmaraghy et al. (2013) state: in dynamic and highly customized markets, companies have to be able to adjust their production to actual and future conditions quickly and efficiently to achieve competitive advantage.

Considering more specifically capacity and resource planning, it is mentioned in the literature that managing resources utilization effectively in the presence of product variants is important for creating sustainable competitive advantage and enhancing productivity (Elmaraghy et al., 2013). Yet, certain factors make the management of resources and capacity complicated. First of all, resources like capacity are always related to cost, including setup (changeover) costs, inventory holding costs, production costs and volume flexible production costs (Elmaraghy et al., 2013). Additionally, in a production environment, real limits on workforce and machine capacities to produce various variants may exist (Elmaraghy et al., 2013).

From the above review it can be concluded that product variety certainly has consequences for business operations in general, but also particularly for manufacturing and planning. If a company wants to be successful in managing a high level of product variety, it has to consider several aspects, including all the relevant costs that might increase and the increasing complexity due to product variety. As Park et al. (2004) conclude: before increasing the variety in their product lines, companies should also take into consideration all the relevant functions and operations effected by higher product variety.

In *Chapter 3*, CIREX's production process will be analysed and the results of this literature study support the advice that was given to CIREX regarding the complexity of its production process.

Typical Production KPIs

The fifth research question, '*Which KPIs are typically used to provide insights in production performance?*', has been answered by means of a systematic literature review. For the complete review, see *Appendix C*. Below, the main findings are presented.

Two main concepts can be derived from this question: 'key performance indicators' and 'production performance'. Answering this question has the aim of presenting which key performance indicators are often selected to show the performance of production. The possible results of the question are narrowed down with the word 'typically'. If the literature gives for example an indication that some key performance indicators are valuable to get insights in the performance, and others less, or some KPIs are often used as standard, this can be considered when formulating an answer.

In the book by Slack, Brandon-Jones & Johnston (2016), performance measurement is defined as the process of quantifying action, where measurement means the process of quantification and the performance of the operation is assumed to derive from actions taken by its management. It is a prerequisite for judging whether an operations is good, bad or indifferent. In the book Operations Management (Slack, Brandon-Jones & Johnston, 2016) it is also stated that it is difficult to 'target' a narrow range of key performance indicators unless strategy is well defined. This shows that the selection of KPIs is a challenging task, hence gaining knowledge on this topic is relevant.

Since the core problem is related to production processes, the answer should be limited to KPIs that give insights in production performance, and not for example services and revenue. To define production performance, first the concept of production processes has to be defined: mechanical or chemical steps used to create an object, usually repeated to create multiple units of the same item, and generally involves the use of raw materials, machinery and manpower to create a product (production process, n.d.). Performance can be defined as how well a person, machine, etc. does a piece of work or an activity (performance, n.d.). Thus, production performance can be defined as how well the production process is doing.

The systematic literature review resulted in a selection of articles that could contribute to answering the research question. First of all, most of the articles highlighted the importance of measuring performance and using key performance indicators to do so. For example Stricker, Echsler Minguillon & Lanza (2017) stated that performance measurement with key performance indicators (KPIs) is a widely used instrument to detect changes in production system performance in order to coordinate appropriate countermeasures. According to Varisco et al. (2018) KPIs are considered to be the core of a performance measurement system, and allow managers to identify the progress in activities and those to be improved, support the setting of new goals, help decision-making in order to reach the desired performance and improvement, etc. Furthermore, also the proper selection of KPIs is addressed in some of the articles. Ante, Facchini, Mossa, & Digiesi (2018) emphasize that in order to guarantee high performance and continuous monitoring of the process control, it is necessary to identify proper indicators in supporting the decision-making process. In addition, Varisco et al. (2018) mention that KPIs should be properly selected to adapt the industry specificity, but general enough to be able to compare different operations. This shows KPIs should be carefully selected to make sure they correspond with the company's strategy and needs. In some of the papers, methods were proposed to identify, select and obtain KPIs. Stricker et al. (2017) proposed a selection process that uses an integer linear programme for objective KPI selection. Although promising, it seemed to be too complex to be applied within this project. Behrens & Lau (2008) presented a less complicated and therefore more appropriate method, see *Figure 3*.

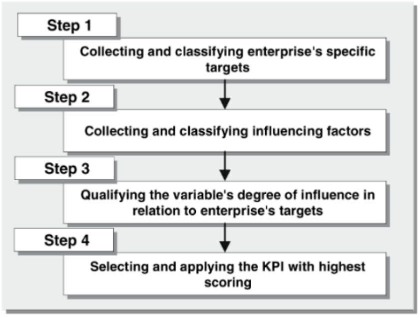

*Figure 3 – Method KPI Selection**

The previous findings focus more on how to select KPIs than which KPIs could give relevant insights in production performance. However, some of the articles also mentioned specific KPIs. The articles by Varisco, Johnsson & Schiraldi (2018) and Varisco et al. (2018) referred to ISO22400, a standard for manufacturing/production KPIs. The ISO22400 provides an overview of KPIs that could be relevant for the research project and is worth further consideration. As Varisco et al. (2018) point out, the ISO22400 is defined at a high abstraction level which makes it difficult to apply the KPIs in practice. This is important to keep in mind when using the ISO22400 to gather suitable KPIs. The mentioned articles can provide information on how to deal with this.

Although none of the articles really indicated which KPIs are most commonly used, besides that the ISO22400 is seen as a 'standard' itself, some of the KPIs were frequently mentioned, such as Overall Equipment Efficiency (OEE). Behrens & Lau (2008) pointed out the OEE as one of the indicators widely used by manufactures to determine productivity at the equipment level. Also, Ahmad & Dhafr (2002) and Ante et al. (2018) used OEE as a main KPI. For the other KPIs, it was possible to make a distinction between types: cost KPIs, quality KPIs, employee KPIs, efficiency/productivity KPIs. See *Table 3* for an overview.

Efficiency/Productivity	Quality	Cost	Employees
Production Rate	Mean Product Quality	Mean Production Costs	Availability of Employee
Utilization Efficiency	Quality Rate	Indirect Costs	Productivity of Employee
Production Process Ratio		Cost of Equipment & Tools	
Throughput Rate		Maintenance Cost	
Performance Ratio		Labor Cost	
Resource Saturation			
Errors [#]			
Material Efficiency			
Availability of Equipment			
Output			

Table 3 – KPI overview

*Adapted from "Key performance indicators for sheet metal forming processes," by Behrens & Lau, 2008, *Production Engineering, 2*(1), 73-78. doi:10.1007/s11740-007-0076-y

Although these outcomes are useful for answering the knowledge question and indicate which KPIs could give insights in production performance, it became clear that it is important to consider the specific company. Thus, the ISO22400 and the KPIs gathered from the articles serve as a starting point, but it can be concluded that especially discussing the KPIs with the principals are an important aspect to select the most suitable KPIs within the context of this project. The method proposed by Behrens & Lau (2008) was used as a guidance in the process of selecting relevant production KPIs, see *Chapter 5*.

Requirements for a Production Dashboard

For research question six, '*What are requirements for a production dashboard (including simulation option)?*', the literature review resulted in the answer as formulated below.

Production dashboard refers to a performance dashboard that relates to production. Dashboards provide visual displays of important information that is consolidated and arranged on a single screen so that information can be digested at a single glance and easily drilled in and further explored (Sharda, Delen, Turban, 2014). The most distinctive feature of a dashboard, according to Sharda et al. (2014) is that it contains three layers of information, namely monitoring (graphical, abstracted data to monitor key performance metrics), analysis (summarized dimensional data to analyse the root cause of problems), and management (detailed operational data that identify what actions to take to resolve a problem).

According to Sharda et al.(2014), all well-designed dashboards possess the following characteristics:

- They use visual components to highlight, at a glance, the data and exceptions that require action.
- They are transparent to the user, meaning that they require minimal training and are extremely easy to use.
- They combine data from a variety of systems into a single, summarized, unified view of the business.
- They enable drill-down or drill-through to underlying data sources or reports, providing more detail about the underlying comparative and evaluative context.
- They present a dynamic, real-world view with timely data refreshes, enabling the end user to stay up to date with any recent changes in the business.
- They require little, if any, customized coding to implement, deploy, and maintain.

The above list can be considered as general requirements of a performance dashboard. Important for a production dashboard is that it captures the right context: it should provide the information that is desired by the specific end users. Because these end users can differ, even though the dashboard is in all cases related to production, it can be useful to consider the type of dashboard that is requested:

this can be either operational, tactical or strategic (Eckerson, 2005). The operational dashboard monitors the main operational processes, providing detailed concise information, mainly used by production staff or their supervisors (Eckerson, 2005). According to Eckerson (2005), company managers use a tactical dashboard to compare the performance of their area or project with the established goals, the projections and the results of the period before. By contrast, a strategic dashboard monitors the execution of strategic objectives, with the goal to align the efforts carried out by different areas of the company with those strategic objectives (Eckerson, 2005). Durcevic (2018) describes a strategic dashboard similarly, but with a focus on the time frame: a reporting tool for monitoring the long-term company strategy with the help of critical success factors. Thus, the type of dashboard will influence the selection of information that is to be visualized on the dashboard.

Specifically for this research project, it was also desired that the dashboard has a simulation function, in order to include a predictive scenario. Simulation can be defined as the production of a computer model of something, especially for the purpose of study (simulation, n.d.). Another suitable definition of simulation is given by Gogg & Mott (1993): simulation is the art and science of creating a representation of a process or system for the purpose of experimentation and evaluation. Experimenting and evaluating can indeed be considered as the purpose of the simulation function that is added to the dashboard. One aspect of simulation is the 'what-if analysis'. According to Golfarelli & Rizzi (2009) what-if analysis is a data-intensive simulation whose goal is to inspect the behaviour of a complex system (i.e., the enterprise business or a part of it) under some given hypotheses called scenarios. This was a possible feature of simulation that could be suitable in the given context.

The findings from this literature study were considered for the design of the dashboard; see *Chapter 5*). No comparison has been made between different dashboard design software: it was requested by the principal to use Microsoft Excel, making a literature study on the most suitable dashboard software unnecessary. CIREX often uses Excel software, thus it was expected that an Excel dashboard could be more easily implemented than a dashboard created with software that is unknown to the company.

3. The Production Process

This chapter provides the answer on the second research question: '*How can a business process model be made of CIREX's production process?*'.

Gathering Information

In order to visualize the production process at CIREX, data was gathered from the ERP system. From this secondary data it could be determined how the different resource steps are connected, indicating the possible flows of the products. However, not all the data was up-to-date or relevant: some resources could be disregarded because they are only occasionally used for prototypes, and others because they are registered in the ERP system without being actively used in reality. This additional information was obtained from the operational manager and production floor manager by means of a semi-structured interview. Since the questions of the interview were quite specific, referring directly to data from the ERP system or particular parts of the production process, the interview questions are not included in this report.

The interview served to gather the necessary information that would enable to visualize the process in such a way that it would be both comprehensive and according to the principals' needs. Thus, decisions had to be made on the elements that should be included in the model. The following definition was given to a 'production step': it is considered to be a production step when the activity directly contributes to the manufacturing of the product, and involves a specific machine or installation, the action of one or more employees, and/or any other element that requires planning. This definition served as a guide to determine which steps should be part of the process model. Since the production process consists of a large amount of steps, the decisions on which particular steps to omit are not addressed within this report.

General Description of The Production Process

From a general perspective, the production process contains a few main steps, starting with the manufacturing of wax models of the products. These wax models have the shape of a tree: to the trunk, multiple product units are attached. After the completion of tasks in the Wax Department and rinsing of the wax trees, the trees are covered with ceramic layers in the Ceramics Department. When the ceramic layers are dried, in a so-called boilerclave wax is melted out of the ceramic tree; dewaxing. Then, in the Casting Department, the ceramic tree is baked at high temperatures (sintering process), after which steel alloy is poured into the tree. Finally, the trees arrive at the Finishing department, where amongst other the ceramic shells are removed and the products are cut from the tree. Also for example heat treatment is done to finish the product. During the production process, some products are transported from the facility in The Netherlands to the facility in the Czech Republic or the other way around, because not all production steps can be done at one location. For example product finishing takes mostly place at CIREX Foundry CZ. For the detailed process model of the complete production process, see *Appendix D Figure 1.*

Complexity of The Production Process

The figures of the production process that are presented in this chapter are not meant to be readable in detail: the purpose of the figures is to show the level of complexity. With the amount of flows that can be observed in the models, it becomes clear which parts of the production process are highly complex.

The business process model of CIREX's production process (*Appendix D Figure 1*) shows that a division can be made between the production departments, based on the complexity. Not all the products that can be manufactured at CIREX follow the same path to becoming a finished product ready for shipment. In the beginning, the products follow mostly the same process steps (creation of a wax model, ceramics, casting), but especially when they arrive in the final production departments, there are a lot of flow possibilities. In these departments, not every product undergoes the same treatment. From *Appendix D Figure 1* and *Table 4* it becomes clear that especially the Finishing 2 department at CIREX Foundry Czech Republic is highly complex. Also the Finishing 1 and Control department at this location, and the Finishing and Control departments at CIREX Foundry The Netherlands are already quite complex.

	Department	Complexity
CIREX Foundry NL	*Wax Model*	Low
	Ceramics	Low
	Casting	Low
	Finishing	Medium
	Control	Medium
CIREX Foundry CZ	*Wax Model*	Low
	Ceramics	Low
	Casting	Low
	Finishing 1	Medium
	Finishing 2	High
	Control	Medium

Table 4 – Complexity of Production Process per Department

Figure 4 on the next page shows the part of the process that is less complex. In the beginning of the production process, most of the products follow the same path.

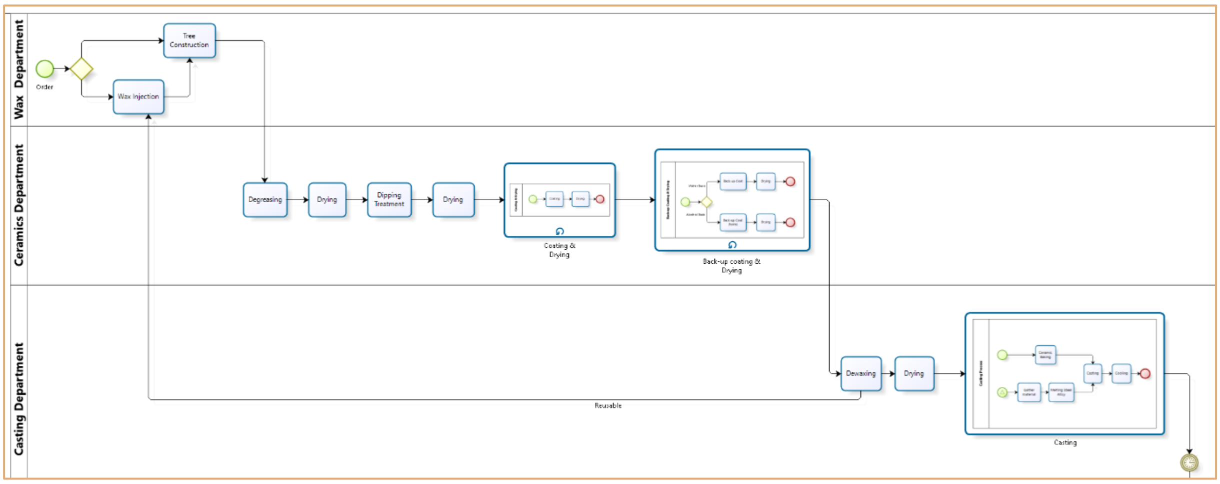

Figure 4 – Wax, Ceramics & Casting Department NL, low complexity

In *Figure 5*, which shows the finishing and control department at CIREX Foundry NL, already more flows between production steps can be observed, indicating that different products follow different paths.

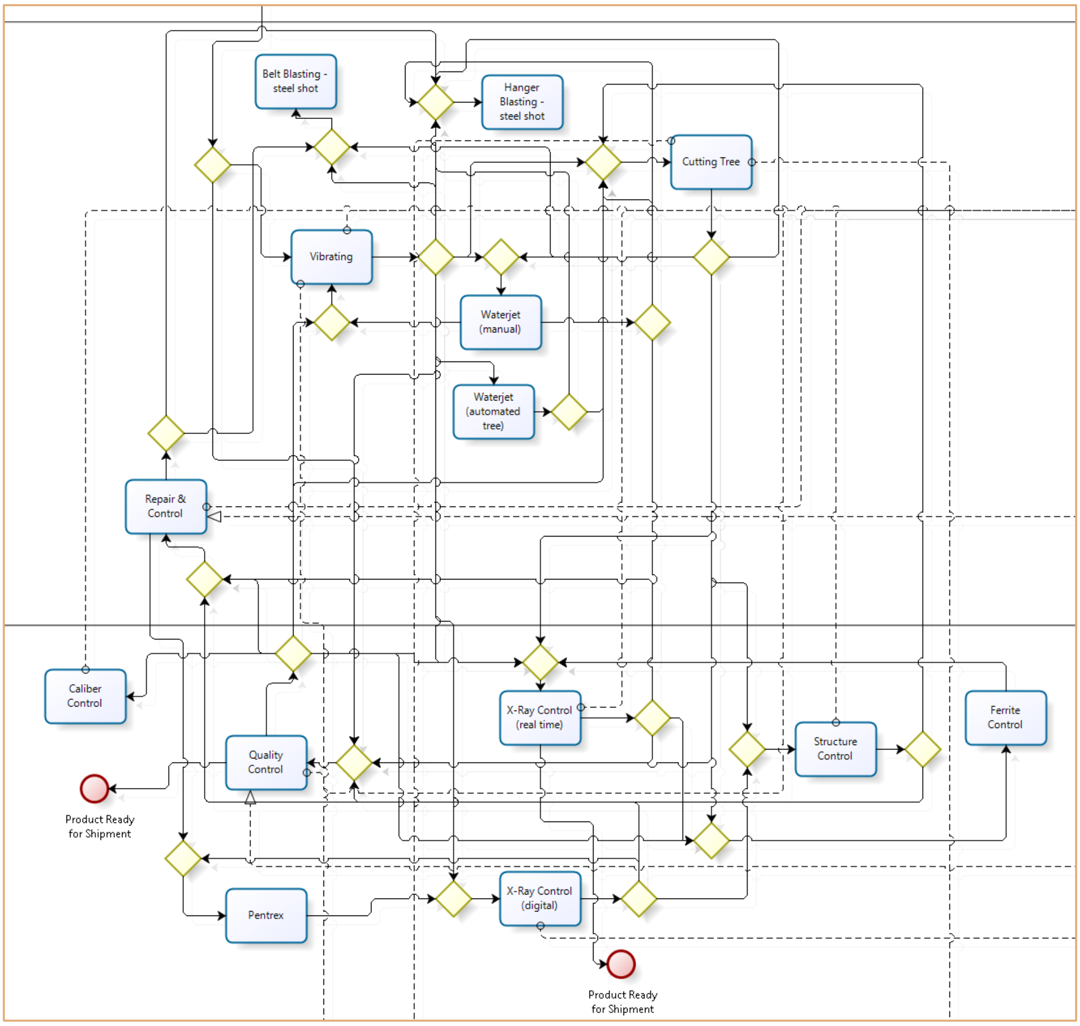

Figure 5 – Finishing & Control Department NL, medium complexity

Figure 6 presents the most complex part of the production process, namely the Finishing 2 Department at CIREX Foundry CZ. This is the department where the product units have been detached from the tree and undergo specific treatment, depending on the product type. Since there are many finishing possibilities and not just every product can follow the same path, the process becomes highly complex.

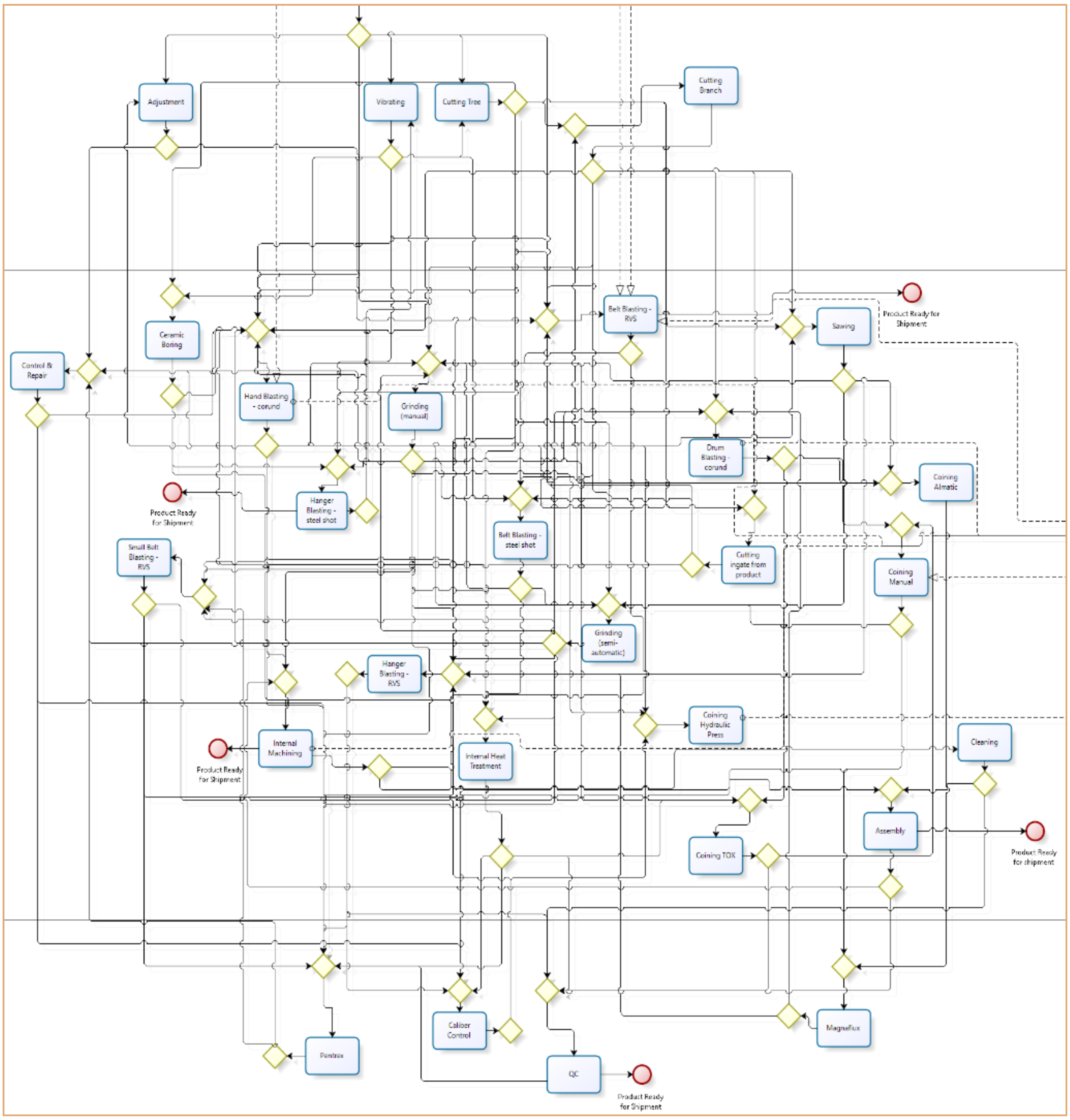

Figure 6 – Finishing & Control Department CZ, high/medium complexity

For a clearer representation of *Figures 4 – 6*, see *Appendix D.* As regards the complexity, it was not the aim of this research to give a solution for this complexity, but the visualization of the complex process indicates that it is highly important for CIREX to manage operations properly and to make well-considered decisions regarding production and specifically planning. If not managed accordingly, the complex production process could result in inefficient product flows and could cause bottlenecks. This research attempts amongst others to contribute to the improvement of CIREX's production data and capacity planning. Although it does not directly provide a solution for the complex production process, it can contribute to management and decision making regarding production: when the data in the ERP system becomes more accurate, management will be better able to make well-founded decisions. Besides that, in order to improve the production process and understand what the consequences of certain adjustments are, it would be useful for the company to have insights in for instance utilization of resources. The planning tool (*Chapter* 5) is a first step towards obtaining such insights.

Product Variety

As mentioned before, it can be imagined that the higher the complexity, the bigger the need for accurate planning to ensure a smooth and efficient flow of units through the process. The large amount of flows in the later stages of the process namely shows that there is an extensive product variety. Increasing product variety might have a strong impact on a firm's business operations (Park et al., 2004). Furthermore, having in mind the possible future changes in demand, product variety management and manufacturing flexibility become important concepts.

From the literature review (*Theoretical Framework, Question 3*) it became clear that indeed a company has to consider several aspects when taking on a high level of product variety. Since CIREX already includes a relatively high level of product variety, which is especially visible in the later stages of the production process, it is important for the company to adopt a strategy that enables to manage this product variety. Focussing on manufacturing and planning; according to Park et al. (2004), management has an important role in making the entire production system flexible both by ensuring that production scheduling, equipment setup, and maintenance policies support the effective utilization of flexible tooling, and by training workers in multiple skills so they can handle the demands of higher variety. The literature review also showed that it is important to manage resource utilization effectively for creating sustainable competitive advantage and enhancing productivity (Elmaraghy et al., 2013). This in combination with the possible impact of product variety on planning activities that were mentioned in the literature review, confirms the assumption that accurate planning of production, capacity and resources becomes crucial with a high level of complexity and product variety.

For the future, CIREX should consider the relevant costs, functions and operations to decide to what extent product variety should be increased in order to anticipate on the changing markets. Namely, as was mentioned in the literature review, beyond a certain level, increased product variety actually results in lower sales (Wan et al., 2012). Thus, for CIREX it will become important to create a strategy that enables them to anticipate on changing demand and market shifts in a beneficial way. The capacity planning tool that was designed as part of this research provides only some insights into this.

Conclusion

Answering the research question '*How can a business process model be made of CIREX's production process?*' required an understanding of the different production steps and the possible flows between them, regardless of the product that is processed. With the use of BPMN, it was possible to visualize the production process. The process model showed a variation in complexity across the production departments. By relating theory to practice, it could be concluded that the complexity is a consequence of a high level of product variety, which can have an impact on amongst others manufacturing and planning. The complexity suggests the need for proper planning, and with the prospect of shifting markets, product variety might become an even more important aspect for CIREX to consider.

4. A Method: Defining & Implementing Production Data

In this chapter, an answer is formulated on research question four: '*How can the data related to the production steps be best defined so that it ensures a consistent and realistic application when implemented in the ERP system and used for planning?*'. A step-by-step description is presented below that shows how the answer on this research question was obtained. The answer relates to the first core problem.

The Problem of Undefined Data

First, it was necessary to get an impression of what the production data that is currently stored in the ERP system actually says, and to check if it corresponds with reality. In order to do so, a high volume product was selected from which the different resource steps and related data were analysed. The principal expected the data to be inaccurate and inconsistent.

In the ERP system, for each of the resource steps a time can be found that shows the time per tree that is needed to complete a specific resource step. These times are used for amongst others costprice calculations. With 'relevant data', the times that belong to the different production steps, are meant. What exactly this time refers to, is unknown: it is most likely an estimation that was once made based on expertise and experience. By actually measuring the time it took per resource step to complete a tree (with a stopwatch next to the machine, in the factory), and comparing it with the system time, a first impression was obtained regarding the extent to which the system time represents reality. It became clear that part of the system data deviated from the measured data. For some of the resource steps, the measurements corresponded with the actual machine time, while for other resource steps the system time was much less or more than what was measured.

Besides that it became clear that the data is inconsistent, the importance of formulating definitions for each of the resource steps was affirmed as well: when performing measurements, questions were raised such as 'Should the loading and unloading time be included as well, or should only the time the tree is processed by the machine be measured?' and 'How do we include an amount of standard losses in the time, that would make the data more realistic?'.

Thus, formulating definitions for the resource steps appeared to be crucial, especially if in the future the data from the ERP system is supposed to be used for planning as well. The method that is proposed in this chapter has the aim of ensuring that the relevant data corresponds with reality and that the data is gathered, implemented and used in a consistent way.

An Overview of The Method

After getting a first impression of the current situation, a method for defining the data and applying the definitions was devised. See *Figure 7* for an overview of the method. In the following sections the steps will be explained in more detail.

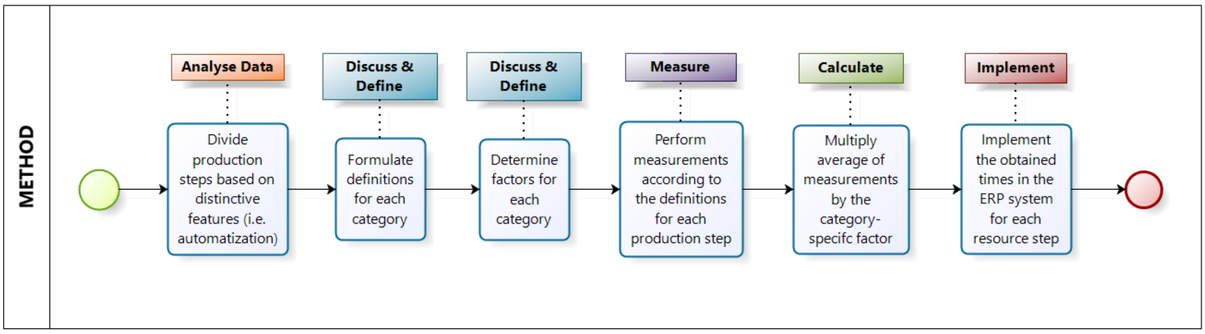

Figure 7 – Method for Defining & Implementing Data

Steps 1 & 2: Categorization & Defining

Instead of defining each of the resource steps seperately, the approach consisted of categorizing them: when looking at the level of automatization of the different processes and the type of resources, it appeared to be possible to divide the resource steps in groups. For each category, it was described what should be included when measuring the time, and what aspects of the operation are expected to cause losses. To make it easier to refer to different time-related terms, first, definitions were formulated for these terms (*Table 5*).

Time-Related Term	Definition
Machine Cycle Time	The actual time it takes for one machine to complete all of its operations on one piece/product/item, applicable for both single-piece and batch processing (Hamel, 2013). Load, unload, and changeover times excluded.
Load & Unload Time	Time that is needed for loading the unit in the machine, and unloading.
Manual Operating Time	The time the operator is busy with carrying out the tasks that are required to complete the operation and that cannot be carried out within the machine cycle time. These manual tasks are indispensable to fully complete the production step: thus, belong to the tasks that were given to the operator.
Total Effective Cycle Time	The time that includes all the handlings, machine and/or manual, that are necessary to complete the operation of a specific resource step.
Losses	Time that is lost because a machine or operator is inactive. Example of losses: planned downtime, breakdown, set-up, adjustments, idling, minor stoppages, reduced speed, quality losses, reduced yield, shift change, or breaks.

Table 5 – Definitions of Time-Related Terms

Table 6 (next page) presents the different categories and related definitions. If for example a resource step has the characteristics of being almost continuously performed by a machine with relatively little interference of human operators, the resource would belong to Category A. In the description of Category A, it is prescribed what measurements should be done to obtain a representative cycle time.

Step 3: Obtaining the Factor for each Category

A factor is assigned to each category. With factor, an amount is meant with which the measured time will be multiplied. In the row 'Impact on Cycle Time & Considerations' (*Table 6*), the reasoning behind the category-specific factor is explained. When the total effective cycle time of a resource step is measured, this time has to be multiplied by the factor to obtain a realistic time that includes an amount of unavoidable losses. See *Appendix E* for a visualization of the interpretation of time in general and for each category.

Measurements and calculations were done for selected resource steps from each category, to decide what would be representative factors. Below, based on an example, a step-by-step description is provided of how the factors were determined.

The resource step 'Vibrating' (Finishing Department), belonging to Category C, is meant to vibrate the ceramics from a tree. The tree refers to a set of products that is attached to a tree trunk. In this stage of the production process, the tree consists of steel material. The ceramic shell is removed. Besides the machine that is operating, additional tasks belong to this resource step, as is distinctive for Category C (see *Figure 8*).

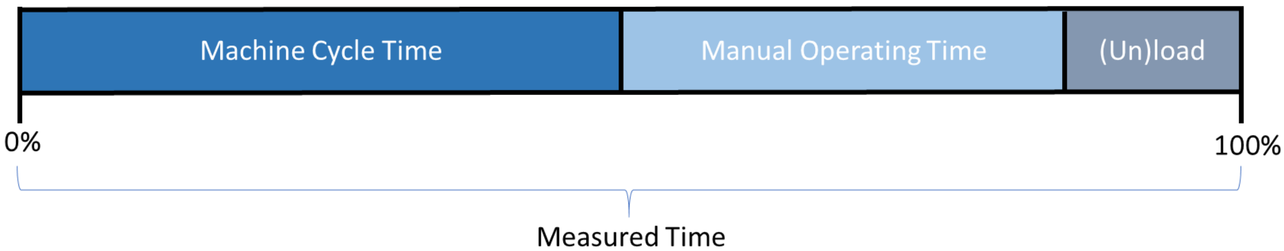

Figure 8 – Division of Time, Category C

In case of Vibrating, first, a batch of trees has to be picked up from the storage location. Next, the end parts from the tree, to which no products are attached, have to be removed: the tree has to be moved manually from the pallet to the sawing machine. After sawing, the tree has to be manually moved from the sawing machine to the vibrating machine. When the machine is finished with vibrating, the tree has to be moved manually to another pallet. Furthermore, the vibrating has to be cleared from redundant ceramic material. When the batch of trees is complete again, the trees can be moved to the next process step.

Category A			
Description	The machine cycle time covers the largest part of the total effective cycle time. The time for loading and unloading is relatively so small, that these can be skipped for measurement. No additional manual operating time has to be considered. To obtain the total effective cycle time that will be used for calculations, the machine cycle time should be measured.		
Impact on Cycle Time & Considerations	Since the manual operating time is relatively small, it is expected that most of the losses are caused by or relate to the machine. Losses include for example minor stoppages, breakdowns, and reduced speed. In this case, machine operations are considered to be more reliable than human operations*.		
Example Resource Steps	Wax Injection & Tree Construction (NL)	*Factor*	1.15
Category B			
Description	This category differs from Category A in the sense that loading and unloading will relatively take more time (each unit has to be separately placed inside the machine, the machine can't run continuously). To obtain the total effective cycle time, the time should be measured starting with the manual task that initiates the operation until the moment everything is ready for the next operation, thus including the machine cycle time and loading/unloading.		
Impact on Cycle Time & Considerations	Although more dependent of human handling, resource steps that belong to this category are not expected to result in many losses caused by manual operating inefficiencies: loading and unloading is a straightforward task with little variation. However, due to an operator being more actively involved, these resource steps are expected to result in more delays than the more automated processes.		
Example Resource Steps	Automated Waterjet	*Factor*	1.20
Category C			
Description	This category involves resource steps that are comparable to category B, but vary in the sense that for category C more additional manual tasks are involved. The time should be measured of the machine cycle time, loading/unloading, and the manual tasks that are part of the resource step: from the moment the unit enters the operating zone (the area in which all the tasks for this particular resource step are done), until the moment this unit leaves the zone again, time should be measured. All inefficiencies and losses should be excluded: it should only cover those operating tasks crucial for completing the resource step.		
Impact on Cycle Time & Considerations	Some tasks will be carried out within the machine cycle time, but if not managed properly, no time can be gained by operating simultaneously, resulting in losses. Furthermore, both errors related to the machine and delays related to manual operating, can result in lost time.		
Example Resource Steps	Vibrating, Dewaxing	*Factor*	1.25
Category D			
Description	Resource steps that belong to category D completely consist of manual tasks; no machine time. To obtain the total effective cycle time, the time should be measured from the moment the operator starts with the first manual task until the moment the operator completes the operation, thus until the item has fully undergone the resource step.		
Impact on Cycle Time & Considerations	Not dependent of machines, thus no losses such as breakdown, idling and stoppages. Equipment is involved that could have failures. Besides that, losses that can have a bigger impact on time are the work speed of the operator, breaks (all tasks of operator stop; no machine that can run in the meantime), and quality losses (more variation in the result of the operation than with a machine).		
Example Resource Steps	Waterjet (manual), Cutting Tree, Repair & Control	*Factor*	1.30
Category E			
Description	Resource steps belonging to this category have a maximum capacity: for example in the ceramic department, the machines could process a relatively large amount of products per time unit, but because of other resource steps in this department, that have a limited capacity, this is not relevant. Therefore, it would be more realistic to consider the whole department instead of each resource step. When maximum capacity is known for the combination of resource steps, determining and applying a factor is less practical.		
Example Resource Steps	Casting Department, Ceramics Department		

Table 6 – Categories, Descriptions and Factors

*Adapted from "Advantages and disadvantages of automation" by Groover, M. P. (2019) in Encyclopaedia Britannica, https://www.britannica.com/technology/automation/Advantages-and-disadvantages-of-automation

When time is properly managed, some of these manual tasks can be carried out simultaneously. Therefore, to determine how long the resource step takes, not the length of all the separate tasks has to be measured, but the overall time that is involved with the resource step. Thus, to obtain the total effective cycle time, the time should be measured starting with the manual task that initiates the operation until the moment everything is ready for the next operation. All the manual tasks that are part of the process step should be included, and all the time losses and inefficiencies should be excluded. Thus, measurements are invalid if they include time losses caused by for instance machine failure. These losses will be represented by the percentage that will be added to the measured time.

To determine the factor with which the measured time should be multiplied, a realistic percentage has to be established that captures the likely losses. It is important to balance between on the one hand including enough losses in the 'time' to avoid an unrealistic planning, and on the other hand adding too much time to the measured time so that bottlenecks cannot be recognized anymore: using a too high factor to calculate the standard time would give the impression that planning is always met, while in reality a lot could be improved.

For determining the factor, the average can be taken from the actual amount of processed trees over a representative number of shifts. Then, the actual amount of processed trees per shift can be compared to the amount of trees that could have been produced per shift using the measured time. Both can be converted to time per tree. The gap represents the losses, caused by for example machine failure or interruption of manual tasks. In case of Vibrating, see *Table 7*, the resulting factor is 1.27.

Resource Step	Category	Measured Time	Real Time	Calculated Factor
Wax Injection & Tree Construction (NL)	A	28.5	33	1.16
Waterjet (automated tree)	B	15	18.2	1.21
Vibrating	C	3.33	4.25	1.27
Waterjet (manual)	D	23	29.82	1.30

Table 7 – Calculated Factors for example Resource Steps

The examples in *Table 7* give an indication of what could be factors that result in a realistic time for the different type of resource steps. These factors cannot blindly be used, but serve as a starting point to determine suitable factors. A group discussion was necessary to come to an agreement regarding the factors and approach. During this discussion in which five CIREX employees from different departments (planning, IT, production) participated, first the method was proposed by means of a presentation. Based on the expected impacts of losses on time, the example calculations, and the outcomes of the discussion, the factors as presented in *Table 6* were the result.

Steps 4, 5 & 6: Application of The Definitions

After obtaining the factors for each category, each of the resource steps was categorized, also the ones that were not included in the example. The remaining part of the method can be applied as follows (see also *Figure 9*):

- For the particular resource step (product-related), measure the total effective cycle time according to the category definition (*Table 6*). The more measurements, the more realistic the measured time will be. In case the resource step processes batches of trees, time should be measured until the batch has been processed: divide measured time by batch size to obtain time per tree.
- Calculate the average time per tree over the total measurements for the resource step.
- Multiply the average measured time with the factor specific for that category. After multiplying with the factor, the time represents the unavoidable losses as well.
- The resulting time is ready to be implemented in the ERP system, and can be seen as 100% from that moment on.

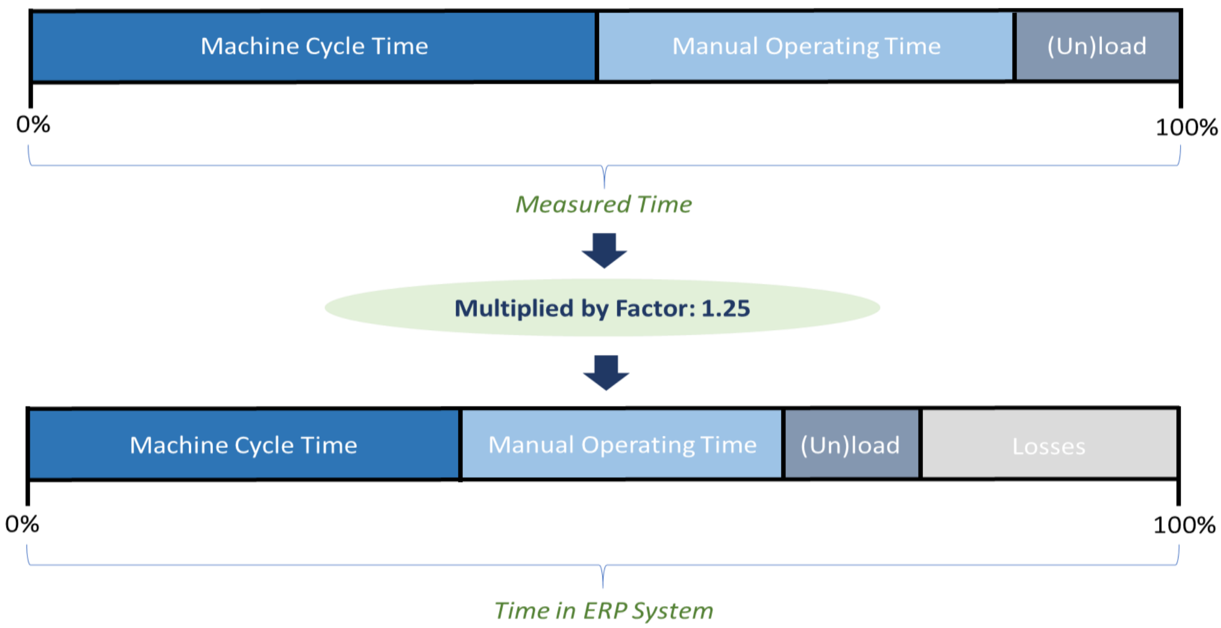

Figure 9– Example of Method Applied to Category C

Advantages of The Method

Categorizing the resource steps, providing these with definitions, and applying factors has several advantages; see the list below. These advantages show that the implementation of the approach is worthwhile.

- From the moment the time is stored in the ERP system, it can be seen as 100%: it can be directly used for planning, without having to take into account possible losses, since this is already included in the time as it is stored in the ERP system.

- Everyone uses the data in the same way: no different interpretations which would result in inconsistent planning.
- With the use of the definitions, it is clear what the times in the ERP system refer to.
- With the use of the categories, it is easier to determine realistic times for resource steps for which no historic data of real production exists. If it is known to which category the resource step belongs, and time can be measured, the factor can be applied and a realistic time is obtained. This is based on the assumption that when resource steps belong to a similar category, the nature of the process is comparable and a similar type of losses is expected to be involved.
- If the well-defined times are used for planning and it appears that planning was not actually met, this could indicate a bottleneck and shows that it would be wise to find out the underlying cause.

Conclusion

To answer the research question '*How can the data related to the production steps be best defined so that it ensures a consistent and realistic application when implemented in the ERP system and used for planning?*', the creation of a method appeared to be most appropriate. Summarizing, the method includes the following steps:

1. Divide production steps into categories. Each category should have distinctive features (i.e. automatization of the operation).
2. Formulate category-specific definitions that describe how measurements should be done and what these measurements refer to.
3. Determine appropriate factors for each category, taking into account the category-specific features that result in relatively more or less losses.
4. Perform a representative amount of measurements for the total effective cycle time of each production step, following the category-specific definition.
5. Calculate the average time per unit (tree) over the total measurements and multiple this with the category-specific factor.
6. Implement the obtained time for the particular production step in the ERP system.

Although during the group discussion with the CIREX employees, everyone agreed on the necessity of the method, some concerns were expressed. These included amongst others that not every resource step can be easily measured and that the factor may not be representative for all the resource steps within a category. Nevertheless, times in the ERP system cannot be properly used as long as there are no general definitions and descriptions of what the time refers to. Thus, at this point, the company needed to have a basic approach that could serve as a starting point. The method is a first step towards integrating accurate data, and ensuring that decisions are not solely based on expertise, but on this well-defined, realistic data.

The company's future aim is to gather measurements for each resource step according to the definitions, make the factors more refined when necessary, and implement all the updated times in the ERP system so that these can be used for planning. This is outside the scope of the research, due to time limitations. However, the outcomes of this part of the research were as much as possible implemented in the design of the dashboard.

5. Creating a Production Tool & Dashboard

The last research question, ‘*How to make a production dashboard that provides CIREX with insights that can be used for capacity planning?*’ will be answered in this chapter. The answer on this question contributes to solving the second core problem.

KPIs Selection

To ensure that the dashboard will meet the principal’s needs, first, the requirements of the dashboard had to be determined. This includes the selection of relevant KPIs and other types of information that are desired by the company. The method as proposed by Behrens & Lau (2008), see *Theoretical Framework (Figure 3)*, was used as a guide for the KPI selection, since this appeared to be a straightforward approach that can be quite easily applicable. Furthermore, the literature study showed that for a proper KPI selection it is most important to consider the specific company’s needs. Thus, an interview (semi-structured) with the principal served as the main input for the selection of KPIs and for determining the requirements of the dashboard. For the interview questions, see *Appendix F*.

Following Behrens & Lau (2008), first, information was obtained on the company’s specific targets in relation to the topic of capacity. In line with the core problem and research goal, the main target can be denoted as ‘managing capacity’. From the problem context and previous gathered information, some auxiliary targets were formulated: ensuring that the resources are efficiently used and that production is flexible enough to handle varying demand are important company targets that are related to managing capacity. A number of factors can influence these targets, and according to the method by Behrens & Lau (2008), next step is to collect the influencing factors. Since there exists a large number of production KPIs that are somehow related to these targets, a pre-selection was made based on the findings of the literature study and the suggestions of the principal. *Figure 10,* shows the targets and

●	*Strong Influence*
◒	*Medium Influence*
○	*Weak/No Influence*

			Production									
			Machines						Operators		Others	
Main Target	***Auxiliary Targets***	KPI	*Resource Utilization*	*Performance*	*Quality*	*Overall Equipment Effectiveness*	*Throughput*	*Machine Downtime*	*Availability of Employee*	*Productivity of Employee*	*Inventory Turns*	*Manufacturing Cycle Time*
Manage Capacity	Efficient Use of Resources		●	●	●	●	●	●	●	●	○	◒
	Flexibility in Production		●	○	○	◒	◒	●	●	◒	●	○

Figure 10 – Classification of Target Influencing Factors

factors. The factors were classified based on the level of influence the factor has on the named target. The classification suggests which KPIs should be selected (KPI with highest scoring). For a description of the KPIs that are presented in *Figure 10*, see *Appendix G*.

From the interview the principal's main request appeared to be the visualization of resource utilization in case of the current demand and possible future demand scenarios. According to the principal, the other KPIs were less relevant or useful to include in the dashboard. For example the Quality KPI is already considered as part of the input data: the company is used to add a certain scrap rate to the demand, before manufacturing of the product even started. Therefore, the company does not store data that indicates quality loss and applying a quality measurement would be less useful. Something similar applies for the Performance KPI: the performance of the resources is already included when applying the factors to the measured times (*Chapter 4*). Since Quality and Performance are part of the Overall Equipment Effectiveness KPI, it was decided to omit this KPI as well. Furthermore, the principal indicated that the dashboard should be approached from a larger perspective: no KPIs should be displayed that result in an abundance of detailed information, such as the Machine Downtime KPI or the Inventory Turns KPI. Thus, it was determined that the utilization of resources as main output of the dashboard would provide sufficient insights for the company.

Dashboard Objectives

Besides monitoring current performance, the dashboard designed for this project also visualizes the results from the planning tool that is incorporated. The planning tool was one of the other elements requested by the principal: the final dashboard should not only show the current situation, but should also have the option to change demand in a hypothetical way. When a possible scenario is created, it can be determined what the impact of change in demand would be on the utilization of the resources. The option to adjust the number of machines and/or the number of employees for each resource was indicated as a useful feature of the tool as well. With this option, it would become possible to discover which changes in capacity are necessary to reach demand in case of the fictional situation.

It was mentioned in the *Theoretical Framework (Question 6)* that the type of dashboard can influence the way information is presented. The dashboard can be operational, tactical or strategic. Based on the findings of the literature study and the purpose of the dashboard as described above, the dashboard can be seen as strategic. According to Eckerson (2005), a strategic dashboard monitors the execution of strategic objectives, with the goal to align the efforts carried out by different areas of the company with those strategic objectives. Durcevic (2018) states that a strategic dashboard is a reporting tool for monitoring the long-term company strategy with the help of critical success factors. Within this project, the strategic objective was seen as the goal to manage the utilization of resources long-term.

However, the dashboard slightly deviates from a typical strategic dashboard: as a result of the KPI selection, the dashboard only shows a limited number of KPIs. Besides that, it does not only monitor current data but includes the option to simulate as well (planning tool). Nevertheless, all included features are aimed at supporting long-term strategic decision making and the dashboard will mainly be used by management professionals. Thus, a strategic dashboard seemed to be appropriate.

Altogether, combining the principal's requests and the outcomes of the literature study, the following list of main requirements for the dashboard was drawn up:

- Visual components are used to show the utilization of the resources in a unified view.
- With the planning tool, predictive scenarios should be created that show the impact of possible change in demand and change in capacity.
- The principal and other interested employees of CIREX should be able to easily understand how the tool can be used and how the dashboard can be interpreted.
- It should require little effort to deploy, adjust and maintain the input data.

Design of The Dashboard

After having determined the dashboard objectives, the dashboard was designed. Microsoft Excel was used for the design, as was requested by the principal. Since CIREX often uses this software, it was expected that an Excel dashboard could be more easily implemented than a dashboard created with software that is unknown to the company. Below, a general description of the design of the dashboard will be given. Illustrations and a detailed description of the design can be found in *Appendix I*. Some parts of the illustrations have been covered because of confidential company data.

Data Model

To illustrate where the data that is used for the design of the dashboard comes from, how it is used and how it contributes to solving the core and action problems, a conceptual data architecture was created, see *Figure 11* (next page). The Archimate modelling language was used to create the architecture. See *Appendix H* for an explanation of the elements that were used in the data architecture.

To get a better understanding of which data was exactly needed, a conceptual data model was made. According to Sherman (2015), a conceptual data model is amongst others a tool to define the data requirements scope. This is in line with the purpose of the data model for this project: creating an overview of the data that was required for the design of the desired dashboard. Although in the literature different interpretations of a conceptual data model can be found, the conceptual data model always includes entities and the relationships between them. These relationships can be with or without cardinality, and attributes do not necessarily have to be defined. It was decided to include cardinality and the attributes as well. *Figure 12* (next page) presents the data model.

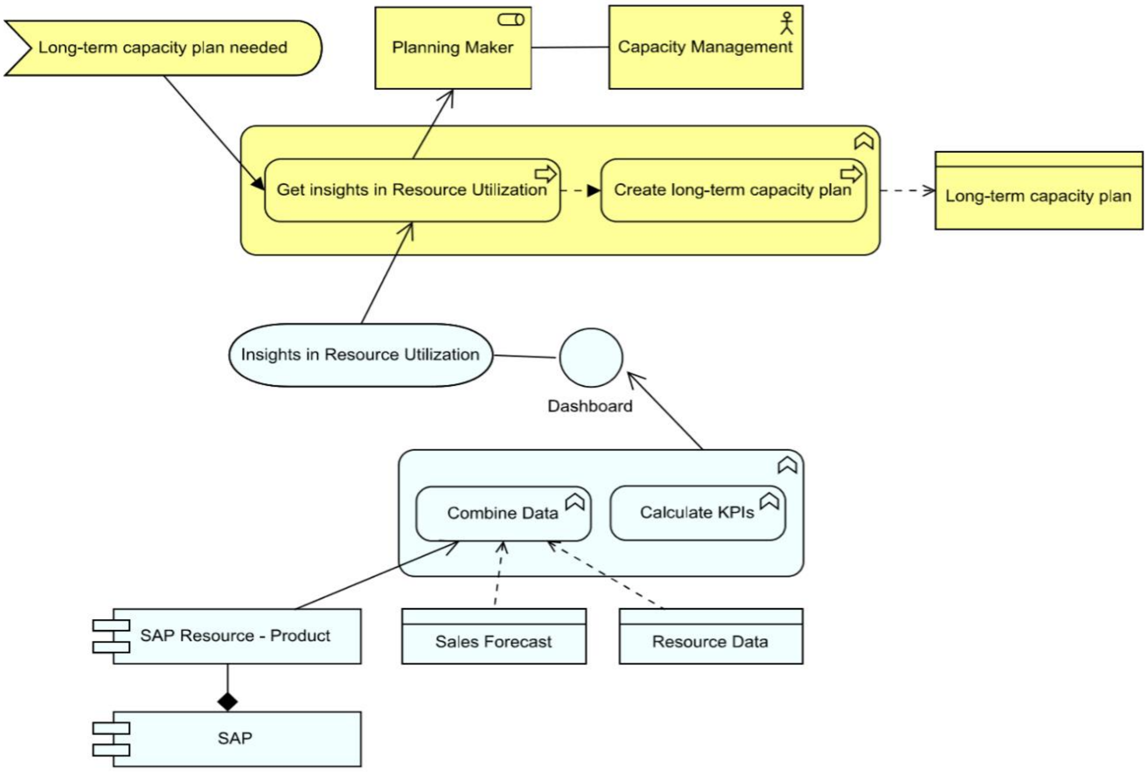

Figure 11 – Conceptual Data Architecture

The entities in the conceptual data model represent the tables that were required for the design of the dashboard. The entities 'Product', 'Product_Resource', 'Resource', and 'Sales' represent the input data. The tables 'Product_Resource_Times' and 'Times' were the result of combining the input data and performing calculations. Below, it will be described in more detail how the data in the different tables was used for the design of the dashboard.

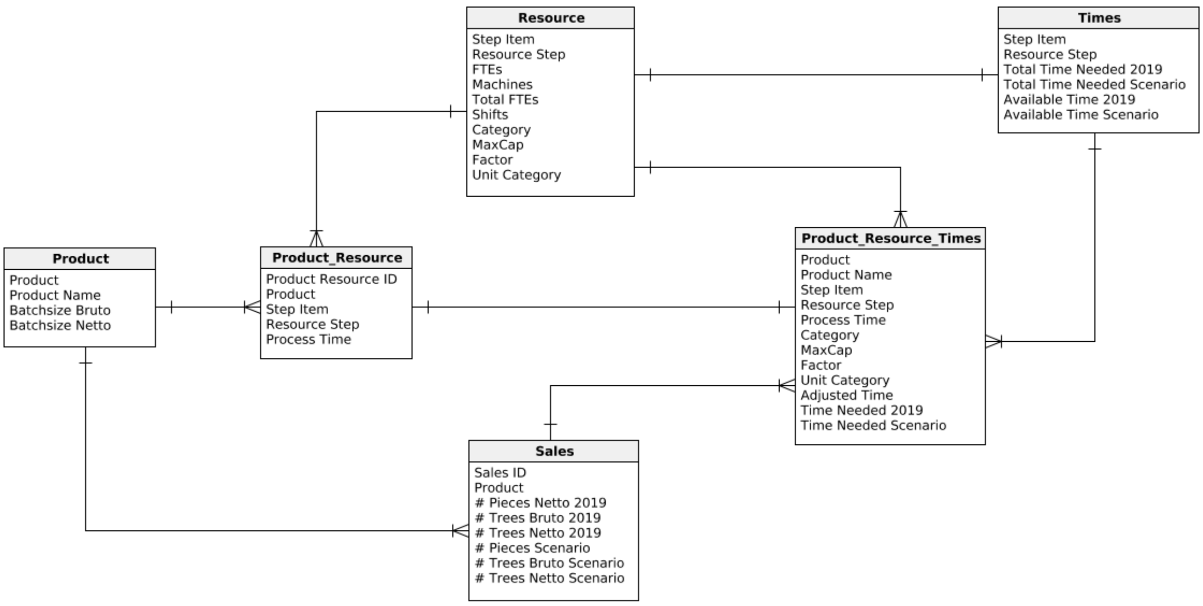

Figure 12 – Conceptual Data Model

Input Data

To retrieve the desired output, a variety of input data was required. This input data is retrieved from different sources: data was selected from the ERP-system, from a sales document and from the resource document that was created during this project, as was presented in *Figure 11* as well.

The data in the 'Product' table was retrieved from the ERP system. Although the conceptual data model in *Figure 12* shows two separate tables ('Product' and 'Product_Resource'), all the ERP system data was merged into one table. The table contains all the products that are stored in the ERP system, together with the resource steps that this product follows during production. These resource steps have a specific code which can be found in the column 'Step Item'. The columns 'Batch Size Bruto' and 'Batch Size Netto' represent the amount of products attached to one tree, with and without an amount of scrap included. This batch size is product dependent. The 'Process Time' that is currently stored in the ERP system, represents the time in hours that it takes for the resource step to process one tree. Times in this column were not retrieved according to the method presented in *Chapter 4*; it is the original ERP system data. Because of the time limit, it was not possible to gather the data by following the method. Thus, these times are not yet accurate enough to provide realistic results, but are assumed to be suitable enough to show how the data can be used to get insights in capacity planning. When CIREX has obtained the correct times, the table can be easily updated. See *Appendix I Figure 1* for an image of the table.

A list of products along with the sales number for each product in 2019 ('# Pieces Netto 2019') served as input for the 'Sales' table. For further calculations, it was necessary to convert the amount of ordered pieces (separate products) into trees (batch). Besides the actual input data, the table also includes columns with scenario sales data: in the tool, which will be presented later on, the user of the dashboard can enter fictional sales data. To store all the sales data in one place, this scenario sales data was added to the 'Sales' table. For detailed information on calculations, see *Appendix I, 'Sales Table'*.

The 'Resource' table contains information on the different resource steps that are part of CIREX's production process. This table was created after the method from the previous chapter was established. It contains information such as the amount of machines and FTEs that are currently being used per shift and the category in which the resource step was classified together with other relevant data (e.g. Factor, Maximum Capacity). See *Appendix I, 'Resource Table'* for details and remarks.

Combining The Data

After gathering all the input data, this data had to be combined and calculations had to be performed. The sheet 'Combined Data', see *Appendix I, Figure 4,* stores for each product from the 'Sales' table, the relevant ERP system and resource data, such as the resource steps that the product follows and the category-specific information. Besides that, columns were added to the table that calculate different times. Amongst others the 'adjusted time' was determined, which applies part of the method from

Chapter 4: the process times are multiplied by the category-specific factor, to include an amount of losses. See *Appendix I, 'Product_Resource_Times Table'* for details and suggestions for future use. The adjusted time is multiplied by the demand that is retrieved from the 'Sales' table, which results in the time that a resource steps needs to meet the demand of a specific product, in the time unit of one year.

However, it is not the time needed per product that is of interest, but the time needed per resource step. Therefore, another table was created that calculates these times: *'Times Table'*, see *Appendix I Figure 7*. In the columns 'Total Time Needed 2019' and 'Total Time Needed Scenario', the total amount of time is determined that each resource step needs to produce all the ordered products. Furthermore, the time that is actually available is calculated and stored in columns 'Available Time'. This available time depends on the amount of machines/FTEs that are available, and the number of shifts.

See *Table 8* for an overview of the KPIs, the columns that contain the KPI data, and the description/calculation of the KPI. Since the resource utilization is a result of step-by-step calculations that depend on certain conditions, it is not presented as a simple formula in *Table 8.* Namely, to combine the input data and retrieve the desired output data, several macros had to be created in Visual Basics (the programming language of Excel). Also Excel functions were used. Detailed explanation of the calculations, codes and functions can be found in *Appendix I, 'Product_Resource_Times Table'*.

KPI	Corresponding Data	Description
Resource Utilization Current	Times Table: Total Time Needed 2019 (h)	Total amount of time needed for each resource step to produce current demand
Resource Utilization Scenario	Times Table: Total Time Needed Scenario (h)	Total amount of time needed for each resource step to produce scenario demand
Available Time Current	Times Table: Available Time 2019 (h)	Active weeks per year * Active days per week * Hours per shift * Shift current * FTE or Machine current
Available Time Scenario	Times Table: Available Time 2019 (h)	Active weeks per year * Active days per week * Hours per shift * Shift scenario * FTE or Machine scenario

Table 8 – Overview KPI, Corresponding Data & Description

The Tool

In the tool, see *Figure 13* (next page), the user can make adjustments according to his needs. See *Appendix I, Figure 9/10* for enlarged images of the tables. In the table on the left, a list is provided with all the products that can be ordered. The third column in this table shows the current demand (sales of 2019), which cannot be changed. The fourth column shows the scenario demand. Production can be influenced if demand changes. The tool makes it possible to simulate a scenario in which demand has changed and analyse the effects this change could have on the utilization of resources. In the fourth column of the table, all cell values can be changed on condition that the total scenario demand is equal to the total current demand. With the information that is provided by the tool, the user can check himself whether the amounts are equal. In addition, when clicking on the 'Show Dashboard' a warning will appear if the amounts are not equal, see *Appendix I Figure 10* .

Product	Product Name	Current Demand (Trees)	Scenario Demand (Trees)
		3536	536
		1075	250
		2196	196
		1	1
		2	2
		10	10
		3	3
		4	4
		15	15
		2	2
		5	5
		0	0
		0	0
		4	4
		4	4
		16	16
		0	0
		1	1
		0	0
		4	4
		0	0
		1	1
		0	0
		0	0
		0	0
		0	0
		42	42
		33	33
		0	0
		0	0
		70	70
		340	1000
		13	13
		110	600
		107	450
		2	2
		2	2
		1	1
		0	0
		55	55
		34	34

Total Current Demand	84340
Total Scenario Demand	84340
	0

Show Dashboard

Set as Default

Marked cells can be adjusted

CIREX Foundry NL	Step Item	Category	Machines	Total FTEs	Shifts
Ceramics Department	NLAGV01	E	1	3	3
Casting - batch hal 1	NLCAS01	E	1	3	3
Casting - batch hal 2	NLCAS02	E	1	3	3
Dewaxing	NLCER29	C	3	2	3
Vibrating	NLFIN01	C	2	3	3
Belt blasting - steel shot	NLFIN02	C	1	0.5	3
Hanger blasting - Steel shot	NLFIN03	C	1	0.5	3
Waterjet (manual)	NLFIN04	D	1	1	3
Cutting tree	NLFIN05	D	1	1	3
Waterjet (automated tree)	NLFIN06	B	2	1	3
Cutting tree (Uni 1)	NLFIN09	D	1	1	3
Repair and control	NLFIN50	D	1	1	3
Wax Department	NLWAX00	A	8	4	3
Wax tree assembly	NLWAX10	D	1	2	3

CIREX Foundry CZ	Step Item	Category	Machines	Total FTEs	Shifts
Casting Department	CZCAS02	E	1	4	3
Ceramics Department	CZCER01	E	1	3	3
Dewaxing	CZCER60	C	2	1	3
Vibrating	CZFIN01	C	1	1	3
Cutting tree	CZFIN02	D	1	1	3
Cutting branch	CZFIN11	D	1	1	3
Cutting ingate from product	CZFIN12	D	1	1	3
Grinding (manual)	CZFIN20	D	2	2	3
Grinding (semi-automatic)	CZFIN21	B	2	1	3
Hand blasting - Grittal	CZFIN27	D	1	1	3
Hand blasting - corund	CZFIN30	D	5	5	3
Hanger blasting - Steel shot	CZFIN31	C	1	0.5	3
Hanger blasting - RVS	CZFIN32	C	1	0.5	3
Belt blasting - steel shot	CZFIN33	B	1	0.1	3
Belt blasting - RVS	CZFIN34	B	3	0.9	3
Small belt blasting - RVS	CZFIN35	B	1	0.1	3
Drum blasting - corund	CZFIN36	B	2	0.2	3
Internal heat treatment	CZFIN40	E	1	1	3
Control and repair	CZFIN50	D	30	30	1
Coining (manual)	CZFIN60	D	1	1	3
Coining Tox	CZFIN61	C	1	1	3
Coining Almatic	CZFIN62	C	3	2	3
Coining Hydraulic press	CZFIN63	C	1	1	3

Figure 13 – The Tool

In the remaining tables on the 'Tool' sheet, adjustments can be made regarding the available machines, FTEs and shifts for each resource step, both for CIREX Foundry NL and CIREX Foundry CZ. These changes influence the available time per resource step. Only the marked cells can be adjusted. For further explanation and remarks, see *Appendix I, Tool.*

When the data in the tool is all set, the button 'Show Dashboard' can be clicked on. This will make sure all the data in the other sheets is updated, see code in *Appendix I Figure 11*. After that, it will automatically show the Dashboard. When clicking on the button 'Set as default', the changes that were made for a scenario will be reversed, and the data from the current situation will be returned.

The Dashboard

Finally, when the user made the desired adjustments in the tool, the dashboard will appear. A part of the dashboard is presented in *Figure 15* (next page), namely the part that shows the results of the CIREX Foundry NL resources. For the CIREX Foundry CZ resources, see *Appendix I Figure 12.*

The graphs show the results of the selected KPI, namely the resource utilization. Current situation and scenario can be compared for each resource step. Usually, the resource utilization is presented as a percentage of the available time. However, it was indicated by the principal that it would be more useful to present the utilization in hours, and the available time as a separate line. Advantage is that it shows the actual data instead of an unspecified ratio. When the scenario available time of a resource step has not been adjusted, it will be equal to the current available time. This explains why the current available time is not always visible in the graphs. *Figure 15* (next page) shows the dashboard in which a few changes were made for the scenario. See the legend in *Figure 14* for a better understanding of the dashboard.

To make it possible for the user to directly see which amounts of FTEs, machines or shifts are related to the resources, tables were added to the dashboard that provide this information. In this way, switching between sheets can be avoided.

The main requirements, presented at the beginning of this chapter, were considered during the design of the dashboard. The design is made in such a way that the input data can be changed in the future without resulting in an unusable dashboard. Furthermore, efforts have been made to make the dashboard user-friendly. Due to the large amount of resources, it was difficult to present the results in a unified view. This has been taken into account in the layout of the dashboard. The requests of the principal have been included as much as possible.

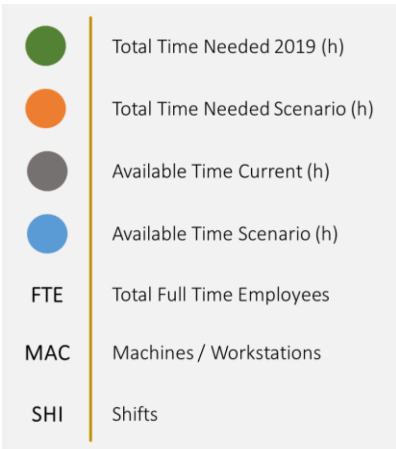

Figure 14 – Legend Dashboard

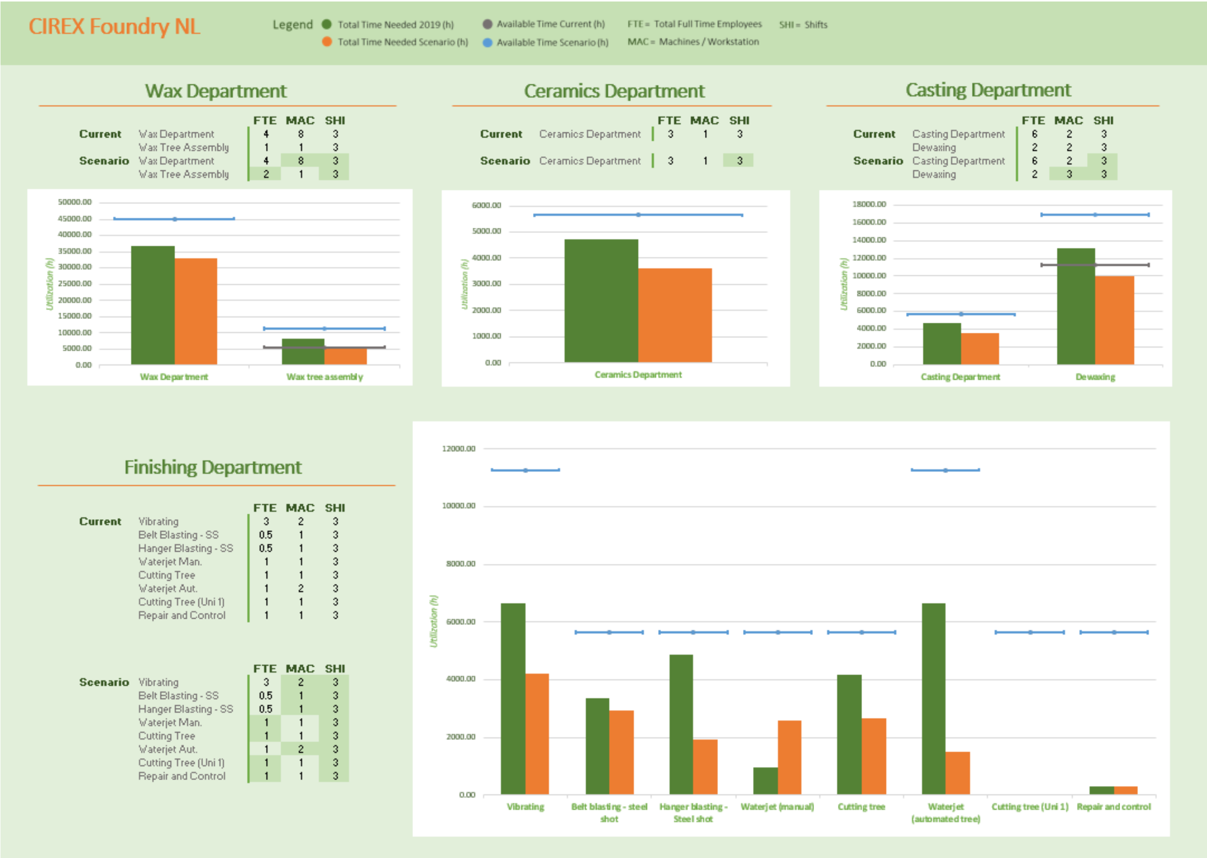

Figure 15 – Part of the Dashboard

Conclusion

This part of the project aimed at answering the following question: '*How to make a production dashboard that provides CIREX with insights that can be used for capacity planning?*'. To get an answer on this question, a first step was to determine which KPIs would be most useful to present on the dashboard. Results of the literature study in combination with the results from the interview with the principal led to the selection of one main KPI, namely the resource utilization. Besides that, displaying information such as the number of machines, FTEs and shifts that are available per resource step, was indicated by the principal as useful as well.

To organize the design of the dashboard and to get a clear overview of all the data that would be needed to obtain the desired output, a conceptual data architecture and model were created. The different tables that are presented in this data model had to be obtained. With the use of Excel functions and several macros in VBA, the dashboard was designed. During design, it was important to keep in mind the dashboard requirements, to ensure that the outcome would be in line with the company's request. This resulted in the following features of the dashboard:

- The dashboard shows how data can be used to obtain insights regarding capacity: input data from different sources was combined to show which influence demand can have on the utilization of the different production resources.
- Besides that the current situation can be analysed, the tool enables to compare the current situation with a possible future scenario. This makes it possible to look ahead: the dashboard can support long-term decision making.
- The dashboard provides insights that can help with decision making and capacity planning. Some examples of questions that can be answered: 'In what way would a change in demand influence the utilization of resources?', 'What are the bottlenecks: for which resources is less time available than needed?', and 'If we adjust the available shifts or machines/FTEs with a certain amount, would this solve the problem of overutilization?'.
- The dashboard is designed in such a way that it facilitates adjustments: if for example input data changes, this can be easily updated without having to change the complete dashboard. Hence, the dashboard is suitable for further use. Besides that, the addition of buttons, legends and a clear lay-out aimed at making the dashboard user-friendly.

Thus, the design of the dashboard resulted in an answer on the last research question. The answer also contributed to solving the second core problem: CIREX now has more knowledge on how to use data to obtain insights that can be used for decisions regarding long-term capacity planning.

For the future, it is suggested to update the dashboard when new data is gathered according to the method that was presented in *Chapter 4*. Details on what to keep in mind when updating the data can be found in *Appendix I.* Furthermore, some data had to be adjusted to obtain a more accurate outcome. It is recommended to the company to check this data, since estimates have been made. Simplifications that were mentioned in this chapter, and more detailed in the appendix, were agreed on by the principal. However, in the future, these simplifications could be adjusted as well to make the dashboard more detailed.

6. Evaluation

After finishing the Design & Development phase and Demonstration phase according to the design science research methodology, the Evaluation phase was entered. In this stage of the project, the results from the previous phases were presented to several CIREX employees, including the principal and the director of the company. After the presentation, there was the opportunity to discuss certain topics, give feedback or make a comment. The results from this group discussion are presented below.

Intended Future Use

During the discussion, comments were made regarding future use of the dashboard. It was mentioned that the dashboard could have different purposes. On the one hand, the company could use it for long-term capacity planning, as was meant: 'which actions should we take if demand changes or if there would a market shift?' This would mainly include decisions on the amount of available machines. On the other hand, it was mentioned that the dashboard can also be used for determining what happens short-term: effect of demand on resource utilization from previous period could be compared with that of the current or next period. Although it is not likely that at short notice the amount of available machines can be changed, it would be possible to use the tool to support decisions regarding the number of FTEs or shifts.

To make the members of the group discussion understand how the tool and dashboard work, a few examples were discussed, such as the results of the resource step '*Wax Tree Assembly*'. See *Figure 16*. It became clear that everybody agreed with the way these outcomes could be used. The example showed that the time the resource is utilized to meet demand is higher than the actual available time. If such a situation appears, a first step would be to solve the problem by adjusting the capacity (machines, FTEs). As a result, the available time will change (see *Available Time Scenario* in the graph). If this would not solve the problem, a separate project could be started to find the underlying causes.

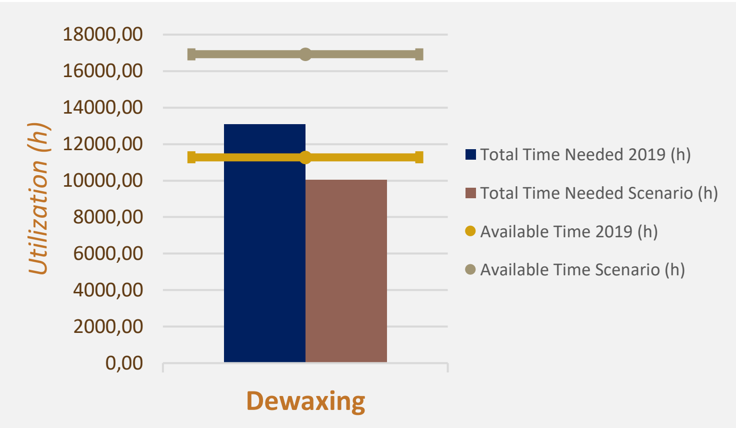

Figure 16 – Example Resource Dashboard

Thus, there was an agreement on how the dashboard could be interpreted and it became clear in what way the company intended to use it in the future. This intended future use appeared to be in line with the initial purpose of the dashboard. The use for short-term decisions that was mentioned can be seen as an additional feature of the dashboard.

Consequences of Implementation

Besides the dashboard, also the method to define the resource data (*Chapter 4*) became again a topic of discussion. It was mentioned that it is important for CIREX to consider the consequences of implementing this method. Consequences that came up during the evaluation:

- The total effective cycles times would really have to be measured for each resource step, according to the definitions. This would be a time-consuming task that has to be set in motion. Employees should be informed about this matter and should be given the task to measure the times.
- The current ways of interpreting the data will have to be changed. At the moment, different production sections have a different approach for planning. When the method is applied and the 'new' times are stored in the ERP system, it is crucial that previous approaches of using the data are avoided. The updated times will already include an amount of losses, since the category-specific factor has been applied. Thus, these times should not be increased by another factor when used in a particular planning tool. This is something that should be carefully considered when applying the method in the future.
- With the decision to include an amount of losses in the resource times that are used for planning, it becomes important to check the related cost prices: currently, it is possible that a factor is included in the cost prices as well. When using both of them for planning calculations, this would lead to 'double adjustment'. Thus, when it is decided to include this factor in the time instead of the cost price, the factor should not be included in the cost price anymore.

Thus, implementation of the method should be done with care. Changing the current situation would mean the start of a gradual process.

Other Remarks

Some other points came up during the group discussion:

- There were some doubts about the accurateness of the current input data that was used for the dashboard. For example, there was a short discussion about some resource steps and the categories to which they should belong. As part of this project, input for the resource data (category, number of machines/FTEs per resource step, etc.) was mainly obtained through consultation with the principal. It would be useful if in the future the input data is checked and agreed on by a selected group of CIREX employees.
- The remark that was already made in *Appendix I, The Tool*, about the relationship between number of machines and number of FTEs was mentioned during the evaluation as well. Indeed the question came forward how for example the number of FTEs for a resource step would increase if the amount of available machines would be increased in the tool. After explaining the reasoning behind the decision to only enable adjustment of one instead of both, an agreement was reached: the

relationship between number of FTEs and number of machines is not so straightforward and determining this relationship requires further investigation for each resource step.

- During the evaluation, some questions were asked that referred to exceptions. Indeed, the results might come across as too general and simplistic. The method and dashboard were developed on a high level, as was requested by the principal at the start of the project: the outcomes of the research were not meant to emphasize on every little detail, but rather to initiate change in the use of data by looking at it from a broader perspective. After emphasizing on the importance of having a general approach before going into every detail, all the members acknowledged that a clear starting point is indeed necessary to change the situation. The change of situation refers to: knowing in advance what might happen with the use of data and how to be prepared on time, instead of relying on expertise and experience when suddenly a problem appears.

Overall, the evaluation had a positive outcome. During the group discussion, it was in particular about how to proceed from this point. This indicates that the findings of the research served as input to continue the progress. It was considered how to apply the results in practice rather than discussing why these results would or would not be suitable yet to use.

7. Conclusion, Discussion & Recommendations

Conclusion

The research aimed at solving two core problems for the company of interest. The first core problem referred to the ERP system that contains unclear and inconsistent data for each of the production steps. The second core problem involved lack of knowledge on how to use data to make a long term capacity planning. From this problem context, the following main research question derived:

How can CIREX use well-defined and realistic data to obtain a capacity planning tool that provides insights that can improve decision making regarding production?

To answer this research question, sub-questions have been formulated. The first sub-question was meant to determine the requirements of a business process model. Three main requirements were derived from the literature: a BPM technique should be flexible, easy to use, and suitable for fulfilling the purpose of the model. Based on these requirements, the BPMN technique turned out to be most appropriate for visualizing CIREX's production process.

With use of the BPMN technique, CIREX's production process was modelled. Data from the ERP system and an interview with the operational manager and production floor manager served as input. The model showed varying levels of complexity: Especially the Finishing 2 department at CIREX Foundry Czech Republic showed a lot of flow possibilities.

To better understand the consequences of the complexity that prevailed in the production process model, a literature study was conducted on the impact of product variety on manufacturing and (capacity) planning. Based on the findings of this literature study, it was concluded that product variety certainly has consequences for business operations in general, but also particularly for manufacturing and planning. If a company wants to be successful in managing a high level of product variety, it has to consider a variety of aspects, including all the relevant costs that might increase and the increasing complexity due to product variety.

After mapping and understanding the production process, it was possible to continue with the fourth sub-question: a method was developed that would ensure a consistent and realistic application of the data that is related to the production steps (resource data). After some observations in the factory, formulating definitions for the resource steps appeared to be crucial. The method consists amongst others of categorizing the resource steps and defining each category. These definitions were formulated in such a way that it would become clear how the resource-related times should be measured and how these times should be implemented in the ERP system. The method is a first step for the company towards integrating accurate data, and ensuring that decisions are not solely based on expertise, but on this well-defined, realistic data.

The final sub-question involved the design of a planning tool and dashboard. Before the design phase could be entered, KPIs had to be selected and the dashboard requirements had to be determined. Literature study showed that for a proper KPI selection it is most important to consider the specific company's needs. Regarding the dashboard requirements: all well-designed dashboards appeared to possess several characteristics. Besides that, the dashboard should provide the information that is desired by the specific end users. These findings, together with the result from an interview with the principal enabled to select the most suitable KPI (resource utilization) and formulate the requirements (i.e. simulation element, easy to use). After that, a data model was created to organize the design of the dashboard. The final outcome of the design resulted in an increase of knowledge for CIREX on how to use data to obtain insights that can be used for decisions regarding long-term capacity planning.

Overall, the different steps that were taken during this research contributed to solving the two core problems and resulted in the answer on the main research question as described above.

Discussion

Contribution to Theory and Practice & Future Research

This research contributed both to theory and practice in several ways. Below, the different ways in which the research contributed to the field are discussed. Although these contributions are valuable, also some opportunities for future research were discovered. These are discussed as well.

First of all, this research showed a clear example of the complexity of a production process. It also showed the relationship between this complexity caused by flows between production steps and the level of product variety a company has. Besides that, it highlighted the possible impact on this high level of product variety on manufacturing and (capacity) planning. However, from the literature study it became clear that especially the impact of product variety on business operations in general has been studied, rather than these particular areas of business. Thus, it could be useful to conduct further research on the impact of product variety for specific departments of a company (i.e. manufacturing, planning). This could provide more knowledge to companies on how to deal with product variety within the different business activities: gathering detailed information on consequences can be a valuable addition to the knowledge that already exists about the impact of product variety on business in general.

Secondly, the method for defining and implementing data that was presented as part of this research can be seen as a contribution to both theory and practice. The method shows a new perspective on how to use the cycle times of production resources to make these applicable for production planning activities in a consistent and realistic way. Limited research has been conducted on this topic. Asmundsson et al. (2009) for instance mention the nonlinear dependency between cycle time and resource utilization and captured this in a production planning model. A study by Puvanasvaran, Teoh & Tay has some similarities in the sense that it defines and implements a planning factor due to the shortcomings of Overall Equipment Effectiveness (OEE) implementation. It is mentioned that the OEE does not take into account the case in which amount of product loaded into a resource is always less than the maximum capacity of that resource, indicating that a planning factor is required. Although these studies both show that production planning is not a straightforward task and in order to plan accurately many different aspects have to be considered, none provide a general approach that has the advantages of the method that was a result of this research.

Regarding follow-up research, it is suggested to explore whether more companies face similar problems as CIREX. If for example it appears that firms often experience difficulty with defining data, using data in a consistent way or adjusting data for planning, the method from *Chapter 4* could indeed be applied more generally. A next step would be to conduct more case studies in which the method is fully implemented to see whether the method has a successful outcome for different companies. The research was formulated in such a way that it can be repeated in the future.

Furthermore, in previous research, no specific connection was made so far between change in demand and impact on resource utilization. This research showed the relationship between these two elements and showed which useful insights can be gathered when analysing this relationship. The dashboard that resulted from this research was approached on a high-level, avoiding little details and complicating factors. It might, however, be useful for further research to look from a more detailed perspective at this relationship.

Limitations

Reflecting on the research approach, it can be stated that the way the research was conducted in general led to the expected outcomes. Following the design science research methodology and applying a combination of methods to gather results seemed to be appropriate for solving the core problems and answering the research questions. Unfortunately, due to time restrictions, it was not possible to directly implement all the outcomes of the study in practice. Although this was also not considered as part of the research, implementation or inclusion of certain aspects could have led to more valid results.

For example the implementation of the method (*Chapter 4*): although the creation of the method can be seen as a great starting point for the company, it still would have to be applied in practice. Times related to the resource steps will have to be measured and these will have to be adjusted so they can be stored in the ERP system. If these measured times would have been available during the project, it would have been possible to use these for the design of the dashboard. Instead, the current process times from the ERP system were used, which were proven at the beginning of *Chapter 4* to be inconsistent. It was assumed that this data was sufficient enough to show how data can be used to provide insights regarding capacity planning. Although this seemed indeed plausible, the results would have been more valid otherwise.

Another example of the unavailability of data can be given. In contrast to measuring the times, categorizing the resource steps and obtaining data on number of machines, FTEs and shifts per resource step was part of the project. However, this data was not directly available either. The principal and one other CIREX employee were consulted to obtain the relevant data, but especially for the CIREX Foundry CZ data, accurateness was not assured. Data could have been more valid if managerial employees from each production department were involved. Nevertheless, it is unlikely that the obtained data deviates a lot, and fortunately this data can be easily adjusted in the dashboard.

Regarding the data gathering method used for evaluation: since during the design phase the requirements of the method (*Chapter 4*) and dashboard (*Chapter 5*) were in detail discussed with the principal and other CIREX employees by means of a group discussion and semi-structured interview, during the evaluation no specific questions were asked. It was expected that due to the close communication with the principal, the design of amongst others the dashboard was according to the needs of the company. Therefore, the evaluation resulted in a free input of the participants. The results from the evaluation appeared to be valuable, because it showed how the company intends to use the findings of the research and consequences of the findings were discussed. However, asking more specific questions to the participants in the form of a semi-structured interview could have led to insights regarding the improvement of the dashboard. This could be considered as a limitation in the data gathering method that was used. Nevertheless, some parts of the evaluation pointed in this direction even though no specific questions were asked, such as the remarks on adjustment of FTEs and machines in the tool.

Most other points of discussion have been pointed out in the evaluation section (*Chapter 6*): especially for discussions regarding the consequences of the results for the company, see this chapter. Something that was not mentioned there concerns the complexity of the production process. Particularly the last parts of CIREX production process appeared to be highly complex, but it was outside the scope of this research to provide a solution for this complexity. Despite this limitation, the research still contributed to the matter. It became clear that accurate planning of production, capacity and resources becomes crucial with a high level of complexity and product variety. Thus, in order to improve the production process and understand what the consequences of certain adjustments are, it is useful for the company to have insights in amongst others the utilization of resources. The planning tool is a first step towards obtaining such insights. Furthermore, when the data in the ERP system becomes more accurate, management will be better able to make well-founded decisions.

Recommendations for CIREX

As part of the different chapters, already several suggestions were made for CIREX how to proceed. Summarizing:

- Increasing product variety might have a strong impact on a firm's business operations (Park et al., 2004). CIREX should consider the relevant costs, functions and operations to decide to what extent product variety should be increased in order to anticipate on the changing markets. Since CIREX already includes a relatively high level of product variety, which is especially visible in the later stages of the production process, it is important for the company to adopt a strategy that enables to manage this product variety.
- Regarding implementation of the method presented in *Chapter* 4, it is suggested that CIREX gathers the measurements for each resource step according to the definitions, makes the factors more refined when necessary, and implements all the updated times in the ERP system so that these can be used for planning. Additionally, to ensure accurateness of the data, it is suggested that the relevant data is checked by several employees. This also includes examining the current cost prices.
- To ensure a smooth change from making decisions based on expertise and experience, to making decisions based on well-defined and consistent data, the progress and steps that are taken should be clearly communicated to the involved employees. If not everyone is aware of the changes that are made, this could again cause inconsistency and misinterpretation.
- It is recommended to update the dashboard when new data is gathered according to the method that was presented in *Chapter 4*. Details on what to keep in mind when updating the data can be found in *Appendix I.*

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Appendix A - Definition of Key Terms

Below, an overview of the main terms with definitions is presented. Definitions are described in such a way that they are relevant and applicable for this research. Some definitions are obtained from literature, others are formulated for specifically this research.

Business Process Modelling	The creation of a model of a business process in order to better that process (business process modelling, n.d.).
Business Process	A series of logically related activities or tasks performed together to produce a defined set of results (business process, n.d.).
Production Process	Mechanical or chemical steps used to create an object, usually repeated to create multiple units of the same item, and generally involves the use of raw materials, machinery and manpower to create a product (production process, n.d.).
Resource/Production Step	An activity that directly contributes to the manufacturing of the product, and involves a specific machine or installation, the action of one or more employees, and/or any other element that requires planning.
Complexity	The state of having many different parts connected or related to each other in a complicated way (complexity, n.d.). More specific: *Technological complexity* is related to the inherent complexity of the system and its technologies, for both products and processes (Khurana, 1999).
Product Variety	The number of different versions of a product offered by a firm at a single point in time (Ulrich & Randall, 2001).
Realistic Data	Data that corresponds with reality, not necessarily meaning that it is real-time data. It is data that is based on measurements, obtained in a pre-described way. It does not involve estimations based on expertise or experience.
ERP system	Enterprise resource planning system, that ties together and define a plethora of business processes and enable the flow of data between them, used to manage day-to-day activities (“What is ERP?”, n.d.).

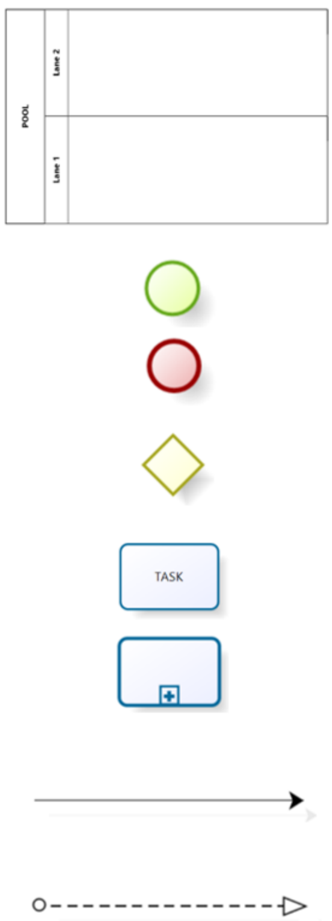
Performance Measurement	The process of quantifying action, where measurement means the process of quantification and the performance of the operation is assumed to derive from actions taken by its management.
Key Performance Indicators	A set of quantifiable measures that a company uses to gauge its performance over time (Twin, 2019).
Production Performance	How well the production process is doing, as indicated by a selection of measures.
Capacity planning	Capacity is the ability of a given system to produce output within the specific time period. Planning of capacity is essential to determine optimum utilization of resources and plays an important role in decision-making processes (Juneja, n.d.).
Planning tool	A program or feature of a program that helps you to do particular things (tool, n.d.), in this case a software tool that helps with making planning decisions.
Production Dashboard	Performance dashboard that relates to production. Dashboards provide visual displays of important information that is consolidated and arranged on a single screen so that information can be digested at a single glance and easily drilled in and further explored (Sharda, Delen, Turban, 2014).

Appendix B – BPMN Characteristics

The Business Process Modelling and Notation technique has the following main characteristics:

- The primary goal of BPMN is to provide a notation that is readily understandable by all business users (Aldin & De Cesare, 2009).
- BPMN has a wide range of different kinds of flow of control and sequences, which makes BPMN well defined and as result an easy to use approach for inexperience stakeholders (Aldin & De Cesare, 2009).
- BPMN allows the representation of extended models for each process and supports the construction of simulation models (Aldin & De Cesare, 2009).
- The modelling elements of BPMN include: process, activity, service/product, role, goal, event, and rule.

In the figure below, a short explanation is given of the elements that were used for the creation of the business process models during this research. Information was retrieved from the IBM Knowledge Center ("Business process elements", n.d.).



Pool: represents a participant in a business-to-business process. A participant is a business entity such as a company, company division, or customer.

Lane: a sub partition within a pool in a business-to-business process, often used for internal roles, systems or an internal department.

Start event: beginning of a process.

End event: ends the flow of a process and does not have any outgoing sequence flows.

Gateway: controls the divergence and convergence of multiple sequence flows. It determines branching, forking, merging, and joining of paths.

Task: a single activity that is included in a process.

Subprocess: a single flow object element that represents a set of activities. A subprocess can be broken down into a finer level of detail (as a process)

Sequence flow: show the order in which activities are performed in a single process. Pool boundaries cannot be crossed.

Message flow: depict the contents of a communication and the flow of messages between two pools that are prepared to send and receive.

App. B, Fig. 1 – BPMN Elements

Appendix C - Systematic Literature Review RQ 5

Step 1: *definition of the knowledge question*

The fifth research question, ‘*Which KPIs are typically used to provide insights in production performance?*’, has been answered by means of a systematic literature review.

Two main concepts can be derived from this question: ‘key performance indicators’ and ‘production performance’. Answering this question has the aim of presenting which key performance indicators are often selected to show the performance of production. The possible results of the question are narrowed down with the word ‘typically’. If the literature gives for example an indication that some key performance indicators are valuable to get insights in the performance, and others less, or some KPIs are often used as standard, this can be considered when formulating an answer.

In the book by Slack, Brandon-Jones & Johnston (2016), performance measurement is defined as the process of quantifying action, where measurement means the process of quantification and the performance of the operation is assumed to derive from actions taken by its management. It is a prerequisite for judging whether an operations is good, bad or indifferent. In the book Operations Management (Slack, Brandon-Jones & Johnston, 2016) it is also stated that it is difficult to ‘target’ a narrow range of key performance indicators unless strategy is well defined. This shows that the selection of KPIs is a challenging task, hence gaining knowledge on this topic is relevant.

Since the core problem is related to production processes, the answer should be limited to KPIs that give insights in production performance, and not for example services and revenue. To define production performance, first the concept of production processes has to be defined: mechanical or chemical steps used to create an object, usually repeated to create multiple units of the same item, and generally involves the use of raw materials, machinery and manpower to create a product (production process, n.d.). Performance can be defined as how well a person, machine, etc. does a piece of work or an activity (performance, n.d.). Thus, production performance can be defined as how well the production process is doing.

Step 2: *defining the inclusion and exclusion criteria*

Tables 1 & 2 present the exclusion and inclusion criteria that will be applied to filter the literature.

Step 3: *defining the databases used*

For the search, the databases ‘Scopus’ and ‘Web of Science’ will be used. These databases provide a large number of reviewed journals that have a multidisciplinary focus, making it likely that relevant articles will be found.

Number	Criteria	Reason for Exclusion
1	Pre 1961-articles	KPIs were first introduced by D. Ronald Daniel and Jack F. Rockart in 1961 (Den Hoed, 2013). It is assumed that articles before 1961 do not refer to KPIs.
2	Articles that focus on KPIs within a context other than that of production	The research question specifically aims at KPIs that relate to production processes and production performance.
3	Sources written in any other language than English or Dutch	I do not understand other languages than English or Dutch enough to draw conclusion from sources that use such a language.
4	Sources that discuss KPIs in a very specific production context	If an article focusses on KPIs that specifically measure for example sustainable production, this is less relevant to the aim of my research, which rather involves the production process in general.
5	Sources that discuss very specific KPIs.	If an article discusses only one specific KPI, even though this KPI is related to production, for instance energy consumption, including such a source would provide too little information to get an adequate answer on the research question.

App. C, Table 1 – Exclusion Criteria

Number	Criteria	Reason for Inclusion
1	Articles that do not answer a similar research question, but discuss KPIs in a production context as part of the article.	Although the article does not give an overview of KPIs, but addresses the topic in a way that is relevant, it can still provide valuable information.
2	Sources that do not indicate if the KPIs are often used.	Even though the source does not mention which KPIs are commonly applied to measure production performance, it still could give a good overview of relevant KPIs.
3	Articles that mention KPIs for a production process that differs from the production process at CIREX.	If for example an article discusses the results from a case study in which the company of interest manufactured cars, the findings on the KPIs that were used could still be applicable to production processes in general. Therefore, such articles will be included.

App. C, Table 2 – Inclusion Criteria

Step 4: *describing the search terms and the used strategy*

Table 3 shows a search matrix. Different terms are derived from the main concepts that could simplify the search and ensure that enough relevant articles are discovered.

Constructs	Related terms	Broader terms	Narrower terms
KPI	Key performance indicators	-	KPI selection
Production	Production process, Manufacturing, Manufacturing process	-	-
Performance	Performance measurement	-	-

App. C, Table 3 – Search Matrix

As mentioned in the slide presentation on Systematic Literature Reviews presented by Noort (2019), the main concepts should be mutually exclusive and collectively exhaustive. The search string will always include these main concepts by connecting them with 'AND'. The operator 'OR' will be used to include the alternative search terms. For example: (kpi OR key performance indicator). Besides the variations in search strings that will be made, also phrasing will be done to connect for example the terms 'production' and 'performance': "production performance". This could lead to more specific results. Furthermore, the search terms should be mentioned in the article title, abstract, or keywords of the article. This can be done by using the search field functionality of the database. Also a 'date' filter will be added. In case too many results are obtained, more terms will be added to the search string. When the search is executed accordingly, it has to be determined which entries meet the inclusion and exclusion criteria. A first selection of relevant entries will be made by doing a quick scan (title, abstract). Then, by scanning the full text of the remaining articles, extra attention will be paid to the criteria. Besides looking at the criteria, also questions such as 'Is it from a good journal?' and 'Is it cited a lot?' (Noort, 2019) will be considered. For the remaining entries, a more detailed analysis will be done to make sure the final selection of sources include the most relevant ones. This requires fully reading the article and determining how it would contribute to answering the research question.

Step 5: *listing the number of articles found, the number of duplicates, the final set of articles*

The table below shows the search report.

Search String	Scope	Date of search	Date range	Number of entries
Search protocol for Scopus				
(kpi OR "key performance indicators") AND "production performance"	Article title, Abstract, Keywords	14-04-2019	1961-present	38
(kpi OR "key performance indicators") AND "manufacturing performance"	Article title, Abstract, Keywords	14-04-2019	1961-present	14
(kpi OR "key performance indicators") AND "production process"	Article title, Abstract, Keywords	14-04-2019	1961-present	131
(kpi OR "key performance indicators") AND "manufacturing process"	Article title, Abstract, Keywords	14-04-2019	1961-present	85
"kpi selection" AND ("production process" OR "manufacturing process" OR "production performance" OR "manufacturing performance")	Article title, Abstract, Keywords	14-04-2019	1961-present	2

(kpi OR “key performance indicators”) AND (production OR manufacturing) AND “performance measurement”	Article title, Abstract, Keywords	14-04-2019	1961-present	105
Search protocol for Web of Science				
(kpi OR “key performance indicators”) AND “production performance”	Topic	14-04-2019	1961-present	14
(kpi OR “key performance indicators”) AND “manufacturing performance”	Topic	14-04-2019	1961-present	9
(kpi OR “key performance indicators”) AND “production process”	Topic	14-04-2019	1961-present	43
(kpi OR “key performance indicators”) AND “manufacturing process”	Topic	14-04-2019	1961-present	29
“kpi selection” AND (“production process” OR “manufacturing process” OR “production performance” OR “manufacturing performance”)	Topic	14-04-2019	1961-present	3
(kpi OR “key performance indicators”) AND (production OR manufacturing) AND “performance measurement”	Topic	14-04-2019	1961-present	52
Total in EndNote				525
Removing duplicates				-174
Removed after scanning (title, abstract)				-238
Removed after applying exclusion and inclusion criteria (full text scan)				-90
Removed after detailed analysis				-16
Total selected for review				7

App. C, Table 4 – Search Report

Step 6: *Conceptual Matrix*

The following articles were selected for review:

1. Zorzut, S., Jovan, V., & Žnidaršič, A. (2006) - *Key performance indicators in plant-wide control.*
2. Varisco, M., Johnsson, C., & Schiraldi, M. M. (2018) - *Proposal for a classification of ISO22400 KPIs for manufacturing operations management.*
3. Ahmad, M. M., & Dhafr, N. (2002) - *Establishing and improving manufacturing performance measures.*
4. Stricker, N., Echsler Minguillon, F., & Lanza, G. (2017) - *Selecting key performance indicators for production with a linear programming approach.*
5. Ante, G., Facchini, F., Mossa, G., & Digiesi, S. (2018) - *Developing a key performance indicators tree for lean and smart production systems.*
6. Varisco, M., Johnsson, C., Mejvik, J., Schiraldi, M. M., & Zhu, L. (2018) - *KPIs for Manufacturing Operations Management: driving the ISO22400 standard towards practical applicability.*
7. Behrens, B. A., & Lau, P. (2008) - *Key performance indicators for sheet metal forming processes.*

Table 5 shows the key findings of the articles listed above. Because the concepts of KPIs and production performance are closely related within these articles, an overall summary will be given that includes both concepts instead of distinguishing between the concepts.

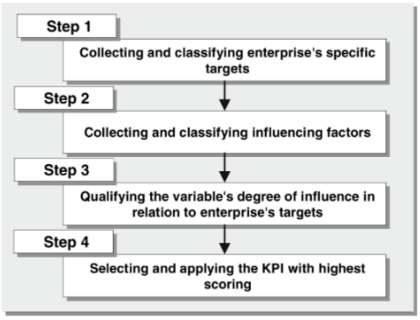
Article	Key findings regarding the Main Concepts of KPIs and Production Performance
1	The article mentions that on a production management level the implementation of KPIs is a rather new concept. According to Zorzut, Jovan & Žnidaršič (2006), the solution lies in defining an appropriate set of KPIs that are specific to the observed production process, and in defining the strategy for using KPIs to efficiently manage that process. Five principal KPIs for process-oriented productions were presented: Safety and Environment; Production Efficiency; Production Quality; Production Plan Tracking; and Employees Issues. The KPI approach was applied in a case-study. For this particular case study, Zorzut, Jovan & Žnidaršič (2006) chose three production KPIs: Productivity (other terms: actual production rate, production yield) defined as the amount of all products that were produced over a set production period, Mean Product Quality calculated as the mean value of the quality factors for the batches completed in the set time window, and Mean Production Costs calculated as the sum of all production costs within a time window, divided by the amount of all products produced in this time window. According to Zorzut, Jovan & Žnidaršič (2006), in this way the production control concept and the role of a production manager are slightly changed; instead of monitoring and controlling many process variables at a low production level, a production manager monitors and controls only a few major production KPIs with the aim of achieving the most important implicit production objectives.
2	The article refers to the ISO22400 standard in which KPIs for manufacturing operation management are defined. The problem was identified that some of these standard KPIs are too vaguely defined. The article provides useful information, because it mentions common manufacturing KPIs and shows the specific initial application context of some of these KPIs, which allows managers to understand which KPIs can be currently computed with a given set of data (Varisco, Johnsson & Schiraldi, 2018). The tables that are presented in the article can be used to select KPIs based on type and context classification. Since my research will focus mainly on the types 'time', 'quality', and 'mixed-production', it can be easily derived from the table that KPIs such as utilization efficiency, production process ratio, throughput rate, performance ratio, and overall equipment effectiveness index are relevant.
3	This paper sets out the basis to establish KPIs in manufacturing companies. It does not only describe how KPIs can be selected and obtained, but also presents KPIs that could assist in dealing with the possibility of improving the utilization of a process manufacturing plant (Ahmad & Dhafr, 2002). The study focusses on the KPI 'dependability', which was divided into customer complaints, on-time-in-full delivery to customers (OTIFc), on-time-in-full delivery from suppliers (OTIFs), and overall equipment effectiveness (OEE). Especially the latter seems relevant to my bachelor assignment, because this focusses more directly on utilization of production capacity. The measure determines how reliable the assets are and their capability to deliver the outstanding performance expected from a world class operation (Ahmad & Dhafr, 2002).
4	As stated in the article, performance measurement with key performance indicators (KPIs) is a widely used instrument to detect changes in production system performance in order to coordinate appropriate countermeasures. The main challenge in planning KPI systems consists in determining relevant KPIs. Stricker, Echsler Minguillon & Lanza (2017) proposed a selection process that uses an integer linear programme for objective KPI selection. Although this mathematical programming approach to KPI selection seems promising, it is too complex to apply to the research project. It does, however, give some useful insights on what to consider when selecting KPIs. Selected KPIs need to allow for a comprehensive measurement of system performance meaning that changes in any unselected KPI must be detectable in selected KPIs, a proper number of KPIs has to be selected (as high as necessary and as low as possible as not to overstrain the cognitive abilities of decision-makers), and it has to include future users in the selection process as to ensure acceptance in practice (Stricker et al., 2017).

5	Although the article focusses on a lean production system, and the lean method is not applied at my host organization, it still gives insights in KPIs that are related to measurement of production performance. It is emphasized that in order to guarantee high performance and continuous monitoring of the process control, it is necessary to identify proper indicators in supporting the decision-making process (Ante, Facchini, Mossa, & Digiesi, 2018). The paper proposes a description of a performance measurement system as a KPIs tree. A distinction is made between three 'elements': supporting elements (data directly monitored and collected during the production phases), quantity elements (information on issues related to product quality and quantity), and maintenance elements (information related to maintenance and repair issues of machines). KPIs are selected from the ISO22400 standard, and the KPI tree shows the relations between the different KPIs in a hierarchical way. The following KPIs were included to evaluate the performance at the final stage of the case projects: OEE, Resource saturation, Errors [#], and Indirect costs.
6	In this paper, a framework is presented that helps to overcome the problem that the KPIs from the ISO22400 standard are defined at a high abstraction level, which makes it difficult to apply in practice (Varisco et al., 2018). According to the article, KPIs are considered to be the core of a performance measurement system, and allow managers to identify the progress in activities and those to be improved, support the setting of new goals, help decision-making in order to reach the desired performance and improvement, etc. It is also mentioned that KPIs should be properly selected to adapt the industry specificity, but general enough to be able to compare different operations. The ISO22400 standard KPIs and the improved versions are not presented in the article, but an example is given for the KPI 'Direct Energy Consumption Effectiveness'. Although it does not directly contribute to answering the knowledge question, it still provides useful information in the sense that it emphasizes the need for careful consideration of the ISO22400 KPIs.
7	The article focusses on the sheet metal forming process in a manufacturing industry. Although CIREX does not have the same production process, there are some similarities, such as the application of several operation steps. The article describes a method to identify relevant KPIs and proposes relevant indicators. The relevant key performance indicators (KPIs) can be used to support the decision-making process for production planning purposes (Behrens & Lau, 2008). As is also the case with the production process at CIREX, there are numerous different influences on productivity as well as product quality and cost, e.g. tools, machines, material properties, tribology or the process parameters themselves (Behrens & Lau, 2008). According to the article, the interdependencies of these technical and organizational parameters have to be identified in order to be considered for the improvement of the process. The indicators were supposed to meet several requirements. Some of them would be suitable for selecting KPIs during this project as well: ability to describe an enterprise from a technical and organizational point of view, ability for benchmarking, adaptability according to user's specifications, little time requirements and a small effort to collect and update the data, and possibility to analyse from a past, present and future perspective (Behrens & Lau, 2008). Furthermore, the proposed method seems general enough to be used for a proper selection of KPIs for CIREX as well. The OEE was pointed out as one of the indicators widely used by manufactures to determine productivity at the equipment level. Other KPIs mentioned as well, such as: material efficiency, quality rate, availability of equipment, output, availability of employee, productivity of employee, and cost KPIs.

App. C, Table 5 – Conceptual Matrix

Step 7: *Integration of the theory*

The systematic literature review resulted in a selection of articles that could contribute to answering the research question. First of all, most of the articles highlighted the importance of measuring performance and using key performance indicators to do so. For example Stricker, Echsler Minguillon & Lanza (2017) stated that performance measurement with key performance indicators (KPIs) is a widely used instrument to detect changes in production system performance in order to coordinate appropriate countermeasures. According to Varisco et al. (2018) KPIs are considered to be the core of a performance measurement system, and allow managers to identify the progress in activities and those to be improved, support the setting of new goals, help decision-making in order to reach the desired performance and improvement, etc. Furthermore, also the proper selection of KPIs is addressed in some of the articles. Ante, Facchini, Mossa, & Digiesi (2018) emphasize that in order to guarantee high performance and continuous monitoring of the process control, it is necessary to identify proper indicators in supporting the decision-making process. In addition, Varisco et al. (2018) mention that KPIs should be properly selected to adapt the industry specificity, but general enough to be able to compare different operations. This shows KPIs should be carefully selected to make sure they correspond with the company's strategy and needs. In some of the papers, methods were proposed to identify, select and obtain KPIs. Stricker et al. (2017) proposed a selection process that uses an integer linear programme for objective KPI selection. Although promising, it seems to be too complex to be applied within this project. Behrens & Lau (2008) presented a less complicated and therefore more appropriate method, see *Figure 1*.



*App. C, Fig. 1 – Method KPI Selection**

The previous findings focus more on how to select KPIs than which KPIs could give relevant insights in production performance. However, some of the articles also mentioned specific KPIs. The articles by Varisco, Johnsson & Schiraldi (2018) and Varisco et al. (2018) referred to ISO22400, a standard for manufacturing/production KPIs. The ISO22400 provides an overview of KPIs that could be relevant for the research project and is worth further consideration. As Varisco et al. (2018) point out, the ISO22400 is defined at a high abstraction level which makes it difficult to apply the KPIs in practice. This is important to keep in mind when using the ISO22400 to gather suitable KPIs. The mentioned articles can provide information on how to deal with this.

Although none of the articles really indicated which KPIs are most commonly used, besides that the ISO22400 is seen as a 'standard' itself, some of the KPIs were frequently mentioned, such as Overall Equipment Efficiency (OEE). Behrens & Lau (2008) pointed out the OEE as one of the indicators widely used by manufactures to determine productivity at the equipment level. Also, Ahmad & Dhafr (2002) and Ante et al. (2018) used OEE as a main KPI. For the other KPIs, it was possible to make a distinction

*Adapted from "Key performance indicators for sheet metal forming processes," by Behrens & Lau, 2008, *Production Engineering, 2*(1), 73-78. doi:10.1007/s11740-007-0076-y between types: cost KPIs, quality KPIs, employee KPIs, efficiency/productivity KPIs. See *Table 6* for an overview.

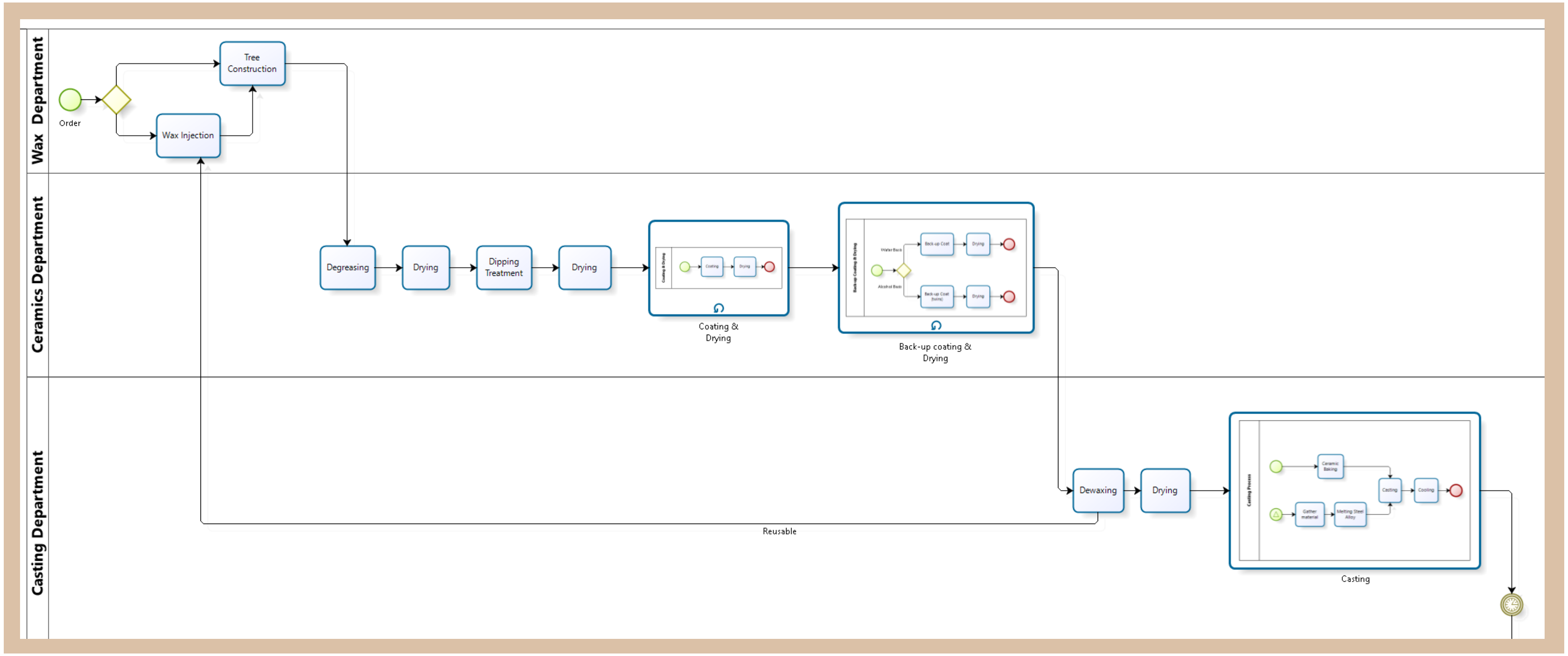
Although these outcomes are useful for answering the knowledge question and indicate which KPIs could give insights in production performance, it became clear that it is important to consider the specific company. Thus, the ISO22400 and the KPIs gathered from the articles will serve as a starting point, but it can be concluded that especially discussing the KPIs with the principals will be an important aspect to select the most suitable KPIs within the context of this project. The method proposed by Behrens & Lau (2008) will serve as a guidance in this process of selecting relevant production KPIs.

Efficiency/Productivity	Quality	Cost	Employees
Production Rate	Mean Product Quality	Mean Production Costs	Availability of Employee
Utilization Efficiency	Quality Rate	Indirect Costs	Productivity of Employee
Production Process Ratio		Cost of Equipment & Tools	
Throughput Rate		Maintenance Cost	
Performance Ratio		Labor Cost	
Resource Saturation			
Errors [#]			
Material Efficiency			
Availability of Equipment			
Output			

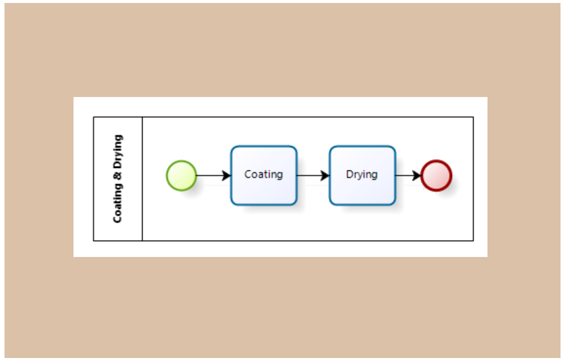
App. C, Table 6 – KPI overview

Appendix D - The Production Process

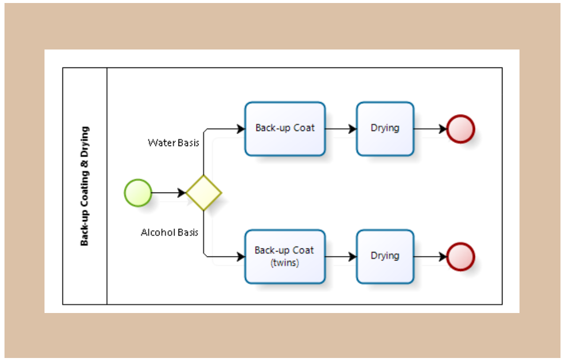
App. D, Fig. 1 – Complete Production Process



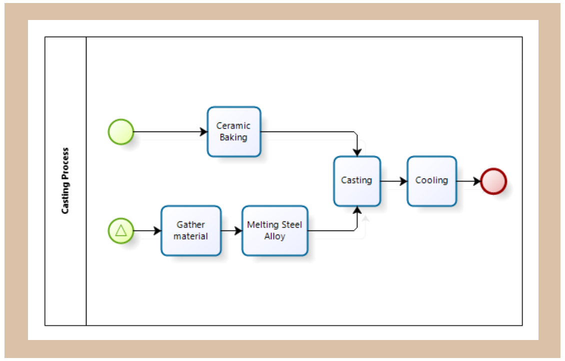
App. D, Fig. 2 – Low Complexity; First steps in production process NL



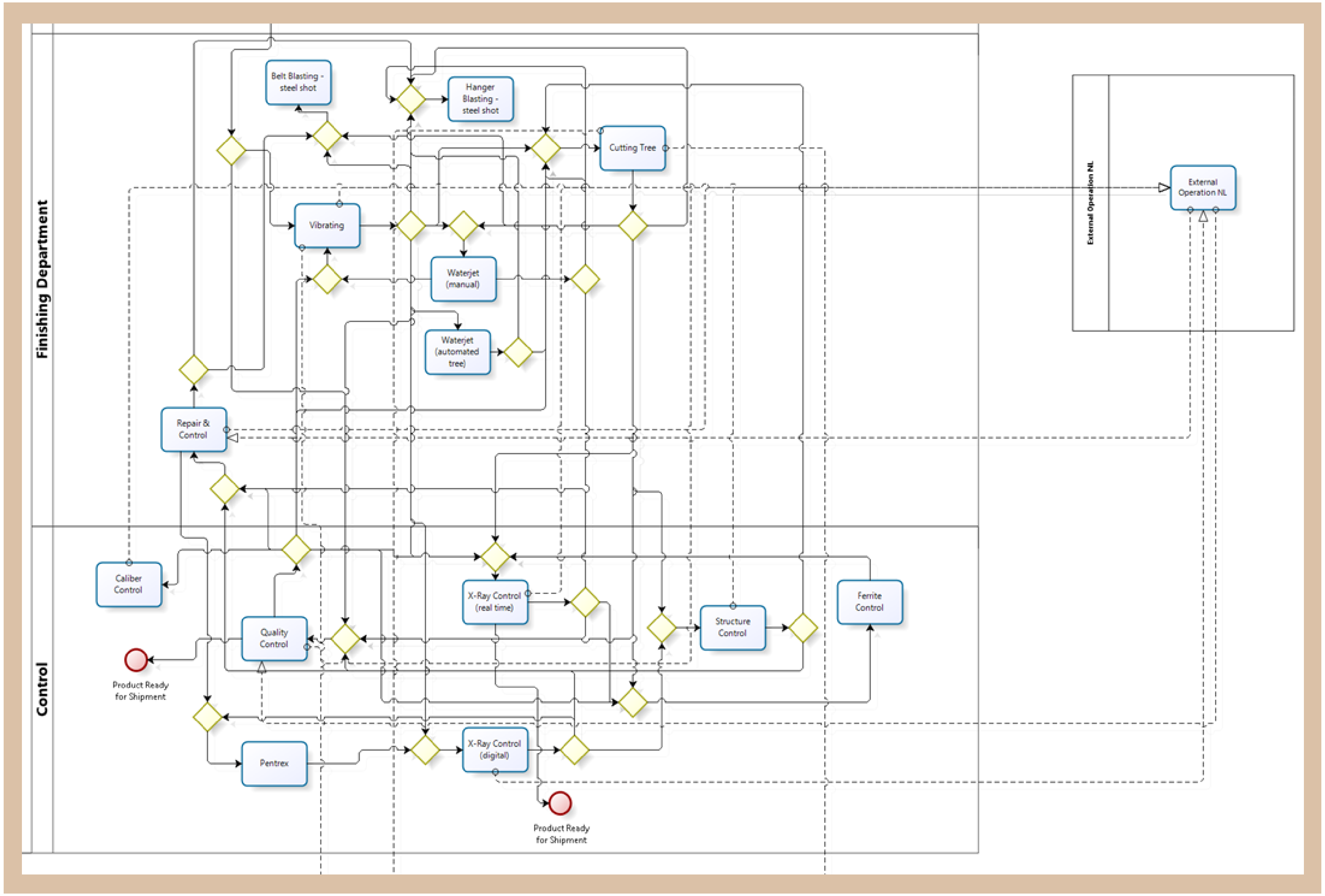
App. D, Fig. 3 – Subprocess: Coating & Drying NL



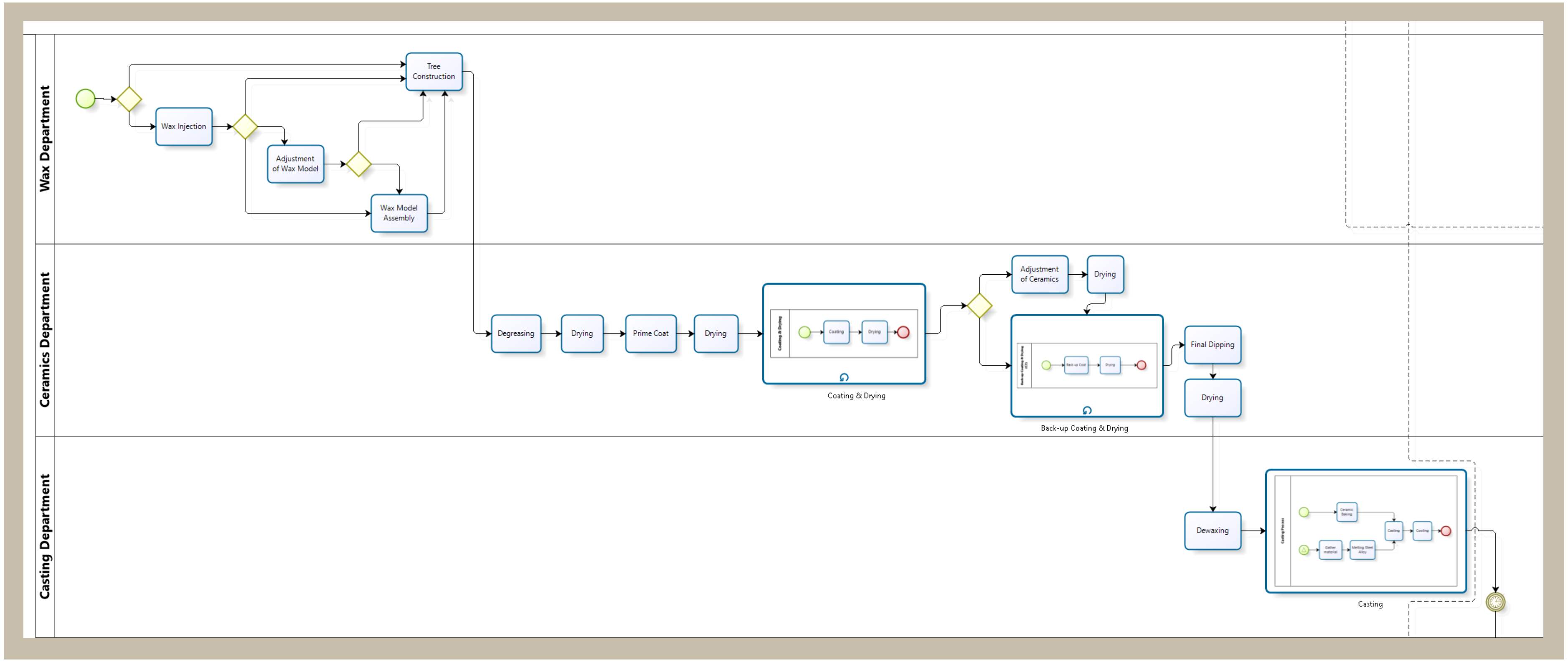
App. D, Fig. 4 – Subprocess: Back-up Coating NL



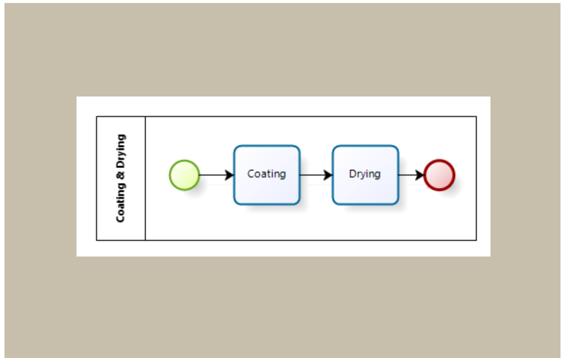
App. D, Fig. 5 – Subprocess: Casting NL



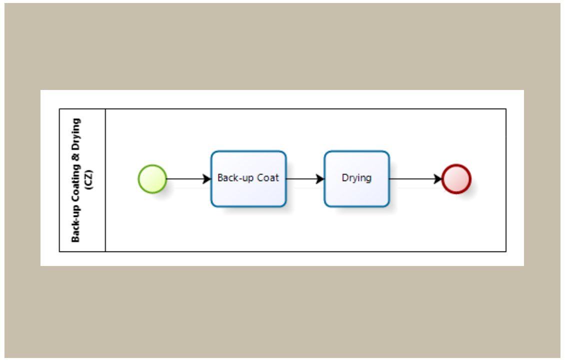
App. D, Fig. 6 – Medium Complexity: Finishing & Control Department NL



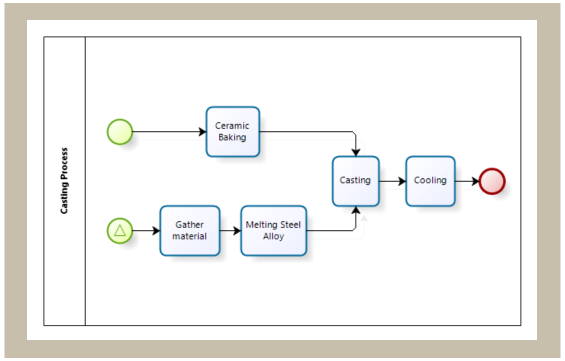
App. D, Fig. 7 – Low Complexity; First steps in production process CZ



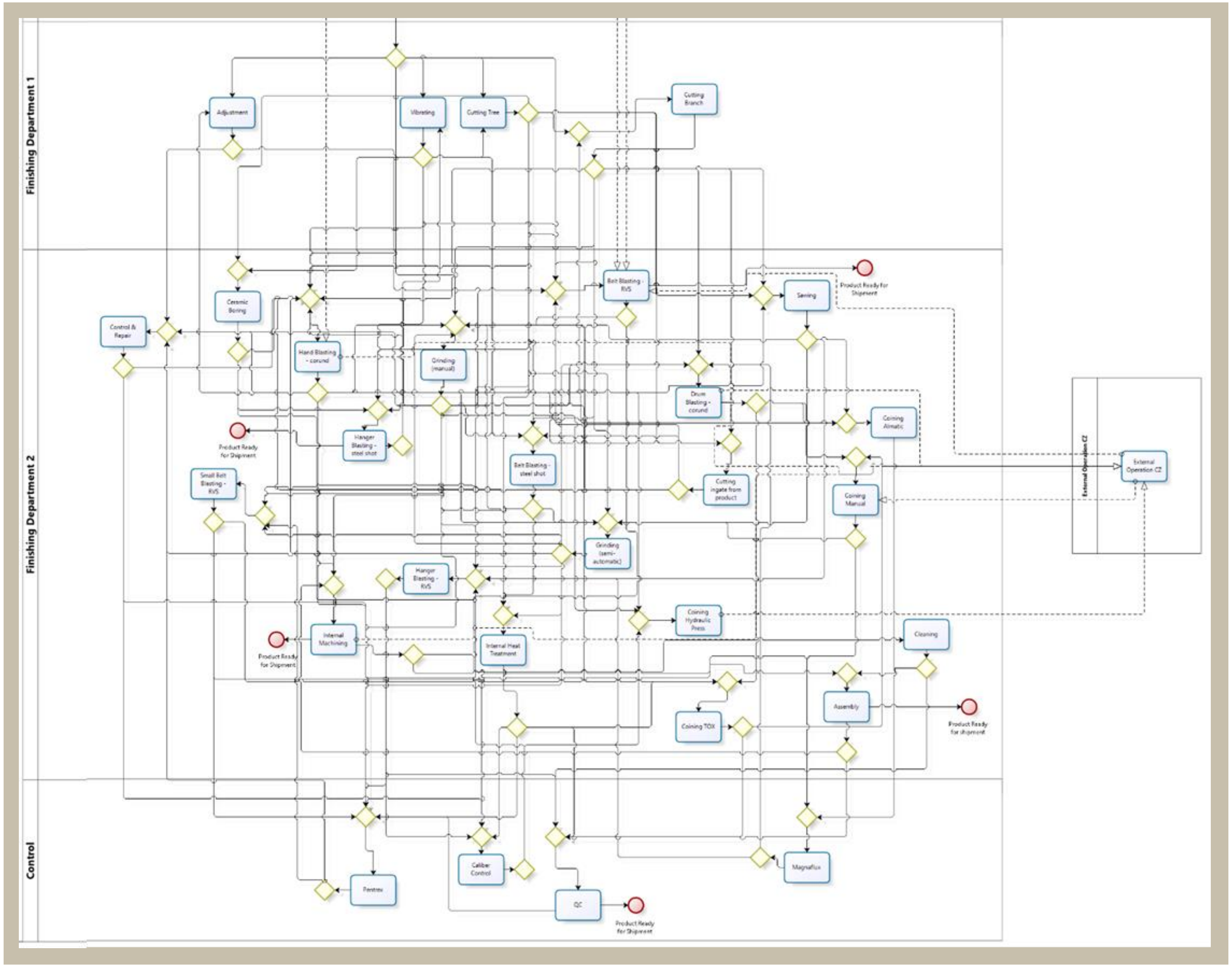
App. D, Fig. 8 – Subprocess: Coating & Drying CZ



App. D, Fig. 9 – Subprocess: Back-up Coating CZ



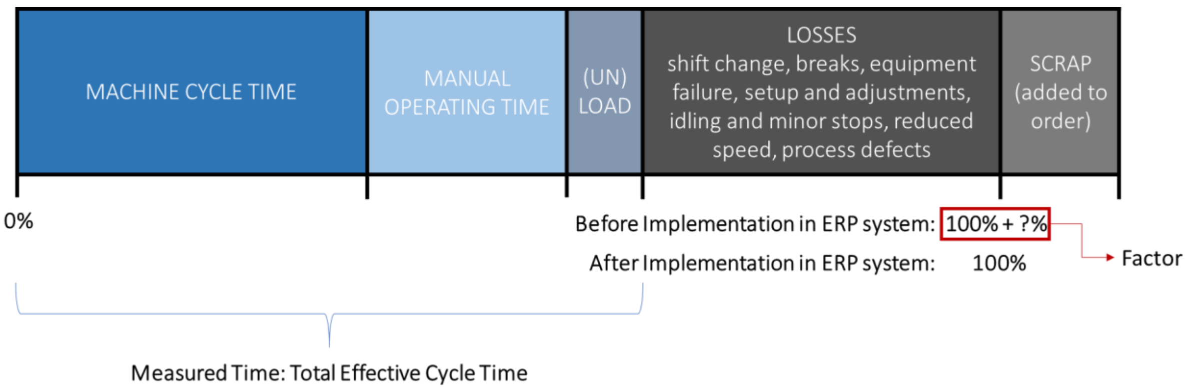
App. D, Fig. 10 – Subprocess: Casting CZ



App. D, Fig. 11 – Medium/High Complexity: Finishing & Control Department CZ

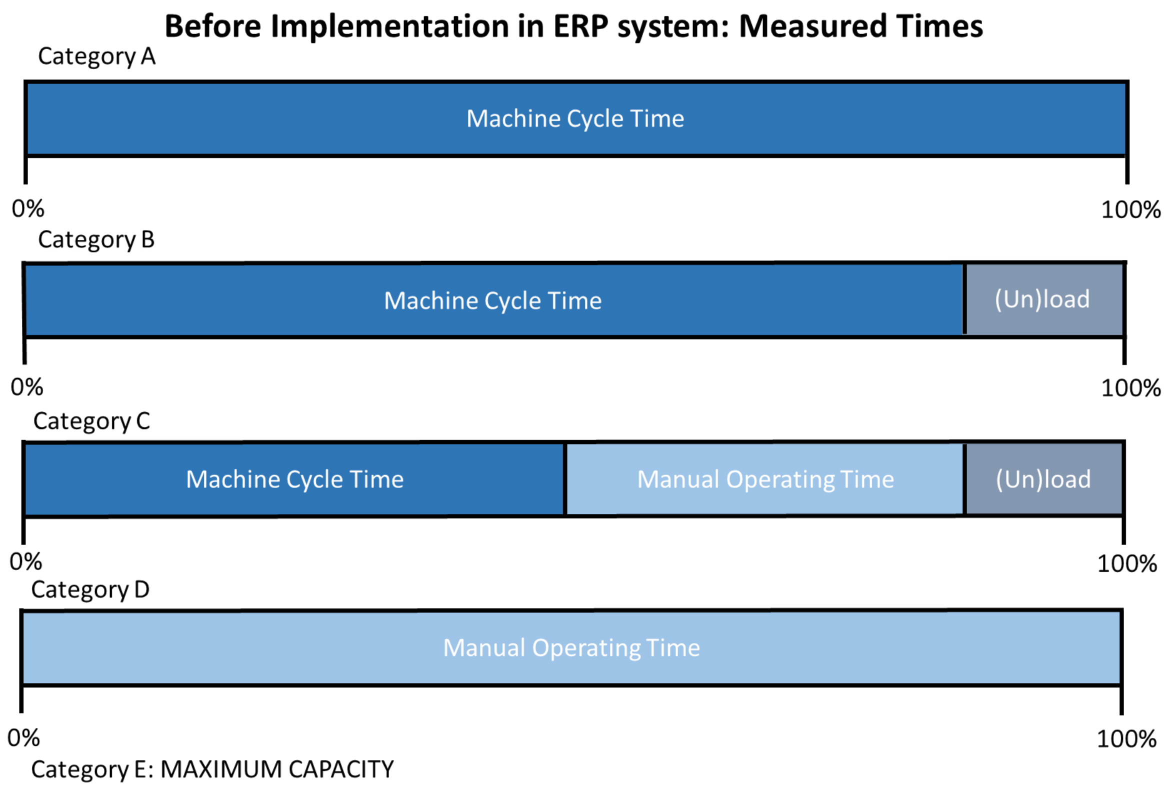
Appendix E - Method of Defining Data

Division of Time



App. E, Fig. 1 – Division of Cycle Time

Categories



App. E, Fig. 2 – Categories Method

Appendix F - Interview Questions

Interview KPI Selection & Dashboard Requirements

The guide the interview, the following questions were used:

- *Could you explain for each of the pre-selected KPIs if and why you think this KPI would be useful to include in the dashboard?*
- *What would you imagine the dashboard to look like?*
- *Which features/functions must the dashboard certainly include?*
- *In what way do you imagine the dashboard to contribute to the company's target of managing capacity?*

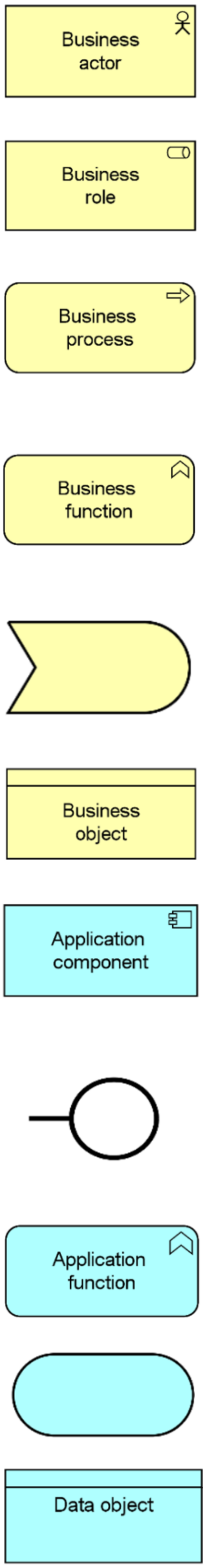
Appendix G - KPIs with Definitions

Pre-selected KPIs from *Chapter 5* with definitions:

Resource Utilization	The number of hours of work assigned to a resource or group of resources as a percentage of their availability for a given period (Paul, 2009).
Performance	The ratio of the actual operating speed of the equipment (e.g. the ideal speed minus speed losses, minor stoppages and idling) to its ideal speed. Can also be calculated as (ideal cycle time * output) / operating time. In that sense, it is the actual deviation in production in time from ideal cycle time (Garza-Reyes, Eldridge, Barber & Soriano-Meier, 2010).
Quality	The proportion of defective production to the total production volume (Garza-Reyes, Eldridge, Barber & Soriano-Meier, 2010).
OEE	Overall Equipment Effectiveness; result of multiplying three mutually exclusive components: availability, performance, and quality (Garza-Reyes, Eldridge, Barber & Soriano-Meier, 2010).
Throughput	Measures how much product is being produced on a machine, line, unit, or plant over a specified period of time (Davidson, 2013).
Machine Downtime	Includes scheduled downtime for maintenance, setups and unscheduled downtime and can include machine changeover (Gehringer, 2019).
Productivity of Employee	Helps to measure workforce efficiency over time. Can be determined by taking the total company revenue and dividing it by the total number of employees (Jessee, 2018).
Inventory Turns	Ratio calculation to measure the efficient use of inventory materials. It is calculated by dividing the cost of goods sold by the average inventory used to produce those goods (Davidson, 2013).
Manufacturing Cycle Time	Measures the speed or time it takes for manufacturing to produce a given product from the time the order is released to production, to finished goods (Davidson, 2013).

Appendix H – ArchiMate Elements

Below, the elements that were used for the conceptual data architecture are explained. Information is retrieved from The Open Group ("ArchiMate Specification", 2017).



A business actor is a business entity that is capable of performing behaviour.

A business role is the responsibility for performing specific behavior,to which an actor can be assigned, or the part an actor plays in a particular action or event.

A business process represents a sequence of business behaviors that achieves a specific outcome such as a defined set of products or business services.

A business function is a collection of business behavior based on a chosen set of criteria (typically required business resources and/or competencies), closely aligned to an organization, but not necessarily explicitly governed by the organization.

A business event is a business behavior element that denotes an organizational state change. It may originate from and be resolved inside or outside the organization.

A business object represents a concept used within a particular business domain.

An application component represents an encapsulation of application functionality aligned to implementation structure, which is modular and replaceable. It encapsulates its behavior and data, exposes services, and makes them available through interfaces.

An application interface represents a point of access where application services are made available to a user, another application component, or a node.

An application function represents automated behavior that can be performed by an application component.

An application service represents an explicitly defined exposed application behavior.

A data object represents data structured for automated processing.

App. H, Fig. 1 – Selected ArchiMate Elements

Appendix I - Dashboard Design

Below, an addition is provided to the description of the dashboard design in *Chapter 5*. Illustrations of amongst others the tables are presented, together with more detailed explanations of codes and calculations that have been used. Furthermore, some remarks have been added regarding the adjustment of the design for future use.

Product Table (Sheet SAP Data)

	A	B	C	D	E	F	G
1	Product	Product Name	Step Item	Resource Step	Batch Size Bruto	Batch Size Netto	Process Time (h)
2	10-00000-00	dummy artikel voor eenmalige proto in NL	30-00000-00	dummy artikel voor eenmalige proto in NL	45	40	3
3	10-00000-00	dummy artikel voor eenmalige proto in NL	NLWAX00	Wax injection and tree construction (automatic)	45	40	0.0833
4	10-00000-00	dummy artikel voor eenmalige proto in NL	NLAGV01	Spoelen	45	40	0.0833
5	10-00000-00	dummy artikel voor eenmalige proto in NL	NLAGV02	Drogen A na Spoelen	45	40	0.3333
6	10-00000-00	dummy artikel voor eenmalige proto in NL	NLAGV09	Dippen 1	45	40	0.0833
7	10-00000-00	dummy artikel voor eenmalige proto in NL	NLAGV10	Drogen A na Dippen 1	45	40	0.6667
8	10-00000-00	dummy artikel voor eenmalige proto in NL	NLAGV17	Voorschillen 1	45	40	0.0833
9	10-00000-00	dummy artikel voor eenmalige proto in NL	NLAGV18	Drogen A na Voorschillen 1	45	40	0.6667
10	10-00000-00	dummy artikel voor eenmalige proto in NL	NLAGV90	Output keramiek	45	40	0.0833
11	10-00000-00	dummy artikel voor eenmalige proto in NL	NLCER05	Back-up coat (twins)	45	40	0.0833
12	10-00000-00	dummy artikel voor eenmalige proto in NL	NLCER19	Drying - Back-up coat (twins)	45	40	0.6667
13	10-00000-00	dummy artikel voor eenmalige proto in NL	NLCER29	Dewaxing	45	40	0.1667
14	10-00000-00	dummy artikel voor eenmalige proto in NL	NLCER20	Drying - dewaxing	45	40	0.6667
15	10-00000-00	dummy artikel voor eenmalige proto in NL	MAT999	dummy materiaal	45	40	0.041
16	10-00000-00	dummy artikel voor eenmalige proto in NL	NLCAS08	Ceramic baking - small	45	40	0.0167
17	10-00000-00	dummy artikel voor eenmalige proto in NL	NLCAS12	Melting and casting - small	45	40	1
18	10-00000-00	dummy artikel voor eenmalige proto in NL	NLCAS04	Cooling - tree - hal2	45	40	0.0833
19	10-00000-00	dummy artikel voor eenmalige proto in NL	NLCAS05	Waiting after cooling	45	40	0.5
20	10-00000-00	dummy artikel voor eenmalige proto in NL	NLFIN01	Vibrating	45	40	0.05
21	10-00000-00	dummy artikel voor eenmalige proto in NL	NLFIN04	Waterjet (manual)	45	40	0.0833
22	10-00000-00	dummy artikel voor eenmalige proto in NL	NLFIN01	Vibrating	45	40	0.0833
23	10-00000-00	dummy artikel voor eenmalige proto in NL	NLQC04	Quality control	45	40	0.0833
24	10-00000-00	dummy artikel voor eenmalige proto in NL	10-00000-00	dummy artikel voor eenmalige proto in NL	45	40	0
25	10-00000-00	dummy artikel voor eenmalige proto in NL	NLFIN50	Repair and control	45	40	0.0167
26	10-00000-00	dummy artikel voor eenmalige proto in NL	NLQC05	Measuring	45	40	1
27	[redacted]				84	76	0
28	[redacted]				84	76	1.6212

Adjusted Data for Calculations

SAP Data | Sales Data | Resource Data | Combined Data | Time Data | Graph Data | Tool | Dashl ...

App. I, Fig. 1 – Product Table

- Cells marked in yellow show the data that had to be adjusted: some data that was needed for the calculations did not exist and had to be estimated.
- The process time does not correspond with the method that was proposed in *Chapter 4*. In the future, this column can be updated with times that are retrieved according to the method.
- Cells that contain confidential information are hidden.

Sales Table (Sheet Sales Data)

	A	B	C	D	E	F	G	H	I	J
1	Product	Sales ID	Batchsize Bruto	Batchsize Netto	# Pieces Netto 2019	# Trees Bruto 2019 (1)	# Trees Netto 2019 (2)	# Pieces Netto Scenario	# Trees Bruto Scenario (1)	# Trees Netto Scenario (2)
2	[redacted]	1	126	83	293450	3536	2329	44488	536	353
3		2	126	83	89250	1075	708	20750	250	165
4		3	117	83	182300	2196	1558	16268	196	139
5		4	160	153	200	1	1	200	1	1
6		5	132	128	300	2	2	300	2	2
7		6	48	43	431	10	9	431	10	9
8		7	80	72	200	3	3	200	3	3
9		8	96	94	400	4	4	400	4	4
10		9	24	20	300	15	13	300	15	13
11		10	192	189	300	2	2	300	2	2
12		11	252	226	1134	5	5	1134	5	5
13		12	100	90	0	0	0	0	0	0
14		13	504	494	0	0	0	0	0	0
15		14	120	108	400	4	3	400	4	3
16		15	192	170	600	4	3	600	4	3
17		16	280	252	3947	16	14	3947	16	14
18		17	76	69	0	0	0	0	0	0
19		18	68	61	63	1	1	63	1	1
20		19	0	0	0	0	0	0	0	0
21		20	120	108	420	4	4	420	4	4
22		21	0	0	0	0	0	0	0	0
23		22	70	63	85	1	1	85	1	1
24		23	8	7	0	0	0	0	0	0
25		24	4	3	0	0	0	0	0	0

Adjusted Data for Calculations

SAP Data | Sales Data | Resource Data | Combined Data | Time Data | Graph Data | Tool | Dashl ...

App. I, Fig. 2 – Sales Table

- *'# Pieces Netto 2019'*: total amount of pieces that have been ordered in the year 2019, per product.
- *'Batchsize Netto'* and *'Batchsize Bruto'* were obtained from the *Product Table* with the Excel VLOOKUP function. These batchsizes were used to convert the amount of pieces into trees: the process times in the ERP system refer to trees, thus, the separate products had to be converted to trees for further calculations.
- At CIREX it is common to increase the demand with a certain amount to cover the scrap: more products are produced than the amount that will eventually go to the customer. *'Batchsize Bruto'* refers to the amount of products attached to a tree with the scrap included. At the end of the process, after control and repair at CIREX Foundry CZ, the '*Batchsize netto'* remains.
- *'# Trees Bruto'*: amount of trees that has to be produced to cover the scrap, and hence meet the customer demand.
- *'# Trees Bruto'*: the amount of products that remain after control and repair, converted to trees.
- *'# Trees Bruto Scenario'*: fictional demand that the user of the dashboard entered in the *Tool*. From these values, *'# Trees Netto Scenario'* and *'# Pieces Netto Scenario'* are retrieved.

Resource Table (Sheet Resource Data)

	Resource No.	Resource Description	FTEs	Machines	Total FTEs	Shifts	Selection Defined Resources 0/1/2	Category	MaxCap	Factor	Unit Category	Comments
3	CZCAS02	Melting and casting - tree	4	1	4	3	0	E	26.67	0.00	1	
6	CZCER01	Degreasing	3	1	3	3	0	E	26.67	0.00	1	Max Cap = 400 trees per week
46	CZCER60	Dewaxing	1	1	1	3	0	C		1.25	1	
50	CZFIN01	Vibrating	1	1	1	3	0	C		1.25	1	
51	CZFIN02	Cutting tree	1	1	1	3	0	D		1.30	1	
53	CZFIN11	Cutting branch	1	1	1	3	0	D		1.30	1	
54	CZFIN12	Cutting ingate from product	1	1	1	3	0	D		1.30	1	
56	CZFIN20	Grinding (manual)	1	2	2	3	0	D		1.30	1	
57	CZFIN21	Grinding (semi-automatic)	1	1	1	3	0	B		1.20	1	
58	CZFIN27	Hand blasting - Grittal	1	1	1	3	0	D		1.30	1	
60	CZFIN30	Hand blasting - corund	1	5	5	3	0	D		1.30	1	
61	CZFIN31	Hanger blasting - Steel shot	0.5	1	0.5	3	0	C		1.25	1	
62	CZFIN32	Hanger blasting - RVS	0.5	1	0.5	3	0	C		1.25	1	
63	CZFIN33	Belt blasting - steel shot	0.1	1	0.1	3	0	B		1.20	1	
64	CZFIN34	Belt blasting - RVS	0.3	3	0.9	3	0	B		1.20	1	
65	CZFIN35	Small belt blasting - RVS	0.1	1	0.1	3	0	B		1.20	1	
66	CZFIN36	Drum blasting - corund	0.1	2	0.2	3	0	B		1.20	1	
67	CZFIN40	Internal heat treatment	1	1	1	3	0	E	40.00	0.00	1	Max Cap = 600 trees per week
68	CZFIN50	Control and repair	1	30	30	1	0	D		1.30	1	
69	CZFIN60	Coining (manual)	1	1	1	3	0	D		1.30	2	
70	CZFIN61	Coining Tox	1	1	1	3	0	C		1.25	2	
71	CZFIN62	Coining Almatic	1	2	2	3	0	C		1.25	2	
72	CZFIN63	Coining Hydraulic press	1	1	1	3	0	C		1.25	2	
73	CZFIN64	Coining PAG	1	1	1	3	0	C		1.25	2	
75	CZFIN71	Honing	1	1	1	2	0	D		1.30	2	
76	CZFIN72	Deburring	1	1	1	2	0	D		1.30	2	
77	CZFIN73	Fanuc	1	4	4	2	0	B		1.20	2	
78	CZFIN74	Hyundai Milling Centre	1	2	2	3	0	B		1.20	2	
79	CZFIN75	Profika CNC Lathe	1	3	3	3	0	B		1.20	2	
80	CZFIN76	Chiron FZ08W	1	1	1	3	0	B		1.20	2	
81	CZFIN77	FNG-VCM Milling Centre	1	1	1	2	0	D		1.30	2	

Adjusted Data for Calculations

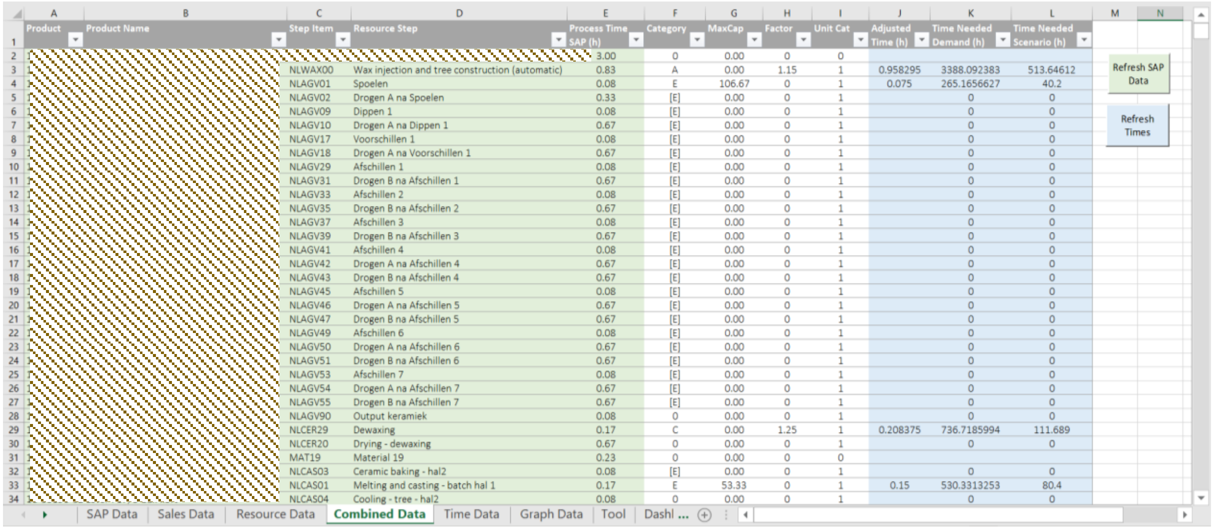
SAP Data | Sales Data | **Resource Data** | Combined Data | Time Data | Graph Data | Tool | Dashl ...

App. I, Fig. 3 – Resource Table

- *'FTEs'*: number of fulltime employees that is available per machine or workstation, per shift.
- *'Machines'*: the amount of machines or, in case of manual tasks (Category D), the amount of workstations that is available.
- *'Total FTEs'*: the total number of FTEs that is available per shift. Calculated by multiplying '*FTEs'* by *'Machines'*.
- *'Shifts'*: amount of shifts per day

- *'Selection Defined Resources'*: not all the resources from the ERP system had to be categorized. To easily filter the resource that were defined, this column was added. '0' shows the resources that are presented in the dashboard.
- If a resource step belongs to Category E, there is no factor available. Instead, a maximum capacity (maximum amount of trees that can be produced) per shift was entered. Therefore, the category and amount of MaxCap are only active for the first resource step of the department. The category and MaxCap for the other resource steps in a Category E department are entered in square brackets, to ensure that these are not included in calculations. For example in case of the Ceramics department, only the 'Degreasing' resource step is used. Steps such as coating and drying are not used for the calculation. To shows these resource steps, '2' can be selected in column '*Selection Defined Resources'*.
- *'Unit Category'*: after the resource step 'Control and Repair', bad quality products are removed (scrap). To distinguish between the resource steps that process the bruto amount of trees and the resource steps that process the netto amount of trees, this column was added to the table. The resource steps that process the bruto amount of trees are labelled with '1', and the resource steps that process the netto amount of trees (all CZ steps after Control and Repair) are labelled with '2'.
- *Remark*: in the ERP product data, some resource steps that have a lower 'Step Item' than Control and Repair can still come after Control and Repair in the production process. Current calculations would in that case use the bruto amount of trees, even though scrap would than already be removed. It is suggested to consider this simplification when improving the dashboard.

Product_Resource_Times Table (Sheet Combined Data)



	Product	Product Name	Step Item	Resource Step	Process Time SAP (h)	Category	MaxCap	Factor	Unit Cat	Adjusted Time (h)	Time Needed Demand (h)	Time Needed Scenario (h)
2					3.00	0	0.00	0	0			
3			NLWAX00	Wax injection and tree construction (automatic)	0.83	A	0.00	1.15	1	0.958295	3388.092383	513.64612
4			NLAGV01	Spoelen	0.08	E	106.67	0	1	0.075	265.1656627	40.2
5			NLAGV02	Drogen A na Spoelen	0.33	[E]	0.00	0	1		0	0
6			NLAGV09	Dippen 1	0.08	[E]	0.00	0	1		0	0
7			NLAGV10	Drogen A na Dippen 1	0.67	[E]	0.00	0	1		0	0
8			NLAGV17	Voorschillen 1	0.08	[E]	0.00	0	1		0	0
9			NLAGV18	Drogen A na Voorschillen 1	0.67	[E]	0.00	0	1		0	0
10			NLAGV29	Afschillen 1	0.08	[E]	0.00	0	1		0	0
11			NLAGV31	Drogen B na Afschillen 1	0.67	[E]	0.00	0	1		0	0
12			NLAGV33	Afschillen 2	0.08	[E]	0.00	0	1		0	0
13			NLAGV35	Drogen B na Afschillen 2	0.67	[E]	0.00	0	1		0	0
14			NLAGV37	Afschillen 3	0.08	[E]	0.00	0	1		0	0
15			NLAGV39	Drogen B na Afschillen 3	0.67	[E]	0.00	0	1		0	0
16			NLAGV41	Afschillen 4	0.08	[E]	0.00	0	1		0	0
17			NLAGV42	Drogen A na Afschillen 4	0.67	[E]	0.00	0	1		0	0
18			NLAGV43	Drogen B na Afschillen 4	0.67	[E]	0.00	0	1		0	0
19			NLAGV45	Afschillen 5	0.08	[E]	0.00	0	1		0	0
20			NLAGV46	Drogen A na Afschillen 5	0.67	[E]	0.00	0	1		0	0
21			NLAGV47	Drogen B na Afschillen 5	0.67	[E]	0.00	0	1		0	0
22			NLAGV49	Afschillen 6	0.08	[E]	0.00	0	1		0	0
23			NLAGV50	Drogen A na Afschillen 6	0.67	[E]	0.00	0	1		0	0
24			NLAGV51	Drogen B na Afschillen 6	0.67	[E]	0.00	0	1		0	0
25			NLAGV53	Afschillen 7	0.08	[E]	0.00	0	1		0	0
26			NLAGV54	Drogen A na Afschillen 7	0.67	[E]	0.00	0	1		0	0
27			NLAGV55	Drogen B na Afschillen 7	0.67	[E]	0.00	0	1		0	0
28			NLAGV90	Output keramiek	0.08	0	0.00	0	1		0	0
29			NLCER29	Dewaxing	0.17	C	0.00	1.25	1	0.208375	736.7185994	111.689
30			NLCER20	Drying - dewaxing	0.67	0	0.00	0	1		0	0
31			MAT19	Material 19	0.23	0	0.00	0	0			
32			NLCAS03	Ceramic baking - hal2	0.08	[E]	0.00	0	1		0	0
33			NLCAS01	Melting and casting - batch hal 1	0.17	E	53.33	0	1	0.15	530.3313253	80.4
34			NLCAS04	Cooling - tree - hal2	0.08	0	0.00	0	1		0	0

App. I, Fig. 4 – Product_Resource_Times Table

- A macro was created in Visual Basics to obtain the product data from the *Product table* for each sales product from the *Sales table*, see *Figure 5*. In case the input data changes, the data can be refreshed by clicking on the first button, displayed on the right side of the sheet. CIREX uses SAP as ERP system, so the data is referred to as '*SAP data'*.

- VLOOKUP function was used to return the resource data for each row in the table. This function looks up and returns data from a specific column in a table. Although the same result could have been achieved with a code, macros in VBA were only used when necessary; excessive use of code can make it difficult for someone else to adjust the dashboard in the future.
- Time calculations are dependent on the category to which the particular resource step belongs. See *Figure 6* for the code that was used. This code is connected to the button '*Refresh Times'*.
- In case of the *'Adjusted Time'*, for categories A, B, C and D, the process time is multiplied by the category-specific factor. For category E, MaxCap is used to calculate the time that is needed to process one tree.
- *Remark*: if in the future the method from *Chapter 4* is applied, this would mean the times in the ERP system would already be adjusted by the factor. However, to make it possible to determine the effect of changes in these factors, it was decided to include these in the calculations. Thus, it is suggested to insert the average of the measured times as 'Process time' in this tool, instead of the times that are already adjusted by the factor.
- *'Time Needed'*: in these last two columns, adjusted time is multiplied by the demand in trees. Dependent on the resource step, the '*# Trees Bruto'* or the '*# Trees Netto'* was used. For all steps after Control and Repair, indicated with Unit Category '2', adjusted time is multiplied by '*# Trees Netto'*. For all steps before Control and Repair, indicated with Unit Category '1', adjusted time is multiplied by '*# Trees Bruto'*.

```
Combine_SAP_Data - 1

Option Explicit

Sub CombineData1()

'To speed up running time
Application.ScreenUpdating = False
Application.Calculation = xlCalculationManual

Dim i As Integer
Dim n As Integer
Dim k As Integer
Dim LastRow As Integer
Dim LastRow2 As Integer
Dim SAP As Worksheet
Dim Combined As Worksheet
Dim Sales As Worksheet

Set SAP = Sheets("SAP Data")
Set Combined = Sheets("Combined Data")
Set Sales = Sheets("Sales Data")

'Determine last row in tables
LastRow = Sales.Cells(Rows.Count, 1).End(xlUp).Row
LastRow2 = SAP.Cells(Rows.Count, 1).End(xlUp).Row

'Return for each product in Sales the SAP information
k = 2
For i = 2 To LastRow
    For n = 2 To LastRow2
        If SAP.Cells.Item(n, 1).Value = Sales.Cells.Item(i, 1).Value Then
            Combined.Cells.Item(k, 1).Value = Sales.Cells.Item(i, 1).Value
            Combined.Cells.Item(k, 2).Value = SAP.Cells.Item(n, 2).Value
            Combined.Cells.Item(k, 3).Value = SAP.Cells.Item(n, 3).Value
            Combined.Cells.Item(k, 4).Value = SAP.Cells.Item(n, 4).Value
            Combined.Cells.Item(k, 5).Value = SAP.Cells.Item(n, 7).Value
            k = k + 1
        End If
    Next n
Next i

Application.ScreenUpdating = True
Application.Calculation = xlCalculationAutomatic

End Sub
```

App. I, Fig. 5 – Code Combine SAP Data

```
TimeCalculations - 1

Option Explicit

Sub AdjustedTime()

'To speed up running time
Application.ScreenUpdating = False
Application.Calculation = xlCalculationManual

Dim s As Integer
Dim LastRow5 As Integer
Dim Combined As Worksheet

Set Combined = Sheets("Combined Data")

'Determine last row in table
LastRow5 = Combined.Cells(Rows.Count, 1).End(xlUp).Row

'Determine Adjusted Time; time resource step needs to process tree
'Category dependent:
'If Category A, B, C or D, then process time * factor
'If Category E, then hours in a shift (8) / MaxCap
For s = 2 To LastRow5
    If Combined.Cells.Item(s, 6).Value = "A" Or Combined.Cells.Item(s, 6).Value = "B" Or Combined.C
ells.Item(s, 6).Value = "C" Or Combined.Cells.Item(s, 6).Value = "D" Then
        Combined.Cells.Item(s, 10).Value = Combined.Cells.Item(s, 8).Value * Combined.Cells.Item(s,
 5).Value
    ElseIf Combined.Cells.Item(s, 6).Value = "E" Then
        Combined.Cells.Item(s, 10).Value = 8 / Combined.Cells.Item(s, 7).Value
    End If
Next s

Application.ScreenUpdating = True
Application.Calculation = xlCalculationAutomatic

End Sub
```

```
Sub TimeNeededCurrent()

'To speed up running time
Application.ScreenUpdating = False
Application.Calculation = xlCalculationManual

Dim i As Integer
Dim j As Integer
Dim LastRow6 As Integer
Dim LastRow7 As Integer
Dim Combined As Worksheet
Dim Sales As Worksheet

Set Combined = Sheets("Combined Data")
Set Sales = Sheets("Sales Data")

'Determine last row in tables
LastRow6 = Combined.Cells(Rows.Count, 1).End(xlUp).Row
LastRow7 = Sales.Cells(Rows.Count, 1).End(xlUp).Row

'Determine time needed per resource step to meet demand
'Dependent on Unit Category:
'Resource steps before CZFIN50, unit category '1': adjusted time * bruto amount of trees
'Resource steps after CZFIN50, unit category '2': adjusted time * netto amount of trees
i = 2
For j = 2 To LastRow7
If Combined.Cells.Item(i, 1).Value = Sales.Cells.Item(j, 1).Value Then
    If Combined.Cells.Item(i, 9).Value = "1" Then
    Combined.Cells.Item(i, 11).Value = Combined.Cells.Item(i, 10).Value * Sales.Cells.Item(j, 5).Va
lue
    ElseIf Combined.Cells.Item(i, 9).Value = "2" Then
    Combined.Cells.Item(i, 11).Value = Combined.Cells.Item(i, 10).Value * Sales.Cells.Item(j, 6).Va
lue
    End If
    i = i + 1
    j = 1
End If
Next j

Application.ScreenUpdating = True
Application.Calculation = xlCalculationAutomatic
```

App. I, Fig. 6a – Code Calculate Times

```
TimeCalculations - 2

End Sub

Sub TimeNeededScenario()

'Similar to Sub TimeNeeded, but scenario demand from Tool used

Application.ScreenUpdating = False
Application.Calculation = xlCalculationManual

Dim i As Integer
Dim j As Integer
Dim LastRow6 As Integer
Dim LastRow7 As Integer
Dim Combined As Worksheet
Dim Sales As Worksheet

Set Combined = Sheets("Combined Data")
Set Sales = Sheets("Sales Data")

LastRow6 = Combined.Cells(Rows.Count, 1).End(xlUp).Row
LastRow7 = Sales.Cells(Rows.Count, 1).End(xlUp).Row

i = 2
For j = 2 To LastRow7
If Combined.Cells.Item(i, 1).Value = Sales.Cells.Item(j, 1).Value Then
    If Combined.Cells.Item(i, 9).Value = "1" Then
    Combined.Cells.Item(i, 12).Value = Combined.Cells.Item(i, 10).Value * Sales.Cells.Item(j, 8).Va
lue
    ElseIf Combined.Cells.Item(i, 9).Value = "2" Then
    Combined.Cells.Item(i, 12).Value = Combined.Cells.Item(i, 10).Value * Sales.Cells.Item(j, 9).Va
lue
    End If
    i = i + 1
    j = 1
End If
Next j

Application.ScreenUpdating = True
Application.Calculation = xlCalculationAutomatic

End Sub
```

App. I, Fig. 6b – Code Calculate Times

Times Table (Sheet Time Data)

	A	B	C	D	E	F
1	Step Item	Resource Step	Total Time Needed 2019 (h)	Total Time Needed Scenario (h)	Available Time 2019 (h)	Available Time Scenario (h)
2	CZCAS02	Melting and casting - tree	4558.88	6854.59	5640.00	5640.00
3	CZCER01	Degreasing	4558.88	6854.59	5640.00	5640.00
4	CZCER60	Dewaxing	8039.93	11524.09	5640.00	11280.00
5	CZFIN01	Vibrating	2934.96	4087.49	5640.00	5640.00
6	CZFIN02	Cutting tree	4014.70	6980.77	5640.00	5640.00
7	CZFIN11	Cutting branch	2813.12	4315.33	5640.00	5640.00
8	CZFIN12	Cutting ingate from product	730.11	730.11	5640.00	5640.00
9	CZFIN20	Grinding (manual)	5374.62	11367.04	11280.00	11280.00
10	CZFIN21	Grinding (semi-automatic)	14467.15	16451.84	5640.00	11280.00
11	CZFIN27	Hand blasting - Grittal	0.00	0.00	5640.00	5640.00
12	CZFIN30	Hand blasting - corund	11267.26	12085.88	28200.00	28200.00
13	CZFIN31	Hanger blasting - Steel shot	1381.03	1381.03	5640.00	5640.00
14	CZFIN32	Hanger blasting - RVS	3167.91	2923.39	5640.00	5640.00
15	CZFIN33	Belt blasting - steel shot	4415.78	6098.02	5640.00	5640.00
16	CZFIN34	Belt blasting - RVS	6200.87	8756.05	16920.00	16920.00
17	CZFIN35	Small belt blasting - RVS	1271.65	1271.65	5640.00	5640.00
18	CZFIN36	Drum blasting - corund	1147.91	2027.46	11280.00	11280.00
19	CZFIN40	Internal heat treatment	8615.69	7303.58	5640.00	5640.00
20	CZFIN50	Control and repair	53894.61	96210.87	56400.00	56400.00
21	CZFIN60	Coining (manual)	3254.55	2488.96	5640.00	5640.00

Refresh Available Time 2019 (h)

SAP Data | Sales Data | Resource Data | Combined Data | Time Data | Graph Data | Tool | Dashl ...

App. I, Fig. 7 – Times Table

- SUMIF function is used to return the total amount of time that is needed to produce all the ordered products that follow this resource step. If *'Step Item'* cells from sheet *'Combined Data'* match the *'Step Item'* cell from sheet *'Time Data'*, the corresponding times in column *'Time Needed Demand'* from sheet *'Combined Data'* are summed. The same happens for the scenario demand.

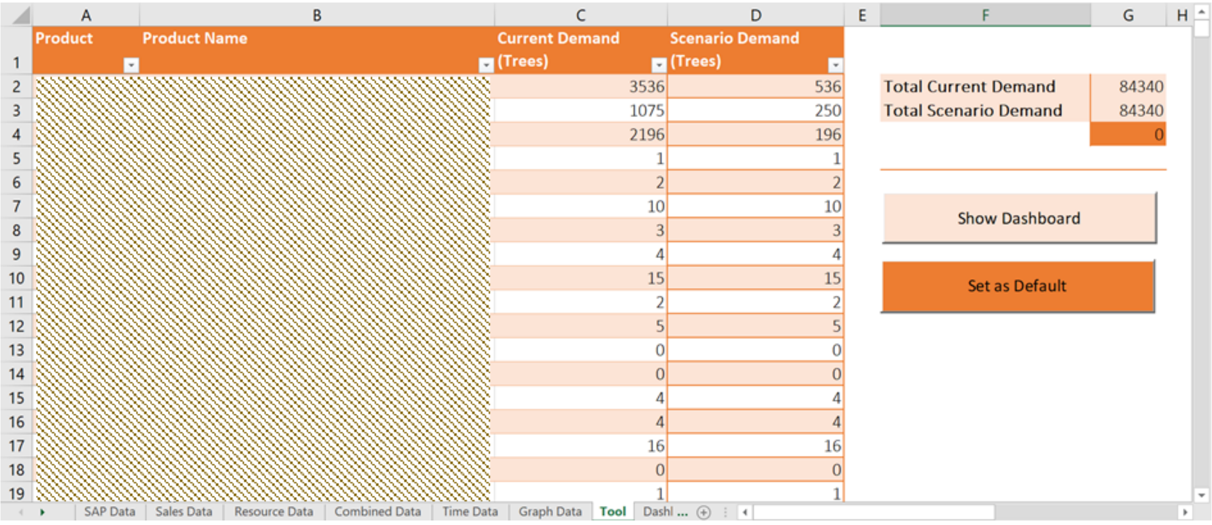
- *'Available Time'*: it has been assumed that CIREX is active 47 weeks per year, 5 days per week. The amount of shifts varies per resource step: normally 3 shifts per day, in some cases 2 shifts per day. One shift lasts 8 hours. Dependent on the amount of available machines or FTEs, the total available time for the resource step increases proportionally. It depends on the category whether the available time includes number of FTEs or number of Machines. If the resource data changed, data in this table can be refreshed by clicking on the button *'Refresh Available Time 2019'*. See code in *Figure 8.*
- *'Available Time Scenario'*: this column is refreshed when the button '*Show Dashboard'* in the tool is activated. Code can be found in *Figure 8* as well; sub '*RefreshAvailableTimeScenario*'.

```
Sub RefreshAvailableTime()

Dim Time As Worksheet
Dim Resource As Worksheet
Dim w As Integer
Dim q As Integer
Dim LastRow1 As Integer
Dim LastRow2 As Integer

Set Time = Sheets("Time Data")
Set Resource = Sheets("Resource Data")

'Determine last row in tables
LastRow1 = Resource.Cells(Rows.Count, 1).End(xlUp).Row
LastRow2 = Time.Cells(Rows.Count, 1).End(xlUp).Row

'To speed up running time
Application.ScreenUpdating = False
Application.Calculation = xlCalculationManual

'Calculate Available Time for current situation
'Dependent on Category:
'machine dependent categories, number of Machines used
'human operator dependent category, number of FTEs used
'Available Time = weeks per year * days in a week * hours in a shift * number of shifts * FTE/Machines
q = 2
For w = 2 To LastRow1
    If Time.Cells.Item(q, 1).Value = Resource.Cells.Item(w, 1).Value Then
        If Resource.Cells.Item(w, 8).Value = "E" Or Resource.Cells.Item(w, 8).Value = "A" Or Resource.Cells.Item(w, 8).Value = "B" Or Resour
ce.Cells.Item(w, 8).Value = "C" Then
        Time.Cells.Item(q, 5).Value = 47 * 5 * 8 * Resource.Cells.Item(w, 6).Value * Resource.Cells.Item(w, 4).Value
        ElseIf Resource.Cells.Item(w, 8).Value = "D" Then
        Time.Cells.Item(q, 5).Value = 47 * 5 * 8 * Resource.Cells.Item(w, 6).Value * Resource.Cells.Item(w, 5).Value
        End If
        q = q + 1
        w = 1
    End If
Next w

Application.ScreenUpdating = True
Application.Calculation = xlCalculationAutomatic

End Sub
```

```
Sub RefreshAvailableTimeScenario()

Dim Time As Worksheet
Dim Tool As Worksheet

Dim w As Integer
Dim q As Integer

Dim LastRow2 As Integer
Dim LastRow3 As Integer

Set Time = Sheets("Time Data")
Set Tool = Sheets("Tool")

LastRow2 = Time.Cells(Rows.Count, 1).End(xlUp).Row
LastRow3 = Tool.Cells(Rows.Count, 17).End(xlUp).Row

Application.ScreenUpdating = False
Application.Calculation = xlCalculationManual

'Similar to Sub RefreshTotalTime
'Data not from Sheet Sales, but Tool
q = 2
For w = 3 To LastRow3
For q = 2 To LastRow2
    If Time.Cells.Item(q, 1).Value = Tool.Cells.Item(w, 17).Value Then
        If Tool.Cells.Item(w, 18).Value = "E" Or Tool.Cells.Item(w, 18).Value = "A" Or Tool.Cells.Item(w, 18).Value = "B" Or Tool.Cells.Item
(w, 18).Value = "C" Then
        Time.Cells.Item(q, 6).Value = 47 * 5 * 8 * Tool.Cells.Item(w, 19).Value * Tool.Cells.Item(w, 21).Value
        ElseIf Tool.Cells.Item(w, 18).Value = "D" Then
        Time.Cells.Item(q, 6).Value = 47 * 5 * 8 * Tool.Cells.Item(w, 20).Value * Tool.Cells.Item(w, 21).Value
        End If
    ElseIf Time.Cells.Item(q, 1).Value = Tool.Cells.Item(w, 10).Value Then
        If Tool.Cells.Item(w, 11).Value = "E" Or Tool.Cells.Item(w, 11).Value = "A" Or Tool.Cells.Item(w, 11).Value = "B" Or Tool.Cells.Item
(w, 11).Value = "C" Then
        Time.Cells.Item(q, 6).Value = 47 * 5 * 8 * Tool.Cells.Item(w, 12).Value * Tool.Cells.Item(w, 14).Value
        ElseIf Tool.Cells.Item(w, 11).Value = "D" Then
        Time.Cells.Item(q, 6).Value = 47 * 5 * 8 * Tool.Cells.Item(w, 13).Value * Tool.Cells.Item(w, 14).Value
        End If
    End If
    Next q
Next w

Application.ScreenUpdating = True
Application.Calculation = xlCalculationAutomatic

End Sub
```

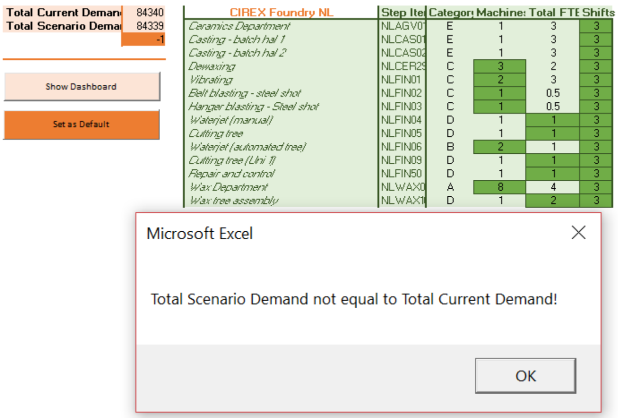
App. I, Fig. 8 – Refresh Available Time

The Tool



App. I, Fig. 9 – Tool Demand

- Column *'Scenario Demand (Trees)'* can be adjusted. Sum of the cells in this column has to be equal to the sum of the cells in column *'Current Demand (trees)'*. The difference between the amount of demand is returned in the orange-marked cell. If not equal, a message box will appear when clicking on the button *'Show Dashboard'*, see *Figure 10*.



App. I, Fig. 10 - Tool Text Box Unequal Demand

- *'Set As Default'*: with this button, all the changes that were made for the scenario will be reversed. See code in *Figure 11* on the next page. In this figure, also the code that is connected to the *'Show Dashboard'* button is presented.
- *Remark:* as mentioned before, it is only possible to adjust either the amount of machines or the amount of FTEs and not both. This depends on the category to which the particular resource step belongs. When including the adjustments of both the amount of machines and FTEs for each resource step, additional assumptions would be required: if an extra machine is added for a resource step, this does not automatically increase the number of FTEs that are needed with a similar amount. It cannot be stated that there is a directly proportional relationship between the amount of FTEs and the amount of machines. Namely, it could be the case that one extra machine would only require 0.5 additional FTEs. It is recommended to consider this relationship in the future in order to make the outcomes of the dashboard more detailed.

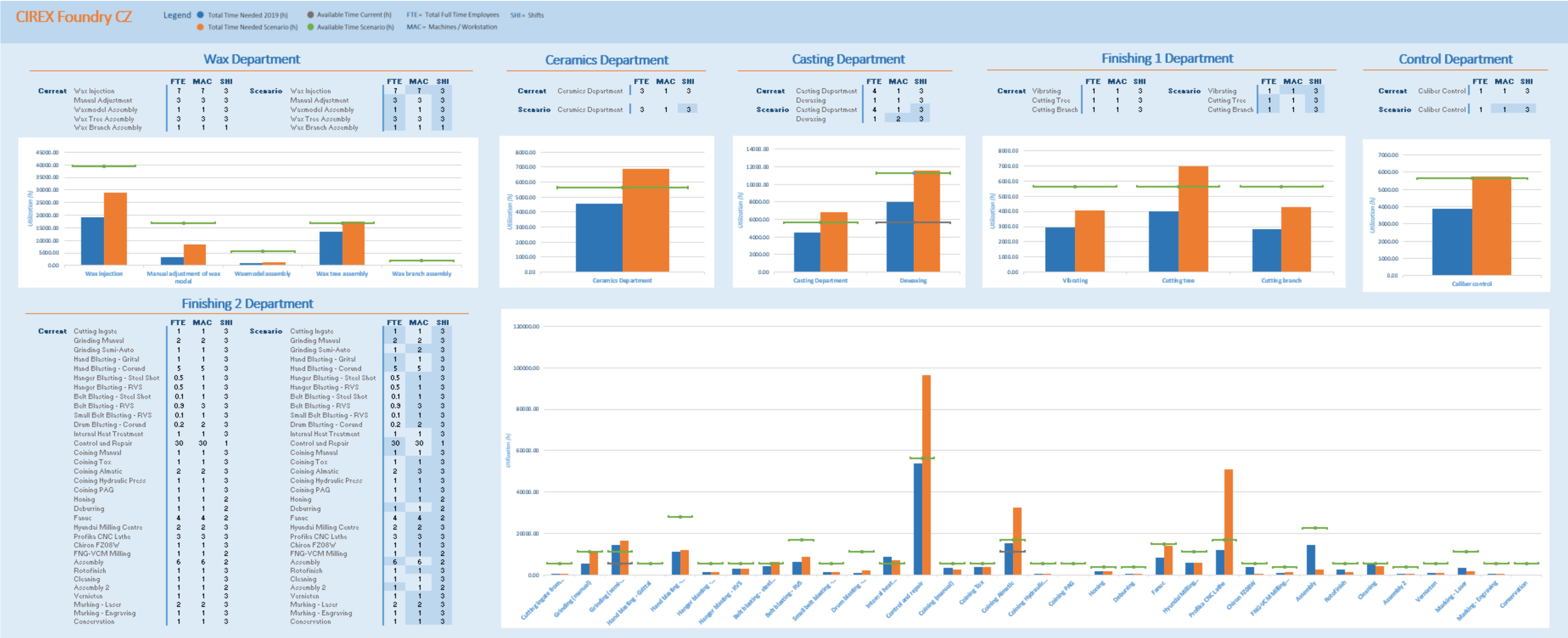
```
Private Sub SetAsDefault_Click()

Dim Tool As Worksheet
Dim Resource As Worksheet
Dim i As Integer
Dim j As Integer
Dim k As Integer
Dim LastRow As Integer
Dim LastRow1 As Integer

Set Tool = Sheets("Tool")
Set Resource = Sheets("Resource Data")

'To speed up running time
Application.ScreenUpdating = False
Application.Calculation = xlCalculationManual

'Determine last row in tables
LastRow = Tool.Cells(Rows.Count, 1).End(xlUp).Row
LastRow1 = Resource.Cells(Rows.Count, 1).End(xlUp).Row

'Delete values in cells that can be adjusted for the scenario
Tool.Range(Cells(2, 4), Cells(Rows.Count, 4)).ClearContents
Tool.Range(Cells(3, 12), Cells(Rows.Count, 12)).ClearContents
Tool.Range(Cells(3, 13), Cells(Rows.Count, 13)).ClearContents
Tool.Range(Cells(3, 14), Cells(Rows.Count, 14)).ClearContents
Tool.Range(Cells(3, 19), Cells(Rows.Count, 19)).ClearContents
Tool.Range(Cells(3, 20), Cells(Rows.Count, 20)).ClearContents
Tool.Range(Cells(3, 21), Cells(Rows.Count, 21)).ClearContents

'Return current demand in column scenario demand
For i = 2 To LastRow
Tool.Cells.Item(i, 4).Value = Tool.Cells.Item(i, 3).Value
Next i

'Return current resource data as default, table NL
j = 3
For k = 2 To LastRow1
    If Tool.Cells.Item(j, 10) = Resource.Cells.Item(k, 1) Then
        Tool.Cells.Item(j, 12).Value = Resource.Cells.Item(k, 4).Value
        Tool.Cells.Item(j, 13).Value = Resource.Cells.Item(k, 5).Value
        Tool.Cells.Item(j, 14).Value = Resource.Cells.Item(k, 6).Value
        j = j + 1
    End If
Next k

'Return current resource data as default, table CZ
j = 3
For k = 2 To LastRow1
    If Tool.Cells.Item(j, 17) = Resource.Cells.Item(k, 1) Then
        Tool.Cells.Item(j, 19).Value = Resource.Cells.Item(k, 4).Value
        Tool.Cells.Item(j, 20).Value = Resource.Cells.Item(k, 5).Value
        Tool.Cells.Item(j, 21).Value = Resource.Cells.Item(k, 6).Value
        j = j + 1
    End If
Next k

Application.ScreenUpdating = True
Application.Calculation = xlCalculationAutomatic


End Sub
```

```
Private Sub ShowDashboard2_Click()

Dim cell As Integer
Dim Tool As Worksheet
Dim Dashboard As Worksheet

Set Tool = Sheets("Tool")
Set Dashboard = Sheets("Dashboard")

cell = Tool.Range("G4").Value

'If sum of current demand is equal to sum of scenario demand, update scenario data in other tables and show dashboard
'If not, show message box
If cell = 0 Then
Call TimeNeededScenario
Call RefreshAvailableTimeScenario
Dashboard.Activate
Else: MsgBox "Total Scenario Demand not equal to Total Current Demand!"
End If

End Sub
```

App. I, Fig. 11 – Code Set As Deafult & Show Dashboard

Dashboard

- Data that is used to design the graphs for the dashboard was summarized in the sheet '*Graph Data*'.
- For the dashboard part that shows the results for CIREX Foundry CZ, see *Figure 12*, on the next page.
- *Remark*: although the dashboard is designed in such a way that it could be easily improved or adjusted for future use, the pre-selected resources that are displayed in the dashboard are more difficult to change. Some tables and the layout of the dashboard would have to be adjusted.



App. I, Fig. 12 – Dashboard CIREX Foundry CZ