MASTER

Transparency in material availability for S&OP decision making within Hilti AG

Wagemakers, Obe C.

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Department of Industrial Engineering and Innovation Sciences
Architecture of Information Systems Research Group

Transparency in material availability for S&OP decision making within Hilti AG

By
Bsc. O.C. (Obe) Wagemakers
Student number 1236478

Master of Science
in Operations Management and Logistics

Supervisors:

dr. L. (Laura) Genga, TU/e, IS
dr. S. (Shaunak) Dabadghao, TU/e, OPAC
M. (Markus) Frey, Hilti AG
H. (Helder) De Oliveira, Hilti AG

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Abstract

Hilti uses Hilti Integrated Planning which aims to create one integrated planning environment to globally manage Hilti's end-to-end supply chain. Part of this method is the Sales & Operations Planning process. This process aims to close the gap between the demand and the available capacities in the production plants. The available capacity is measured for machinery, man power and materials. Currently, there is sufficient information on the machinery and man power capacity but there is a lack of transparency in material availability.

The current project aims to provide transparency in material availability. A dashboard is designed that combines information from multiple sources and displays the material availability as a table and two visuals. It also includes various filtering options on for example the production lines. The dashboard is initially built for two production lines of Hilti's production plant in Thüringen, Austria. However, it is built such that it can be scaled over multiple production lines and plants.

Executive Summary

Research problem

S&OP aims to close the gap between customer demand and available plant capacities. The expected demand is based on the global forecast and is expressed in pieces and hours. The capacity is measured on three levels: machinery, man power and materials. Machinery and man power are measured in hours and can be compared to the demand. Currently, there is no measurement for the material availability that can be compared to the demand. The reason for this is that no inventory of the materials is held at the moment of the S&OP meetings. Production only starts in the same month as the demand should be satisfied, while the S&OP meetings take place before the discussed month starts. Possible shortages in materials are found during the same month as the demand should be satisfied. In the current situation, it happens that man power and machinery cannot work as planned because there is a sudden shortage in materials. This leads to redundancy and inefficiency of the process. Each material that is produced consists of multiple components. If these components are available at the start of the month, the materials can be produced in that month as well. To find the expected material availability, the availability of the components should be found first. The component availability can be determined based on the current and in-transit inventories. However, it is computationally expensive to do these calculations for each component and material individually. Therefore, the goal of the current project is to create a tool that defines the material availability. A dashboard is created that combines the demand data with the data on component availability to identify possible shortages before the month starts. The dashboard is created such that it can be used as input for the S&OP models and supports tactical decision making. The main research question is based on this development:

How can a tool be designed that provides the material availability to support S&OP decision making within Hilti?

The scope of the current project includes two production lines of Hilti's production plant in Thüringen, Austria. This plant is called Plant XZ and is part of Hilti's Power Tools & Accessories department. The dashboard is initially built for the analysis of data of one month and two production lines, called Z1 and Z2. These production lines cover the production of 33 and 106 materials, respectively. However, the dashboard is built such that it can be scaled over multiple production lines and periods.

Dashboard design

The component availabilities are found by combining data from multiple sources and formats. These are combined into one structure that is the input for the dashboard. The different elements of this structure can be found in figure 1. The core of the structure is the Bill of Materials which includes the materials and their components. The demand for each material is based on the global forecast. The capacity is determined for each component and is based on the inventory. The inventory depends on orders placed at the suppliers. These can be external suppliers or other Hilti plants. To be able to compare the demand to the capacities, the demand is translated to component level as well.

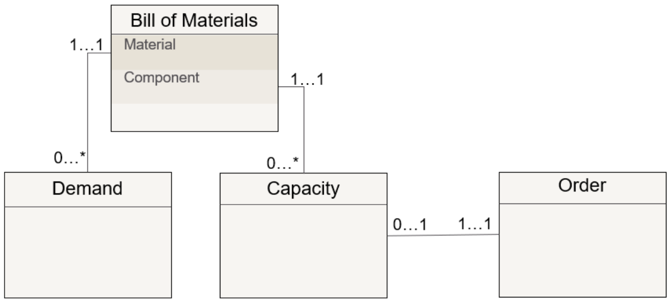

Figure 1: The elements for the dashboard

The dashboard translates the information of these different elements into a format that can be using during S&OP. It consists of a table, two visuals and multiple filtering options:

- **Visuals** Two types of visuals are included in the dashboard. The first is the 'component availability' graph and makes a distinction between green, yellow and red components:

  - Green components can cover the demand by their current inventory
  - Yellow components can cover the demand by the combination of their current and in-transit inventory
  - Red components cannot cover the demand

  Red items indicate a shortage in materials. This information is the core of S&OP and helps the stakeholders in defining what actions are required. The second visual is the 'Stock coverage' and is similar to the first graph but includes an additional colour:

  - Blue components can cover the demand at least five times by their current inventory

  The blue components help in identifying high inventory levels. These indicate high inventory costs but also room for extra production.

- **Table** The table includes information that can support decision making in case of a shortage. It is based on the initial structure of figure 1 and is supplemented with information on for example external supply. In case of shortages, the stakeholders can check who the supplier is and if components can still arrive in time with the given lead time.

- **Filters** The filters support in finding the right information in the dashboard. For example, filters on production lines and component numbers are included.

Case study

For the case study, the dashboard is created for production lines Z1 and Z2. The visuals are displayed below, where the left chart represents Z1 and the right chart represents Z2. It can be seen that the red components account for 31.8% to 22.1% of the total amount of components in scope. This means that for these components a shortage in components is expected, which indicates a shortage in the materials it is used for as well. During the case study, each red component is evaluated and extra orders are placed when needed.

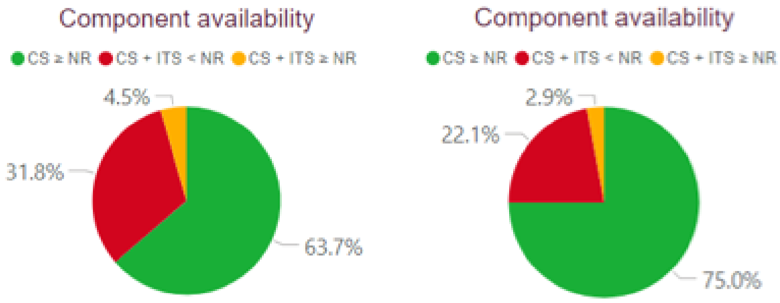

Figure 2: Visual component availability for Z1 and Z2

Scalability test

In addition to the case study, a scalability test is done. For this test, the dashboard is created for eight additional production lines in Plant XZ. This test confirms that the dashboard is scalable and finds results for production lines that were initially not in scope. The main finding of the scalability test is that there can be made a distinction between production lines with high inventories (blue labels) and high certainty and production lines with lower inventory levels and lower certainty. A balance should be found here.

Conclusions

The dashboard created in the current project provides transparency in material availability. It is a combination of multiple data sources that result in a table, two visuals and multiple filtering options. The dashboard can be used in S&OP to find the current material availability but also to run it for scenario analysis by changing the input values. In this way, it supports S&OP decision making.

Preface

This thesis is the result of my graduation project conducted at Hilti AG. It is the final requirement for the degree of Master of Science in Operations Management and Logistics. Therefore, it also marks the end of my career as a student. I have enjoyed the last 5 years at TU/e where I got the opportunity to develop myself in both academic and social ways.

First of all, I would like to thank my first supervisor Laura Genga for supporting me throughout the project. You have helped me to take the project to the next level. I appreciate your genuine enthusiasm for the development, which made me feel that we were in this together. I would also like to thank my second supervisor, Shaunak Dabadghao, who advised me to conduct the thesis at Hilti and encouraged me to keep thinking out of the box.

Second, I would like to express my gratitude to Roeland Baaijens and Ruediger Kuebler to give me the opportunity to conduct the thesis at Hilti. It was a great experience to be able to travel to Liechtenstein three times during the project and to do my final presentation at the office in these beautiful surroundings. Despite that I was not physically at the office the entire duration of the project, I felt supported by the people I was working with. A special thank you to my supervisors Helder de Oliveira and Markus Frey. Helder, you introduced me to the Hilti ways of working, which was a very positive experience for me. You were there for me when I needed support. Markus, you helped me get steps ahead during useful brainstorming sessions and motivated me to get the best out of my abilities.

Finally, I would like to thank my family and friends for their support during my 5 years as a student. You have supported me in my decisions and helped me to challenge myself and never give up.

Obe Wagemakers

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List of Abbreviations

Abbreviation	Definition
BA	Business Area
MO	Market Organization
BU	Business Unit
E2E	end-to-end
WH	Warehouse
CW	Central Warehouse
HS	Hilti store
HIP	Hilti Integrated Planning
GLM	Global Logistics Materials Management
S&OP	Sales & Operations Planning
SFI	Sales Forecast Integration
MPS	Master Production Schedule
BoM	Bill of Materials
M^2BOM	Multi-level BoM
TOC	Theory of Constraints
DBR	Drum-Buffer-Rope
SPT	Special Procurement Type
ER	Entity Relationship
PO	Production order
NPI	New product introduction

Chapter 1

Introduction

1.1 Company introduction

Hilti AG, further referred to as Hilti, is a manufacturer that was founded in 1941 by two brothers called Martin and Eugen Hilti (Hilti, 2020b). In 1957, Hilti had its first breakthrough with the first powder-actuated tool in the world. Today, their products range from fire stops to anchor systems and the company is active in more than 120 countries. The headquarters is located in Schaan, Liechtenstein. With 30,000 employees they contribute to making work on construction sites simpler, faster and safer. Their mission statement "*We passionately create enthusiastic customers and build a better future*" highlights the importance of customer relationships and the importance of innovation and quality in the long term (Hilti, 2020a). The core values of Hilti are integrity, courage, teamwork and commitment (Hilti, 2020c). These contribute to successful relationships with customers, partners and suppliers. To ensure development and improvement, about 6% of total sales is reinvested in research and development every year.

The organization of Hilti starts with a 7-member Board of Directors. The chairman of the board is in direct contact with the CEO, who leads the Executive Board. Each member of the Executive Board is responsible for a certain area of business and has its Executive Management Team. The heads per region and the heads of the primary business areas (BAs) are also part of this team. Hilti has divided its operations into 9 regions all over the world. Each region consists of multiple Market Organizations (MOs) which usually represent a country (de Kruijf et al., 2020). Each MO is active in multiple BAs. The primary BAs are Supply Chain, Human Resources, IT, Finance, Strategic Marketing and Business Units (BU's). There are two main BAs worldwide: BA Electric Tools & Accessories and Fastening & Protection. The first consists of BU Diamond, BU Measuring and BU Power Tools & Accessories and the second consists of BU Screw Fastening, BU Anchors and BU Fire Protection and Installation.

Hilti has an end-to-end (E2E) supply chain. This means that they control the majority of the processes in their supply chain themselves (de Kruijf et al., 2020). The E2E supply chain is illustrated in figure 1.1, where everything in the grey box is managed by Hilti. Components are ordered from external suppliers and are delivered to either the plants, local warehouse (WH) or the central warehouse (CW) in the MO. Components can be processed or assembled at a plant and be kept in temporary storage at a WH or CW or they can be directly shipped to a Hilti Store (HS) or to the customer. The Hilti stores provide the possibility for customers to buy their tools physically. However, shipping directly to the customer is also possible. The Hilti tools are further referred to as materials. The supply chain gets complex because Hilti focuses on retail as well as direct customer deliveries (van Lierop, 2020). In case of direct shipments from an external supplier to a WH or CW, no processing is done in any of the Hilti plants. These are products that are produced by Hilti allied suppliers and do not require any further processing before they are sold.

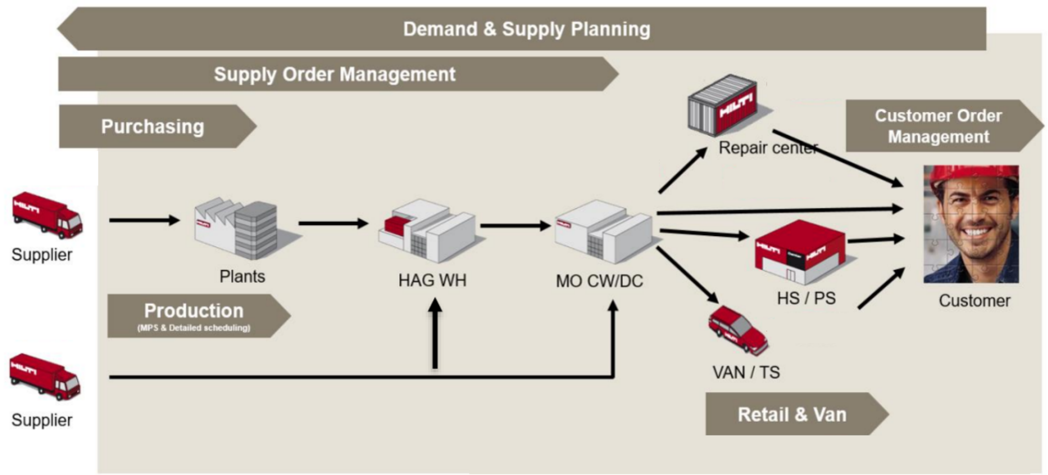

Figure 1.1: Hilti's E2E Supply Chain

In 2019, Hilti implemented Hilti Integrated Planning (HIP), which is a project started by Global Logistics Materials Management (GLM). The goal of HIP is to have one integrated planning environment to globally manage Hilti's E2E supply chain (de Kruijf et al., 2020). Before the introduction of HIP, Hilti's planning took place in individual departments instead of globally. The core of HIP is Sales & Operations Planning (S&OP), which aligns Hilti to one single sales and production plan. The goal is to narrow down inefficiencies in both sales and production. The Thesis objective is to contribute to the global HIP process by making an improvement within S&OP.

1.2 Hilti S&OP

S&OP is the core of HIP and helps to maintain Hilti's E2E supply chain. The current report focuses on the S&OP process, which is a monthly process and consists of two consecutive parts called Sales planning and Operations planning. Both parts include multiple steps, displayed in figure 1.2.

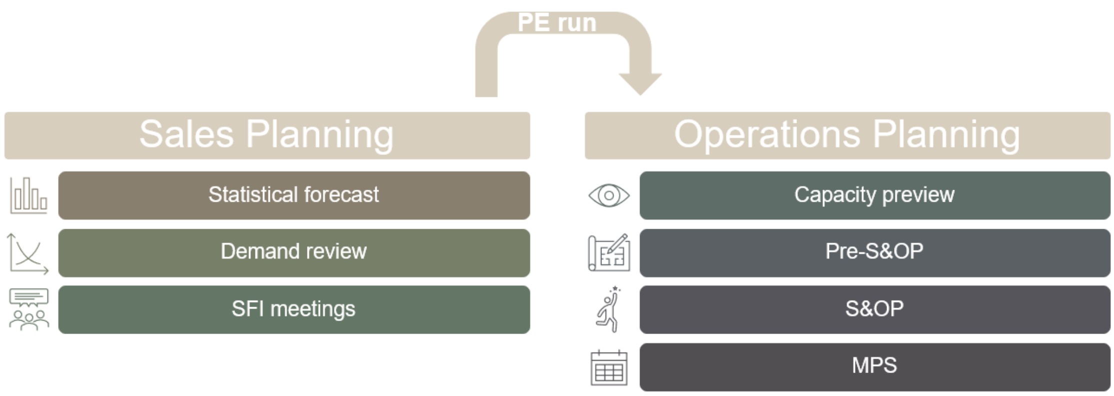

Figure 1.2: The steps in Hilti's S&OP

Sales planning is initiated by a global statistical forecast created for the upcoming twelve months and updated once a month. This forecast is the input for the demand review, where market intelligence is used to evaluate it. Examples of market intelligence are information regarding new product launches, promotions or events that can influence the forecast (de Kruijf et al., 2020). After the demand review, the Sales Forecast Integration (SFI) combines marketing and sales information gathered at the previous steps. At this point, the focus is shifted from global forecasting to forecasting for specific regions. This means SFI takes place for each region separately. Hilti aims to satisfy markets equally. Therefore, the forecasts that came out of the SFI are discussed between the different regions. In this way, plans for the upcoming months can be compared and adjustments can be made such that the equal spread is realized. The outcome of these discussions is an aligned consensus forecast.

In between Sales planning and Operations planning, the PE run takes place. PE stands for Planning Engine and refers to an external engine that runs to transform data. Here, the consensus forecast is translated to the net requirements per material per production plant. This means the focus shifts from regions to specific production plants and even specific materials. The net requirements are provided in pieces and form the basis for the Operations planning, the second part of Hilti's S&OP.

Operations planning is plant specific and therefore executed within the plant but the approach is the same for each plant. The first step is the capacity preview, where net requirements from the PE run are translated to the number of production hours required per material. The reason for translating from pieces to hours is to be able to compare the net requirements to the plant capacities. The plant capacities are expressed on three different levels: machinery, man power and materials. Machinery capacity is dependent on the available machines and their technical limits, while man power capacity is dependent on the number of employees and their labour contracts. Both capacities are measured in hours as machines work in production hours and employees in labour hours. Contrary to this, materials are measured in pieces. These can therefore be compared to the original net requirements that are expressed as pieces.

Possible imbalances between the net requirements and the available capacities are discussed during the pre-S&OP meeting, which is the next step of Operations planning. During the meeting, the balance between net requirements and the available capacities is discussed for each production line in the plant separately. The basis for this discussion is data that is delivered by Blue Yonder. This is an Excel-based program that derives data from SAP and combines it into a suitable format. An example is displayed in table 1.1. This is dummy data for September that provides the forecast for the upcoming four months for one production line. This is the minimum amount of months that is discussed during S&OP. In the current project, the focus is on the next month only. However, the solution is designed such that it can be scaled over multiple months. Therefore, this is not a limitation of the analysis. The reason that only one month is considered is due to the limited time of the current project. Only the findings of one month can be evaluated during the case study, as the project ends one month after the case study.

	Oct 2022	Nov 2022	Dec 2022	Jan 2023
Req (PC)	16,961	17,267	12,834	17,340
Req (H)	425	432	321	434
Min man power capacity (H)	400	400	250	300
Max man power capacity (H)	600	550	500	550
Max machinery capacity (H)	800	800	800	800

Table 1.1: Blue Yonder example data

The first value in the table is Req (PC). This is the number of pieces that is required to be produced on this production line to satisfy the net requirements. In October, Req (PC) is equal to 16,961 pieces. As explained, this number is translated to the number of hours required. This value is labelled as Req (H) and is equal to 425. This means that it takes 425 hours to produce almost 17 thousand pieces on this production line. It is important to note that this number is a combination of the requirements of all the materials that are produced on this production line. To find the capacity of the plant, the next three values of the table are evaluated: Min man power capacity, Max man power capacity and Max machinery capacity. Min man power capacity (H) and Max man power capacity (H) represent the minimum and maximum available labour hours for this production line. In this case, the minimum available capacity is less than the required capacity and the maximum available capacity is more than the required capacity. This means requirements can be satisfied. The Max machinery capacity (H) represents the number of production hours available in terms of machinery. This means there are machines available for 800 hours on this production line. No minimum number of hours is assigned to the machinery as this would always be zero. There are no restrictions such as labour contracts that set a minimum of working hours for the machines.

During the pre-S&OP meeting, the net requirements are compared to the available capacities for each production line. It can be seen that the maximum man power, as well as machinery capacity, are equal to or higher than the net requirements of 425 hours. Based on this comparison, each production line gets assigned a colour: green, yellow or red. Green means that there is no expected problem for this production line and net requirements can be covered by the available capacity. Red is assigned when it is certain that the net requirements cannot be covered by the available capacity so there is expected to be a problem. Yellow stands in between green and red and is applied when there is some uncertainty on the gap between net requirements and the available capacity. An example of a yellow line is when there are multiple employees currently on sick leave. There is uncertainty in the availability of these employees for the upcoming period. The production line is therefore closely monitored and potentially other (temporary) employees are assigned to the shifts.

The focus during the pre-S&OP meetings is on improving the red lines. The gap between the net requirements and the available capacities should be closed to be able to satisfy customer demand. Possible solutions to solve this problem are discussed during the meeting. These discussions are led by the Central Planner and require input from the others in the meeting, such as the materials managers. An example of a solution could be to place an extra order at an external supplier when a shortage of a certain material is expected. Plans are made to close the gap and these plans are worked out in detail by the Central Planner after the pre-S&OP meeting. These are then presented during the S&OP meeting, which is the follow-up meeting.

The goal of the S&OP meeting is to align the plans made during the pre-S&OP meeting with management. This involves tactical decision making while keeping strategy in mind. Management listens and reviews the plans and the preferences of the Central planner, who leads a possible discussion as well. Based on this discussion, adjustments to the plans are made where needed. The output of the S&OP meeting is an aligned capacity planning which can be used as input for the Master Production Scheduling (MPS). This is the final step of Operations Planning and creates a detailed planning for production. The MPS system is automated.

Based on the description of the different steps in S&OP, decision points can be identified. The goal of S&OP is to close the gap between the net requirements and the available capacities. The decision that should be made is on how much capacity to set available for the production of minimally the next four months. This decision is made for each production line for machinery, man power and materials. In general, there are two scenarios in which a gap between the net requirements and the available capacities exists:

Scenario 1: Net requirements are higher than plant capacities When the net requirements are higher than the plant capacities, it can be due to a shortage in machinery capacity, man power or materials. The first step is to check whether the capacities can be increased. For machinery, the availability of other machines with the same purpose but on another production lines can be checked. For man power capacity, the possibility to ask employees to work extra shifts or to hire extra (temporary) employees is explored. For materials, the possibility to acquire additional materials is evaluated. If this is not possible for one of the three facets, the lowest capacity is set to the bottleneck capacity. The deployed capacities for the other two facets are also set to this bottleneck. This can be illustrated by the following example: if there is a shortage in man power and both machinery and materials can cover the requirements for the production of this specific material, the capacities of machinery and materials are set to the same level as man power. If these would not be adjusted, this situation would lead to idle machines and unused materials. It is possible that these machines and materials had been used for another finished good, if planned correctly beforehand.

Scenario 2: Net requirements are lower than plant capacities In this case, there is more capacity available than required to satisfy the net requirements. The decision that arises here is what to do with the excess capacity. It can for example be used to help in other production lines for the production of another material. Employees can be assigned to other production lines and components used for similar materials can be assigned to another line as well. However, the excess capacity can also remain on the same production line and be used for pre-production. If a shortage in capacities is expected later in the year, it could be a good idea to do pre-production. In that way, the expected shortages are already covered beforehand.

According to the monthly summary reports of 2021, the most common supply constraint lies with materials. On average, missing materials accounted for over 60% of all supply constraints for these months. Another 30% is due to machinery and man power constraints. The remaining 10% is exceptional and is due to a production plant shut down because of a Covid-outbreak. The big share of material constraints highlights the importance of the current project. The availability of materials is not monitored like machinery and man power capacities. As described before, it is measured in pieces instead of hours. These can be compared to the Req (PC). However, is it common that there is no inventory in the plant and all inventory in the (C)WHs is assigned to confirmed orders. The reason for this is that the production often takes place in the same month as the orders are completed. Each material consists of multiple components. Data on the inventories to define material availability is derived before the S&OP, which is before the start of the discussed month. At that moment in time, there is little to no inventory for the materials. However, there is an inventory of the components that are used to produce this material. Information on the component availability can be combined to predict the material availability. In the current situation, the availability of the materials is estimated based on the experience of the S&OP stakeholders and available historical data. The data includes the historical estimated material availability and the historical actual requirements. More specifically, the data from previous months is used to check if there is a backlog. In the case of a backlog, extra production is required and therefore extra materials are required. This indicates a shortage of materials in the previous period which means that extra attention is required for that material such that the backlog does not continue in successive periods.

1.3 Research problem

The previous section describes how decisions in S&OP are based on the gap between net requirements and the capacities available at the plant. The net requirements are provided in pieces and hours. The capacities of machinery and man power are provided in production hours, while the capacity of materials is measured in pieces. However, currently there is no measurement of the material availability that can be used as input for S&OP. It can only be measured by combining data on the availabilities of the components that are used to produce the material. However, doing this for every material is computationally expensive and there is no time to do this manually during the S&OP process. The available capacities and net requirements are compared during the pre-S&OP meeting. If the individual component availabilities would be used as input for the pre-S&OP meeting, the stakeholders would not able to use it directly due to the detailed level of information. Therefore, It should be translated to material level first to create a tactical overview that can be used during the pre-S&OP meeting.

Not knowing the material availability before the month starts has negative consequences. Material shortages might be identified during the month orders should be satisfied which is too late to take action. This leads to excess man power and machinery. The MPS is created for the upcoming months but is refreshed weekly. However, machinery and man power are already scheduled for a production line more than one week in advance. A change in the MPS requires changes in this plan, while this has negative consequences in reality. The problem that is run into is that it is too late to assign them to another time slot or production line. This leads to idle machines and people staying at home during their shifts.

To summarize, the problem is the lack of visibility in the material capacity. The material capacity is equal to the number of materials that are expected to be available in a certain period. However, these materials are not kept in inventory because they are produced during the same month as the demand is satisfied. Therefore, the capacity of components should be investigated and combined to find the capacity of the materials.

1.3.1 Research contribution

The motivation for the current project is to contribute to the development of S&OP. It is part of HIP which was rolled out in 2019. This means the method is quite new and is not fully developed yet. The current process works as there are experienced employees that can make estimations that are close to reality. However, it is shown that there are still disruptions in production, with material availability accounting for 60% of these disruptions. Providing insight into the material availability would help to anticipate on previously unexpected situations. Hilti has all the data available that is required to tackle this problem but there has not been a translation from the operational data (component level) to data that can be used in the S&OP process (material level). By gathering all the required data and combining it into one overview, S&OP can be improved. In this way, no attention has to be paid to materials for which material availability is ensured and the focus can be on materials for which a shortage is expected. It decreases uncertainty within S&OP and enables the stakeholders to anticipate on expected shortages before the next month starts.

Current literature on the improvement of supply chains often assumes sufficient supply. More specifically, deterministic supply is assumed, indicating that there are fixed order amounts and fixed delivery times. Reality shows that today's supply chains deal with unexpected disruptions and that supply is stochastic, rather than deterministic. Therefore, the current report defines a methodology to determine the expected material availability, based on fluctuating supply. This methodology covers the translation of operational data to data for tactical decision making. This translation is recognized as the main challenge in the literature on decision support.

In the current project, operational data is combined into a dashboard that displays the findings such that it can be used in tactical decision making. With this, the project contributes to the literature on both the translation from operational to tactical data and in finding the realistic material availability.

1.3.2 Research questions

The main research question is defined based on the research problem. It aims to support decision making in S&OP by providing transparency in the material availability. The material availability can be combined with the machinery and man power capacities to make decisions on the to-be-used capacities during the pre-S&OP meetings. The sub-questions described in this section support in finding an answer to the main research question.

How can a tool be designed that provides the material availability to support S&OP decision making within Hilti?

Hence, the current project provides a tool that supports decision making in S&OP, by providing insight into the material availability. To understand what is required in this tool, sub-question 1 starts by sketching the current S&OP process and identifying the decision points.

Sub-question 1 *What is the current process in S&OP and what are the decision points?*

The description of the current situation is based on background searches and interviews. The Introduction describes Hilti's E2E supply chain and HIP. Section 1.2 provides a detailed description of S&OP and the decision points.

Sub-question 2 *What data is required for full transparency in S&OP decision making?*

The S&OP process tries to find a balance between net requirements and the available capacity in terms of machinery, man power and materials. The capacities of machinery and man power are known but the missing information lies with the material availability. To get full transparency, data on the material information is required. This is further described in chapter 3.

Sub-question 3 *How can the data be combined and visualized as a foundation for S&OP decision making?*

Multiple data sources are required to find the material availability. A method to combine this data into one overview is covered by this research question. The method and the output are described in chapter 3. The product structure consisting of materials and components has never been visualized before within Hilti. Therefore, a visualization is included that provides insight into the data and especially shows how materials are interrelated with the different components of other materials.

Sub-question 4 *What methodologies on decision making support by information systems are found in the literature?*

The literature review that is conducted as preparation for the current project is described in chapter 2. It starts with information on how to understand and describe product structures. This is followed by literature on how to use insights into material availability to improve S&OP. The literature is linked to Hilti and the usability in the specific S&OP process steps.

Sub-question 5 *What variables should be included in the final model?*

Based on the available data and literature, the variables that should be included in the model are defined. The variables aim to provide insight into the material availability and the gap between the net requirements.

Sub-question 6 *How can the model be translated to business values?*

S&OP is a tactical process, which is based on operational information. In the current project, operational information from multiple sources is combined to find the component availability of the materials in scope. However, the outcome should be translated into findings that are useful for tactical decision making. The findings contribute to the scenarios presented in the S&OP meetings.

1.3.3 Research approach

The approach of the current project is based on the Problem Solving Cycle by Van Aken and Berends (2018), which is depicted in figure 1.3. The cycle starts on top with the problem definition. To define the problem, the theoretical background is combined with interviews, observations and data. Investigating the current process helps to understand the different steps involved and can lead to the identification of a possible problem. By presenting this problem to multiple stakeholders during interviews, it can either be confirmed or rejected. In case of rejection, the problem can be redefined and discussed again. Observations help to get a hold of the size and complexity of the process. This includes visiting the production plant and attending multiple pre-S&OP meetings. During the plant visit the construction of a material is better understood as all components required are physically available. Moreover, the different steps involved in the assembly can be seen as well. By attending the pre-S&OP meetings, the current state and present-day problems are identified. This can also confirm or indicate possible adjustments to the problem statement. The final type of information is found in data. A shortage in components is found in the data as well if the data is updated and correct. Multiple data sources can be combined to find the right information required. The problem definition is discussed in chapter 1.

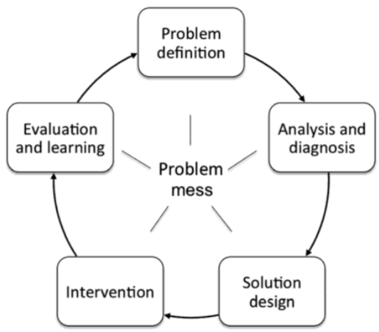

Figure 1.3: Problem Solving Cycle

To solve the problem found, the next step is analysis and diagnosis. Within this stage, the problem and its context are further analyzed. Data is gathered and combined to find the causes and consequences of the problem. It is important to find and understand the causes and consequences, to be able to design a suitable solution. Furthermore, possible solution methods are found in literature. Multiple Scholarly search engines like Scopus and ABI Complete are used to find suitable literature. The goal is to find one or multiple useful methods or tools that can be used to support the definition of a method or tool for the current project. Chapter 3 covers the analysis and design of the structure that covers all the data required to determine material availability. This format is used as input for chapter 4, where the analysis and design of the dashboard are discussed. If sufficient information is found and validated, a solution is designed according to the next step of the problem solving cycle.

The goal of the solution design is to find a solution for the problem defined. The solution design is also part of chapter 3 and chapter 4 for the solution design of the structure and dashboard, respectively. This results in two solution designs for which the first is used as the basis for the second. The solution designs are implemented during the intervention. In this stage, the suitability of the solution in the business context is tested. While implementing the solution, the first results become clear and the added value of the solution can be defined. It is important in this stage that employees on operational as well as tactical level are involved in the implementation such that they are on the same page and no confusion arises. Only part of the intervention step is included in the current project. This is discussed in chapter 5. The output of the project is a prototype of the solution design.

The final step of the Problem Solving Cycle covers evaluation and learning. The solution must be maintained after implementation . If the solution works differently than expected, it happens that employees fall into their old patterns and prefer this over the new solution. Therefore, close monitoring is required to make it a success. The evaluation and learning step is not part of the current project. However, recommendations on this aspect are given in chapter 6. If adjustments are needed or problems arise, the Problem Solving Cycle can start again and is therefore depicted as a circle in figure 1.3.

1.4 Scope

Hilti owns 8 different production plants worldwide that each have their own S&OP process, based on the standardized global S&OP process. The plant that is in scope for the current project is plant XZ, which is located in Thüringen, Austria. It consists of 33 active production lines that each produce multiple material types. Two production lines are selected based on their complexity and size: Z1 and Z2. These production lines consist of 33 and 106 materials, respectively. These production lines represent the complexity of the other production lines in XZ as well as they produce a range of different materials that are related to each other. There is an overlap in the structure of the two production lines, which means they share components that are used for the production of different materials. The choice to include these production lines in the scope is made by the Central planner of plant XZ. Both production lines are part of the Business Unit called Production materials & Accessories (PT&A).

The dashboard that is created requires information from the capacity preview in the operations of S&OP. The outcome is used during the pre-S&OP meetings. Therefore, the scope within S&OP is defined as the capacity preview and pre-S&OP meetings. The dashboard is presented during the pre-S&OP meetings and actions after the pre-S&OP meetings are out of scope.

Each production line produces multiple materials. These materials consist of components that are either sourced from external suppliers, at other Hilti plants or are produced in-house. For in-house production, the underlying layer is known as well. This is illustrated in figure 1.4. On the right-hand side are the MOs and the CWs. The MOs and CWs place orders at the plant and can therefore be seen as customers from this perspective. Layer 0 represents the final assembly of the materials, which requires all components that are used for this particular material. The assembly only starts when all components are available in the plant. Layer 1 represents the components coming from different sources: external production, production at another Hilti plant and in-house production. External production happens at an external supplier for which the availability of the component and its lead time is known.

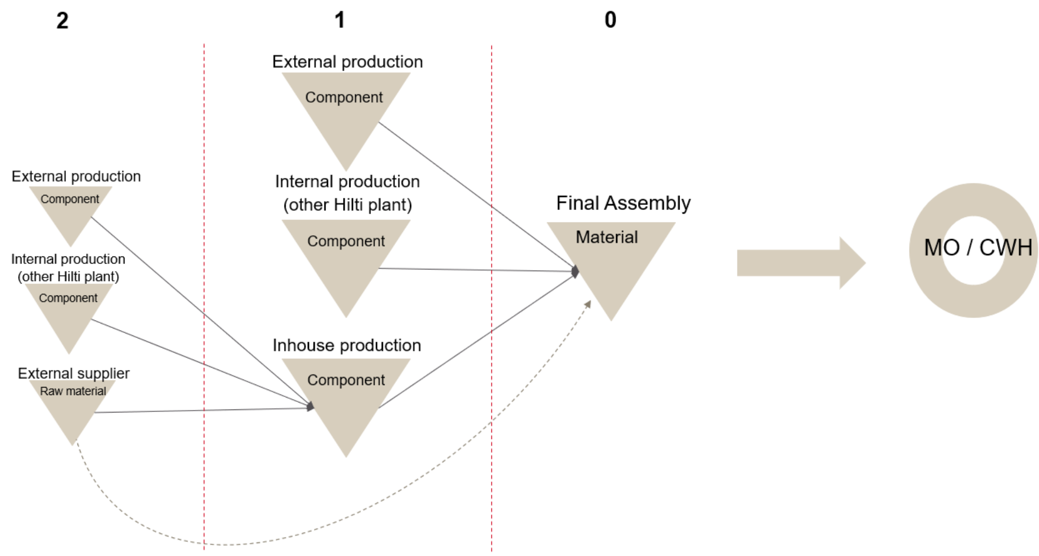

Figure 1.4: The assembly process at Hilti

Production at another Hilti plant is treated the same as an external supplier in this project, as often only the availability and lead times are known as well. No additional information is registered at plant XZ for this type of supplier. The in-house production happens at plant XZ and for this, more information on the production is available. However, this is limited to knowledge of the production steps and estimations of their production times. There is no information available on the times between these production steps. To consider the total production times, this information would be required in addition to the production times of the individual steps. The in-house production combines multiple components, which are combined into one intermediate product. This intermediate can then be used for the final assembly. The different components used in in-house production can be bought externally or produced in-house as well. The structure in figure 1.4 is therefore expanded with another layer. In theory, this structure could go on until there are no deeper layers left. In practice, there are only two layers within the production in scope: the components of layer 1 and the sub-components of layer 2. The solution design will be anyway generic and consider n layers.

The dashboard aims to find the material capacity of the materials produced in the two production lines. Information on the product structure and the suppliers is required. However, costs and production times are kept out of scope to narrow down complexity. The costs are dependent on multiple currency rates as Hilti operates worldwide. If the components are available at the start of the month, it is assumed that there is enough time and money to produce the materials.

1.5 Key deliverables

There are two key deliverables for the current project. The first key deliverable is a structure that includes all the data related to material availability. The scope for the current project includes production lines Z1 and Z2 for production plant XZ. The structure created includes the data that is needed for transparency in material availability for the materials that are produced on these production lines. This structure is displayed in a table format using Excel. It includes inventory data, demand data and data on suppliers.

The second key deliverable is a dashboard that displays the material availability for each material and its components produced on production lines Z1 and Z2. The dashboard consists of a table, visuals and filters. The table displays the data used to find the material availability and provides additional information that can be used in decision making. The visuals provide a high-level overview of the material availability in the plants. Filters can be applied to materials or components to find the data for a specific item.

1.6 Thesis outline

Chapter 1 covers the introduction which introduces the company and gives a description of the research approach. It covers the problem definition which is the first step of the problem solving cycle by Van Aken and Berends (2018). Chapter 2 is the literature review which combines multiple sources and discusses how the findings apply to Hilti. The third chapter 'BoM analysis' includes the solution design and the results for the desired structure including all the information required to find material availability for the materials and components. This is followed by chapter 4, that includes the solution design and the results for the dashboard. The final steps of the problem solving cycle by Van Aken and Berends (2018) are partly discussed in chapter 5. However, discussion and further recommendations are discussed in chapter 6. This chapter also includes the conclusions that provide an answer to the research questions.

Chapter 2

Literature Review

Hilti is a manufacturer that operates globally. Today's competitive and global markets ask for a well-designed and managed supply chain. Especially globalisation, increasing supply chain complexity and unexpected disruptions ask for a well-designed supply chain structure (Seeling et al., 2021). For manufacturing companies, the supply chain starts with procurement. Over the last few years, the definition of procurement has expanded. It started with purchasing, where procurement and purchasing were used interchangeably (Pereira et al., 2014). However, according to Pereira et al. (2014), procurement not only covers purchasing nowadays but also includes the management of resources and suppliers. This means decisions on the capacity of suppliers, logistics data, pricing, discounts and other product information are managed by the internal procurement team as well. The procurement side of the supply chain often includes incoming components and inspection. These are important steps and account for 50 to 60% of the total costs of an enterprise (Jing et al., 2021). Also, the components are the basis of production so the quality of the components has a direct influence on the quality of the finished goods (Jing et al., 2021). This highlights the importance of procurement. Procurement has a responsibility for increasing competitiveness when the company is in an unstable environment or fluctuating market (Pereira et al., 2014).

According to Seeling et al. (2021), the main challenge of a global manufacturer is related to the interpretation of information. Data from different sources and sizes is gathered and combined to find useful information. The current project focuses on finding and quantifying the material availability within Hilti. The demand and other resources are already known and quantified such that these can be used during S&OP. The challenge lies in finding and combining all the required data to define material availability. The availability is dependent on the supply of these materials. Existing literature on supply chain optimization assumes a deterministic supply of components. This means fixed delivery quantities and delivery times. This can be illustrated by different models in literature. Kundu and Chakrabarti (2015) introduce an inventory model with an imperfect production process. The model focuses on defects that happen during production and the expected effect on inventory levels. However, inventory levels start with an external supply of components. The model assumes fixed order quantities and fixed delivery times for external supply, despite its big influence on the inventory levels. Tundys and Wiśniewski (2020) introduce an optimization model for food supply chains where the focus is to handle the uncertainty in demand. A similar assumption on deterministic supply is applied here as well. The focus is on uncertainty in demand, which is directly related to the supply. Fluctuations in demand lead to changing order quantities. To be able to order according to the demand a stochastic supply should be considered. Another optimization model is introduced by Kallina and Siegfried (2021). This model includes supply chain optimization based on the Bill of Materials. Here, the delivery reliability of the different components of the BoM is considered. However, this is the delivery from the company to its customers and not from the suppliers to the company. To be able to correctly estimate the deliveries to customers, a company needs to know how many components they have or expect to have available. The first model focuses on inventory management, the second on uncertainty in demand and the third on improving customer satisfaction. Despite the different purposes of these examples, they all share the assumption or idea that there are no uncertainties in supply from an external supplier to the company. While supply chains years ago were smaller and less complicated, today's growing competitive market asks for quick responses to change (Pereira et al., 2014).

This can be challenging for a company in today's global supply chains as they are exposed to unexpected disruptions. In the last years, the pandemic and global political tensions played a big role in the global economy. International economic trade was slowed down and limited by the government (Fernández-Miguel et al., 2022). Before the pandemic and political tensions, international integration of the economy was increasing for decades. Therefore, many companies off-shored their production to another country to cut costs in the long term. In today's economy, this is not as beneficial anymore as off-shoring increases the risks of losing control due to distance, cultural and legal differences and language barriers. The pandemic and political tensions lead to the near-shoring and re-shoring of international companies back to their country of origin (Fernández-Miguel et al., 2022). In the past, economic recessions have taken place. A recession is a period that is characterized by a sudden unexpected change in economic growth (Alvarado-Vargas and Kelley, 2019). It could happen again due to the pandemic and political tensions. The consequence of a recession is a change in the buying behaviour of customers. In general, the consumption of customers reduces and changes to a stochastic pattern rather than a deterministic pattern (Alvarado-Vargas and Kelley, 2019). This behaviour influences the supply chain as demand fluctuates and production amounts and timing change accordingly. In terms of production, this can lead to redundant inventories or shortages. Not only do big disruptions such as the pandemic and political tensions have consequences in the supply chain, but also smaller events can disrupt the supply chain. An example is a power disturbance that slows down or even stops production for an amount of time. Due to this, downstream companies might not receive their demand in time (Thomas and Fung, 2022). The consequence of this disruption is visible in redundant inventory or uncertainty for employee shifts for example. Adjusted planning has to be made based on the changed capacity in production, where it is not transparent how long the disruption is going to continue or if it will happen again. Therefore, the right information to create this planning might not always be available at the time it is required. This causes inefficiencies and uncertainty in the supply chain. Both bigger and smaller disruptions ask for quick adjustments in the supply chain. Finding a balance between demand and supply is complicated due to this as these factors are reliant on multiple parts of the supply chain. The developments in supply chain analysis show that companies cannot afford to ignore uncertainty in supply anymore. Supply chains aim to be as efficient as possible. This requires transparency and a realistic image of the supply pattern. Strategies to cover uncertainty include multiple sourcing, preferably near the parent company. Plant-specific, adding extra production capacity decreases uncertainty (Vali-Siar et al., 2022). However, costs increase when applying these methods.

For the current project, demand data is available based on global forecasts. These global forecasts are translated into the demand per plant. To balance the demand and the supply, the expected supply should be known as well. The goal of the current project is to determine the expected supply for procurement within Hilti. The production includes multiple steps for which each produced material consists of multiple components. Each of these components has its own availability. These can be combined to find the availability of the materials they are used for. To do this, first the product structure between the materials and components should be understood. The next section starts with two methodologies to visualize a BoM structure: BoM visualization with nodes and edges and as extension Sankey diagrams. This is followed by an alternative notation for the BoM using binary values. It should be noted that in preparation for the current report, a Literature Review was conducted. This chapter covers the parts of the literature review that are relevant and applicable to Hilti and the development of the project.

2.1 Material structure evaluation

BoM visualization with nodes and edges

The BoM includes all the required information on product structures. A BoM can contain many materials and relations, which can complicate the structure. Furthermore, each material and relation can contain a description, for example, how much of the item is required to produce one successor or what the name and use of the material are. These are called the node ID and node attributes, respectively (Hu et al., 2017). A simplified BoM structure is visualized in figure 2.1. It can be seen that both Product 1 and Product 2 consist of three parts. The numbers below the part names represent the number of parts required to produce one item of the product in the level above (the successor).

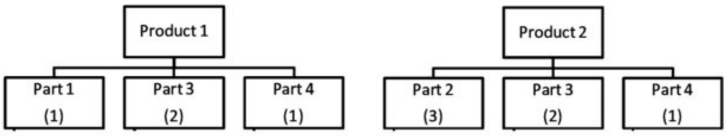

Figure 2.1: Simplified Bill of Materials (Hu et al., 2017)

A Multi-level Manufacturing Bill of Materials (M^2BOM) is a tree-like structure that shows the levels of a product structure, as in figure 2.1. Within manufacturing, there can be multiple M^2BOMs which could be combined into one main M^2BOM (Brockhoff et al., 2021). In the example in figure 2.1, Part 3 and Part 4 are used for both end products. When analyzing these parts and considering only the relation in one tree, the other relation is neglected. For example for Part 3, it is important to analyze both products as this Part is required for both products. To be able to see the consequences of a change for a part in all the products that it is linked to, combining the BoMs would be helpful. Each node can only appear once in the M^2BOM graph such that all incoming and outgoing links of this node are in one place. Therefore, often contraction of nodes is required. In the example, this would mean that Part 3 and Part 4 would be contracted and one tree with two Products on top exists. It is assumed that links are directed from higher-level nodes to lower-level nodes, which means one higher-level node consists of one or multiple lower-level nodes (Cinelli et al., 2017). A contraction of two or multiple BOMs is called aggregation. In the case of aggregation, even the top nodes can be aggregated (Cinelli et al., 2017). It is important to keep attention to the node attributes in contraction or aggregation. These attributes are preferred to be in the same structure for each item. The reason for this is to remain similar structures such that they can be correctly combined or linked to each other (Lee et al., 2012). If there is much overlap in the BoM structures, an option-aware M^2BOM is proposed. This is made out of a shared M^2BOM and its different options. The options can occur in each layer and subprocess. An example is given in figure 2.2.

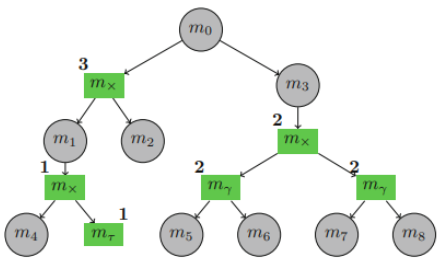

Figure 2.2: Option-aware BoM structure (Brockhoff et al., 2021)

It can be seen that material m_0 consists of m_3 and either m_1 or m_2. For m_3, the choice is between either m_5, m_6, m_7 or m_8. m_τ represents a node that will continue on the bottom of the figure in a similar structure. Therefore, if one chooses m_τ at m_1, there will be even more decisions to be made. BoMs can be updated frequently. To remain overview, process mining can help to keep the BoM complete and up-to-date by combining data from multiple sources and stakeholders, where necessary (Jokonowo et al., 2018).

BoM visualization as Sankey graph

An alternative visualization of the BoM is the Sankey graph. This type of graph was initially used for depicting the energy efficiency of steam engines (Schmidt, 2008). However, nowadays, it is also used for depicting production flows for manufacturing companies and supports in identifying the most efficient path to the finished good. An example of this is given on the left flow in figure 2.3. The resources are on the left-hand side of this flow. The costs for these resources are 750$ and 120$, respectively. However, there are also costs of labour, capital costs and waste costs. These are included in the total costs of production as well. When looking at the top of the graph, the second flow is a combination between the 750$ resource costs and 550$ labour and capital costs. This gives a total of 1300$. Similarly, the last flow is a combination of the three cost flows coming in there. In the end, both resources and all other costs are combined into the price of the final product. This gives insights into the production process at the cost level and represents how the materials are related. The figure above flows in one direction, while it is also possible to flow in the other direction. This is illustrated in figure in the figure on the right-hand side.

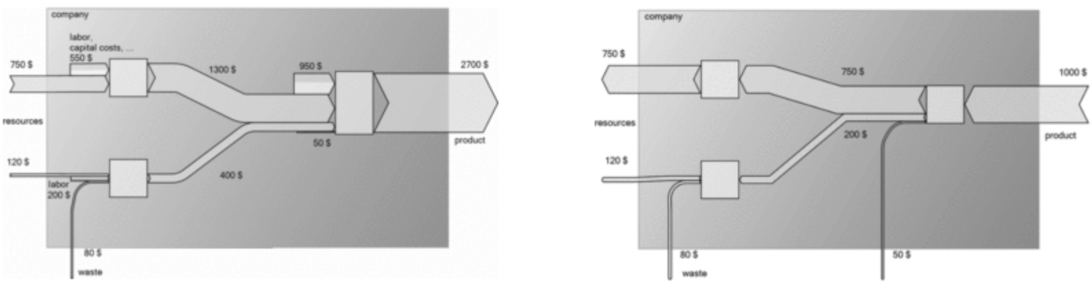

Figure 2.3: Forward and backward production flows in Sankey graphs (Schmidt, 2008)

In this case, there is a budget of 100$ to produce the end product. This budget has to be divided over the different resources to produce the end product. It can be seen that it is not only important to consider the costs of raw materials (components) but also to include the costs of waste. If only raw materials would have been considered, there would be a shortage of 80$ + 50$ in waste costs.

Binary BoM notation

Due to the high complexity of the BoM structure, Romanowski and Nagi (2005) propose an alternative to the visualizations. Consider the trees in figure 2.4 as two variants of a product structure. The top of the structure is similar but a difference occurs in the third layer, at component C. The schemes represent the alternative notation. In the alternative notation, either a zero or one is assigned to each relation. A zero is assigned when there is no direct relation between the nodes and a one is assigned when there is a direct relation between the nodes. For tree 1, it can be seen that node A is directly related to nodes B and D. This is confirmed by the figure. Node B is directly linked to nodes A, C, K and L. Here is where the two trees are different. For the second tree, it can be seen that node B is only directly related to nodes K and L. The corresponding relations are marked grey.

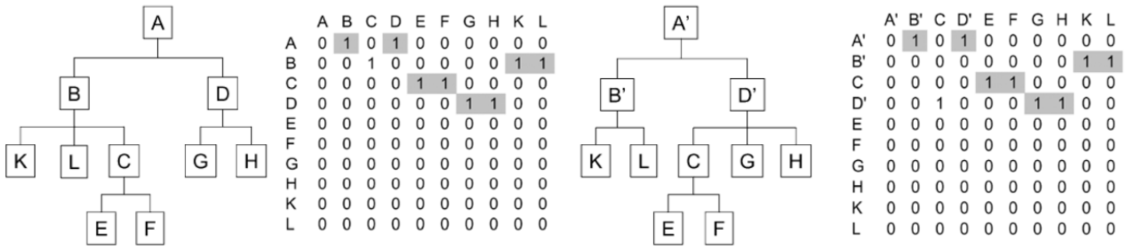

Figure 2.4: Two similar tree structures and their binary notations by Romanowski and Nagi (2005)

The advantage of the BoM representation with binary values is that easily calculations on for example the node complexity can be done. An example is given based on the values in table 2.1. The research of Shin and Park (2020) describes node complexity as a measure to calculate supply chain complexity. Node complexity reflects the number of nodes and their relations with other nodes in the network. This is important when there are multiple possible links for the same product. If the average node complexity of a tree is higher than the other, the structure with less complexity can be preferred. This is illustrated by an example for tree 1 node B. Node B can in theory be linked to nodes A, C, D, E, F, G, H, K and L. This is a total of nine possible links. In the figure, B is linked to only three other nodes. The node complexity of node B is then equal to 4/9 = 44%. In tree 2, the node complexity of node B is equal to 3/9 = 33%. It is found that the node complexity of node B in tree 1 is higher than in tree 2. When a decision has to be made for which tree design to choose, the supply chain complexity can be calculated. This is the average of all the node complexity scores of all the nodes in the trees. Table 2.1 shows how the calculations are done.

	Tree 1		Tree 2	
Node	Link count	Node complexity	Link count	Node complexity
A	2	2/9	2	2/9
B	4	4/9	3	1/3
C	3	1/3	3	1/3
D	3	1/3	4	4/9
E	1	1/9	1	1/9
F	1	1/9	1	1/9
G	1	1/9	1	1/9
H	1	1/9	1	1/9
K	1	1/9	1	1/9
L	1	1/9	1	1/9
Total	18	2/9	18	2/9

Table 2.1: Calculation for node complexity

It can be seen that the average complexity of both trees has a score of 2/9. The conclusion that can be drawn is that both trees are evenly complex and there is no preference. The advantage of a structured BoM with all the present links is the flexibility. Moreover, BoMs can be combined or split up based on the set criteria. Also, different attributes can be added or deleted for each node individually and can link them to other nodes in the BoM. A disadvantage of visualizing the BoM is the messiness of the picture. In a complex structure, complexity can be illustrated by visualizing the BoM. However, it is hard to find the right information from this figure. Therefore, it is required that filtering options are included on for example specific terms in the product description or predetermined groups of materials such as product families. The binary notation of the BoM can support in calculations.

When the relations with the BoM are understood, they can be used for calculations on capacity and demand. If for example the demand for one material is known, it can be translated to the demand per component used for this material by doing backward calculations. This is done for the costs in the example on the right-hand side of figure 2.3. A similar approach is applied to the current project. When material availability is defined, it can be used in decision making within S&OP. Multiple methodologies on how it can be applied in decision making are discussed in the next section by translating component availability to materials availability.

2.2 Applications

As described in the previous section, the material availability can be found by combining the information for multiple components. The question arises of where this transparency is useful and how it can be applied in the supply chain, more specifically in procurement. This section describes multiple applications of transparency in material availability. The first part is related to identifying and improving bottlenecks, while the second part focuses on improving the supply chain with a certain objective.

Capacity bottleneck
The knowledge of material availability can be used to find bottlenecks in the system. The theory of constraints (TOC) aims to find bottlenecks in a system. It views a manufacturing organization as a chain where the entire system is as strong as its weakest link (Pegels and Watrous, 2005). The TOC is developed by Goldratt and Cox (2016) in their book called "The Goal: A Process of Ongoing Improvement". The theory is described by the Drum-Buffer-Rope (DBR) mechanism. For DBR, there is one manufacturing step that determines the pace of the other steps because of its low speed. This manufacturing step is the constraint and is called the drum. A buffer is placed right in front of the constraint to ensure that the constraint is never without work. For manufacturing companies, this buffer is a material inventory. The rope controls the system The buffer is controlled by the rope. The rope is linked from the buffer to the rope to control the process and make sure that the production can continue all the time. If the buffer decreases, the rope triggers the previous production steps to increase the buffer. Having and controlling such a buffer takes time and resources, as inventory is kept. Therefore, Hinckeldeyn et al. (2010) introduce slot planning. This type of planning is similar to TOC but has no buffer. Bottlenecks in slot planning can be identified in multiple dimensions: workload, space or machine functionality. Slots can be seen as empty cells that are filled by customer orders with due dates. Based on this the order start time is computed with backward scheduling to the bottleneck resource. The similarities and differences between the two methods are as follows:

- Both methods use a top-down approach where customer requirements are translated into the production planning. However, TOC uses a forecast planning while slot planning is based on actual customer orders.
- The bottleneck resource determines the pace for the non-bottlenecks in both methods.
- TOC initially uses a buffer, while slot planning only introduces a buffer for specific cases when a problem arises. The first method has a higher certainty but also higher costs, while the second has less certainty but also lower costs.

- TOC creates a detailed scheduling for the bottleneck resources based on the forecasts. This is not possible for slot planning as this is dependent on actually confirmed customer orders, instead of forecasts.
- The bottleneck resource for TOC is related to workload and capacity. For slot planning this is extended as the bottleneck can also be due to expertise or information.

The method that is most applicable to Hilti and the current project is TOC. The first reason for this is that the production of Hilti is based on forecasts and production is planned beforehand. The second reason is that the current project covers material availability and can find the bottleneck in terms of material, which is a type of capacity. Hilti aims to find a balance between low uncertainty in material availability and inventory costs. However, there is always a small buffer for the materials that have a known factor of uncertainty due to the suppliers' capabilities. It can be said that the TOC methodology is already applied to Hilit's production and that it can be improved by including transparency in material availability due to bottleneck identification.

Optimization constraint
The material availability can also support in optimization. The most common objective in optimization for manufacturing is related to costs: maximize revenue or minimize costs. To satisfy these objectives, the product mix can be evaluated. The article of Bagalagel and ElMaraghy (2020) introduces a mathematical optimization model which aims to find the optimal product mix. The objective is then to maximize the net profit of the company (Keskin et al., 2010). The net profit is equal to the revenue minus the total costs. This can be compared to getting rid of abundant (unnecessary) links in the BoM, but now it is based on a mathematical calculation. In the paper of Quetschlich et al. (2021), a mathematical optimization model is proposed to minimize costs by minimizing the flow and inventories. The most important parameters of this model, where the relation between i and j represents the flow between nodes, are related to time, demand, inventory and capacity.

- Indices:

  T = time periods t=1,2,..

  P = set of items p element of P

  N = set of nodes n is element of N

  A = set of tuples for edges A element of (i,j): i,j element of N, i isnot j

- Parameters:

  $l_{i,j}$ = process lead time at edge (i,j)

  d = demand

  $inv_{n,p,t}$ = inventory of item p at node n at the beginning of period t

  $c_{i,j,t}$ = capacity at edge (i,j) at period t

- Decision variables:

  $f_{i,j,p,t}$ = Flow of item p at edge (i,j) during period t

  $inv_{n,p,t}$ = Inventory of item p at node n at the beginning of period t

The objective function of the proposed model is: Min$(\sum_{t\in\mathcal{T}}\sum_{p\in\mathcal{P}}(\sum_{n\in\mathcal{N}} inv_{npt}+\sum_{(i,j)\in\mathcal{A}} f_{ijpt}))$. It minimizes the inventory $inv_{n,p,t}$ over all time periods T, items P and nodes N, as well as the flow of material $f_{i,j,p,t}$, over all time periods T, items P and edges (i,j) A. There are multiple constraints related to the process lead times, demand, inventory and capacity control. All are given parameters with constraining values.

The material availability found in the current project can be included in such an optimization model by setting minimum and maximum levels for certain material capacities. For Hilti, this methodology would be applied per production line. A minimum and maximum boundary for the materials per production line can be used as input for the pre-S&OP meetings. These boundaries are expressed in pieces and can be compared to the total requirements in pieces based on the demand forecast. For optimization, different boundaries for the materials can be tested. Different boundaries lead to different optimal values. Hilti can for example test whether increasing the maximum material availability for a certain production line, increases their profit.

2.3 Conclusions

For Hilti, there are two sides to the data gathering. On the one hand, there is demand which is provided by the forecasts, as explained in chapter 1. On the other hand, there are the capacities of manufacturing. The current project focuses on one production plant that produces tools for the global market. Therefore, global demands need to be compared to the capacities per production plant. The capacity is expressed in terms of man power, machinery and materials. For the first two, capacity boundaries are known from the Blue Yonder data. For materials, there is little insight. This is related to the challenge of information gathering. The operational data on the component level is available and can be manually combined from different formats to find the material availability. However, this is time-consuming and does not happen frequently in reality. No format displays the material capacities on a tactical level such that it can be used during S&OP. Therefore, the current situation assumes sufficient supply unless someone explicitly mentions it.
For decision making in S&OP, insight into the material availability is missing for Hilti. For defining and applying the material availability, the first three types of visualizations and notations for the material structures are found in literature: a BoM visualization with nodes and edges, a Sankey diagram and a numerical schematic notation. The advantage of regular BoM visualization is the direct link with reality. Connections are easy to be found between the different nodes. However, this is also complex when the number of links and edges increases. Therefore, the decision can be made to split up the visualization into, for example, product families to keep an overview. The Sankey diagram is a tool that visualizes the BoM in another way, in a flow diagram. A distinction is made between a forward and backward flow. Finally, the numerical notation is based on the BoM as well but provides the opportunity to do calculations. For example, calculate node complexity and with this supply chain complexity. The advantage of this type of calculation is that multiple visualization options can be compared based on their complexity and the best one is chosen. Hilti has a complex product structure that has never been visualized before for the production lines in scope. Therefore, the current project visualizes the product structure of these two production lines. If this is visually complex, it can be split up into groups. It can be extended with the numerical notation to do calculations on the complexity.

The product structure is used as the foundation for finding the material availability. The material availability is dependent on the nodes that are linked to the top node in the BoM. This information can be used to improve the supply chain structure, especially the procurement structure in S&OP. The first step is to identify bottlenecks. In this chapter, two types of bottleneck evaluations are discussed: the first is according to the TOC and the second is according to slot planning. TOC is more applicable to Hilti's production as the production is based on forecasts that are made beforehand and not on the actual customer demands. For TOC, a buffer is proposed while for slot planning there is no buffer as production is based on confirmed orders.

Each company has one or more objectives. Hilti's objective in terms of materials is to balance the available capacity with the demand to minimize costs and maximize availability. The optimization techniques discussed in this chapter help to define an optimal value for material boundaries where the material can be introduced as a constraint.

Chapter 3

BoM analysis

As discussed in chapter 1, decision making in S&OP relies on three facets: machinery, man power and materials. Currently, machinery and man power capacities are known and contribute to the decision making within S&OP. However, the availability of materials is not fully transparent in the current situation. Therefore, the focus of the current project is on finding and quantifying the availability of the materials. The question that needs to be answered is if there is enough material available to satisfy the demand within a given time window. The goal of this chapter is to discuss the methodology followed to identify and link the relevant data and discuss the obtained data structure. This data structure includes the data that is required to find if sufficient material is available to satisfy the demand within a given time window.

The desired structure and elements of the data are depicted in figure 3.1. This is an Entity Relationship (ER) diagram that includes all the entities for the desired structure and shows how these are related. The structure is a table format in which each row contains information from the different entities. There are five entities: the BoM, demand, capacity, order and supplier. The BoM is the core of the structure. Each row in the BoM includes a material and a component. This results in a unique material-component combination for each of the rows. A material consists of multiple components, which means one material has multiple rows with different components. The next entity is the demand, which is directly linked to the materials in the BoM. This means that demand is initially expressed as number of materials. There are multiple rows with the same material and each of these gets assigned the related material demand. This leads to redundant information as multiple rows have the same demand. This is corrected and combined in a later step in the Data handling section. Another entity is the capacity, which is directly linked to the components. This means that the capacity is initially expressed in number of components. Each row that contains a specific component gets assigned the related capacity, based on the inventory. The same type of redundancy as for the demand occurs, which is also solved in the Data handling section. The next entity covers the orders. Each order represents a order at a supplier that contributes to the in-transit inventory level of the ordered component. In addition to the BoM information, the demand and the capacity, there is also information added on the orders. This is only applicable to the rows in which a component is ordered at a supplier, which are rows that have an in-transit inventory. The final entity is therefore the supplier. This can be an external supplier or another Hilti plant. The components produced in-house do not have in-transit orders. Each entity and its relation to the others is discussed further in this chapter.

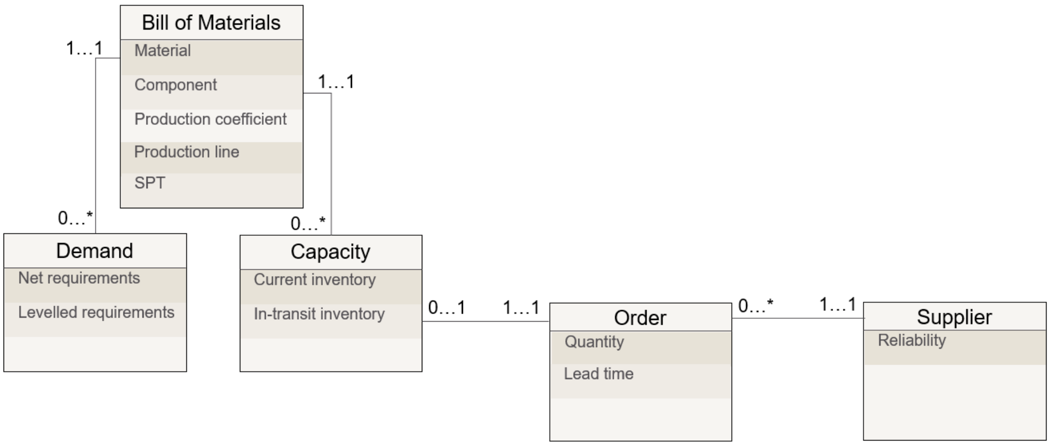

Figure 3.1: ER diagram for desired structure

3.1 Data handling

Bill of Materials
To define the material availability, first the structure of the materials should be understood. As explained in the Scope, a material consists of multiple components. The relation between a material and its components is described in the BoM. For Hilti, it is possible to derive the BoM for each material individually or multiple materials at once via SAP. The query used to derive the BoM is given in appendix A.1. The output of this query is a table displayed in SAP including multiple columns. Each row represents a material-component combination and contains information on this relation. To be able to make adjustments to this table, it is exported to a table in Excel.

The desired entities of the dashboard include the material names and numbers, the component names and numbers, the production coefficient and the Special Procurement Type (SPT). Each row has a production coefficient which is a number that shows how many components in the row are required to produce one item of the material in the same row. The SPT is a label that is assigned to each row to describe if the production of the component happens in-house, external or at another Hilti plant. This division is according to the explanation in the Scope. The possibilities for the SPT labels are displayed in table 3.1. It can be seen that SPT label A indicates external production, which means that the component in the specific row is produced externally. It is important to keep in mind that this is related to the component, and not the material. SPT label B covers the in-house production of a component. This means for the current project that the component is produced in plant XZ. The labels C, D, E and F represent production at another Hilti plant. The final SPT label is G, which represents a dummy. A dummy covers a combination of multiple components used in the related material. Imagine that a physical production line consists of two corners, each covering one production step for the production of a material. It starts at the first production step, which combines for example three components into one. The combination of these three components is stored temporarily until production step two is initiated. The starting point of the production step here is the output of the previous step. This output/input is the dummy. It is a combination of multiple components that are only included in the BoM for administrative matters and are not sold or used as themselves. Therefore, the dummies are filtered out of the data.

SPT	Definition
A	External production
B	In-house production
C	Production at Hilti plant 16
D	Production at Hilti plant 92
E	Production at Hilti plant 44
F	Production at Hilti plant 08
G	Dummy

Table 3.1: SPT labels

Rows with an empty value for the material or component number or name are filtered out as well. Empty values in the SPT column and production coefficient column are evaluated and the reason for this is tracked down. Based on the reason for the missing value, either the row can be deleted or a replacement value can be considered. When there is for example an SPT label missing due to administrative issues it can be entered manually. If there is no production coefficient available, it is assumed to be equal to 1 and set to 1 manually in the data.

An empty data frame is created using Python programming language. This is supplemented with six columns that are directly retrieved from the cleaned BoM file: material number, material name, component number, component name, production coefficient and SPT. These six columns form the basis of the data frame which is further referred to as the core data frame. This data frame is supplemented with additional data on the demand and the capacity. The entities and their relations are visualized in figure 3.1. The capacity, demand and the orders are discussed individually.

Capacity
The capacity is expressed as the number of materials available. This is dependent on the expected inventory level which consists of the current inventory and the in-transit inventory. The current inventory is equal to the physical stock at the plant. However, for materials produced in PT&A, no inventory is held for the materials. One material consists of multiple components. It is assumed that if all the components required to produce one material are available at the start of the month, the material is finished in time. Therefore, it is possible to consider the current inventory of the components instead to find the expected inventory of the materials. For the in-transit inventory, the same reasoning holds. These are also on component level and include all the orders that are shipped by the supplier and are on their way to the plant. Orders that are placed by the plant but are not yet shipped by the supplier are left out of scope in the current project. The reason for this is the timing of the analysis. The inventory data is retrieved once a month, just before the pre-S&OP meeting. This is around the 20^{th} of the month. It can be assumed that orders that are already shipped at this point arrive in time for next month's production. However, orders that are not yet shipped by the supplier have less certainty to arrive in time. Therefore, only the orders that are shipped are considered in-transit inventory. The availability of a material is then a combination of the availabilities of the components used to produce this material. Each component has a current inventory and an in-transit inventory that have a value of zero or higher. The current and in-transit inventories are added to the core data frame. Each row in the core data frame covers a unique material-component relation. However, the components themselves are not unique and can be used for multiple materials. This complicates the analysis as the inventories are not assigned to a unique material-component combination but to a component only. Therefore, each component gets assigned its current and in-transit inventory level, despite the material it is used for.

The current inventory can be found by the SAP query described in appendix A.1. The query is run for every component in scope. The output of this query is a table format including multiple columns. The main columns are the component name and number and the current inventory level.

The current inventory includes the safety stock. However, there is also an additional column that shows the safety stock on its own. The table is exported to a table in Excel, such that it can be added to the core data frame. By using Python programming language, the current inventory is added to the core data frame. Each component in the core data frame is compared to the components in the current inventory file. When a match is found, the core file is supplemented with the current inventory level for each row that includes the specific component. In addition, the safety stock is added in the same way.

The in-transit inventory can also be found by the SAP query described in appendix A.1. The query is also run for every component in scope. The output is exported to Excel as well. This in-transit inventory table includes unique supplier-component relations in each row. Each component can be supplied by one or more suppliers. Each supplier-component has an in-transit inventory value. As described before, only the in-transit inventory that is already shipped by the supplier is included in the analysis. Therefore, the table is filtered on these orders only. The in-transit orders are similarly added to the core data frame as the current inventories: based on the component numbers. Each component in the core data frame is compared to the components in the in-transit inventory file. When a match is found, the core data frame is supplemented with the in-transit inventory level for each row that contains this specific component. The supplier names and numbers are added to the core data frame later.

Demand

The demand consists of two elements: the net requirements and the levelled requirements. Both are indicated as pieces, which means materials. This is different from the inventories, which were represented as a number of components. To be able to compare them, the demand is first translated to the number of components.

The net requirements are found in a table in the format of figure 3.2. In this table, the Req (PC) include the net requirements in pieces that result from the demand forecast. To translate this to the number of components required, the production coefficient is used. First, the net requirements are added to the core data frame in terms of materials by searching for corresponding values in the materials column. Each material in the core data frame is evaluated and when the same material number is found for the net requirements file, the value for net requirements is added to each row that contains this material. Translation to components is done after combining the net requirements with the levelled requirements. The net requirements file also includes information on the production line per material. During the pre-S&OP meeting, data is analyzed and discussed per production line. Therefore, it is important to be able to group materials from the same production lines together. The core data frame does not include the production lines yet. Therefore, this information is added in this step. In the same way as the net requirements are added to the core data frame, the production lines are added as well.

	Oct 2022	Nov 2022	Dec 2022	Jan 2023
Req (PC)	16,961	17,267	12,834	17,340
Req (H)	425	432	321	434
Min man power capacity (H)	400	400	250	300
Max man power capacity (H)	600	550	500	550
Max machinery capacity (H)	800	800	800	800

Table 3.2: Dummy Blue Yonder data

A similar approach is used for the levelled requirements. As discussed before, the data is derived around the 20^{th} of the month. The net requirements cover the requirements for next month based on the demand forecast. However, there is a gap of about 10 days until next month starts when data is derived. This time gap is covered by the levelled requirements. These represent the confirmed customer orders that are produced during the remaining days of the month. The available inventory is partly needed for these customer orders. Therefore, it is important to include these orders as requirements as well. The levelled requirements are available in SAP as well and are found by the query described in appendix A.1. The output of the query is exported to a table in Excel. Each material in the core data frame is evaluated and compared to the materials in the levelled requirements table. The value for the levelled requirements is added to each row that contains the same material value as the core data frame. A new column is created in the core data frame that is called 'total requirements' which is the sum of the net requirements and the levelled requirements.

Each row contains a production coefficient that represents the number of components that are required to produce one material. This is material-component combination specific which means that each row has its own production coefficient. Later, an additional column is created in the core data frame that covers the component requirements. The calculations to find the component requirements can be found in appendix A.2 and are applied in chapter 4. The component requirements are the total requirements per material multiplied by the production coefficient for this material-component combination. The new column can be used to compare the required components to the available components.

Orders and suppliers
The in-transit inventory level per component is dependent on the orders at different suppliers. Each order has a quantity and a lead time which are directly related to the suppliers. The order and supplier information is only available for components that are ordered at external suppliers. Components that are produced in-house or at another Hilti plant do not have this specific information. Therefore, the order and supplier information is only added to the rows containing components with an in-transit inventory ordered at external suppliers. There is a separate query in SAP with which the suppliers per component can be derived. This query is described in appendix A.1 and uses the components in scope as input. The output is a table that is exported to Excel. The suppliers are added to the core data frame based on the component numbers. Each component in the core data frame is evaluated and compared to the components in the supplier file. Based on this, the supplier information is added to the core data frame. As explained, only components with SPT label A, which stands for external production, have supplier information. The other components are either supplied by other Hilti plants or are produced in-house. This query only covers external suppliers. Which other Hilti plant is the supplier is already covered by the SPT label itself. The lead time of a specific component is dependent on the order and its supplier. One component can be covered by multiple orders which can be supplied by one or more suppliers. This means that each row in the structure can get multiple suppliers and corresponding lead times as well. No lead time information is available for in-house production or production at other Hilti plants.

The final source of information is the product availability file. This information is included in an Excel-based table that can be refreshed at any time and is linked to data in SAP. It contains historical data on orders where each row in the file represents an order that was ordered by the plant at an external supplier. Each order is scored on the delivery time and the delivery quantity. For both the delivery time and the delivery quantity, either a zero or one is assigned per order. A zero represents a late or incomplete order and a one represents an on-time and complete order. The combination of these leads to the general Product Availability (PA) score. For this score, data on multiple orders are combined. A one is only assigned to an individual order when it was complete and arrived in time. When it is either late or incomplete, a zero is assigned, despite the other possible positive factor. The PA score for a specific supplier is computed by summing all the scores for historical orders and dividing them by the number of orders. This is calculated using Python programming language. There are two possible ways to calculate this score: based on the components or based on the supplier. The first leads to a PA score per component and the second leads to a PA score per supplier. Based on a discussion with the stakeholders of the current project, the PA scores are calculated for each supplier. The reason for this is that these scores can then be used to compare different suppliers, in the case of multiple suppliers for one component. The PA scores are added to the core data frame based on the supplier numbers. Therefore, this is part of the supplier entity in the ER diagram. Each row in the core data frame is evaluated and compared to the product availability file. If a matching supplier is found, the PA score is added to a new column in the core data frame. This column is called the 'PA score' and represents the supplier reliability.

The output of the data handling is the core data frame including information on the BoM, the capacities, the demand, the orders and the suppliers. To get more insight into the relations between the materials and their components and to better understand the complexity of the computations, first the BoM visualization is elaborated on in the next section.

3.2 BoM Visualization

The BoM is the core of the data structure. It includes all materials and components that are in scope. Components can be used in multiple materials which means there is an overlap in the relations between the materials and the components. To get a better understanding of this structure, a BoM visualization is created. The visualization method used is a Sankey Graph. In the Literature Review, multiple visualizations and notation techniques have been described. Hilti's BoM has never been visualized before and therefore the BoM visualization is preferred over the numerical notation for the current project.

The production flow of Hilti starts with the materials and their components. There exist links between each material and components that are related. These links each have a production coefficient that represents how many components are required to produce one material. These flows are illustrated in a Sankey Graph. To do this, the BoM with materials, components and the production coefficients is required. Components that should not be included are filtered out after the data cleaning, such as dummies. This means no redundant links are present anymore. It starts with the visualization of one material, consisting of multiple nodes. An example is given in figure 3.2.

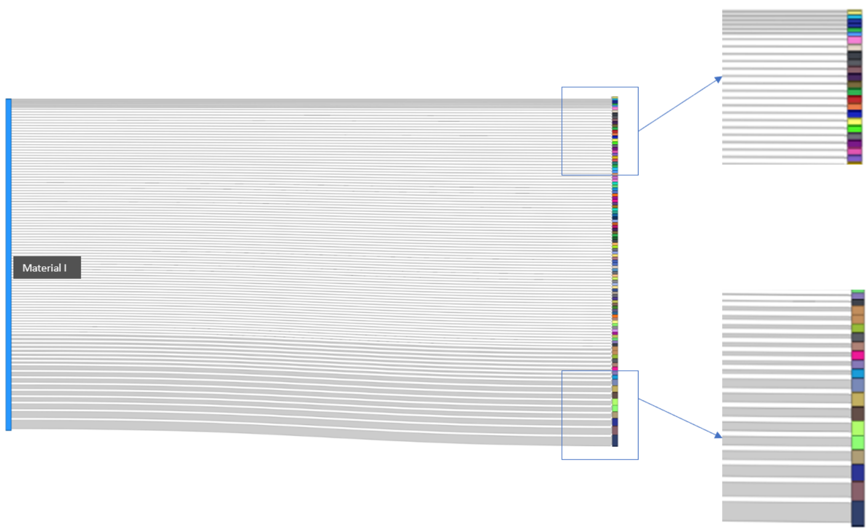

Figure 3.2: Sankey graph for one material

On the left-hand side there is one node, representing the material. This material is connected to multiple other nodes on the right-hand side that represent the different components used for the production of the specific material. Next to the graph, there are two zooms available. These are used to illustrate the different connections between materials and their components. As discussed, each material-component combination has a production coefficient value. This value represents the number of components required to produce one material. This number can range from just above zero to many pieces. Most material-component combinations have a production coefficient of 1. Some examples of production coefficients lower than one are found in the top zoom of the figure. The upper components have thinner lines and smaller boxes than the ones below. The higher in the figure, the lower the production coefficient. A value smaller than one can occur if for example two materials are sold in one case. Then, the case has a production coefficient of 0.5. The opposite is found in the zoom at the bottom of the figure. The lowest components have the highest production coefficients, which can be recognized by the thicker lines and the bigger boxes.

One component can be used for multiple materials. Therefore, it is interesting to combine the BoM structures of multiple materials into one figure. To illustrate this, first the BoMs of two materials are combined and visualized in figure 3.3. On the left-hand side, two materials are shown. Each material consists of multiple components, which are shown on the right-hand side of the graph. A distinction can be made between components that are only used for material I, components that are only used for material II and components that are used for both. The zoom next to the figure shows the components that are used for both materials. It can be seen that there are two lines attached to the component boxes. The production coefficient is related to each material-component combination and it can therefore happen that a component has a production coefficient of one for one material and a production coefficient of two for another material, for example. This would be visible in the thickness of the lines between the materials and their components.

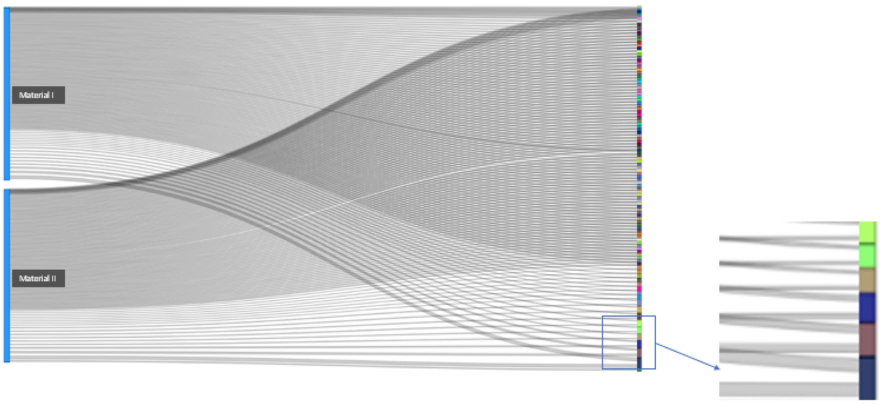

Figure 3.3: Sankey graph for two materials

The scope of the current project covers production lines Z1 and Z2. These include the production of 33 and 106 materials, respectively. This makes a total of 139 materials. The visualization of all these materials and their components together is shown in figure 3.4.

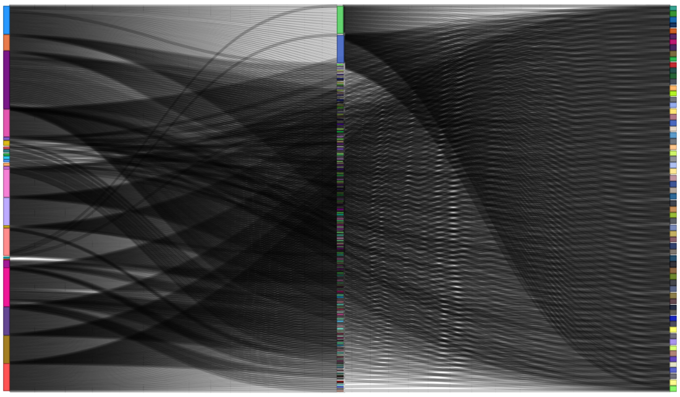

Figure 3.4: Sankey graph for all materials of Z1 and Z2

This is quite different from the previous figures as there are three layers of nodes instead of two, which makes this structure a multi-level BoM (M^2BOM). This means that there are more than two layers and a material can consist both of components from the most right layer as well as the middle layer. The components in the middle layer consisting of multiple components from the right layer as well. The middle layer can be seen as a layer with "intermediates", which are used for the assembly of materials but are already in in-house production because some pre-processing took place. This graph includes links for which it should be kept in mind that the production coefficient, and therefore the thickness of the lines, is related to a specific component-material relation. This means that a component can be used once for one material while it is used twice for another material or even intermediate.

Especially the Sankey graph for two materials shows how the product structure of multiple materials overlaps. To analyze this type of structure, a node complexity score can be assigned to each node. The node complexity reflects the number of links that go in and out of each node. This means a node with multiple nodes either consists of multiple other nodes or is used for multiple other nodes. The increasing number contributes to the complexity of the model. The most complex nodes can be identified in the BoM analysis to find bottlenecks and points of improvement. They can be found by analyzing the binary notation of the BoM structure explained in the Literature Review.

The Sankey graph can be complemented with additional information on inventory levels and requirements. This would make it possible to find the consequences of different decisions. Changes within a node are reflected in its related nodes as well. This could be useful when for example demand increases and the company wants to know how much more components are required. However, this method is time inefficient in the analysis of the results as the consequences of each node can be evaluated individually only. By aggregating the information useful insights can be derived. For example, the inventories of a specific component give a warning for stock-outs but when there are above the safety stock level these are not really meaningful. When combining the information with the material-component relations, it can be seen how many components should be spread over the different materials. This can be compared to the requirements to see if there is sufficient supply. The data can be visualized in a table or graph to provide a better understanding. Therefore, the next chapter creates a dashboard that enables scenario analysis and finds the consequences of certain decisions for all related nodes in both a graphical and a table format.

Chapter 4

Dashboard development

The output of the previous chapter is a structure including all data that is required to determine the availability of materials. The goal of S&OP is to identify gaps between availability and demand. This gap is labelled as a shortage of a certain material. Each material consists of multiple components. The component shortages are used to determine the material shortages. The shortages are the main values of this analysis. The goal is to develop a dashboard that includes the availability of components and identifies the shortages. The dashboard is created in the analysis and visualization tool Power BI. Power BI enables its user to translate numerical data to visuals and link data between different files by using Power Query. The dashboard consists of three elements: the table, the visuals and the filters. The table includes quantitative information on the component availability. The visualizations capture how many of the components in scope result in a shortage. There are two types of visuals: a pie chart and a bar chart. In addition, multiple filters are included. An elaborate explanation and examples of the table, visuals and filters are given in this chapter. The dashboard is then tested in a case study on two production lines. The results and the evaluation of this case study are discussed in section 4.2. The model is made in a generic way such that it can be scaled to other production lines or plants in the future. To test the scalability, also a scalability test for four other production lines is done. The results of this trial run are described in section 4.3. This chapter finds an answer to Sub-question 6 '*How can the data be combined and visualized as a foundation for S&OP decision making?*' by creating the dashboard.

4.1 Dashboard design

Dashboard requirements

The goal of the tool is to present the material availability and possible shortages such that this information can be used for tactical decision making during the pre-S&OP meeting. The basis of the dashboard is a table, including all the information required to find the material shortages. During this meeting, each production line is discussed individually. Moreover, for each production line, the materials that expect to cause shortages are discussed. Therefore, the possibility to filter on production line and the presence of a shortage should be available. To get a better understanding of the share of shortages, visuals are added.

The three steps that are leading to create the dashboard are displayed in figure 4.1. The first step is to create a structure that includes all the information required to find the material availability in the Data generator. This structure is built on data from different sources: SAP and Blue Yonder. This step is covered in the previous chapter. The structure is further processed in the Table generator where it is transformed such that it can be used as input for the dashboard. Finally, the dashboard is created in Power BI where multiple visualizations and filters are created.

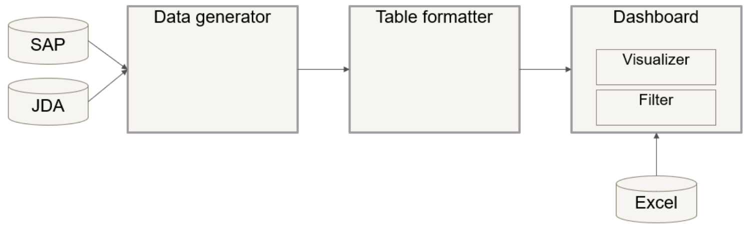

Figure 4.1: Diagram for dashboard construction

The Data generator covers the data processing that is done in the previous chapter. As explained, each row in this structure includes information on a unique material-component combination. This means that the same component types can occur on multiple rows in combination with different materials. The number of different components used for a material can be found by filtering on the specific material. The adjusted structure should be such that each row contains a unique component type. The reason for this is that each component type has its own inventory, for which is it not defined what materials these are assigned to yet. It would not be correct to assign the same inventory levels to each material-component combination that contains this particular component type. However, it would not be correct either to divide the components over the different materials as the division is dependent on the demand for the materials. In case of excess inventory or shortages, a decision should be made on what amounts of components to assign to each material. This cannot be done correctly at this stage. Therefore, the structure is transformed such that each row in the table contains information on only one component type. This is covered by the table formatting step. The following adjustments are made to the particular columns and values:

- **Materials**: A component can be used for the production of one or more materials. In the current structure, each material-component combination has its own row. This is transformed such that each component type has its own row. The Table.Group query in Power BI is used to group materials that use the same components. By grouping the material numbers and material names based on the components, each row contains a unique component type but can include one or more materials.

- **Production lines**: A component may be used for multiple materials that are produced at different production lines. Therefore, the production lines are grouped as well. The grouping is directly related to the materials and therefore the production lines are grouped in the same way as the materials.

- **Suppliers**: The same methodology as for materials is applied to the suppliers. A component can be supplied by one or more suppliers. The Table.Group query is used to group all suppliers that supply a particular component into the same line as the unique component type is displayed. This is applied to the supplier name as well as the supplier number.

- **Lead time**: The lead time is unique for each component-supplier combination. Due to the possibility of multi-sourcing, multiple lead times can be visible in one column as well. The lead times are displayed next to each other. An example of the lead times is (5, 10) which indicates that the first supplier has an average lead time of 5 days and the second supplier has an average lead time of 10 days. The lead times are not combined into one average value to ensure visibility per supplier.

- **PA score**: The PA score is unique for each supplier. Therefore, the PA scores are grouped as well using the same methodology as for the lead times. This means that multiple PA scores can be included in one cell when there are multiple suppliers. The same reasoning as for lead times applies here.

After grouping the columns as described above, multiple calculations are done to find the total requirements per component and to identify possible shortages. Both the grouping and the calculations are done every time the dashboard is run, due to new data. These steps are the steps involved in the Table formatter. To enable these calculations first the variables are defined.

Values and calculations
The possible shortages are dependent on the demand and the capacity. As explained in the previous chapter, the demand consists of net requirements and levelled requirements and the capacity consists of current inventory and in-transit inventory. All these are represented as a variable such that calculations can be done. The shortages can be found by subtracting the capacity from the demand. If this number is higher than zero, there is an expected shortage. To be able to work with multiple materials and components, sets are assigned to both of them. The mathematical notation is used such that this information can be used still when the model is scaled.

The sets are displayed in table 4.1. The first set includes the set of output materials. These represent all the materials that use components to be produced. The set of input materials are the components that are used for the production of the materials, so the input materials are used for the production of the output materials. The link between the input and output materials is represented by nodes and edges. This is based on the relationship between materials and components as designed in the previous chapter. Each material and component can be seen as a node and the link between them can be seen as edges. In the current model only one period is considered, which is the month after the pre-S&OP meeting. However, in the future, the model can be used for forecasts further ahead. A specific period in the future or a combination of multiple periods can be analyzed if the data that applies to these periods is imported. Each period stands for 1 month. The production lines in the current project are production lines Z1 and Z2 and these could be extended as well. To make sure the model is scalable, the periods and production lines are added as sets that can be supplemented. This section provides an answer to Sub-question 5 '*What variables should be included in the final model?*'

Set	Description
$\mathcal{M}^{\mathrm{O}}$	Set of materials (output)
$\mathcal{M}^{\mathrm{C}}$	Set of components (input)
$\mathcal{M} := \bigcup_{x\in\{O,C\}} \mathcal{M}^{\mathrm{x}}$	Set of all materials
$\mathcal{E} \subset \mathcal{M} \times \mathcal{M}$	Set of directed connection (from the Bill of Materials) between two materials: $(m, m') \in \mathcal{E}$ if and only if material m serves as input for material m'
$\mathcal{P}$	Set of periods in months
$\mathcal{L}$	Production lines

Table 4.1: Sets

A distinction is made between independent and dependent variables. The independent variables are given but can be adjusted manually. The dependent variable is dependent on the independent variables. The independent variables are related to capacity and demand. The dependent variable is the expected production quantity of a material m from which it is possible to derive a possible shortage. All variables are listed in table 4.2.

Variable	Description	
$B_{m,m'}$	Production coefficient of input material m to produce one unit of m'; $B_{m,m'} > 0$, if and only if connection $(m, m') \in \mathcal{E}$,	$m \in M$
$R_{m,p}$	Net requirements of material m at period p,	$m \in M, p \in P$
$L_{m,p-1}$	Levelled requirements for material m for period $p - 1$,	$m \in M, p \in P$
$x^{\text{IS}}_{m,p}$	Current inventory of material m at period p,	$m \in M, p \in P$
$x^{\text{IT}}_{m,p}$	In-transit inventory of material m at period p,	$m \in M, p \in P$
$x^{\text{P}}_{m,l,p}$	Expected available quantity of material m at line l at period p	$m \in M, l \in L,$ $p \in P$

Table 4.2: Variables

Calculations

In the following text, the set of equations that are needed to find the expected shortages are displayed. These include values for both capacity and demand.

Total requirements of material m for period p, expressed in materials:

$$T_{m,p} = R_{m,p} + L_{m,p-1}, m \in M^O, p \in P$$

Total requirements of material m for period p, expressed in components:

$$T_{m,p} = R_{m,p} + L_{m,p-1}, m \in M^C, p \in P$$

Total expected production of material m' based on the current inventory of m and the production coefficient:

$$x^{\text{Ps}}_{m',l,p} = x^{\text{IS}}_{m,p} * B_{m,m'}, m' \in M^O, m \in M^C, l \in L, p \in P$$

Total expected production of material m' based on the current inventory and in-transit inventory of m and the production coefficient:

$$x^{\text{Pi}}_{m',l,p} = (x^{\text{IS}}_{m,p} + x^{\text{IT}}_{m,p}) * B_{m,m'}, m' \in M^O, m \in M^C, l \in L, p \in P$$

Expected shortage excluding the in-transit stock:

$$S^{\text{IS}}_{m,l,p} = T_{m,p} - x^{\text{P}}_{m,l,p}, m \in M, l \in L, p \in P$$

Expected shortage including the in-transit stock:

$$S^{\text{IT}}_{m,l,p} = T_{m,p} - (x^{\text{P}}_{m,l,p} + x^{\text{IT}}_{m,p}), m \in M, l \in L, p \in P$$

The shortage shows the gap between the capacity and the demand. However, when comparing different shortages only on their value, they may be hard to compare. For example: component I has a demand of 100 pieces and a shortage of 10 pieces and component II has a demand of 20 pieces and a shortage of 10 pieces. Considering only the number of shortages for both components, would mark them as equally high (10 pieces). When trying to narrow down or solve the shortages, there may be no preference for one of the two components because they seem to have the same criticality. However, when considering also the requirements (100 and 20 pieces), the shortages can be expressed as 10% and 50% respectively. This insight may change the order of handling the shortages during S&OP. Therefore, the coverage percentage is also calculated.

The coverage percentage is the coverage of the total requirements by the expected material production, based on the current stock levels (no in-transit) expressed in percentages:

$C_{m,l,p} = x^{\mathrm{P}}_{m,l,p}/T_{m,p} * 100, m \in M^O, l \in L, p \in P$

The most important variables are the expected shortages: $S^{\mathrm{IS}}_{m,l,p}$ and $S^{\mathrm{IT}}_{m,l,p}$. These values can be used to find the expected situation during S&OP in terms of material availability. Scenario analysis includes changing the independent variables, for which the consequences are visible in the dependent variables. The calculated values are added as new columns to the existing structure, resulting in a structure containing the columns in the table below. A distinction is made between data based columns and calculation based columns.

Data based	**Calculation based**
Production line	Total requirements in materials
Component number	Total requirements in components
Component description	Total expected production in components
Material numbers	Expected shortage excluding in-transit
Material descriptions	Expected shortage including in-transit
Supplier	Coverage by current stock (%)
Lead time	
PA score	
Special Procurement Type (SPT)	

Table 4.3: Available data and calculated data

When the calculations are applied and new columns are created in the structure, some remaining zero or missing values are changed. When there are missing values for the PA score, this cell is replaced by the text “No info available”. When there are missing values for the Lead times, this cell is replaced by the text “No info available” as well. For supplier name and number the missing values it is assumed that the supplier is phased out. This assumption is agreed to by the central planner. The missing values for suppliers are therefore replaced by “Vendor phased out or inhouse”. This means that when there is no supplier information available the vendor is either phased out when it is external production. However, when it is not external production, there is no supplier because components are sourced at other Hilti plants or produced in-house.

The elements of table 4.3 form the basis of the table in the dashboard. This is further discussed in the next subsection.

4.1.1 The table

The contents of the table in the dashboard are all derived from the structure of table 4.3. However, not all columns of this table are included due to limited space in the dashboard table. The selection of the columns has been done in consultation with the Central Planner of XZ. The columns that are selected and part of the dashboard table are written in italics in table 4.4. The total expected production is not included in the table. The reason for this is that this is already covered by the shortages that are calculated. The lead times, PA scores and SPT labels are not related to the previous calculations but provide insight into the scenario of a shortage. If the SPT label shows that the component is sourced externally, the next step in case of a shortage is to find possibilities to get more of the components this supplier supplies. Providing information on the lead times helps to give an idea to the user on the possibilities of in-time supply of this specific component. For example, if the lead time is only 1 day, an order can be placed in the upcoming days and the component will still be in time for the production of the material. When the lead time is for example 30 days, it gets more difficult and it is uncertain if the component will arrive in time. In this scenario, it can be useful to include supplier reliability. This is represented by the PA score in the structure. This is a score between 0 and 1 and represents the reliability of the supplier based on historical delivery data.

Data based	**Calculation based**
Production line	Total requirements in materials
Component number	*Total requirements in components*
Component description	Total expected production in components
Material number	*Expected shortage excluding in-transit*
Material description	*Expected shortage including in-transit*
Supplier	*Coverage by current stock (%)*
Lead time	
PA score	
Special Procurement Type (SPT)	

Table 4.4: Available data and calculated data included in dashboard

In the table in the dashboard, each row represents a component. A component can be used for the assembly of multiple different materials. A shortage in components is reflected as a shortage of the materials as well and is caused by a shortage in current or in-transit stock for the components that are used for the production of the material. For this reason, the construction of the table focuses on the availability of the components.

4.1.2 The visuals

The next part of the dashboard includes the visuals. Two kinds of graphs are created, a pie chart and a bar chart. Hilti uses a colour scheme which is leading for all Hilti-based graphics and tools. However, the red, yellow and green used in the tool are not part of the main colour palette of Hilti. The reason for this is that the green, yellow and red should give the message that the situation is good, average, or bad. The original Hilti colours are softer and do not deliver this message as desired. Therefore, the decision is made to devote from the colour palette and choose bright colours instead. This decision is approved by the S&OP team.

The legend for the visuals is displayed in figure 4.2 and has three items. This legend is created as a table in Excel and exported to Power BI to be able to include it in the final dashboard. This legend is linked to the table in the dashboard as can be seen in the final part of the diagram in figure 4.1. The reason for this is that when filtering in the table, the visuals or the filters only the parts of the legend are shown that are applicable to the selected data.

Abbreviation ▲	Meaning
CS	Current stock
ITS	In transit stock
NR	Net requirements

Figure 4.2: Legend for dashboard visuals

An example of the visuals is provided in figure 4.3. The pie chart is called ‘Component availability’ and is either green, yellow or red. The bar chart is called ‘Stock coverage’ and is either green, yellow, red or blue. The colours are based on the availability of each component in the table. An additional column is added to the table which is called ‘KPI light’. This colour is the same as the colour in the ‘component availability’ visual. This light is green, yellow or red based on the values in the table.

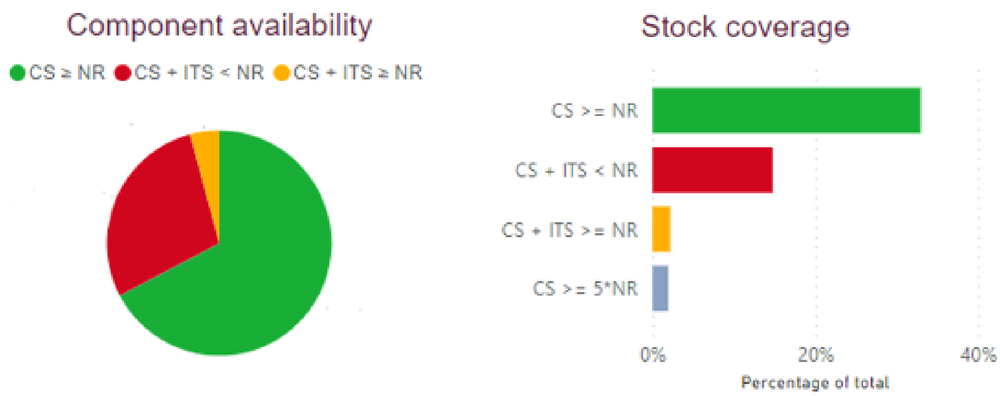

Figure 4.3: Example of the visuals of the component availability dashboard

The meaning of the colours can be found in table 4.5. Green is assigned to a component when the current stock covers the total requirements. This means no problem in capacity is expected. A yellow label is assigned when the total requirements cannot be covered by the current stock only, but they can be covered when the in-transit inventory is considered as well. The in-transit included in the model is assumed to arrive in time for production. Therefore, no problem in capacity for the yellow components is expected either. The green and yellow both refer to a safe situation. However, the distinction is made because there is even more certainty in the green label. A red label is assigned to a component when neither the current inventory nor the combination of the current and in-transit inventory can cover the total requirements. A shortage in components is expected, which is an undesired situation. The final label is blue and is assigned to a component when the current inventory covers five or more times the total requirements. This provides certainty for the production of next month and also indicates a high inventory level. Five is chosen as a factor in consultation with the Central Planner. The third column in the table shows the calculations that are underlying the colour coding for the KPI light and are similar to the textual explanations.

colour	Definition	Calculation
Green	Current stock covers the requirements	$x^{\text{Ps}}_{m',l,p} \geq T_{m,p}$
Yellow	Current stock + in-transit stock cover the requirements	$x^{\text{Pi}}_{m',l,p} \geq T_{m,p}$
Red	Current stock + in-transit do not cover the requirements	$x^{\text{Pi}}_{m',l,p} < T_{m,p}$
Blue	Current stock covers 5 times the requirements	$x^{\text{Ps}}_{m',l,p} \geq 5 * T_{m,p}$

Table 4.5: Colour definitions

The ‘Component availability’ visual provides an overview of the share of components that are expected to be available or not. The ‘Stock coverage’ visual is a bar chart with two axes. The horizontal axis is a percentage measure that shows how much of the total number of components is green, yellow, red or blue. This is similar to the pie chart but an additional colour is added. The blue label helps in the awareness of high inventory levels. These blue labelled components are part of the green share in the pie chart.

4.1.3 The filters

There are seven types of filters included in the dashboard: filters on the production lines, the SPT label, the component level, the component numbers, the material numbers, the colours and the table columns. The choice for filtering options is based on the preference of the stakeholders in the pre-S&OP meetings because they are the users of the dashboard.

- Production lines: The standard procedure during a pre-S&OP meeting is to evaluate the availabilities per production line. Therefore, the filter on production lines is added. When selecting one or multiple production lines, the visuals and the table automatically adjust to this filter. This is useful as the visuals show how many of the components that are used on the production lines have shortages. The results in the table can be evaluated one by one.
- SPT label: The second filter is the SPT label which makes it possible to distinguish between external production, production at another Hilti plant or in-house production. For production at another Hilti plant, specific plants can be filtered on as well.
- Material number: Filtering on material number is useful to identify which components are used for the production of this material and to identify if there are any shortages related to this material. If filtering on a specific material results in only green labelled components, the availability of this material is secured. However, if there are one or more items that are red, further investigation into these materials may be required. This filter can also be used to determine if a scale-up in production is possible. If all the components required for this material have a blue label in the bar chart, they are all available five times or more than the total requirements for next months. This means, a scale-up is possible for sure. However, not necessarily five times the requirements have to be available to be able to scale up. Therefore, the coverage percentage of the green components can be evaluated as well. A coverage percentage of more than 100% means that there is room for scaling. Yellow and red items do not allow for scaling.
- Component level: The Scope describes that a material structure can consist of multiple component levels. The material is the upper level which consists of components from layer 1. When these components are produced in-house, there may be information on the sub-components that are used for this production as well. These sub-components are part of layer 2. In a similar way, the layers can increase to n layers. This filter enables the user to filter on the different layers. This is specifically helpful when there is for example a shortage in layer 1 and the reason is due to missing sub-components in layer 2.
- Component number: This filter is especially useful in combination with the component level filter. When the underlying sub-components of a missing component need to be found, this filter can be used.
- colour: This filter is not part of the filter pane on the dashboard but is included in the visuals of the dashboard. When clicking on a colour in the visuals, the table is automatically filtered on this colour as well. As the focus during the pre-S&OP meeting is on red components, it is useful to be able to filter the red items such that they can be discussed one by one.
- Columns: Another functionality that is not part of the filtering pane but which can be useful is the filter per column in the table. This can filter textual columns from A to Z or the other way around and can filter numerical columns from low to high or the other way around. During S&OP, first the production lines are filtered using the filter in the filter pane. Next, the red items are filtered by clicking on the red colour in one of the visuals. This results in a table with multiple red components. The most critical red components are evaluated

first, due to time restrictions. Filtering the coverage percentage from low to high makes it possible to rank the components from most critical to least critical. The criticality is then defined as the number of total requirements that can be covered by the inventories. If there is for example only a coverage percentage of 5%, this component is more critical than a component with a coverage percentage of 95%. Both need attention but it is expected that more rigorous measures have to be taken for the first component. There is no time to discuss all the components one by one during the pre-S&OP meeting, so the other one could be evaluated after the meeting when there is more time. The criticality can be defined also and the filter can be applied accordingly.

4.2 Case study

The dashboard is tested in a case study on two production lines of plant XZ: production lines Z1 and Z2. The case study is executed in July 2022, while analyzing the data for August 2022. The goal is to define the material availability and the possible shortages for the month August. To find this information, the required data is derived first:

- BoM: First the BoM is derived to find the material-component combinations that are part of production lines Z1 and Z2.
- Net requirements: The net requirements are derived from the Blue Yonder data sheet that is created during the PE run in July. This includes the net requirements for August.
- Levelled requirements: The levelled requirements are derived from SAP by the query in Appendix A.1. The input for this query contains all the materials that are produced on production lines Z1 and Z2. The date is set from the date of the derivation to the end of July. In this way, all the levelled requirements for the remaining of July are included.
- Current inventory: The current inventory is derived from SAP by the applicable query in Appendix A.1. The input for the query includes all the components that are used to produce all the materials of production lines Z1 and Z2. These components are found in the BoM. The date is set to the date of derivation.
- In-transit inventory: The in-transit inventory is derived from SAP as well by the applicable query described in Appendix A.1. The input for this query is equal to all the components that are found in the BoM. The date is set to the date of derivation.

The data is gathered the day before the pre-S&OP meeting such that it is up to date and can be used as input for this meeting. For July, the pre-S&OP took place at the 20^{th}, which means the data was derived on July 19. This data is combined and displayed in the dashboard in Power BI. This dashboard consists of a table, two visuals and multiple filters. For the production lines filter there are now only two options: Z1 and Z2. The results of the case study are shown and explained in the next subsection. The dashboard only contains material that have a demand for August. For the case study, these materials only contain one level of components. Therefore, the component level filter is not visible and applicable to the case study. These results are validated during a meeting with two materials managers who participate in each pre-S&OP meeting. One of them is responsible for the materials for in-house production and the other is concerned with external supply. Both work at plant XZ and are involved with all the production lines in this plant. With their knowledge, the results of the case study on production lines Z1 and Z2 are evaluated.

4.2.1 Results case study

The dashboard with the results of the case study is displayed in appendix C. The visuals of the dashboard can be found in figure 4.4 as well. It can be seen that 69.7% of all components have a green label. This means that over two third of all the components in scope are expected to be available for next month's production. Another 3.6% of the component have a yellow label, which means that there is only enough availability to cover the requirements when both current and in-transit inventory are considered. The in-transit inventory that is used in the dashboard is assumed to arrive in time for next month's production. Therefore, the components with the yellow label are marked safe as well. The focus during the pre-S&OP meeting is on the red components. These are the components that are expected to cause a shortage. The red components account for 26.6%, which is more than a quarter of all components. The bar chart on the right shows the inventory coverage of the components in production lines Z1 and Z2. The yellow and red labels are the same as for the pie chart. Only the green label is now split up into green and blue. The blue label represents components for which the current inventory covers five or more times the requirements for next month. This indicates low uncertainty but also high inventory levels. Most of the components are green and only a small part of it is shifted to blue. This means most of the inventory can cover the requirements between one and five times.

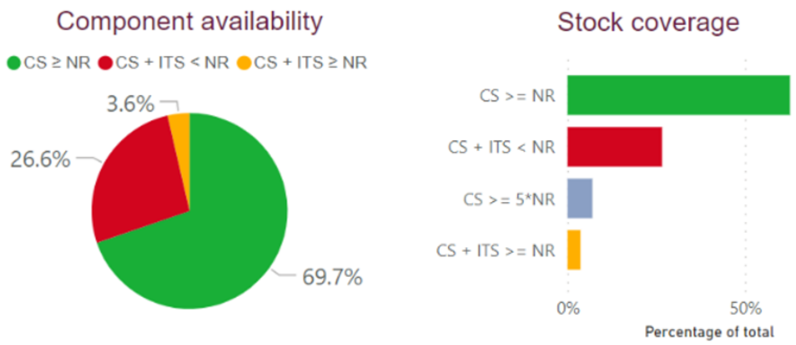

Figure 4.4: Visuals of the component availability dashboard for Z1-Z2

The previous results show the numbers for production lines Z1 and Z2 combined. However, it provides more insights to evaluate the results of the production lines individually. The 'Component availability' chart is shown for both production lines in figure 4.5. The chart on the left-hand side represents Z1 and the graph on the right-hand side represents Z2. The second line has a greater share of green labelled components, compared to the first line. This could be explained based on the type of materials that are produced on these production lines. The main difference between the materials in Z1 and Z2 is that Z2 contains the production of a NPI (new product introduction) material, while Z1 does not. NPI is Hilti's new product launch that is monitored closely and is of great importance to Hilti. The NPI materials are an improvement to the current materials but are similar to them. Because of the newness, production is closely monitored. For NPI, there is little to no historical data available to determine demand forecasts. Therefore, more inventories are kept to ensure enough production capacity. Production line Z1 does not include NPI materials. It can be seen that Production line Z1 has a share of 31.8% of red components and production line Z2 has a share of 22.1% of red components. As discussed, a distinction between the components can be made based on the available filters. The filter on production line is already applied here. Next, the filter on the SPT label provides more insight into the results.

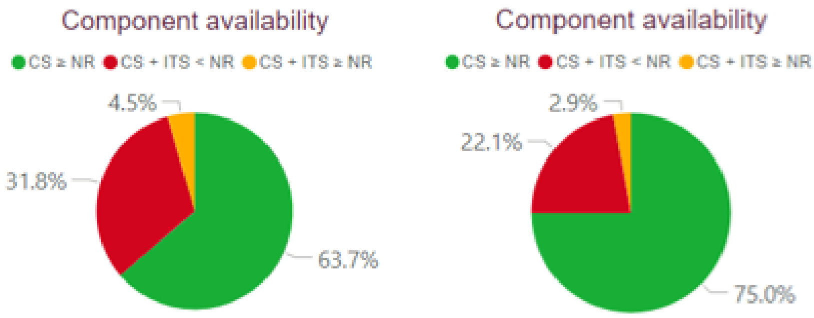

Figure 4.5: Visual component availability for Z1 and Z2

Table 4.6 shows the shares categorized per SPT label in the total shortage of the components. The first column covers the different SPT labels: A, B, C, D, E and F. These include external production, in-house production and production at other Hilti plants. Which other Hilti plants aree specified in the column. In the table, there is made a division between "Unique" and "Count". The first represents the number of unique component types missing, indicating that these each have a unique component name and number. The second represents the number of components missing, despite the component name and number. The difference is illustrated by the following example: imagine that there are missing components for component numbers I, II and III. Component I is missing 30 items, component II is missing 20 items and component III is missing 10 items. The shortage in unique components would be three, as three unique component numbers are missing. The shortage count is the sum of all the missing components: 60 items. It is interesting to include this division in the analysis to see if the missing components are due to only a few components or many of them. An example is found in the shortages in production line Z2. The table shows that external production accounts for 83,893 missing components, while in-house production accounts for 37,902. When looking only at these numbers, it would be expected that about two times the number of unique components is responsible for the missing components of external compared to in-house production. The column 'Unique' shows that this is not true and that the shortage for external components is spread over 239 unique component numbers, while the shortages for in-house are only spread over 9 unique components. The table is further evaluated in this section based on the distinction between external sourcing, in-house production and production at other Hilti plants. The percentages in the table are based on the counted column.

	Production line Z1			Production line Z2		
	Unique (#)	Count (#)	Percentage	Unique (#)	Count (#)	Percentage
A (External)	24	72,217	49%	239	83,893	50%
B (In-house)	7	22,882	15%	9	37,902	23%
C (Plant 16)	4	8,607	6%	9	11,517	7%
D (Plant 92)	14	44,711	30%	13	30,841	18%
E (Plant 44)	0	0	0%	1	2,873	2%
F (Plant 8)	0	0	0%	0	0	0%
Total	49	148,417	100%	271	167,026	100%

Table 4.6: Shortage division for production lines Z1 and Z2

External sourcing
For both production lines Z1 and Z2, about half of the shortages are due to external production. This means plant XZ expects around 50% of the components that should arrive from external production are expected not to arrive in time to satisfy next month's requirements. At his point, lead times are checked: for some items there may be short lead times for which orders are not placed yet and there is no in-transit stock. The lead times of these suppliers lie between 1 and 14 days with some exceptions of more than 40 days. This means that the biggest part of the components can be ordered at the moment of the pre-S&OP and arrive in time to cover next month's requirements. However, it is important to monitor this and check the orders after the pre-S&OP meeting. The components with lead times higher than 40 days should have been ordered further in advance. For these components, the suppliers can be contacted to find out if there are any possibilities for expedited delivery. Another option is to contact other Hilti plants to check if the component is in inventory there, and can be shipped to XZ. The table filter allows the user to filter the lead times from high to low and identify critical components.

To get a better understanding of the different scenarios with external production, figure 4.6 shows the table of the component availability dashboard for three items that are produced at an external supplier.

- The first component, AT4739, is used in two material types and has a shortage of 182 pieces. There is no in-transit stock because the shortages including and excluding in-transit are the same. The current stock covers 38.9% of next month's requirements, which means more than 60% is missing. To react to this, the information on the right-hand side of the table can help. The supplier is SUPPLIER B, who has a lead time of 10 days for the delivery of its components. This means components can be ordered after the pre-S&OP and still arrive in time to satisfy next month's requirements. The PA score is 0.69 which means that there is a 69% chance that the component will be delivered on time and in the right quantity by this supplier. This helps to define the reliability of the supplier, which can be useful in the decision to for example only order extra or also contact the supplier to make sure the order arrives in time.

- The second component, GF2739, has a shortage of 1010 pieces when in-transit is considered. However, when in-transit is not considered there is a shortage of 1330 pieces. This means the coverage by the current stock is only 50.5%. The supplier and its reliability are the same as for the previous component.

- Finally, the third component, ER2937, has a shortage of 0 and a coverage percentage of 141.1%. This means that the total requirements of next month can almost be satisfied one and a half times by the current stock. No extra orders have to be placed at this point.

KPILight	Production Line	Component number	Component description	Total requirements (PC)	Tool numbers	Tool names	Tool shortage (incl. transit) (PC)	Tool shortage (excl. transit) (PC)	Coverage by current stock (%)	Vendor	Lead time (days)	PA (score)	Special procurement
●	Z2	AT4739	*	298	TOOL A, TOOL B	*	182	182	38.9	SUPPLIER A	10.0	0.09	A
●	Z2	GF2739	*	2686	TOOL A, TOOL B , TOOL C, TOOL D, TOOL E, TOOL F, TOOL G, TOOL H, TOOL I, TOOL J,	*	1010	1330	50.5	SUPPLIER B	10.0	0.69	A
●	Z2	ER2937	*	3511	TOOL A, TOOL B	*	0	0	141.1	SUPPLIER C	25.0	No info available	A

Figure 4.6: Table of the component availability dashboard

In-house production
The in-house production accounts for 15% of the shortages in production line Z1 and 23% for production line Z2. When taking a closer look at the figures for in-house production for the production lines combined, it can be seen that there are only red and green components, and no yellow ones. The figure is displayed in figure 4.7. The reason that there are no yellow labelled components is that the in-transit stock is zero for all in-house production. During the analysis, it is made sure that only in-transit stock that is already shipped and is expected to arrive in time is considered in the model. For in-house production, there are no in-transit stocks that meet this requirement. Therefore, no in-transit stocks are considered for in-house production. In reality, in-house production labels in-transit stock as production orders (POs) and assigns a finish date to them. However, this finish date is assigned by SAP and not confirmed by the in-house employees. Therefore, this label cannot be considered in-transit stock in the model. For full transparency, a type of in-transit inventory stock should be identified for in-house production. This is discussed in the limitations and recommendations section.

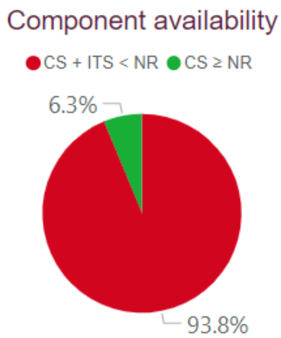

Figure 4.7: Visual of the component availability dashboard - SPT B

Other Hilti plants
The other Hilti plants include plant 16, plant 92, plant 44 and plant 8. Table 4.6 shows that plant 8 does not cause any shortages in components. This plant only supplies two component types that are each currently available. Plant 44 only has a shortage in production line Z2. This is one component type that is missing 2873 components. The other two plants, plants 16 and 92, have a higher share of missing components. Especially plant 92 has a high percentage. The reason for this is discussed in the evaluation of the case study in the next section.

4.2.2 Validation case study

The findings of the scalability test are discussed with in-house and external materials managers. This discussion took place on the 5^{th} of September, which is the month after the execution of the case study. It should be noted that the information on shortages found during the case study is not used to take any action. Therefore, it is of good use to compare the situation in which there was no reaction to the material but just regular ways of working. The component availability of four components was discussed during the evaluation. The information is provided in the table below. All these components have a red label which means that the total requirements of next month are expected not to be covered by the current stock and the in-transit stock. This is compared to the situation in reality. When the case study run took place, no action was taken based on the outcome of the dashboard. The reason for this is that expected shortages can in this case be compared to the actual shortages. If action would have been taken, the validity of the dashboard would have been difficult to measure.

Component	Used for materials (Nr)	Total requirements (PC)	Current stock (PC)	In-transit stock (PC)	Safety stock (PC)	SPT
AA1287	37	11,483	3,249	640	9,396	C
BA3286	16	6,258	1,985	0	1,358	C
AB1668	10	4,047	1,904	0	1,313	B
CA3341	13	4,251	3,066	0	1,367	B

Table 4.7: Given data for red labelled scalability test

Component	Material shortage incl transit (PC)	Material shortage excl. transit (PC)	Coverage (%)
AA1287	7,594	8,234	28,3
BA3286	4,273	4,273	31,7
AB1668	2,143	2,143	47
CA3341	1,185	1,185	72,1

Table 4.8: Calculated data for red labelled scalability test

- **AA1287:** Table 4.7 shows that the component has a current stock of 3,249 pieces and an in-transit stock of 640 pieces. The total requirements are equal to 11,483 pieces. When considering only the current stock, there is a shortage of 8,234 pieces. When considering also the in-transit stock the shortage decreases to 7,594 pieces. This is however not enough as there is still a shortage. The special procurement type is D which is Hilti production plant 92. The expectation is that an additional order is placed at this plant to get the components in time still to satisfy next month's demand. Reality shows that indeed an extra order was placed for which a delivery of 10,000 pieces arrived at the start of the next month. This information is provided by the materials managers. They explain that plant 92 receives a demand preview in advance, which is based on the forecasts. This means plant 92 can ship their components in time to be able to satisfy the demand in the demand preview. There is only a short lead time, so the components were not yet shipped during the S&OP meeting but were shipped later. The numbers that rolled out of the dashboard are correct based on the data gathered in preparation for the pre-S&OP meetings. However, the to-be-shipped orders based on the demand preview were not included. Therefore, a red label was assigned while this was not necessary. Despite this, it shows the dependency and the importance of the demand preview for plant XZ: the dashboard enables the user to check if the expected orders were indeed placed. A recommendation would be to include the demand preview in the dashboard. The components that are part of this preview are expected to arrive according to the planned demand. However, this expectation is not as certain as the current stock of the current model. Therefore, the expected components should not be included in the green label. The recommendation would be to include them on the yellow label, indicating that the components are expected but there is no guarantee.

- **BA3286:** This component has total requirements of 6,258 pieces. The table shows that this component only has a current stock and no in-transit stock. The current stock of 1,985 cannot cover the total requirements and therefore a shortage is expected. The SPT of this component is C, which indicates production plant 16. This plant does not receive a demand preview from plant XZ as plant 92 did. Therefore, it is not expected that they will send a shipment based on the forecasts. However, the materials managers told that after the pre-S&OP meetings three deliveries of 360 pieces arrived at plant XZ. These were not yet shipped when the data was derived. This is the reason that they were not included in the in-transit stock. Together with the current stock, the components add up to a total of 3,065 pieces as available components in reality. This is not enough to cover the total requirements of 6,258 pieces. In case of an expected shortage, the advice is to contact the supplier, in this case plant 16 and ask them for the possibilities in extra supply. The materials managers confirmed that they contacted plant 16 after the evaluation meeting and placed an extra order. This order is still in time due to a short lead time.

- **AB1668:** This component is different from the previous two as it has SPT label B, which means the component is produced in-house. In-house production has no in-transit stock, only released production orders. These production orders do not have an expected finish date that can be considered in the model and are therefore not included. The current stock is equal to 1,904 pieces while the total requirements are equal to 4,047 pieces. The current stock only covers 47% of the total requirements, as can be seen in the column 'Coverage'. This means a shortage is expected. The materials managers confirm the numbers and explain that the remaining components were already in production. These were not visible as current stock but only as released production orders. The recommendation would be to investigate the production orders and include them as a type of in-transit inventory in the dashboard. This is further discussed in the Company recommendations.

- **CA3341:** The final component is similar to the previous in-house component with SPT label B. It can be seen that there is indeed no in-transit stock but only current stock. The current stock is not enough to cover next month's total requirements. However, the coverage is 72,1% which is higher than for the previous component. It is confirmed by the materials managers that the data is right but that there were also planned production orders in-house for this component. Therefore, no shortage was experienced in reality.

A remarkable finding of the case study is that 30% of the shortages are due to missing components of plant 92. This is confirmed by the plant as plant 9 has been having trouble with its raw materials. A shortage in their raw materials led to a slowdown in production which means that fewer components were available to be shipped to plant XZ.

It can be concluded that the dashboard and underlying calculations using Python and Power Query are right. The current model makes it possible to identify components that are certain to be available, having a green or yellow label. These can be left out of further analysis during S&OP. The goal of S&OP is to identify possible shortages in materials, due to a gap between capacity and demand. Before the introduction of this dashboard, there was no insight into this. The dashboard identifies possible shortages and enables further investigation of the components. Each of these components can be evaluated to see if any aspects were not covered during the analysis in the dashboard. For example, the demand preview and the in-transit stock of the in-house production are not covered in the current model. Including these would improve the accuracy of the dashboard and provide even more insights. This is further discussed in the Limitations and Company recommendations. The benefits of proactively acting on the component shortages is twofold. On the one hand, shortages can be overcome such that there is no shortage of materials and customer orders can be satisfied in time. This saves time and money. On the other hand, possibilities for pre-production or scale-up can be identified earlier than in the current situation. In the current situation, the knowledge on any leftover components is only gained after production took place. The dashboard enables the users to identify leftover components before production starts. This means pre-production or scale-up can take place earlier. This is beneficial for profits.

4.3 Scalability test

Due to the growing competitive markets, the need for scalable applications increases. It is of growing importance that applications can be scaled over different processes within and outside of a company. This benefits the efficiency of the company's processes. Therefore, the dashboard is implemented in eight additional production lines in plant XZ. To test scalability, Zamboni et al. (2019) identify six stages of scaling: preparatory stage, initial planning, stakeholder workshop, follow up and scale-up. The meaning and the applicability of the current dashboard are evaluated in this section.

Figure 4.8: The six stages of scaling by Zamboni et al. (2019)

Preparatory stage During the preparatory stage, the identification of dimensions that can be scaled takes place. For the current dashboard, the dimensions that can be scaled are the production lines and the periods. In the case study, there are only two production lines and one period. In the scalability test for plant XZ, there are eight production lines and one period. This can be scaled to higher numbers, depending on the production line and plant it is applied to.

Initial planning The initial planning stage focuses on identifying stakeholders. In the current project, the initial stakeholders are the materials managers and central planners of plant XZ. In addition, the other attendants of the pre-S&OP meeting should be able to understand the outcomes of the dashboard as well to be able to participate in a discussion about the results. However, the central planners and materials managers are the people that work with the dashboard. When scaling the dashboard, the stakeholders shift towards a more managerial level. Management needs to understand the dashboard to be able to confirm if it can be scaled over other plants. Next, employees from other plants need to be assigned to further implement the dashboard in their plant. The manager that decides for the current dashboard is the Head of Global Logistics.

Stakeholder workshop All stakeholders come together during the stakeholder workshop. The goal is to give a demonstration of the dashboard and ensure understanding among the different stakeholders. For the current project, the stakeholder workshop is twofold. The first part takes place during the final presentation of the current project. Here, management is first introduced to the dashboard as a pilot. The results are discussed and management discusses the importance of the dashboard with the stakeholders of the plant. The other part is a guide that is created for the usage of the dashboard. This guide is a set of slides that describes all the steps required to update the dashboard with the desired data.

Follow up The follow-up stage aims to refine the pilot. This means feedback from the stakeholder workshop is used to make the required adjustments to the dashboard. In the current project, adjustments to the dashboard are made based on the case study, the scalability test and the stakeholder workshop. The follow-up marks the end of the current project as the responsibilities are at that point carried over to the stakeholders. Still some adjustments can be made to the dashboard after the project is carried over.

Scale up The scale-up stage includes the scaling of the dashboard. For the current model, this implies scaling the dashboard first over multiple production lines in plant XZ. This is followed by scaling over multiple production plants.

The data is gathered the day before the pre-S&OP meeting such that it is up to date and can be used as input for this meeting. For July, the pre-S&OP took place at the 20^{th}, which means the data was derived on July 19. This data is combined and displayed in the dashboard in Power BI. This dashboard consists of a table, two visuals and multiple filters. For the production line filter there are now only two options: Z1 and Z2. The results of the case study are shown and explained in the next subsection. These results are validated during a meeting with two materials managers who participate in each pre-S&OP meeting. One of them is responsible for the materials for in-house production and the other is concerned with external supply. Both are involved with all the production lines in plant XZ. With their knowledge, the results of the case study on production lines Z1 and Z2 are evaluated.

As part of this process, the dashboard is run for eight additional production lines that are part of Plant XZ. This can be marked as the scale but it still using the pilot version. Therefore, it is seen as part of the follow-up stage. The names of the production lines are: X1, X2, Y1, Y3, Y4, Y5, Y6 and Y7. There is a similarity between the production lines in scope and the additional production lines tested as they are both part of Plant XZ and BU PT&A. However, the number of materials and components is different and the links between them are different as well. Also, the length of the inventory, requirements and supplier data is different. The test took place on the 21^{st} of September, which is one day before the pre-S&OP meeting. During this meeting, at least the next four months are discussed. However, this test only includes the data in October. Before starting the scalability test, all data is gathered:

- BoM: The BoM is derived for all the materials that are produced on the eight production lines included in the scalability test. The BoM structure consists of a maximum of three layers, which is the same number as for the case study.

- Net requirements: The net requirements are derived from the Blue Yonder data sheet that is created during the PE run in September. This includes the net requirements of October for all the materials produced on the production lines included.

- Levelled requirements: The levelled requirements are derived from SAP by the query in Appendix A.1. The input for this query contains all the materials as well and the date is set from the date of the derivation to the end of September. In this way, all the levelled requirements for the remaining of September are included.

- Current inventory: The current inventory is derived from SAP by the applicable query in Appendix A.1. The input for the query includes all the components that are used to produce all the materials of the production lines included. These components are found in the BoM. The date is set to the date of derivation.

- In-transit inventory: The in-transit inventory is derived from SAP as well by the applicable query described in Appendix A.1. The input for this query is equal to all the components that are found in the BoM. The date is set to the date of derivation.

This data is combined by using Python and the results on the material availability are displayed in the Power BI dashboard. It contains a table with, two visuals and multiple filtering options. The results are discussed in the next subsection.

4.3.1 Results scalability test

The results of the scalability test are displayed in the visuals in figure C.2 in Appendix C. Three of these production lines are evaluated individually: Y3, Y6 and X2. The component availability visual of these production lines is displayed in figure 4.9. It can be seen that the components cover between 85.2% and 93.8% of the total requirements for these production lines. A problem is identified only for 5% to 13.3% of the components. Comparing this to figures from production lines Z1 and Z2 in figure 4.4, there is a significant difference in green and red labelled components. The reason for this difference can be found in the stock coverage figures of these production lines.

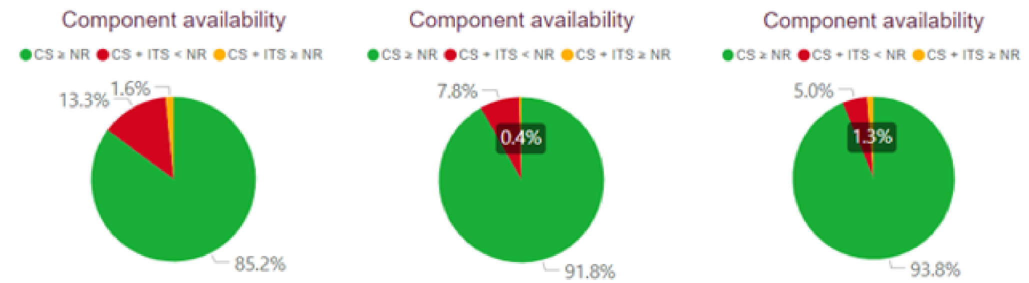

Figure 4.9: Component availability visual for Y3, Y6 and X2

The stock coverage figures are displayed in figure 4.10. It is expected that high inventories are kept for the eight production lines, resulting in high availability. This is confirmed as the blue label bar accounts for almost 50% of all components in scope. This means that for almost half of the components a current stock level is maintained that could satisfy the demand five times or more.

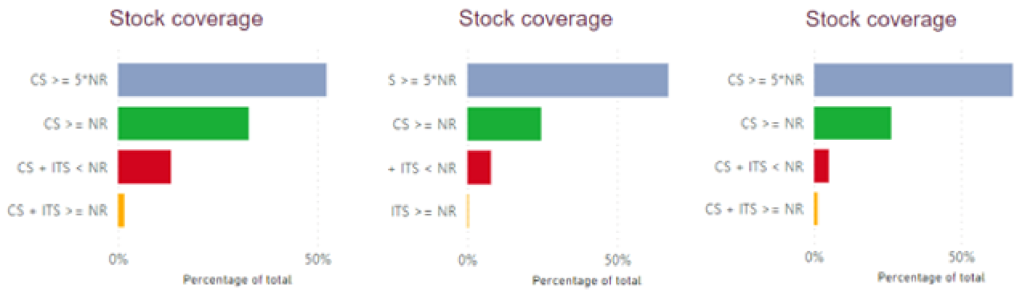

Figure 4.10: Stock coverage visual for Y3, Y6 and X2

4.3.2 Validation results scalability test

The results in section 4.3.1 show that for each production line more than 50% of all components have enough stock to cover over five times the total requirements for next month. The combination of the blue and green bars account for the biggest part of the components. This implies that these production lines keep high inventories in the production lines, leading to certainty in the production.

The findings of the scalability test are discussed with the materials managers working for plant XZ. The blue bars are bigger for the scalability test than for the case study in figure 4.4. For some high inventory components, there is an explanation. The reason for these high inventory levels can lie in the risk assessment of its suppliers. Hilti's department of risk management evaluates the risk of each supplier and assigns them a Business Interpretation (BI) risk. This assessment includes the advised level of safety stock for the plant. If there is a high risk for a certain supplier, the safety stock level is advised to be higher as the safety stock is part of the current inventory. This explains part of the components that have a blue label.

Based on the findings from the case study and the scalability test, two possible strategies for inventory management arise. The first is found for the case study and includes lower stock levels and more uncertainty on the coverage of the requirements. The second is found for the three production lines in the scalability test and includes higher stock levels and less uncertainty on the coverage of the requirements. Ideally, a balance should be found between inventory levels such that there are no unnecessarily high inventories and that requirements are certain to be covered. Finding this balance is part of the recommendations in chapter 6.

Chapter 5

Business implementation

The Power BI dashboard provides transparency in component availability. This increases the quality of decision making in S&OP. This chapter answers sub-question 6 "*How can the model be translated to business values?*" by describing how the dashboard can be implemented in the business environment and how it can be further scaled to other production lines and plants.

5.1 Model implementation

The dashboard provides insight into component availability by combining data from multiple sources. These insights are used to compare the required components to the available components. The goal is to identify possible shortages. The dashboard is applicable at two moments in the Operations Planning phase of S&OP, as illustrated in figure 5.1. The first moment is between the capacity preview and the pre-S&OP meeting. The pre-S&OP meeting takes place around the 20^{th} of the month, considering the demand for the next months. The output of the capacity preview, which is the input of the pre-S&OP, is a datasheet that includes the net requirements per material expressed in production hours and pieces. These can be compared to the available capacities in terms of man power and machinery. The dashboard extends the current situation by providing the component availability, such that the net requirements can be compared to the available man power, machinery and components in the new situation.

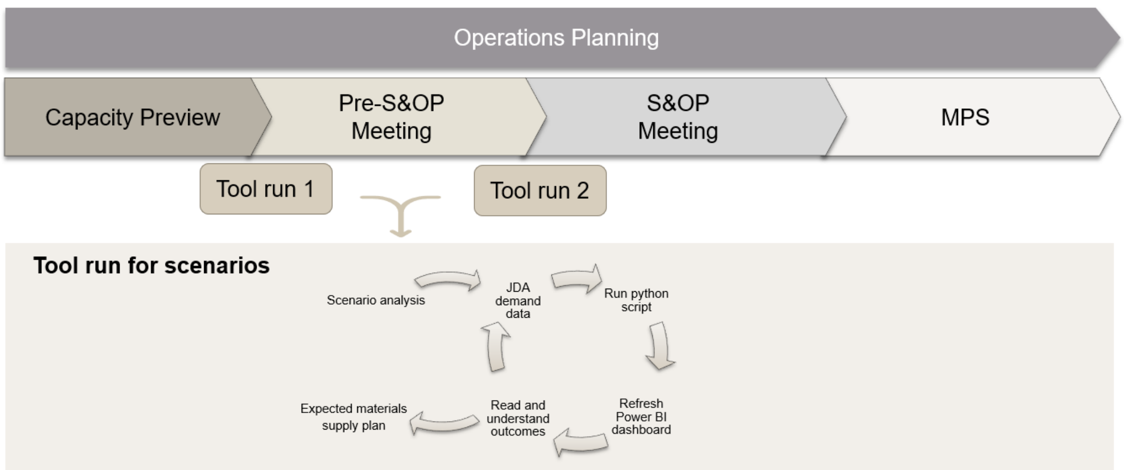

Figure 5.1: Dashboard application in Operations Planning

To prepare for tool run 1, all required data is gathered by using the queries in Appendix A.1. The next step is running the Python script, which results in a dataframe including all required data. The dataframe is exported to Excel. After this, the dashboard in Power BI retrieves the Excel data and is run manually by clicking on the refresh button in the Home tab. It provides the output as the component availability dashboard. How to read and understand this dashboard is explained in section 4.1.

The dashboard provides support in decision making for S&OP. As explained in section 4.1.3, multiple filtering options are available. Filtering on SPT makes it possible to divide the data into three different types of sourcing of the components: externally sourced components, components produced at another Hilti plant and in-house produced components.

For externally sourced components, the supplier name, supplier number, lead time and PA score are provided in the dashboard. This enables the stakeholders to easily capture where the components come from and identify the problem based on this knowledge. If the lead time is such that ordering after the pre-S&OP meeting will have components arriving on time, there may not be a problem. It can be checked if there are planned orders that cover this. If the lead time is high, the supplier can be contacted to find out if there are any possibilities for a shorter lead time. The same goes for external Hilti plants. The plant can be recognized by the SPT label provided in the table. Based on the shortage and background knowledge within the pre-S&OP a plan can be made.

For in-house production only current inventories are considered. If the current inventories do not cover the requirements for next month, the production can be checked. Some components may be in production and will be finished in time. For in-house products, the problem can be located a layer deeper. Therefore, the filters on component number and component layers can be used.

The blue label highlights components that have a current stock level that covers five times or more the requirements for next month. During S&OP, there is no time to anticipate the blue label but when it is noted, action can be taken after the meeting. If the inventories can cover the next five months, no extra ordering is required. Future planned orders can be checked and reconsidered. Moreover, high inventories lead to inventory costs as well and costs are desired to be minimized.

The second tool run takes place after the pre-S&OP meeting and before the S&OP meeting. This tool run aims to enable scenario analysis. This means it can be run multiple times at this point in the process, based on different values that are adjusted. The application is illustrated by the following example: it is the pre-S&OP meeting in April, looking at the data for the next four months. Summer is coming up and part of the employees is going on holiday in June. During the comparison between the demand and the capacities, it seems that there is access machinery and man power availability in May. Looking at the dashboard it is found that the components involved in this dashboard are also labelled green. This means it is expected that enough components are available to cover the demand and that there may be room for pre-production in May. The coverage percentage column shows how many times the current stock can cover the demand of next month. However, it could be convenient to be able to test different increases in production and see what the effect is on the component availability. The net requirements can be adjusted manually in the Blue Yonder data first. This is shown in the loop in figure 5.1. After adjusting the data, the Python file is run again. This output is used for the dashboard. The dashboard is run again in Power BI as well which results in new information on the adjusted data. The increased requirements of the dashboard are translated to component requirements as well. If all the components are still green, this confirms that the increase in production is possible on the material side and helps in the decision to what extent pre-production can be planned. The ongoing circle in figure 5.1 illustrates that the dashboard can be run multiple times. Multiple scenarios can be tested based on changes in the Blue Yonder demand data. The dashboard can be run until the outcome is satisfactory.

The implementation as described gives an answer to the main research question "*How can a tool be designed that provides the material availability to support S&OP decision making within Hilti?*". The dashboard provides insight into the component availability and provides the opportunity to react to the finding and do multiple scenario analyses to anticipate possible future scenarios. The current model supports scenario analysis for one period. However, it is built in a generic way such that it can be applied to a longer time horizon as well. This is discussed as scalability in section 5.3.

5.2 Decision support

The scenario analysis is the core of decision making support in S&OP. Testing multiple scenarios helps to define production planning. The initial goal of S&OP is illustrated by the gap between the total requirements and the available capacity. If the demand is higher than the availability of the materials, there is an expected shortage of materials. The decision to be made during the S&OP meeting is how to react to this. The production could be slowed down such that fewer materials are produced. However, there may be an option to order extra components. If the lead time is such that the components arrive in time for production, an extra order can be placed. Otherwise, the supplier can be contacted to see if there are any possibilities for an earlier arrival. The table supports this process by providing the supplier name, the average lead time and the PA score per component. The PA score is based on historical data and represents the reliability of the supplier. This number is between 0 and 1. It can help to get insight into the probability that the supplier will supply in time if an order is placed after the pre-S&OP meeting. When there is no possibility of getting the remaining components in time, a decision has to be made on how to divide the available components over the production. This is currently based on estimations to equally spread the components over different markets. This scenario could be further optimized and is part of the Company recommendations.

If the demand is lower than the capacity of materials, there are excess materials. This means that there is room for extra production. If a busy period is coming up with many orders the team can decide to do pre-production. However, the machine and man power capacities should be checked to see if there is excess capacity too on these aspects. In the current project, the capacity of materials and man power are not considered. The scenario analysis could be run to see what the effect of the excess components is on the materials. One component can be used for multiple materials so there are options to use these components for one or more of the materials. The dashboard provides the option to filter on material as well. By filtering on material, the dashboard displays all the materials required for the production of the materials and shows what their availabilities are. In that way, it can be seen if all the components required have excess capacity. If there is only one component with excess capacity it may not be of use to increase the production of this material.

If the decision is made to use the excess capacity and increase production, the question is to which materials the available capacity is assigned. Hilti works according to the 'Fair share logic' which means they aim to spread order satisfaction over the markets. This means that they prefer to serve each market for 50% rather than 100% and 0%. The proposed models in the Literature Review focus on profit or sales. Hilti's priority does not lie with the sales or profits but with the explained logic. There are for example 100 extra components that can be used to produce either 100 times materials for region A, 100 times materials for region B or another division. According to the logic, each material would get 50 components assigned such that there is an equal spread in markets. However, in more complicated situations, for example when there are more materials included that each have a different demand and require different amounts of pieces of a component, this decision might get difficult. The decision making in S&OP is on tactical level so calculating the best division manually is too detailed and is computationally expensive. Therefore, it is proposed to use a model that calculates the optimal division, based on the Fair Share Logic. This model is not developed within the current project but is included as a suggestion for future research.

5.3 Scalability

The dashboard created during the current project is a prototype that can be adjusted to be used in other production lines and plants that are not in scope of the current project. The condition is that the same type of input files have to be used that result from the queries in Appendix A.1. The core file of the data structure is the BoM. As explained in the Scope, the materials and components in the scope of the current project cover three layers: the materials and two component layers. However, in other production lines there can be more than three layers. To cover this, the possibility to include multiple product layers in the dashboard is included. It is related to the multi-layer BoM structure of the materials and components. Each material consists of multiple components. For in-house production there is additional information available: the 'sub-components' that are used to produce this component. The BoM shows which sub-components are used and the dashboard enables the user to filter on this sub-component. By using the filter on components, the availability of the sub-components can be found as well. The dashboard recognizes the different layers and imports all the relations and their information on demand and capacity into the dashboard. If there are more materials than in the scope there may be more components as well. The demand, inventory and supplier information can still be derived and imported in the same way, despite the length of the files. A similar approach is used for scaling in the periods. In that way, it is possible to combine multiple months or create the dashboard for a specific month in the future.

The output of the queries can have a different order of columns, depending on the setting of the person that runs them. This does not influence the dashboard, as the dashboard looks at the column names. However, some employees run their queries in German, instead of English. In that case, the column names are not recognized. A choice had to be made between referring to the column name or column number while writing the code. As it is more common that people derive the data in another column sequence than that they do in the same sequence but then in German, the choice to focus on the column names is made. The code gets information from in total 9 columns with an English label. To cover also the German language, a small translator part is included in the code. It searches for the German term and then replaces it with the English term. This, however, works only for the terms that are required for running the code. The translator is made manually and could be extended with other German - English terms when necessary. The Python code for the translator can be found in Appendix A.3. The translator checks all column names for predefined German terms. An example is the German column name 'Komponente'. The translator code recognizes 'Komponente' as a word that has to be replaced by the word 'Component'. To achieve this the rename columns function is used. For this example the (pseudo-)code is:

If 'Komponente' is equal to one of the column names:
Replace 'Komponente' with 'Component'
Return only a column with the replaced column value

Chapter 6

Discussion and conclusions

6.1 Discussion

In the current project, multiple assumptions are made. The assumptions that have the biggest impact on the results are based on the scoping and are discussed in this section. The scope is defined as two production lines in production plant XZ. Both production lines carry out the production of multiple materials. These materials consist of one or more components. Some of these components are used for many different materials and are assumed to have an unlimited supply. These are for example boxes, labels or instruction manuals. This assumption is realistic as there are high stock levels and no stock out occurred before.

The dashboard designed during the current project finds the component availability of the components in scope. By comparing the availabilities to the demand a possible gap can be identified. This gap indicates that there is a shortage in a certain component and the advice is to order extra. However, while giving this advice no cost or inventory constraints are considered. It is assumed that there is enough money and space assailable to order extra components, when necessary. In reality, however, money and inventory space are limited so these would contribute to the actions taken as well. Despite this, the constraints are agreed to when scoping the project as the focus is on the component availabilities.

Furthermore, the availability of the components is quantified based on the current inventories and the in-transit inventories. There are multiple types of in-transit inventories defined within plant XZ. On the one hand, some orders have been placed but are not yet shipped by the supplier. On the other hand, some orders have already been shipped by the supplier. The in-transit stock in the current project and dashboard only cover the second type: the in-transit stock that is already shipped by the supplier. Due to this, it is realistic to assume that all in-transit stock arrives in time to satisfy next month's requirements.

Each component that is ordered externally has a supplier. However, for some components that are sourced externally no supplier information is available. For these, it is assumed that the supplier is phased out and that there is expected to be enough inventory to cover the rest of the components required. The case study only finds one component for which the external supplier is not available and therefore assumed to be phased out. The data shows that the coverage percentage of this component is 1459%, indicating that the net requirements of next month can be satisfied almost 15 times by the current stock. This confirms that the assumption is realistic.

The designed dashboard labels each component by the colours green, yellow or red. The green colour is assigned when the availability of the components is higher than the requirements. A special case occurs when the requirements for a certain component are equal to zero. These components are left out of the dashboard results as these would all account for a green label and the visual would be further from reality. By only considering the components that have requirements higher than zero, the performance is better measured.

Next to the green, yellow and red labels, there also exists a blue label. This is part of the green but indicates that the current stock cannot only cover the requirements once but even five times or more. This indicates high inventory levels. On the one hand, the high inventory levels result in high certainties for the satisfaction of the requirements. On the other hand, they result in high inventory costs. The reason for these high inventory levels can lie in the risk assessment of its suppliers, which is explained in the case study results in section 4.2.1.

6.2 Company recommendations

Based on the development and results of the current project, multiple recommendations for Hilti are defined. The content in the recommendations helps to further develop the current dashboard.

- **Scale the dashboard** The main recommendation is to scale the dashboard. This starts with the other production lines in XZ and can later be extended to the other production plants. The sectionrefsec:trialrun does a scalability test run for a selection of the production lines in plant XZ and confirms that it is possible to scale the model. The next step is to scale the dashboard over multiple periods. However, before scaling it, some aspects of the dashboard should be evaluated to ensure accuracy.

- **Include planned production orders as part of in-transit inventory** As mentioned in the Discussion and conclusions, only orders that are shipped by the supplier are considered as in-transit inventories in the dashboard. For in-house production, there are no in-transit orders but there are planned POs. These POs represent the planned productions within the plant for a certain component. Currently, these POs cannot be considered as in-transit stock as no end date is correctly assigned to these orders. The employees know the expected finish dates but manual adjustments are not possible due to authorization in SAP. Moreover, this is too time-consuming and the employees lack time to do these manual adjustments. The recommendation is to change the PO end dates based on historical data on the production times. When the in-transit inventories for in-house production and the demand preview for external supply are included, the distinction between the yellow and green labels should be re-evaluated.

- **Include demand previews as part of in-transit inventory** This methodology applies to the components that are sourced externally from other Hilti plants. Components are ordered and shipped to plant XZ. Specifically for supply from other Hilti plants, the in-transit inventories should be adjusted based on the demand preview. Some Hilti plants that supply plant XZ receive an updated demand preview every month for the upcoming twelve months. Based on this preview, orders are planned in advance. With short lead times, these orders are not yet shipped when data is derived for the pre-S&OP meeting. However, there is already a planning that these components to arrive in time.

- **Automate the dashboard** The next recommendation is to automate the current dashboard. Currently, data is derived manually from SAP and Blue Yonder. Both data sources are combined in the Python script which is run afterwards. The output of this Python script is then used in the dashboard which is refreshed in Power BI. The recommendation is to link SAP and Blue Yonder to Python such that the Python code can be run within manual data derivations. The next step is to link Python to Power BI such that when the dashboard in Power BI is refreshed, the Python code runs again as well.

- **Evaluate the blue labelled components** The final recommendation is to investigate the blue labels discussed in the discussions. Blue labels represent high inventory levels. The recommendation is to look into the high inventory levels and check their BI risk label. If the BI risk is not the reason for the high inventory levels, the reason should be tracked down and the high inventories can be evaluated.

6.3 Future research

The current dashboard identifies the possible gap between component availability and its requirements. This shortage is quantified and used to determine if action is required to close the gap. The first step would be to explore the option to order extra components. However, when it is not possible to get them in time to satisfy the requirements, a decision should be made on which orders to satisfy and which not. Future research could include an optimization tool that supports scenarios where there is a gap between the required components and the available components. How these remaining components are divided over the different materials that should be produced, is based on the priority setting. To do this, first the prioritization should be determined by the stakeholders.

The foundation of prioritization is the Fair Share logic. This aims to divide the components equally over the different markets. However, there are also exceptional cases. For example, some customers have a long-lasting and high-quality relationship with Hilti. These are also called VIP customers and can get priority over other customers. Another exception is the NPI platform, which consists of multiple newer versions of materials. At this moment, Hilti's prioritization lies with the development of these materials. In the scenario where there are several components available and they should be divided over a regular material and an NPI material, it could be possible that the preference lies with the NPI material. Another example would be to focus on profit. This is not Hilti's priority but there might be materials with much higher profits than older versions of the material. In that case, maybe the buyer could be convinced to buy another type of material or something else. There are multiple scenarios in which the Fair share logic is not the only leading factor for prioritization. Therefore, the first step is to explore this prioritization and define it quantitatively. It can then be applied to an optimization model.

Chapter 3 describes the complexity of the product structure and shows the Sankey Graph to illustrate this. It is mentioned that there may be redundant links in the network that could cause a bottleneck. A topic for future research could be to quantify the node complexity of all the nodes in the structure and evaluate the nodes with the highest complexity. The method and calculations for this are described in the Literature Review. Based on these values, possible elimination of nodes can be considered to simplify the structure. By doing this, the uncertainty decreases as there are fewer links between nodes.

6.4 Conclusions

Answers to the sub-questions are found to create the dashboard and answer the main research question.

Sub-question 1 "*What is the current process in S&OP and what are the decision points?*"

This sub-question is answered by conducting research on the theoretical background of Hilti's S&OP and doing interviews with multiple stakeholders. The description of the current S&OP process and the decision points can be found in the Introduction chapter. It is found that there is a lack of transparency in material availability. This leads to missing information for decision making. The decisions are related to the actions that need to be taken in case of a shortage.

Sub-question 2 "*What data is required for full transparency in S&OP decision making?*"

The data that is required for full transparency in S&OP decision making is related to the material availability in the current project. To define the material availability, information on the capacity and the demand is required. This is elaborated in chapter 3.

Sub-question 3 "*How can the data be combined and visualized as a foundation for S&OP decision making?*"

The data that is defined in sub-question 2 is combined into one data frame using Python programming language. The core of the structure is the BoM which includes the link between materials and the components that are required to produce this material. The BoM is supplemented with information on the demand, inventories and supplier information. To get a better understanding of the structure, a visualization of the BoM is given as a Sankey graph. This is elaborated on in section 3.2. The structure and the visualization conclude part A of the current report.

Sub-question 4 "*What methodologies on decision making support by information systems are found in the literature?*"

The currently available solution methods for decision making are discussed in the Literature Review. The focus of the literature is on the decisions related to the identification of bottlenecks and optimization by using transparency in material availability.

Sub-question 5 "*What variables should be included in the final model?*"

Sets and variables are defined in chapter 4. The sets include the materials and components, the periods as months, and the production lines. The current project only covers one month and two production lines but by including these as sets, the model can be scaled over multiple lines and periods. For the variables, a distinction is made between independent and dependent variables. The dependent variable is the expected amount of production, which is dependent on the availability and the requirements. This variable is used to identify shortages.

Sub-question 6 "*How can the model be translated to business values?*"

The output of the current project is a dashboard that quantifies the component availability of the components in scope. The chapterrefchapter:implementation describes how the dashboard is used for a case study and scalability test in XZ.

The information gathered and combined for the sub-questions are the answer to the main research question stated below. The output is a dashboard that includes a table, visuals and filters which identify the material availability and support in decision making in case of shortages or excess materials.

How can a tool be designed that provides the material availability to support S&OP decision making within Hilti?

6.5 Limitations

The limitations discussed in this section have an influence on the current project but also on the further development of the dashboard. The limitations are related to the Company recommendations.

The first limitation is related to the in-transit inventory for in-house production. As discussed, there are POs instead of in-transit inventories for in-house production. These POs do not have an expected finish date that is not always correct. Therefore, these PO dates could not be considered in the dashboard. This leads to scenarios where the dashboard shows that there will not be enough components available to satisfy the requirements, while in reality POs are outstanding that can cover this demand. The lack of information for in-house production is a limitation. The POs should be included in the dashboard, which is described in the Company recommendations.

The next limitation is also related to data availability and specifically to the authorization. For some parts of SAP there was only limited access. For example, one of the queries could not be derived correctly without the help of employees in the plant, due to authorization. This results in scenarios where there was a waiting time for the data. This is related to Covid, which was a limitation as well. Due to the pandemic, I was not able to visit the office for a longer period and meet people in person. This makes communication harder.

The main recommendation is to scale the model over multiple production lines and plants. The challenge in scaling the model lies in the differences between plants. They can for example derive data in another structure. In that case, the structure should be transformed. If this is not possible, the Python script should be evaluated and adjusted based on the available structure. This can be hard if the structures have many differences and can be experiences as a limitation. It requires work to change the general structure as this is the same for all plants to my knowledge.

6.6 Contributions

The current report fills a gap in the literature that assumes sufficient supply in supply chain management. Literature on decision making methods often assumes stochastic supply with no uncertainty. However, reality shows that today's supply chains deal with multiple unexpected disruptions in supply that have negative consequences for the rest of the supply chain. In the current report, a dashboard is developed that displays the material availability such that it can be used in tactical decision making. With this, the project also contributes to the translation of operational data to data that can be used on a tactical level. This is found as the main challenge for global manufacturers today. By providing insight into the material availability, possible bottlenecks or other points of improvement can be identified. Besides the insight into the material availability in the current situation, multiple scenario analysis can be done with the dashboard. Furthermore, this project supports the building of further doctoral research being performed by de Oliveira (2022). These are the contributions to scientific literature.

The contributions to the business are related to the BoM structure and the transparency in material availability. The output of the first part of the current report is a combination of all the data that is required for decision making on material availability within S&OP. This structure is also visualized using a Sankey Graph, which illustrates the complexity of the product structures. The complexity of the product structure was never visualized within Hilti before. Therefore, this is the first business contribution.

Due to the dashboard designed in the current project, decisions in S&OP can be made not only on machinery and man power but also on materials. Multiple scenario analyses can be done with the designed dashboard as well. This helps answering questions such as "*If I order n extra components, how much of the demand do I cover*?" and "*Is there room for pre-production for a specific material*?". Before the current project, only manual computations led to transparency in material availability. This is computationally expensive and did not happen often. The dashboard designed combines all the operational data to present the availability such that it can be used for tactical decision making in S&OP. The dashboard is the second and main business contribution.

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Appendix A

Appendix A: Data

A.1 SAP queries to derive data

- BoM: P11 → zsq01 → Z_HQ_PP → ZHQ_BOMMulti (BOM mass explosion)
- Inventories: P11 → zsq01 → Z_HQ_MATMAN → MD05
- In transit stock: P04 → Production Planning → RRp4 (Receipts view)
- Net requirements: Blue Yonder data
- Suppliers per material: P11 → zsq01 → Z_HQ_MATMAN → MD13
- Supplier PA: Refresh excel based file in the main folder
- Levelled orders: SAPAPO → RRp1 (Requirements view)

A.2 Calculations

For every item in the structure:

If the net requirements are bigger than zero:
Component requirements = net requirements * production coefficient

If the net requirements are smaller than zero:
Total requirements = sum of the net requirements of its sub-components
Component requirements = Total requirements * production coefficient

If the net requirements are equal to zero:
Print 'Mistake'

A.3 Translator

The translator*:

If 'Komponente' is equal to one of the column names:
Replace 'Komponente' by 'Component'
Return only a column with the replaced column value

If ’Liefrant’ is equal to one of the column names:
Replace ’Liefrant’ by ’Supplier’
Return only a column with the replaced column value

If ’Produktnummer’ is equal to one of the column names:
Replace ’Produktnummer’ by ’Product number’
Return only a column with the replaced column value

If ’Objekt text’ is equal to one of the column names:
Replace ’Object text’ by ’Product description’
Return only a column with the replaced column value

*: There are more words included in the translator than there are described above. These are not included here due to confidentiality.

Appendix B

Appendix B: Assumptions

- Only the in-transit stock that is already shipped by the supplier is assumed to arrive in time for the start of the next month. In-transit stocks with other labels are assumed not be in time and are therefore not considered in the calculations.
- The supply of packaging is assumed to be infinite.
- The supply of instruction manuals is assumed to be infinite.
- There are no inventory restrictions in the plant.
- There are no cost restrictions.
- All suppliers deliver full quantity products (so no broken or missing pieces).
- If no supplier information (lead times, costs) is available in SAP it is assumed that there is sufficient inventory for these components left and P04 will not order at this supplier anymore until the phase-out of the tool.
- If there is no production coefficient available in the BoM data, it is set equal to 1.
- It is assumed that a material can be produced in the same month if all required components are available at the start of the month.

Appendix C

Appendix C: Dashboards

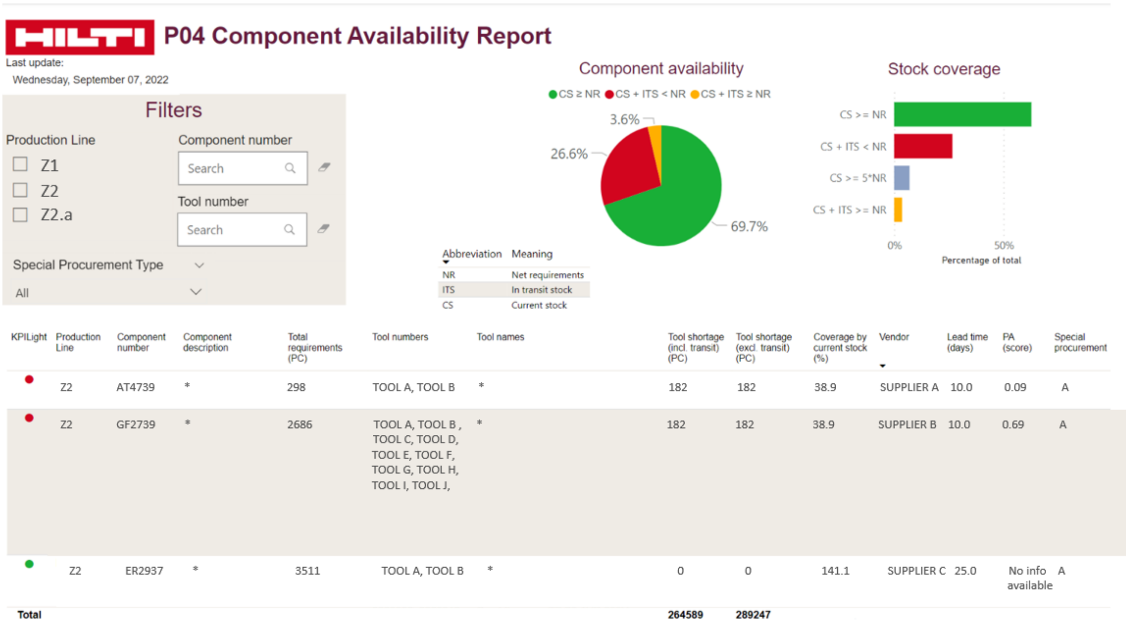

Figure C.1: Component Availability Dashboard

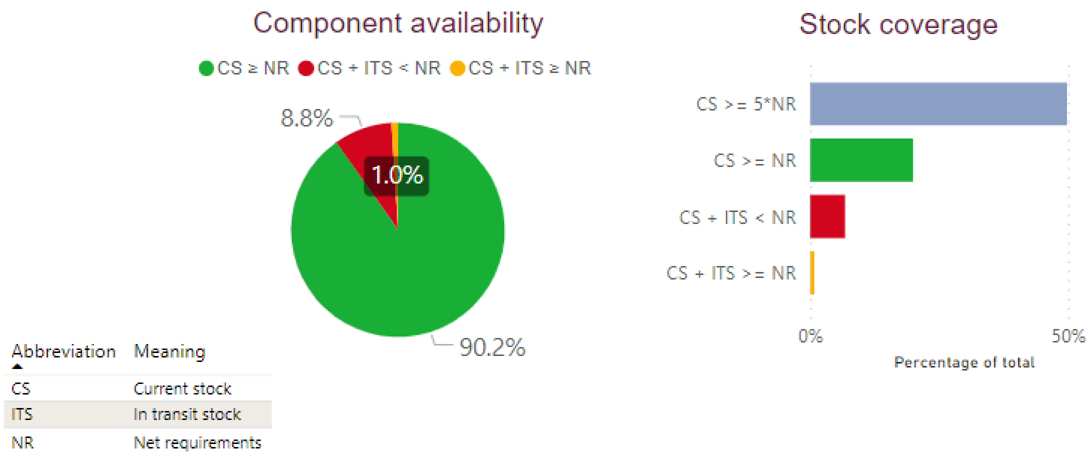

Figure C.2: Visuals of the component availability dashboard for the scalability test