Vaasan yliopisto
UNIVERSITY OF VAASA

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# Design and Implementation of Flow Dashboard for Production Planning and Control

School of Technology and Innovations
Master's thesis in industrial management
Master of Science in Economics and Business Administration

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**UNIVERSITY OF VAASA**
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**ABSTRACT:**

Visual management tools of which some have existed for dozens of years are still an important aspect of increasing the performance of production operations. Visual management tools such as dashboards are a vital part of lean production principles which emphasize concepts such as production flow, minimizing waste and maximizing the customer value. Visual management tools provide the factory with tools to increase the efficiency and output of the whole factory. Visual management tools are increasingly becoming more digital and are able to combine many million rows of data from different data sources into one single dashboard to bring better insights for all stakeholders of the value chain.

The purpose of this thesis was to design and implement a flow dashboard to improve case company's operations and production planning & control function. There was a demand to improve the visibility and increase the transparency in the production operations between the functions in a new factory building. The new factory was still partially in a ramp-up phase thus it was still missing many of the performance and visual management tools.

The thesis utilized design science research methodology which aims to design and develop solutions to real world business problems. At first the problem was studied and requirements to solve the problem were formed based on discussions with the stakeholder groups. Once the requirements were known an iterative development process followed, where a first a prototype dashboard was developed. As the first prototype was ready feedback for further development iteration was requested from the stakeholder groups for total of three development iterations. Once the final version of the dashboard was ready it was demonstrated for the user groups and set on a display at the factory floor.

The first research question related to the requirements of the identified user groups. The requirement concepts emphasized by the user groups were the importance of understanding the production priorities, targets, performance, and production flow metrics. The second research question provided insights on how the dashboard improved production planning and control of the factory. The key benefits included that the current level of work-in-progress and production lead time trends were able to be visualized, providing a useful tool to track and improve the production flow. Third research question focused on how the dashboard improved efficiency of the production operations. The benefits included a new model for visualizing priorities and visualisation of production performance and targets which help the shop floor workers and production management alike.

**KEYWORDS:** visual management, production planning and control, industry 4.0, dashboard, data, lean, theory of constraints

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**TIIVISTELMÄ :**

Visuaalisen johtamisen työkalut joista osa on ollut käytössä jo useita vuosikymmeniä ovat yhä tärkeä osa tuotannon tehokkuuden parantamisessa. Visuaalisen johtamisen työkalut kuten kojelauta-näkymät ovat tärkeä osa lean tuotannon periaatteita jotka painottavat asioita kuten tuotannon virtausta, hukan minimointia ja asiakasarvon maksimointia. Nämä työkalut mahdollistavat tehtaan saavuttavan paremman tehokkuuden ja suuremmat tuotantomäärät koko tehtaan tasolla. Visuaalisen johtamisen työkalut ovat yhä enenevissä määrin muuttumassa digitaalisiksi järjestelmiksi. Niiden avulla voidaan yhdistää miljoonia rivejä tietoa useista eri tietolähteistä, joiden avulla kaikki tieto on mahdollista tiivistää yhteen näkymään auttaen näin saavuttamaan paremman käsityksen koko arvoketjun kaikille toimijoille.

Tämän tutkielman tarkoituksena oli suunnitella ja käyttöönottaa virtaukseen liittyvä kojelauta-näkymä kehittämään tuotannon tehokkuutta ja tuotannonsuunnittelutoimintoa. Työnantajayrityksellä oli tarvetta kehittää tuotannon näkyvyyttä ja parantaa läpinäkyvyyttä eri toimintojen välillä uudessa tehdasrakennuksessa. Uusi tehdas on vielä osittain ylösajovaiheessa joten monia suorituskykyyn ja visuaaliseen johtamiseen liittyviä työkaluja ei ollut vielä käytössä.

Tutkielman suorittamiseen käytettiin suunnittelutieteen tutkimusmenetelmiä, jossa tarkoituksena on suunnitella ja kehittää ratkaisuja yritysten käytännön ongelmiin. Aluksi ongelmaa tutkittiin ja vaatimukset ongelman ratkaisuun muodostettiin yhteisissä keskusteluissa sidosryhmien jäsenten kanssa. Kun eri sidosryhmien vaatimukset olivat tiedossa niin ratkaisun kehitysprosessissa hyödynnettiin iteroivaa toimintaa. Kun ensimmäinen prototyyppi oli valmis niin sidosryhmiltä pyydettiin kehitysehdotuksia muodostaen yhteensä kolme kehitysiteraatiota. Kun viimeinen kehitysversio valmistui ja käyttäjäryhmien tarpeet oltiin tyydytetty niin kojelauta-näyttö esiteltiin sidosryhmille ja asetettiin se näkyville tuotannon tiloihin.

Ensimmäinen tutkimuskysymys liittyi eri sidosryhmien tarpeisiin. Sidosryhmät painotti tarpeissaan tuotannon prioriteettin parempaa ymmärtämistä, tavoitteiden merkitystä, prosessitehokkuuden mittausta ja tuotannon virtaukseen liittyvää mittarointia. Toinen tutkimuskysymys liittyi siihen kuinka kojelauta-näkymä kehitti tehtaan tuotannonsuunnittelutoimintoa. Avainhyötyinä nähtiin näkymä keskeneräisen tuotannon määrästä ja kuinka tuotannon läpimenoaika on kehittyny yli ajan, tarjoten näin erinomaisen työkalun tuotannon virtauksen parantamiseksi. Viimeinen tutkimuskysymys keskittyi siihen kuinka kojelauta-näkymä auttoi kehittämään tuotannon toimintoja. Hyötyinä nähtiin uusi ratkaisu tuotannon prioriteettien näyttämiseen ja tuotannon etenemän visualisointi suhteessa tavoitteisiin, joka hyödyttää työntekijöitä ja tuotannon johtoa.

**AVAINSANAT:** visuaalinen johtaminen, tuotannonsuunnittelu- ja ohjaus, teollisuus 4.0, kojelauta-näkymä, data, lean, pullonkaulateoria

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## Abbreviations

| | |
|---|---|
| API | Application Programming Interface |
| BI | Business Intelligence |
| DAX | Data Analysis Expression |
| EDW | Enterprise Data Warehouse |
| ERP | Enterprise Resource Planning |
| KPI | Key Performance Indicator |
| MES | Manufacturing Execution System |
| MRP | Material Requirements Planning |
| PDCA | plan-do-check-act |
| PPC | Production Planning and Control |
| SAP | System Application and Product in Processing |
| WBS | Work Breakdown Structure |
| WIP | Work-in-progress |

# 1 Introduction

According to Hopp & Spearman (2011) It is in the targets of all manufacturing managers to constantly strive for on-time delivery, minimal work-in-process, short customer lead times, and maximizing the resource utilization. These, however, are conflicting goals since with low resource utilization it is easy to finish jobs on time and by having large inventories on hand customer lead times can be non-existent. The goal of production planning and scheduling is to find a balance among these conflicting objectives and by doing so profitably.

A decision looking good at this moment may turn out later to be disastrous. This is also true in production planning and scheduling as the decisions to be made regularly depend on the future. Planners do not have a crystal ball which to use to predict the future, so they must use the current available information to base their decisions on and predict what will be successful in the future. This is due to all production systems having a certain level of variability and randomness baked into them, which can have large impact on the performance of the production system (Hopp & Spearman, 2011).

The above acts as the guiding principle through this thesis. The objective of this research is to increase efficiency of production operations by increasing visibility in the form of a Production Planning and Scheduling flow dashboard.

## 1.1 Background

The study focuses on case company’s Vaasa production facility (Wärtsilä Sustainable Technology Hub). More specifically it is related to the automated assembly line of cylinder heads. In this thesis, an automated production flow dashboard and visual management system will be designed and implemented to develop the company’s operations and production planning and control function.

Although the assembly line of the cylinder heads is referred as an automatic assembly line, it is semi-automatic. It has four manual assembly stations which are utilized for assembly tasks which are challenging to automate such as wirings. The rest of the process is automated, and the line includes a logistical robot in the middle which moves the parts between each station. The assembly line has an almost real time connection with SAP ERP to where confirmation after each assembly activity step is confirmed.

## 1.2 Case company

Wärtsilä is a global leader in smart technologies and complete lifecycle solutions for the marine and energy markets. By emphasizing sustainable innovation, total efficiency, and data analytics, Wärtsilä maximizes the environmental and economic performance of the vessels and power plants of its customers. In 2021, Wärtsilä's net sales totalled EUR 4.8 billion with approximately 17,000 employees. The company has operations in over two hundred locations in sixty-eight countries around the world. Wärtsilä is listed on Nasdaq Helsinki (Wärtsilä). Wärtsilä has three main business lines: Wärtsilä Energy, Wärtsilä Marine Power, and Wärtsilä Marine Systems.

The Vaasa production facility called the Sustainable Technology Hub supplies Wärtsilä's Marine Power- and Energy Businesses with medium and large-sized four-stroke diesel, gas, and dual-fuel engines. The factory also supplies joint venture companies with key engine modules and acts as a spare parts supplier for Wärtsilä's Central Distribution Centre in Kampen, Netherlands. Factory's responsibility starts with signing a delivery plan per order. Product Engineering secures the availability engine design based on which Operational Purchasing ensures the right component delivery times. Logistics in the factory take care of storing materials, inventory control and material flows. In-house machining is used for producing core components. Engines are assembled in the factory's assembly lines and tested before delivery to the customer (Wärtsilä).

Wärtsilä is heavily investing in the Vaasa region by having built the Sustainable Technology Hub, a centre of research, product development and production. Total investment of the Hub area is over 230 million euros, of which Wärtsilä is investing eighty-three million in modern testing and production technology. The old Delivery Centre Vaasa activities will move to the Hub along with logistics and workshop operations from Runsor, Vaasa. In the Hub's factory, robotics, flexible manufacturing systems and additive manufacturing will play a key part in manufacturing. The Hub is also a collaborative ecosystem, where research and development is done with customers, suppliers, start-ups, and universities (Wärtsilä).

## 1.3 Research questions and limitations

The objective of the research is to design and implement a flow dashboard for production planning and control. Thesis work is limited to case company's Vaasa factory. The scope of the thesis work is a subassembly line inside of the factory.

The research questions (RQ) are formed as the following.

Research question 1: *What are the key user requirements for creating the dashboard system?*

Research question 2: *How does the dashboard system improve factory's production planning and control operations?*

Research question 3: *How does the dashboard system improve the efficiency of production operations?*

The first research question was selected due to importance of understanding user requirements when designing visual management and dashboard solutions to users. The user requirements are formulated from the originating business challenge which needs to be solved and the requirements are the key to solve it in a way that satisfies the users. The requirements act as a basis on what type of a solution will be developed in the iterative design and development process.

Research question two and three are related to improving the functions on which the thesis is focusing on. Operations and production planning and control operations each have their own requirements on what is wanted from the dashboard, but the dashboard is also needed to increase the transparency and communication between the two functions. Improving the efficiency of operations and planning will provide the factory with better chances on increasing the output and moving past the ramp-up phase which is currently on-going in the new factory.

# 2 Literature review

This section presents the key literature topics related to the subject of the thesis. It explains what visual management is including tools and best practices, key performance indicators, and dashboards. In the next subsection production planning & control is introduced including its processes and framework. In the last section the paradigm of Industry 4.0 is explained including its benefits and future possibilities. These three topics are the key concepts of this thesis and thus finally a summary of the theoretical topics is presented regarding on what the implications of the theory on the actual thesis work are.

## 2.1 Visual management

According to Jeffrey Liker in his book The Toyota Way (2020), he explains the term visual management as an approach to visually display the present situation of a process, project, or a procedure. Since we as humans are visually oriented, visual management complements us. From that fact is derived the Toyota Way Principle number 7: to support people in problem solving and decision-making, some form of visual control should be used (Liker, 2020).

Eaidgah et al. (2016) explain visual management as the information visualisation or requirement displaying to set the direction. While some visualisation tools such as flow charts are only used solely for information visualisation purposes to allow for better understanding, many visual management systems have embedded in them a performance management aspect. In these cases, tools such as Kanban cards and traffic lights are user for requirements communication and are managing the efficiency or effectiveness of human actions.

Liker adds that the best visual indicators are those that jump at you right at the work site and clearly indicate what is the standard and if there is any deviation from the standard. He also points out in the book that according to Ichiro Suzuki, the chief engineer of Lexus, if only one person uses the information on a personal electronic monitor, it has no chance of working in the broader organisational context. If visual management system enables communication and information sharing in the organisation, it will bring numerous benefits to the organisation (Liker, 2020).

In manufacturing environment, the information such as production order scheduling, release and progress is usually handled by a MES system. Visual management is used when the status of the production is wanted to be presented to the shop floor personnel in the simplest possible way and being perceptible with just a quick glance. The current state of the production must be understood from the visual management system in a matter of seconds and actions related to the production status can be taken immediately based on the system (Fenza et al., 2021).

Fenza et al. (2021) classify visual management into four different semantic groups. Visual indicators provide information on which the receiver is not obliged to act to, such as emergency exits. Visual signal provides a message of which the receiver is prompt and expected to act based on the signal, for example traffic lights. Visual controls limit and guides the actions of humans as the device constraints human action, such as Kanban cards and parking lines. Visual guarantees allow only the wanted outcomes, it is also known as mistake-proofing, for example a machine vision system discard items which do not meet quality standards.

Eaidgah et al. (2016) suggest that for a visual management to reach its maximum potential, it should be combined with performance management to provide input for visual management. They also recommend running continuous improvement initiate which then in part receives input from the visual management system. The visual management system aids in providing managers and process owners information in an open manner related to performance of the process and people's actions. This helps among other benefits to improve transparency and shared ownership as the processes and their influences are better understood through visual management. Visual management connected to continuous improvement initiatives aids in providing data and highlights the improvement opportunities, meanwhile also empowering the team and bringing responsibility.

According to lean production principles the reduction of cycle times and variability are the single most important factor in reduction of waste. Waste is considered any activity which does not add value to the customer. Lean production is considering production to be at the centre of the organisation to facilitate for achieving production related goals. Visual management bring clear benefits to lean production as it can lead to reduction in time the organisation spends communicating and decision making as it makes the process more efficient through visual aids. Visual management is also proven to be reducing variability in production operations and thus visual management is an integral part of lean production (Koskela et al., 2018).

Parry & Turner (2006) point out key visual management success factors related to performance measurement boards based on their three case studies from manufacturing companies. They argue that the team in the production must be empowered themselves to develop their visual management boards as different departments have different goals so standard solutions do not fit everyone. The information on the board must be clearly presented and the progress of the process should be visualized on the board. Visual management systems should be aimed to be as simple as possible with as few metrics as possible, only information which adds value should be presented on the boards. Whenever possible a colourful visual management system should be created. Surprisingly, they strongly suggest against moving the system from physical to electronical version as it may lead to adding unvaluable data and moves the updating of the board to only few persons instead of the whole team.

Furthermore, there are many cases in the literature which provide numerous advantages and disadvantages of digital boards. Advantages of digital boards include that they are often automatically updated, and employees do not need to waste time on updating them and the viewing of the dashboard is not constrained to a one physical location. The data, which is stored can be used for further analysis, show trends based on the historical data, and data from multiple systems can be visualized in one place. The disadvantages include that it may be restricted what can be written or drawn on a digital dashboard and the screen might also stop physically working or something goes wrong in the underlying data. It also costs more, and employees may not identify as well with the digital data, making them overly critical on the data and information presented on the screen (Eriksson et al., 2023).

### 2.1.1 Dashboards

According to Tokola et al. (2016) having most real-time and target-oriented information available starting from the shop floor to the managerial level and all the way to the executive level is a critical success factor for manufacturing companies. Dashboards, or digital display screens, are a solution to this challenge and they make possible visualisation and monitoring of information related to business performance. In their paper, they suggest having dashboards available which are designed by having three hierarchies in mind.

At the first level is a dashboard for the shop-floor personnel called the operational dashboard, which shows what is the status of the factory floor and the job queue. Time interval for such a dashboard is preferably from minutes to an hour. Operational dashboard can show the status of the machines and colour coding may be used accordingly as well as icons to display status of the job queue. (Tokola et al., 2016).

At the second level is a dashboard called tactical dashboard for production managers. It shows relevant information to the managers such as OEE, utilization, lead times and delivery reliability. The recommended time interval for such a dashboard is from a day to a week. At the third level comes to dashboard for executives called the strategy dashboard in a time interval from a month to a year. It displays on-time delivery information, lead time, productivity, costs, and inventories (Tokola et al., 2016).

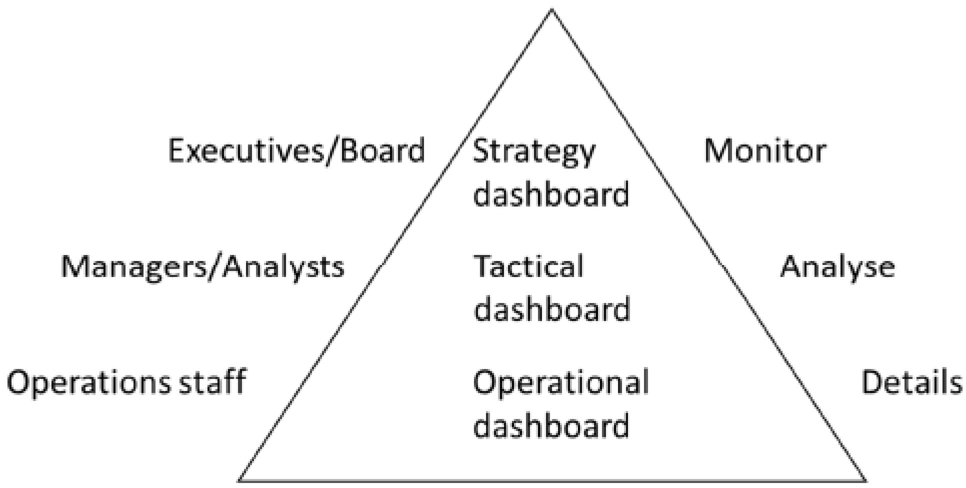



**Figure 1.** Dashboard functionalities for different users, Tokola et al. (2016, pp 621)

Gröger et al. (2013) have identified information needs for the shop floor workers that are process-oriented and relevant to them in the daily operations. They are categorized into 4 context and generally act at the basis for building dashboards in the manufacturing context. The four categories are process context, process performance, process knowledge and process communication.

Process context is related to the overall process such as the information that what goods are to be produced and information on process steps. Process context helps in creating an understanding for the process, goals, their own role, and the importance for the whole company. Process performance on the other hand is related to the managerial and technical performance of the process, it supports decision making and optimization in the work by measuring quantitative goals. It is based on measuring efficiency and effectiveness of both employee-specific and process-wide goals (Gröger et al., 2013).

Process knowledge includes information on the execution of process steps and continuous improvement of the process. Process knowledge enables organisational learning as it includes data such as text and videos, for example in a context of documented work instructions. Process communication relates to the information exchange amid process participants, and it enables interaction between employees for example in a case of unexpected situations (Gröger et al., 2013).

Bititci et al. (2016) highlight in their case study few best practices related to which dashboards elements are found to be important. Utilizing traffic light colours to highlight poorly performing areas of the production where improvement is needed. Utilizing of trend lines of KPIs is also found out to be a great way to gain better visibility on which direction the business and processes are heading. One area was also in the operational dashboards to provide information on customers complaints as it makes the employees on the shop floor more aware of the consequences of poor quality and in turn also helps in identifying corrective actions.

Another case study made by Larsson et al. (2017) emphasized on how to improve current performance measurements. The performance measurement dashboard should be supported with an oral presentation always if something is changed or updated. The explanation should be done in concise, short, and as simple way as possible. All written elements should be explained well while still keeping them simple while avoiding too much information. The topics of the dashboards should be explained by simple words which are understood by everybody in the organisation. Symbols should be used consistently and by using same symbols in the different departments, for example smiley faces as they provide quick to understand visual cues.

According to a case study by Al-Kassab et al. (2014) information visualisation has brought numerous benefits for managers to support decision making and performance management. The information can be used either as a tool for communication, knowledge provider for the organisation and instrument in supporting decision making. By visualising large amounts of data, it made the correlations and patterns in the data visible which were previously undetected. The information visualisation aided managers in enhancing their capability in processing information and providing insights for better decision making. Thus, as they gained better insights into operational processes it allowed to have in place effective and efficient process control which in turn led to more change and innovation.

For the process of designing dashboards there are numerous principles and one possibility is to follow W. Edwards Deming's Plan, Do, Check, Act (PDCA) also known as the Deming cycle. The Deming cycle is a continuous improvement tool which includes first to design the product, making it, releasing it, and finally finding out what the users think about it. The cycle is continued repeatedly which leads to further improvements (Deming, 2000). The downside of this design principle is that it focuses largely on building a completed product at once and not working iteratively towards a product that caters better to the users' needs.

Utilizing Deming cycle in designing and implementation of dashboards begins with the planning of the dashboard by setting objectives for the activity. The next stage of includes the design and creation of the dashboards according to principles. The next stage is the roll-out of the dashboard by placing it on the factory floor and training the users about the dashboard. In the final stage the dashboards are in use on the factory floor and feedback can be collected to further improvements. (Bateman et al., 2016).

Vilarinho et al. (2017) propose a design procedure for development of dashboards consisting of five different stages. In the first phase called the diagnosis phase the current state of production and its challenges must be understood and choosing the development priorities based on that. Then the organisations requirements and needs related to the dashboard need to be understood, to ensure that those are met in the final dashboard. Third stage is the development of the dashboard template where the requirements are converted into a solution as a first prototype. Fourth stage is assuring the necessary resources which involves defining responsible personnel and activities to perform. The last stage is the implementation, evaluation, and improvement where the dashboard is implemented and analysed for further improvements.

Yigitbasioglu & Velcu (2012) summarizes the dashboard design process into four categories which need to be filled. First the dashboard purpose must be understood so that the features can be in line with the purpose as it enables functional of the purpose and features. Second the dashboard users must be understood in relation to their tasks, knowledge and even personalities. Third the design features must be chosen among functional features such as presentation format and visual features such as number of pages and use of colours. Functional features enable the cognitive fit between different kinds of users while visual features increase visualization and decoding of information. Last in the decision making and performance management part the used measurements are chosen such as accuracy and speed.

### 2.1.2 Key performance indicators

Key performance indicators (KPIs) are strategic and calculatable measurements which reflect company's critical success factors. By selecting the KPIs appropriately and understanding the factors behind them they can assist the company in achieving business success. The KPIs are also generally defined by certain standards and norms for different KPIs in different industries by Standard Development Organisations, such as International Organisation for Standard (ISO). This ensures that KPIs are comparable between different companies as they are calculated in the same way (Varisco et al., 2018).

Tokola et al. (2016) have conducted a survey on the most important key performance indicators based on answers from representatives of five manufacturing companies. most important ones are delivery reliability, delivery punctuality, production lead time, utilization rate and OEE. These KPIs were seen important holistically based on workers from all levels of the organisation. Although they also argue that different levels of the organisation need different key performance indicators.

Performance measurements can be summarized into three different types. Static measures are measures which are gathered after the event has occurred. This makes static indicators lagging indicators, which means they show the past performance thus corrective action cannot be made before the outcome is known. Dynamic performance metrics are leading indicators, they are used in predicting the outcome of current work and corrective actions may be taken immediately. Last the motivational performance metrics which can be used in communicating business metrics and bringing them into motivating and actional measures to improve continuous improvement through performance focusing culture (Parry & Turner, 2006).

The picture below presents a dashboard visualisation of a business critical KPIs which are divided into two sections, overall process performance and individual employee performance. The process performance indicators of a factory include KPIs such as current and overall cycle time and customer satisfaction. Personal KPIs include specific process indicators such as actual and target machining times. To assess the current situation in the most optimal way the actual and target values should be as real time as possible and historical view should be available to track values and trends over time. If a process KPI is exceeding a certain value such as lead time, the dashboard can predictively display a warning for the users to take proactive measures and speed up the process (Gröger et al., 2013).

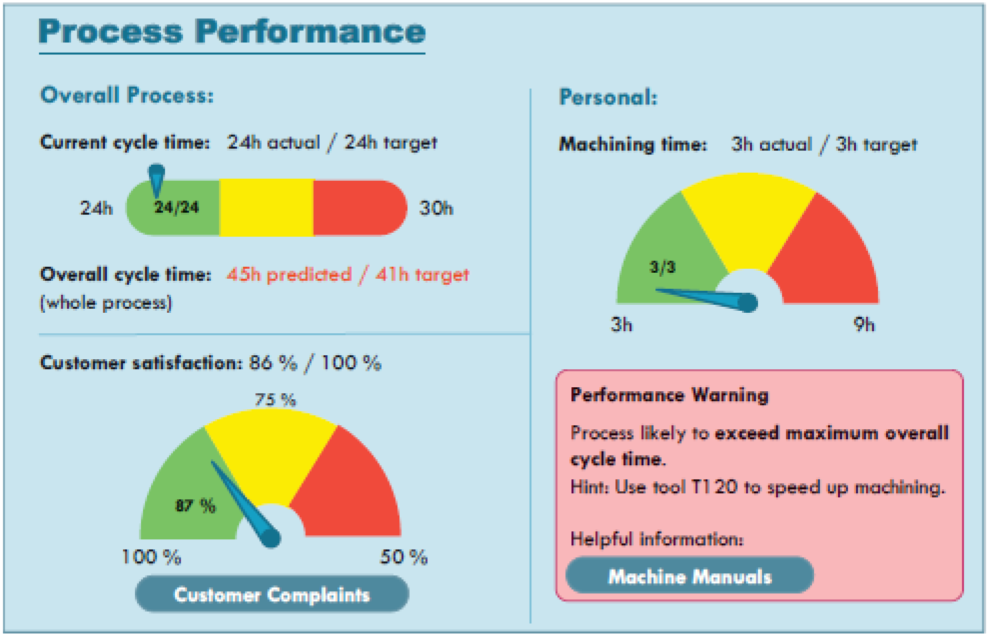



**Figure 2.** Process performance dashboard (Gröger et al., 2013)

## 2.2 Production Planning & Control

Slack et al. (2013) determines planning and control as the activities that attempt to reconcile the market demands and the ability of the operation's resources to deliver. It brings together the supply and demand together with aspects such as systems, procedures, and decisions. Planning and control are often treated together, however there are distinctions between the terms. Planning relates to the formalisation of what is intended to happen in the future. Having a plan is not a guarantee that something will happen in the future as things do not often happen as intended. The term control is defined as the process of mitigating these changes to bring the plan back to reality and achieve the objectives of the plan.

A key term related to production planning and control is scheduling, in which the start and end dates for jobs are determined. Schedules are mainly used in operations, but also planning is generally required to ensure that customer demand is filled on schedule. Scheduling can be divided into two kinds of scheduling activities, forward scheduling where the work is started as soon as it arrives and on the other hand in backwards scheduling the work is started at the last possible moment to avoid being late (Slack et al., 2022).

Theory of constraints (TOC) is a concept that closely ties together with scheduling, in it the planning focuses on the known capacity constraint. In TOC, the scheduling efforts focus on the operation's known bottlenecks. Operations should always be focused on the critical place which determines the output of the system by identifying the constraints' location, removing them, and continuously looking for the next one. Key concept of TOC is the drum, buffer, rope which assists identifying where the bottleneck is. As most work centres generally do not have the same amount of work, that means there is a bottleneck where the jobs are piling up, which should be the control point of the whole process. It is called drum because it sets the rhythm for the rest of the operations and it should always have buffer to make sure it is continuously working on jobs (Slack et al., 2022).

During the digital era, there have emerged numerous enterprise systems to support the PPC function. Material requirements planning (MRP) has evolved into manufacturing resource planning (MRPII) and later into more advanced system called the enterprise resource planning (ERP) have taken their place. To address limitations of the ERP systems, manufacturing execution systems (MES) and advanced planning and scheduling (APS) systems have emerged (Rahmani et al., 2022).

In a case study by Rahmani et al. (2022), they observed that planners are doing many repetitive decisions and spending a lot of time on making the same decisions repeatedly. They observed that there is great potential in automating the PPC function, with potential to reduce manual decision-making by using systems to support the PPC. They also observed that data is often incomplete, delayed and not detailed enough.

According to a planning survey done by BARC research (2016), Excel is used for planning by 74% of the 984 respondents. According to the survey most companies are either laggards or may not have recognized the benefits which a specialized software for planning can bring. The survey shows that Excel based planning is resulting to low business benefits, problems and dissatisfaction compared to specialized planning tools. The survey also emphasizes that as the visual age continues to gain more traction, dashboards as opposed to reports will be increasing in popularity, making it possible to condensate large amounts of data into single icons.

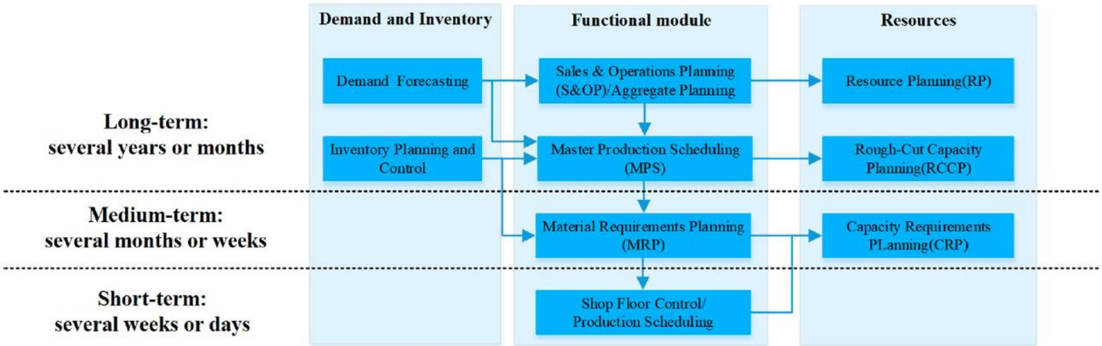



**Figure 3.** The framework of production planning and control (Luo et al., 2022)

Production planning and control framework is generally divided into three separate time frames, as shown in the figure. Strategic and long-term decisions are handled in the sales & operations planning (S&OP) or aggregate planning functions, where the time interval is several years. Master production scheduling is typically handled in the interval of several months to a year. The tactical level from several months to weeks considers the medium-term planning called materials resource planning (MRP). The operational level from several weeks to days are considered in the detailed scheduling or real-time control (Luo et al., 2022).

Luo et al. (2022) realize three challenges of applying frontier technology into the production planning and control function. First, is the complex challenge of integration between data, software, and decisions, especially the integration between physical and virtual systems. Second, by having available massive amounts of data opens both new opportunities and challenges to develop an effective production plan. Third, the challenge to develop the tools which can react in real-time and how to integrate them with the managers and workers (Luo et al., 2022).

Machine learning tools have wide variety of use cases in production planning. It can for example automatically understand the production capacity based on data or simulation. From enough data automated planning model can be created, which can automatically adjust based on the current requirements of the shop floor. This will result in that prescriptive analytics will be widely used in manufacturing and production planning systems. These tools will increase the agility of the production plans which is necessary in today's dynamic and volatile world. (Luo et al., 2022).

## 2.3 Industry 4.0

The Industry 4.0 or Industrie 4.0 term was introduced in Germany in 2011 and it involves the private sector, government, and academia. It aims to create unforeseen value by creating new business models and linking factories both inside and outside through communications networks (Kang et al., 2016). Industry 4.0 is generally considered as the term for the fourth industrial revolution, but other terms such as smart manufacturing or advanced manufacturing are used to describe the theories and technologies related to the fourth industrial revolution as well.

Industry 4.0 has been a dominant paradigm for over a decade now. Industry 4.0 will not lead to empty factories as employees are already aided in complex manufacturing duties by collaborative robots and software agents. The vision of Industry 4.0 puts human at the centre by progressing the society and economy, moving from traditional automation to self-adapting systems which respond quickly to disruptions and changes in customer demands. It also allows to move from mass production to mass customization to better suit the individual customer needs. Industry 4.0 is a pathway to a circular economy which separates growth of the economy from resource usage by upcycling and producing less waste (Kagermann & Wahlster, 2022).

Industry 4.0 brings in new technologies and there are numerous benefits which can be expected. Greatest benefits include additive manufacturing in new product development as it brings quicker design cycles and reduces the amount of material needed. Additive manufacturing assists in accelerating innovation as it enhances co-design and co-creation. Also, cloud connected digital services is a growing trend as they enable for possibility of completely new business models by being able to connect with other products and systems (Dalenogare et al., 2018,).

Further positive operational benefits can be achieved from CAD/CAM systems by enhancing manufacturing design process visibility already in the design phase of the product. Digital automation for process control is also bringing positive operational effects as it enables the production control and data collection in the manufacturing process, of which the inputs can be utilized in manufacturing execution systems. Big data is also seen as an important part of industry 4.0 as it enables detailed data analyses related to use cases such as predictive maintenance and creating self-adapting systems through machine learning (Dalenogare et al., 2018).

Kang et al. (2016) note that for the Industry 4.0 to realize the issues are technical interoperability, technology development in itself and the need to develop technological integration. For the smart manufacturing to apply to whole enterprises and supply chains technology development and application must be supported to develop and introduce practical technology solutions. Figure by Luo et al., (2022) displays the key elements of an industry 4.0 system and how it affects production planning function.

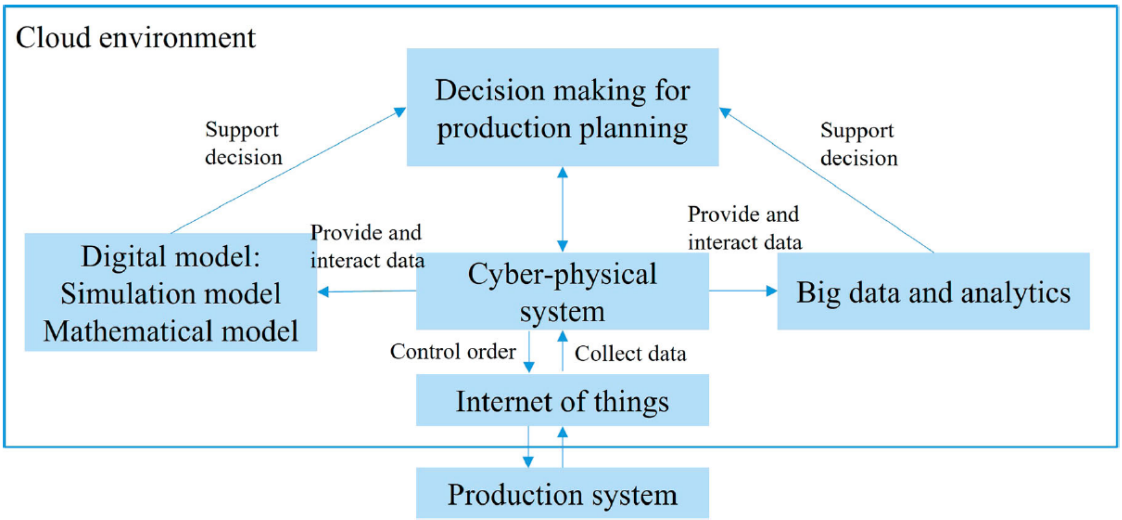



**Figure 4.** The overview of the production planning in Industry 4.0. (Luo et al., 2022).

Industry 4.0 is divided into three integrations which are the horizontal-, vertical-, and end-to-end engineering integrations acting as the main features of Industry 4.0. In a value creation process where a product is at the centre, a large chain of activities is involved from design to production. By integrating this end-to-end chain, a consistent software model of the product can be utilized at every stage of the process to enable customizable products and more efficient processes. Since the product lifecycle includes numerous stages which are often performed by different companies, the horizontal- and vertical integrations are the base layer for the end-to-end engineering process integrations (Wang et al., 2016).

Horizontal integration states that a company will both compete and cooperate with various companies that are related to its business and operations. When companies are horizontally integrated with other related companies, they can produce an ecosystem where material, finance and information can be exchanged fluently between the companies which result in new value networks and possibly new business models. Vertical integration states that a company's factory includes numerous physical and informational systems which are essential to be vertically integrated to enable a reconfigurable and flexible manufacturing system. By vertical integrations, the production machines are forming a self-organized system to dynamically adapt to new product types. It also includes data collection in large amounts to enable to improve and make transparent the whole production process (Wang et al., 2016).

## 2.4 Implications for the thesis

The result of the thesis work will act as a visual management tool as a form of an operational dashboard in the context of production. A dashboard can be considered as part of visual management and in addition the dashboard produced in the thesis work it will use other visual management tools such as colour coding in the dashboard and key performance indicators. The dashboard will be a mix of an operational dashboard including job queue and production targets and a tactical dashboard including lead time of production and trend.

The dashboard will be displayed to wide audience, and it will be displayed at the shop floor to increase the visibility and transparency of the process as well as bring ownership for the different user groups. The aim of the dashboard is to improve decision making and reduce variability by providing current information, priorities, and targets. By combining performance measurement with visual management great benefits can be achieved, thus it is important to add targets for the production as a goal to strive towards to. Understanding and measuring key performance indicators which are critical for the company can bring great business success.

When it comes to the design and development of the dashboard the literature suggests that it is utmost critical to understand the users of the dashboard and their needs and requirements on how the dashboard will be used. The design process should be iterative as first a prototype dashboard should be developed to gather user feedback and based the feedback build the ready version of the dashboard. New requirements can be collected, and features added for example utilizing the plan, do, check, and act cycle also known as the Deming cycle.

Implications for production planning and control are that the dashboard will bring benefits in improving the information flow between planning and production by making information more visible for all the users. Dashboard will also help the production planning to better understand what the production's adherence to the weekly plan is. According to the literature great advantages can be achieved if the planning moves away from Excel based tools to specific planning tools and dashboards to condensate large amount of data into actionable insights.

The dashboard utilizes Industry 4.0 concepts on the data acquisition area. The operational data of the assembly line production orders is collected through an API and transmitted into SAP ERP. The data in stored on a database and utilized for the dashboard. Based on the production data it is possible to control and steer actions towards reaching the goals displayed by the dashboard. The dashboard will also assist in daily decision making and support the users their daily work. Industry 4.0. technologies are also bringing great benefits to production planning and control function by automatizing repetitive tasks and being able to automatically make decisions by a set of business rules.

# 3 Research method

The method part of this thesis first introduces the design science research method based on which the thesis is conducted. This first chapter goes through the theory of design science research including the activities and guidelines to perform efficient design science research. The second chapter goes through how design science research activities will be utilized in practice during conducting the thesis work.

## 3.1 Design science research method

Design science research methodology creates and evaluates IT artifacts which are used in solving organizational challenges and problems. These artifacts may include software, logic, and mathematics. Thus, design science research is effectively a process for solving problems in an organisation. Design science research's fundamental principle is that the understanding and knowledge of the design problem and solution are received in the building and application of the artifact. (Hevner et al., 2004)

The design science method framework includes six activities. First activity is to explicate problem which includes investigating a practical problem and analysing it. It is critical that the problem is clearly constructed and justified by display that it is significant to a certain practice. The next activity is called define requirements,  which displays a solution to the explicated problem by developing an artefact. It draws out the requirements which are the transformation of the problem into needs and demands of the artefact proposed. The third activity is the design and develop artefact where the artefact is created which addresses the explicated problem and accomplishes the earlier defined requirements. Design of artefact must include both the determination of its functionality and structure (Johannesson & Perjons, 2014).

Fourth activity is to demonstrate artefact where the artefact is used in a real-world or illustrative case, also called of proof of concept or prototype, which proves the feasibility and usability of the artefact. The demonstration displays that the artefact can solve the problem instance. The fifth activity is to evaluate artefact where it is determined whether the artefact meets the requirements and to what scale can it solve the original practical problem which was the origin of the research. The framework is not sequential between the activities as design science project is always done in an iterative way, by moving between each activity back and forth. The activities are linked to each other by input-output relationship, where any activity can receive input or output from another activity (Johannesson & Perjons, 2014). Furthermore, Peffers et al. (2014) includes communication as the sixth activity of design science. In the activity the problem and the artefact should be communicated to researchers and other relevant audience when relevant and appropriate.

According to Hevner et al. (2004) there are 7 guidelines for efficient design science research. The first guideline is that the artefact should be a viable solution that addresses an important problem in the organisation. Thus, it needs to be described thoroughly to allow the implementation in the correct domain. Second guideline is that the problem should be relevant so that the artefact provides a solution to an unsolved business problem, as the artefact is designed to change the occurring phenomenon. A problem can be defined based on what is the difference between the current state and the goal state. Third guideline is that the design artefact should be rigorously demonstrated and evaluated by its quality, utility, and efficacy. The artefact is evaluated based on the requirements which come from the requirements set by the business.

Furthermore, the fourth guideline is related to research contribution as design science research must produce a rigorous contribution to the research related to the area of the design artefact. A relevant question regarding the research contribution is that what are the interesting new contributions to the research area. Design science can produce either a new design artefact, foundations, or methodologies. Fifth guideline related to the research rigor which relates to how the research is performed and it needs to be demonstrated in both the artefact construction and evaluation. The key focus in design science research is related to how well the artefact solves the practical problem (Hevner et al., 2004).

In addition, the sixth guideline states design science research is an iterative process to seek for the suitable solution to the problem at hand. The solution is not always perfect and does not solve all the problems , but a satisfactory one which works well for the specified problem. The seventh guideline emphasizes the communication of the research to audience both from technical and managerial backgrounds. Technology-based audience needs details on how to construct the artefact while management-based audience need to determine the resources needed to construct the artefact (Hevner et al., 2004).

## 3.2 Thesis research framework

The thesis will be conducted by utilizing design science research methodology. Design science was chosen as the research approach since the thesis includes developing a design for the dashboard and implementation of the dashboard. Thesis work aims to produce an artefact, a new dashboard system to fulfil the user requirements and organisational objectives. User requirements will be collected through interviews and the dashboard design and development will be done in three iterations. All the development iterations will be based on the user requirements and feedback on the previous iteration

The process of conducting the thesis work will first start by explaining the initial situation and what organisational problem needs to be solved. In the case of the thesis there is a need to increase the visibility related to planning and operations in the case company’s new factory, where there does not yet exist any dashboards or visual management tools as the factory is still partially in ramp-up phase. This produces certain business issues which need to be solved where it is not clear on what is the priority of jobs and the performance of the assembly line. This in turn will have a negative effect on the flow of the production system and reduce the output of the assembly line and the whole factory.

Once the problem statement is clear then the requirements will be collected from the different user groups, and which are their use cases. The requirements form a solution to the original problem in a form of a digital dashboard which aims to improve transparency and visibility. The requirements are based on the use cases of different users and the dashboard aims to solve those that bring the most value to the users and can be done time wise in a scope of the thesis work.

Based on the user requirements the first prototype will be developed, solving the problem partially and introducing further development actions in the later design phases. Every iteration of the dashboard is based on user feedback on the prior design iterations that what should be added or improved. After each design phase the dashboard solution is demonstrated to the identified user group audience for feedback and comments. The design of the dashboard is an iterative process where user feedback is listened, and the dashboard functionality improved between the different development iterations.

Once the dashboard is considered to be ready and it meets the collected users' needs, it will be set on a screen at the factory floor. Once the screen is running the final version will be demonstrated to the target audience and the different functionalities will be explained. A brochure will also be developed to be stored near the screen to explain the functionalities of the dashboard to visitors who visit the factory floor. This demonstration should prove that the dashboard is a feasible solution to the original problem context.

Once the dashboard is set on a screen to the factory floor it will be evaluated on how well it fits the user requirements and needs. The target audience will be interviewed on how well dashboard solved their original problems which were the basis of the dashboard requirements. Further development ideas should also be collected, and the dashboard should be continuously improved on the basis of user feedback. It is likely that the dashboard will receive further development ideas over time which will be implemented outside of the scope of this thesis.

# 4 Design and development of the dashboard

This chapter first describes the initial situation and which data sources were identified to be used in the dashboard. Then it explains the three iteration cycles of the dashboard development. In the first development iteration are discussed the target groups, use cases, data preparation and building the first prototype. Then on the second and third iteration cycle are explained the improvements to the earlier versions and implementing the improvements, keeping closely in mind the key user requirements from the first phase.

## 4.1 Initial situation

The company is in a situation where it is moving production from an old manufacturing plant to a new manufacturing plant, where processes and key performance indicators do not yet clearly exist. This thesis work was established to increase the visibility of priorities and targets in an assembly line.

There were three data sources which were at first identified between discussions with manufacturing and data experts. First is Production Order API database, second the case company's data platform and third the enterprise data warehouse. After identifying the data sources the access to the sources had to be applied for.

Company is utilizing a Manufacturing Execution System (MES) in use, which is used for example to execute production orders and call materials from warehouse to production area. MES is connected with SAP ERP by an Application Programming Interface (API) which handles the messages between the two systems. Report is utilizing the data from the APIs PostgreSQL database and the data which is available is near real time.

The case company's data platform is a cloud platform with numerous data sources including SAP data and is built on top of Amazon Web Services. It also supports citizen developers to build on top of the data platform, providing quick and low-cost solution to add new data sources to the platform to suit user needs. Data is generally updated in 1-hour intervals.

The enterprise data warehouse acts as the main data source for reporting and analytics purposes. It is a central repository of information from multiple internal and external data sources. The source data is updated once per day at night with the ETL (Extract, Transform & Load) process between the source system and the data warehouse. The figure below displays the identified data sources, update frequencies and data contents.

| Table name | Source - Server | Update Frequency | Data contents |
|---|---|---|---|
| V_TS_AFRU | SAP - EDW | Once per day, at midnight | Production order operation level confirmations |
| V_TS_AFKO | SAP - EDW | Once per day, at midnight | Production order header level confirmations |
| V_TD_TIMEDATE | Created manually - EDW | Once per day, at midnight | Calendar table with day, week, month and year granularities |
| v_f_production_order_npd | SAP – Data platform | Once per hour | Production order header level information |
| public production_order_api_productionorder | MES – Individual SQL server | Real time | Production order header level information |

**Table 1.** Data sources of the dashboard

The dashboards update frequency at the beginning will be once per day in the morning, because of the EDW data source update frequency limitation as it updates only once in a day at midnight. The most critical information is the production order operation level confirmations, which would give benefits if the update could be more frequent such as once per hour. The case company has in the development pipeline such a table which will be added to the data platform with one hour update frequency. However, the dashboard in the beginning will be implemented with the old once per day updating table.

Microsoft Power BI was chosen as the tool to begin the empirical thesis work. Microsoft Power BI is a self-service business intelligence (BI) tool, which can connect seamlessly to data sources with support for over five hundred connectors and visualize the data. Power

BI Desktop is the tool which is used in creation of the reports whereas Power BI Cloud handles the sharing and collaboration in the browser (Microsoft).

Power BI was chosen for the thesis work since it is widely used at the case company, it can connect to numerous different data sources, and it is rather simple to use. It also has powerful data transformation capabilities, able to add custom expressions and wide visualization possibilities. Power BI will be used for data exploration, the dashboard development as well as the final dashboard which will be displayed to the end users.

The dashboard will be displayed from a screen at the factory floor near the assembly area. The screen does not have touch or other input capabilities thus the dashboard will be view only and displaying only the most critical indicators of the assembly lines. This needs to be considered in the design phase of the dashboard by considering which indicators to display and the time range that fits the user needs the best. A report especially for the production management also needs to be created with possibilities such as to filter by different variables and selecting the time range but that is not in the scope of this thesis work.

## 4.2 First iteration of the development

### 4.2.1 Users and use cases

The first phase of the design and development was started with discussions between the different stakeholder groups. The stakeholders daily work was observed, and questions were asked related to their work tasks and what they could be seen to be improved. The target group benefiting from the report was identified to be the production workers, production planning & control team and the production management.

The production workers emphasized that in their view it is the most critical to know the priority and the assembly sequence of the upcoming next few production orders. If the priority is known, they can better prepare the required components accordingly for the next assemblies. That would also eliminate the possibility of working on an assembly which is not needed yet and suddenly having to change to the correct assembly, which would be creating excess work in process.

Currently the automated assembly line control systems show the released production orders, of which there are around 20 on average. The production workers do not know based on the view that which production orders need to be done next, so they need to be continuously in contact with the production planning & control team to know what to assemble next. Thus, by introducing a dashboard feature to assist on this, it could be possible to cut these manual checks on what production orders to work on next.

They were also interested on the picking status of materials for the production orders and whether they have been sent to production area from the logistics warehouse or not. Material availability for the production orders is a key enabler for the production and in the worst case the assembly cannot be started if material is missing. The logistical side, however, was decided to be left out of the dashboard since the logistics department had in development reports which would fill this need.

For the production planning and control team, the most benefit could be seen that if the report would display up to date status on the production. This would cut the need to often walk to the shop floor to see the production status. It would also remove the unnecessary habit of having to tell the production workers after each assembly that what to work on next. The production order routings from the previous weeks could also be used to make more accurate production plans, based on the hour confirmation of the historical performance of the assembly line.

For the management, the most needed development was being able to follow past performance and see the targets for the coming days and weeks. Thus, the performance compared to the original production plan could be compared, making it possible to identify bottlenecks in the production. It was also of interest to being able to follow the machine and labour routing hours confirmed by production orders of the assembly line, to better understand the assembly line's performance.

In addition to the target groups having their own use cases related to the dashboard, it will also be used collectively in morning stand-up meetings by the three user groups. The planned agenda utilizes the dashboard to have information on what has been the past performance related to metrics such as lead time and ready pieces. Another important aspect is to understand what the focus area and targets for the upcoming day are, such as which project to work on. The dashboard aims to create more visibility for the target groups related to their use cases and needs and will act as a visual aid in the morning meetings and for the individual needs.

The figure below presents the use case diagram of the flow dashboard based on the discussions with the targets group. Use case diagram displays the relationships between the actors and the use cases. For the actors three distinct groups were discovered, including shop floor workers, production planners and production management. For the use cases five different use cases were discovered, those include production priorities, production targets, adherence to the production plan, production status and process performance.

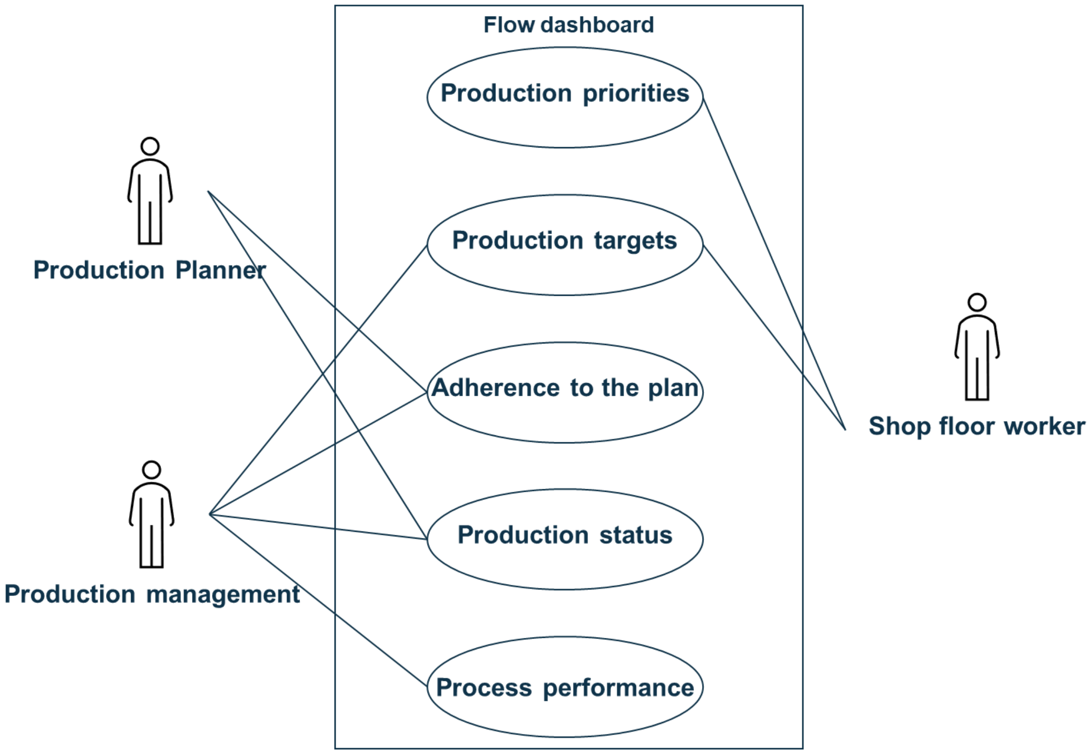



**Figure 5.** Users and use cases diagram of the flow dashboard

The table below presents an overview of use cases, the number of users, usage frequency, and the purpose the usage. It makes distinction between the different users between operations, production management, and the production planning and control operations.

| Use case | Number of users | Frequency and usage |
|---|---|---|
| Production priorities | ~10 | Daily by the shop floor workers to determine the job priorities. |
| Production targets | ~2 | Daily by production management who track the actuals compared to targets and take actions if needed |
| Adherence to the plan | ~3 | Once or twice per week. Used by planning to adjust the production plan if needed |
| Production status | ~15 | Daily by all of the users who are working in the area. |
| Process performance | ~5 | Weekly by the production management to spot bottlenecks and by the planning to track the WIP and lead times |

**Table 2.** Users and usage frequency

### 4.2.2 Data preparation

To start building the report, connections were made to the three identified data sources using Power BI's built in Power Query user interface. Power Query allows user to connect to different data sources and transform the data according to user's needs. Next, key concepts of SAP ERP Production Planning are introduced, to establish better clarity of the applied data filters.

MRP controller is a term in SAP ERP, which is responsible for material requirements planning and material availability. (SAP documentation, MRP Controller). At the case company the 35B MRP controller is used by Component Delivery organisation's planning team.

Production supervisor is a term in SAP ERP. Production supervisor is processing production orders, ensuring that stocks are available in the production and confirms the production order completions. (SAP documentation, Production Supervisor). At the case company the production supervisor 312 is used for the assembly line of which the thesis is written of.

WBS (Work Breakdown Structure) element is an SAP ERP term which models a certain project task into a hierarchy, it essentially shows the work involved in a project. It gives a clear picture of the project to better facilitate for coordination and the project implementation, considering steps such as scheduling, capacity planning and scheduling. (SAP documentation, Work Breakdown Structure (WBS)). At the case company WBS elements are used for new build customer delivery projects.

Plant is an SAP term which defines an operational facility within the company, for example a production facility. It subdivides the enterprise from the view of production, materials planning and procurement within logistics (SAP documentation). Case Company's Vaasa plant in SAP ERP is FI60.

#### 4.2.2.1 Production order API

From production order API the table public_production_order_api_productionorder was identified to hold key information related to production orders. Table is filtered by using filters shown below.

```
= Table.SelectRows(public_production_order_api_productionorder, each ([mrp_controller] = "35B") and ([production_supervisor] = "312") and [scheduled_start_date] > #date(2022, 12, 31))
```

After the filtering and removing unnecessary columns, a clean table is obtained which displays all production orders meeting the filtered requirements. From the table is also retrieved other important data such as material numbers, material descriptions, WBS elements, project names and quantities.

#### 4.2.2.2 Data Platform

From company's data platform the table v_f_production_order_npd, was identified to hold information related to production order and it also holds the status information of each production order. The table is filtered with below filters to retrieve the wanted data.

```
= Table.SelectRows(#"Removed Other Columns", each ([plant_id] =
"FI60") and ([mrp_controller] = "35B") and ([production_super-
visor] = "312"))
```

A new column will be created with the below code to determine the 5 main production order statuses which production orders may have in the case company's assembly line. Since the table loads all the production order statuses in a list of text, below filtering is done to extract the main production order status for each row.

```
= Table.AddColumn(#"Changed Type", "Status", each if Text.Con-
tains([system_status], "PCNF") then "PCNF" else if Text.Con-
tains([system_status], "CNF") then "CNF" else if Text.Con-
tains([system_status], "REL") then "REL" else if Text.Con-
tains([system_status], "CRTD") then "CRTD" else if Text.Con-
tains([system_status], "DLFL") then "DLFL" else null)
```

CRTD or created status is given to all production orders once they are created. REL or release status is given to a created production order which has been released for production. PCNF or partially confirmed status is given after the first confirmation of operation. CNF or confirmed status is given to the production order once production of the order is completed. DLFL or deletion flag is given to an order which is set for deletion and will not further processes. (ERP Great, System status in PP).

Another column is added with below code to display the full status text.

```
= Table.AddColumn(#"Added Conditional Column", "StatusText",
each if [Status] = "PCNF" then "Partially Confirmed" else if
[Status] = "CNF" then "Confirmed" else if [Status] = "CRTD" then
"Created" else if [Status] = "DLFL" then "Deletion Flag" else
if [Status] = "REL" then "Released" else null)
```

One last column is added with below code to create a hierarchy of the statuses a production order has from the creation to completion.

```
= Table.AddColumn(#"Added Conditional Column1", "StatusHierar-
chy", each if [Status] = "CRTD" then 1 else if [Status] = "REL"
then 2 else if [Status] = "PCNF" then 3 else if [Status] = "CNF"
then 4 else null)
```

#### 4.2.2.3 Enterprise Data Warehouse

From case company's Enterprise Data Warehouse two SAP ERP production order related tables were chosen. First the V_TS_AFKO table, which stores header data for SAP production orders. Second, the V_TS_AFRU table, which stores confirmation data for SAP production orders. Last, V_TD_TIMEDATE table, which contains time information.

V_TD_TIMEDATE, is a case company's own dimension table, which contains time information from days to years. The table allows for time intelligence calculations in Power BI. To reduce the number of rows, only dates from beginning of 2023 to end of 2029 were taken with the below filtering.

```
= Table.SelectRows(V_TD_TIMEDATE1, each [DAY_ID] > #datetime(2022, 12, 31, 0, 0, 0) and [DAY_ID] < #datetime(2030, 1, 1, 0, 0, 0))
```

V_TS_AFKO table stores header data for SAP production orders and the following filters are used.

```
= Table.SelectRows(#"Filtered Rows1", each [FEVOR] = "312" and [DISPO] = "35B" and [GSTRP] > 20221231)
```

Since the database has production orders with varying number of leading zeroes, the leading zeroes were eliminated by creating a new column with code below.
= Table.AddColumn(#"Filtered Rows1", "ProdOrder", each Text.TrimStart([AUFNR], "0"))

V_TS_AFRU table stores order confirmation data at the production order operation level. Table is first filtered by SAP plant FI60 and confirmation entry date is after year 2022. Only confirmations after year 2022 is done to reduce the number of rows since the table is lacking MRP controller or production supervisor columns to filter with.

```
= Table.SelectRows(V_TS_AFRU1, each [WERKS] = "FI60" and [ERSDA] > 20221231)
```

The leading zeroes of production orders are eliminated by creating a new column with code below.

```
= Table.AddColumn(#"Filtered Rows", "ProdOrder", each
Text.TrimStart([AUFNR], "0"))
```

Since the table contains both the date and the time of production order operation confirmations in a separate column, those needed to be combined to retrieve a column where date and time are combined in one cell. It is done by below formula.

```
= Table.AddColumn(#"Duplicated Column2", "CNFDateTime", each
Text.Combine({Text.From([#"ERSDA - Copy - Copy"], "en-GB"),
Text.From([#"ERZET - Copy"], "en-GB")}, " "), type text)
```

### 4.2.3 Building the report

Building the visual report started by building the data model between the selected tables as shown in the picture below. In the data sources, public production_order_api_productionorder & V_TD_TIMEDATE acts as the dimension tables and the rest of the tables are fact tables.

In the picture below, each of the box represent a table of data. One line item inside the box is a column of data. The lines which are connecting the boxes represent the relationships between the tables. Power BI makes it possible to build relationships from tables of different data sources. Fact tables consist of observational data values whereas dimension tables contain details about the data (Microsoft, Design a data model in Power BI).

The tables v_f_production_order_npd, V_TS_AFKO & V_TS_AFRU are linked to the dimension table production_order_api_productionorder by production order number. V_TD_TIMEDATE table’s column DAY_KEY is linked to the V_TS_AFRU table’s column ERSDA, which corresponds to the production order confirmation entry date. This is done to make time intelligence calculations possible

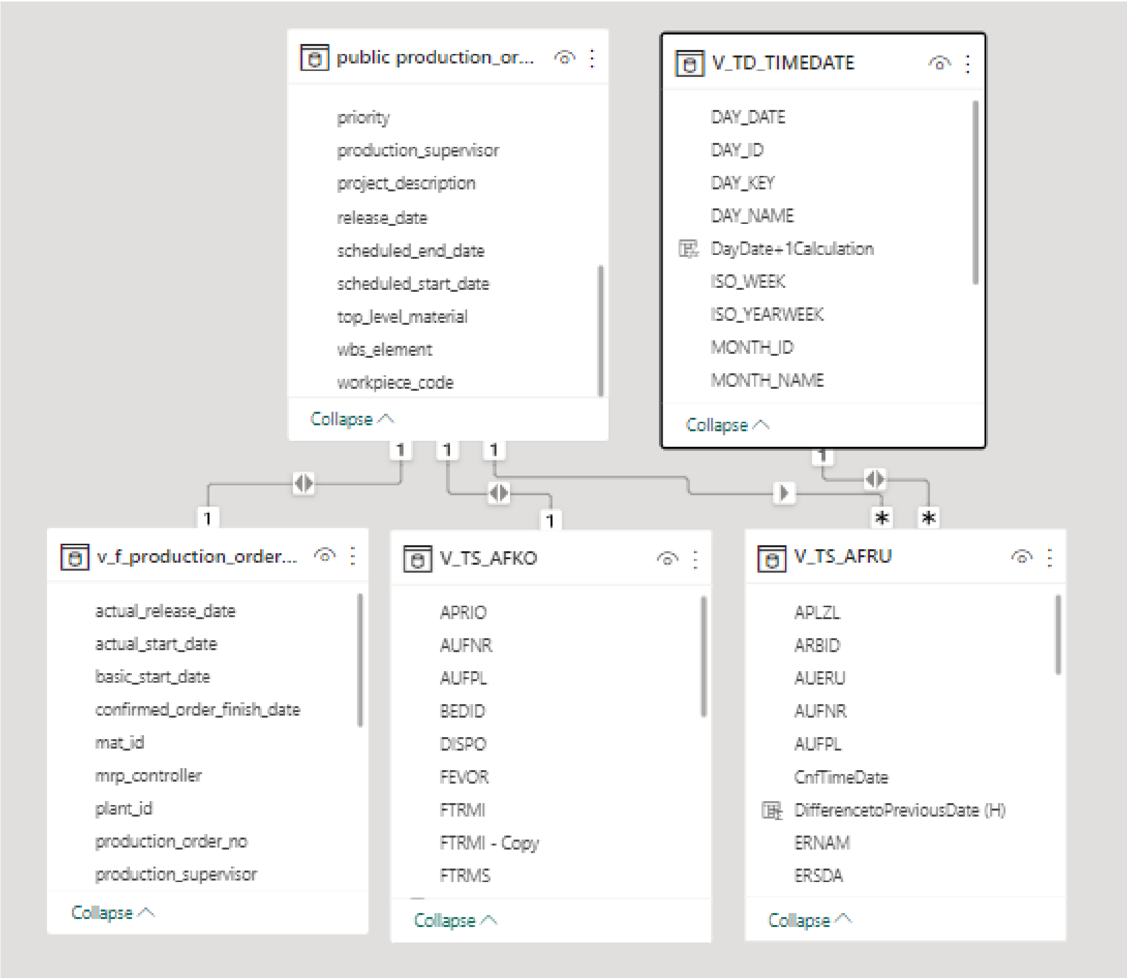


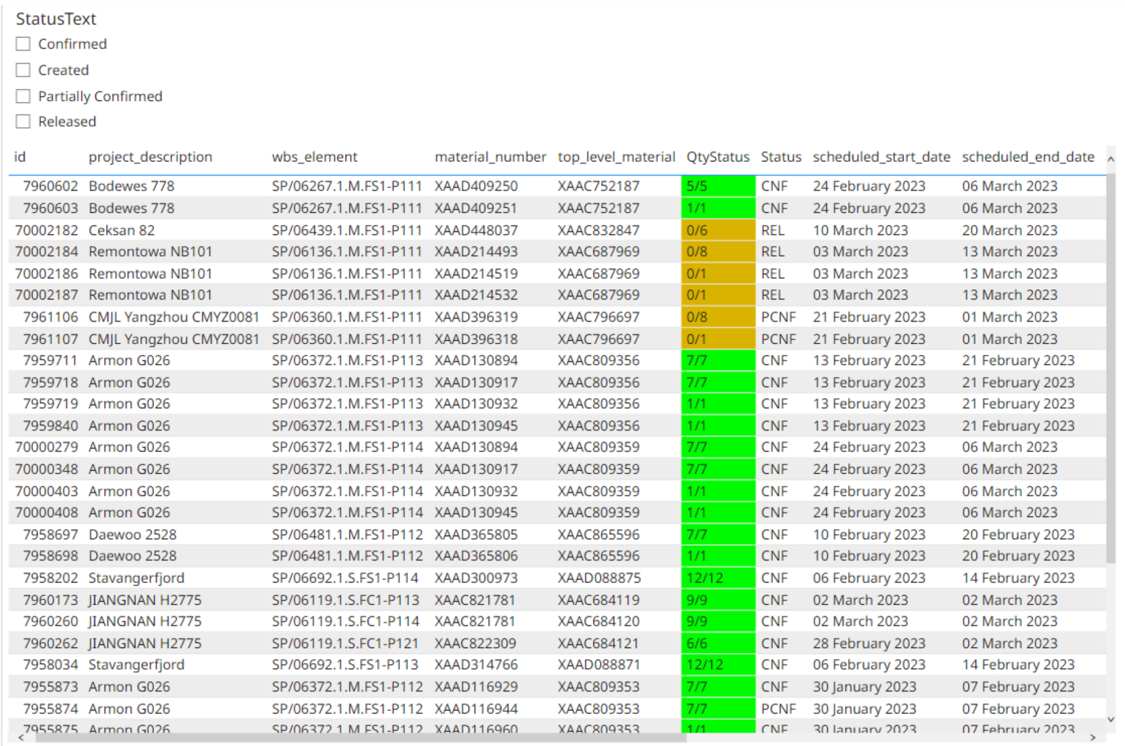

**Figure 6.** Data model

Once the data model has been built, data can be visualized in the Power BI report view. The visualization process started by adding data to a Power BI table visual, which makes it possible to form a quick understanding of the data and what columns are needed and what not.

From the public production_order_api_productionorder table, columns id, material_number, project_description, scheduled_end_date, scheduled_start_date, top_level_material and wbs_element was added. From the v_f_production_order_npd table, column status was added. A filter visual was added to allow filtering based on different order statuses. Also, custom DAX code was created to display the completed quantities for production orders based on the V_TS_AFKO table with the code below.

```
QtyStatus = CONCATENATE(V_TS_AFKO[IGMNG], CONCATENATE("/",
V_TS_AFKO[GAMNG]))
```

The dashboard at this point shows all the production orders for the assembly line in question utilizing a Power BI table visual. For each production order line additional information is displayed, such as project, material number, status, scheduling dates and how many quantities have been completed out of the total amount. User may also filter by the current production order header status, out of four different options. At this stage, the dashboard was made available to the Power BI online service, where anyone in the factory could access it and direct links were also given to the user groups.


StatusText
- [ ] Confirmed
- [ ] Created
- [ ] Partially Confirmed
- [ ] Released

| id | project_description | wbs_element | material_number | top_level_material | QtyStatus | Status | scheduled_start_date | scheduled_end_date |
|---|---|---|---|---|---|---|---|---|
| 7960602 | Bodewes 778 | SP/06267.1.M.FS1-P111 | XAAD409250 | XAAC752187 | 5/5 | CNF | 24 February 2023 | 06 March 2023 |
| 7960603 | Bodewes 778 | SP/06267.1.M.FS1-P111 | XAAD409251 | XAAC752187 | 1/1 | CNF | 24 February 2023 | 06 March 2023 |
| 70002182 | Ceksan 82 | SP/06439.1.M.FS1-P111 | XAAD448037 | XAAC832847 | 0/6 | REL | 10 March 2023 | 20 March 2023 |
| 70002184 | Remontowa NB101 | SP/06136.1.M.FS1-P111 | XAAD214493 | XAAC687969 | 0/8 | REL | 03 March 2023 | 13 March 2023 |
| 70002186 | Remontowa NB101 | SP/06136.1.M.FS1-P111 | XAAD214519 | XAAC687969 | 0/1 | REL | 03 March 2023 | 13 March 2023 |
| 70002187 | Remontowa NB101 | SP/06136.1.M.FS1-P111 | XAAD214532 | XAAC687969 | 0/1 | REL | 03 March 2023 | 13 March 2023 |
| 7961106 | CMJL Yangzhou CMYZ0081 | SP/06360.1.M.FS1-P111 | XAAD396319 | XAAC796697 | 0/8 | PCNF | 21 February 2023 | 01 March 2023 |
| 7961107 | CMJL Yangzhou CMYZ0081 | SP/06360.1.M.FS1-P111 | XAAD396318 | XAAC796697 | 0/1 | PCNF | 21 February 2023 | 01 March 2023 |
| 7959711 | Armon G026 | SP/06372.1.M.FS1-P113 | XAAD130894 | XAAC809356 | 7/7 | CNF | 13 February 2023 | 21 February 2023 |
| 7959718 | Armon G026 | SP/06372.1.M.FS1-P113 | XAAD130917 | XAAC809356 | 7/7 | CNF | 13 February 2023 | 21 February 2023 |
| 7959719 | Armon G026 | SP/06372.1.M.FS1-P113 | XAAD130932 | XAAC809356 | 1/1 | CNF | 13 February 2023 | 21 February 2023 |
| 7959840 | Armon G026 | SP/06372.1.M.FS1-P113 | XAAD130945 | XAAC809356 | 1/1 | CNF | 13 February 2023 | 21 February 2023 |
| 70000279 | Armon G026 | SP/06372.1.M.FS1-P114 | XAAD130894 | XAAC809359 | 7/7 | CNF | 24 February 2023 | 06 March 2023 |
| 70000348 | Armon G026 | SP/06372.1.M.FS1-P114 | XAAD130917 | XAAC809359 | 7/7 | CNF | 24 February 2023 | 06 March 2023 |
| 70000403 | Armon G026 | SP/06372.1.M.FS1-P114 | XAAD130932 | XAAC809359 | 1/1 | CNF | 24 February 2023 | 06 March 2023 |
| 70000408 | Armon G026 | SP/06372.1.M.FS1-P114 | XAAD130945 | XAAC809359 | 1/1 | CNF | 24 February 2023 | 06 March 2023 |
| 7958697 | Daewoo 2528 | SP/06481.1.M.FS1-P112 | XAAD365805 | XAAC865596 | 7/7 | CNF | 10 February 2023 | 20 February 2023 |
| 7958698 | Daewoo 2528 | SP/06481.1.M.FS1-P112 | XAAD365806 | XAAC865596 | 1/1 | CNF | 10 February 2023 | 20 February 2023 |
| 7958202 | Stavangerfjord | SP/06692.1.S.FS1-P114 | XAAD300973 | XAAD088875 | 12/12 | CNF | 06 February 2023 | 14 February 2023 |
| 7960173 | JIANGNAN H2775 | SP/06119.1.S.FC1-P113 | XAAC821781 | XAAC684119 | 9/9 | CNF | 02 March 2023 | 02 March 2023 |
| 7960260 | JIANGNAN H2775 | SP/06119.1.S.FC1-P114 | XAAC821781 | XAAC684120 | 9/9 | CNF | 02 March 2023 | 02 March 2023 |
| 7960262 | JIANGNAN H2775 | SP/06119.1.S.FC1-P121 | XAAC822309 | XAAC684121 | 6/6 | CNF | 28 February 2023 | 02 March 2023 |
| 7958034 | Stavangerfjord | SP/06692.1.S.FS1-P113 | XAAD314766 | XAAD088871 | 12/12 | CNF | 06 February 2023 | 14 February 2023 |
| 7955873 | Armon G026 | SP/06372.1.M.FS1-P112 | XAAD116929 | XAAC809353 | 7/7 | CNF | 30 January 2023 | 07 February 2023 |
| 7955874 | Armon G026 | SP/06372.1.M.FS1-P112 | XAAD116944 | XAAC809353 | 7/7 | PCNF | 30 January 2023 | 07 February 2023 |
| 7955875 | Armon G026 | SP/06372.1.M.FS1-P112 | XAAD116960 | XAAC809353 | 1/1 | CNF | 30 January 2023 | 07 February 2023 |

**Figure 7.** Table visual of the dashboard

## 4.3 Second iteration of the development

After the first phase of the development the dashboard in the table visual form was displayed for the user groups. Further development ideas were requested how it would better fill the use cases of different users and if any new cases would appear. Also, ideas for further improving the visualisation of the dashboard were asked to have more visuals than a table visual.

### 4.3.1 Improvements to the first prototype

Based on the production workers comments, there was more improvement to be done to better display the priorities of the upcoming production orders. Currently after the first phase of the development the report only showed the scheduled start and end dates of the production orders based on MRP calculations. It was noted that especially in the new factory in recent months where there are more cell-based production activities, the production priorities would change rather frequently and the MRP based calculations might not be valid.

It was concluded that the best way to understand the real priorities would be to have the priority originating from the real demand based on the progress of the top-level assembly. More specifically, how the top-level production order operations are being confirmed on the top-level assembly line. As the production order confirmations at the main assembly happen in real time, it would be possible to create a calculated rule based on the data available from the main assembly confirmations in Power BI.

The subassemblies of the assembly line where the thesis is focusing on are needed at the main assembly phase four. Each phase of the main assembly takes on average three days. It was decided that once the first operation of the top-level assembly would be confirmed in the system, it would then send a signal to the dashboard to begin the subassembly of the needed production order for that main assembly. As the subassembly takes between two to three days depending on the component type, the assembled component could be buffered for few days to mitigate any variation in the process.

The assembly line also manufactures other components and modules which are not going to the main assembly line, thus a scheduling approach for those cases had also to be decided. Those assemblies have certain requirement dates in the system based on their real demand from other end customers, where the scheduling data quality is better than in the main assembly. Thus, it was concluded that the most optimal way to schedule these production orders in the dashboard would be to utilize the SAP based MRP dates for priorization and start date of the assembly.

Figure displays the relationship between the main assembly and cylinder head subassembly. As the main assembly's takt time of each phase is three days, a calculated rule could be introduced to indicate an optimal time to start the subassemblies. A signal would be received to the dashboard that first phase of the main assembly is completed to start the subassembly. As the subassembly demand is at phase four and the subassembly production time is between three to four days, buffer of few days is achieved.

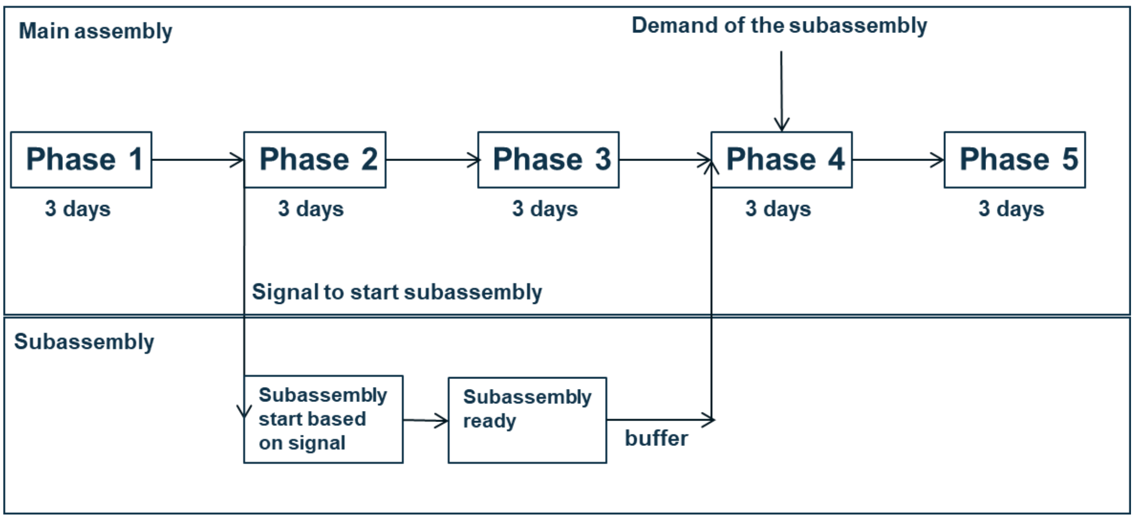



**Figure 8.** Main assembly and cylinder head subassembly

Some experiments with the available data were also done related to the possibilities of flow-based performance measurements and adherence to the actual production plan based on the SAP MRP dates. Although the adherence of the production plan currently in relation to the SAP MRP dates is not at a good level due to reason explained above, it was seen as an important measure in the future to understand the gap between the production plan and the actual production.

The flow-based performance measurements and adherence to the production plan indicators were discussed with the production management and production planners. Especially of interest were some key performance indicators which could be obtained such as days from order release to the final confirmation and how many hours the production order has been in the process. It was however decided that these indicators would be left on the last development cycle and currently focus on gaining improvements to the production priorities as it was agreed to be the most critical of the development objectives.

### 4.3.2 Implementing the improvements

To implement the changes related to the improvement of the priorities, two new tables had to be created to track status of the top-level production orders. The table public production_order_api_productionorder_TopLevel for production order header level information and V_TS_AFRU_TopLevel for the production order operation level information.

The table public production_order_api_productionorder_TopLevel was filtered with the main assembly's MRP controller 16A and production supervisor ASM. Production order scheduled start date was filtered to be in the year 2023 or later to reduce the number of rows as older data would not be needed for an operational dashboard. The below code was used resulting in a table with needed top level production order header level information.

```
= Table.SelectRows(public_production_order_api_productionorder, each ([mrp_controller] = "16A") and ([production_supervisor] = "ASM") and ([scheduled_start_date] > #date(2022, 12, 31))
```

The table V_TS_AFRU_TopLevel is first filtered with plant FI60, operation number 0010 as it is the first confirmation of the top-level production order wanted to be tracked and the confirmation dates filtered to be in the year 2023 or later. A below code was used for the filtering.

```
= Table.SelectRows(#"Removed Other Columns", each ([WERKS] = "FI60") and ([VORNR] = "0010") and ([ERSDA] > 20221231))
```

The leading zeroes of production orders are eliminated by creating a new column with code below.

```
= Table.AddColumn(#"Filtered Rows", "ProdOrder", each Text.TrimStart([AUFNR], "0"))
```

After the filtering, the two tables were merged based on the production order. The table merging is needed since the only way to connect the top level and subassembly production orders are by WBS element and in addition the production order operations table (V_TS_AFRU_TopLevel) does not include the WBS for the operation confirmations. The merging is done by the following code.

```
= Table.NestedJoin(#"Removed Other Columns1", {"ProdOrder"}, #"public production_order_api_productionorder_TopLevel", {"id"}, "public
```

After the merging, only the WBS element column from the table public production_order_api_productionorder_TopLevel was expanded. Other columns were deleted apart from the WBS element, production order number and the confirmation date of the first operation, as those columns are only needed to have understanding when the first operation is confirmed.

```
= Table.ExpandTableColumn(#"Merged Queries", "public production_order_api_productionorder_TopLevel", {"wbs_element"}, {"public production_order_api_productionorder_TopLevel.wbs_element"})
```

To receive the start dates for the modules outside of the main assembly where there are no prior operation confirmations but a set start date by MRP calculation, a query appending had to be done. The appending was done with the original v_f_production_order_npd table into the V_TS_AFRU_TopLevelDemand table, and to filter the wanted production orders WBS element should include “FC”. It was done with the following code.

```
= Table.Combine({#"Filtered Rows1", v_f_production_order_npd})
= Table.SelectRows(#"Appended Query", each Text.Contains([wbs_element], "FC") or [wbs_element] = null)
```

Finally, the columns with the main assembly and other WBS elements were merged with the following code.

```
= Table.CombineColumns(#"Merged Columns",{"public production_order_api_productionorder_TopLevel.wbs_element", "wbs_element"},Combiner.CombineTextByDelimiter("",
QuoteStyle.None),"WBS")
```

The resulting table thus produces data for all the WBS elements, utilizing either the first operation confirmation date from the main assembly or the MRP start date for those production orders not going to the main assembly. The table includes three columns: production order number, WBS element and the date for either the confirmation or start date.

After the two tables were built and data was cleaned and filtered, it can be utilized in the report. Before that, a new column was created to the V_TS_AFRU_TopLevelDemand table to count the dates from the start of main level assembly or the component demand with below DAX formula. Another column was created to manage the errors for the null values for those WBS elements where the first operation is not yet confirmed.

```
DaysFrom1stPhase = (V_TS_AFRU_TopLevelDemand[StartOr1stPhaseDone] - TODAY()) /1
```

```
DaysFrom1stPhaseCalculation = IF(V_TS_AFRU_TopLevelDe-
mand[DaysFrom1stPhase] <= -1000, 0, V_TS_AFRU_TopLevelDe-
mand[DaysFrom1stPhase])
```

The below Figure displays the dashboard in its current state with the priority column on the right for all the orders without confirmed status. The column would display a zero if the first operation is not yet confirmed or the module demand is in the future, otherwise it would show how many days late from the demand it is.

StatusText
- Confirmed
- Created
- Partially Confirmed
- Released

| id | project_description | wbs_element | material_number | top_level_material | QtyStatus | Status | scheduled_start_date | scheduled_end_date | Priority |
|---|---|---|---|---|---|---|---|---|---|
| 7961422 | DSIC G175K-1 | SP/06662.1.S.FC1-P111 | XAAC847929 | XAAD059069 | 0/8 | REL | 09 March 2023 | 09 March 2023 | -25 |
| 7961423 | DSIC G175K-1 | SP/06662.1.S.FC1-P112 | XAAC847929 | XAAD059118 | 0/8 | REL | 09 March 2023 | 09 March 2023 | -25 |
| 70002182 | Ceksan 82 | SP/06439.1.M.FS1-P111 | XAAD448037 | XAAC832847 | 5/6 | PCNF | 10 March 2023 | 20 March 2023 | -3 |
| 70003323 | Remontowa NB101 | SP/06136.1.M.FS1-P112 | XAAD250589 | XAAC687974 | 5/8 | PCNF | 20 March 2023 | 17 March 2025 | -3 |
| 70003839 | Rocket Launch Platform for Blu | SP/06578.1.S.FS1-P113 | XAAD253324 | XAAC992149 | 0/6 | REL | 15 March 2023 | 23 March 2023 | 0 |
| 70005187 | CHI Yangzhou N1070 | SP/05796.1.S.FC1-P111 | XAAC817076 | XAAC532722 | 0/9 | REL | 03 April 2023 | 05 April 2023 | 0 |
| 70005194 | CHI Yangzhou N1070 | SP/05796.1.S.FC1-P112 | XAAC817076 | XAAC532723 | 0/9 | REL | 03 April 2023 | 05 April 2023 | 0 |

**Figure 9.** Dashboard with priority calculation

Based on evaluating the dashboard it works as intended and the priority is working correctly as it is prioritizing the correct production orders the most with the most negative number. With short experience the subassembly components are seeming to be completed at the optimal moment if started when the report gives the signal. This can be seen from the third and fourth line of the picture as the production orders are partially completed and almost ready three days after the status change. The first and the second line the priority is showing correctly but the production of those orders is delayed due to material shortages.

In the future it is also easy to change how to control the priority and when to start the work by changing the parameters, if necessary, to either reduce or increase the size of the buffers. It was concluded that while the behaviour works as intended, it is still needed to improve the way how to better visualize the priority. The signal to start the production should be more apparent and better jump to the viewers eye, and more colour coding could be utilized.

## 4.4 Third iteration of the development

In the third iteration of the dashboard are introduced the process performance measurements, key performance indicator cards and the visualisation will be improved and finalized. First are explained the improvements to the second prototype which focuses mainly on introducing the process performance metrics. Then the steps for the implementation of the improvements are explained including calculations for lead time and cycle time. Finally, a snapshot of the final version of the dashboard is presented along with future development possibilities.

### 4.4.1 Improvements to the second prototype

Little's Law acts as the basis for the process flow performance measurements in the dashboard. According to Little's Law which was introduced by John D. C. Little (1961), there is a relation between number of units in the system (L), time spent by unit in the system (W) and time between consecutive arrivals to the system ($1/\lambda$), which can be expressed as $L = \lambda W$. It is a fundamental principle of the queuing theory, and it can be utilized in production context as well.

In the production context Little's Law can be utilized by relating work-in-progress (L), cycle time (W) and throughput time ($\lambda$). Where work in progress is the number of items in the process, cycle time is the time it takes for one unit to move through the system and throughput time is the rate which unit of work is completed. Little's Law is a great tool to visualize and improve flow of production by focusing on reducing cycle times and work-in-progress (Slack et al. 2022).

Currently at the assembly line the throughput times are rather high thus by limiting work-in-progress (WIP) it should be possible to decrease the throughput times. This is one use case of the dashboard thus in this iteration functionality to track these metrics will be added. To the dashboard will be added a chart to display the production lead time over time, cycle times for production orders and current level of work-in-progress. This provides a great way to internally start reducing the work-in-progress gradually and see how the lead time performs.

On top of the earlier introduced functionality including the table visual and priority of the upcoming production orders, the dashboard will be included with a graph of ready-made parts of the last 7 days. This is important information since there are production goals related to the number of ready-made parts in the previous 7 days and it can also be compared with the original production plan if the performance is up to the planned level. All the component types assembled in the assembly line have similar cycle time thus it is possible and value adding to measure number of ready-made parts in the history.

### 4.4.2 Implementing the improvements

To create the dashboard visual for the parts made in the last 7 days functionality, three tables must be utilized. V_TS_AFRU table provides the production order operation confirmations, public production_order_api_productionorder table provides the material descriptions and V_TD_TIMEDATE table provides the time intelligence calculation possibilities. Last 7 days was chosen as the time range since the dashboard will be used in morning meetings and weekly production management meetings thus that time range will fill the user requirements. Based on possible future feedback the 7-day time range can quickly be changed in the report if it is beneficial for the stakeholders. Also, not too much data is wanted to be shown to keep a good level of readability of the dashboard at a quick glance.

The parts made in the last 7 days visual uses the Power BI stacked column chart. From the table V_TS_AFRU the sum of the column GMNGA is utilized as the Y-axis, the column has the information on the confirmed yield for each operation. The filtering of the dashboard is also utilizing the column MEILR from the V_TS_AFRU table, which describes whether a milestone confirmation has been carried out, which indicates that the last operation is confirmed and thus the part is ready. From the public production_order_api_productionorder table is used the material_description as the legend of the chart, it displays the material description as it is more informative to a wider audience than a material number for example. Finally, the V_TD_TIMEDATE table the column DAY_DATE is used as the y-axis to display the dates and to filter for the last 7 days.

To create the dashboard visual for the production lead time visual, only data included in the V_TS_AFKO table is needed which displays the production order header level information. The visual will be in the form of a line chart because it is easier to read with multiple lead time values and with line chart showing the trend of the lead time is achieved. The lead time is calculated from the production order release date to when all the production order operations are confirmed, and thus it is ready. Also, a trend line will be added which displays the moving average of the last 30 days allowing the users to understand the trend of the lead time.

The lead time visual utilizes the line chart of where in the X-axis is the GLTRI column from the V_TS_AFKO table which records the actual finish date of the production order. The dashboard is filtered by production order finish dates for the last 2 months which allows to better spot trends on how the lead time is developing. The first line on the y-axis is based on a calculated column which calculates the time in days from release to finish with the code below. FTRMI column is the production order release date and the LastFinishedOperationDate is a calculated DAX measure which returns the date of the last production order operation confirmation based on the V_TS_AFRU table's ERSDA column.

```
Release to Finish (D) = DATEDIFF(V_TS_AFKO[FTRMI], [LastFinishedOperationDate],DAY), where
    LastFinishedOperationDate = LASTDATE(V_TS_AFRU[ERSDA - Copy])
```

The second line in the y-axis is the 30-day moving average line which calculates the average of the lead time for the last 30 days. This helps to get a clear view on the trend where the lead time is moving to over time and smoothens the noisy data. In case there are multiple production orders confirmed in the same day, the formula calculates the average lead time between the production orders, which explains why there are decimal numbers in the visual.

```
MA30 =
AVERAGEX(
     DATESBETWEEN(V_TS_AFKO[GLTRI], MAX(V_TS_AFKO[GLTRI]) -30,
MAX(V_TS_AFKO[GLTRI])),
    CALCULATE(AVERAGE(V_TS_AFKO[Release to Finish (D)]))
)
```

The cycle time for each production order is calculated based on the V_TS_AFRU table. First there is need to determine that at what time the first production order item has received the first operation confirmation. It acts as the start date and time for the production order. There are no other triggers indicating when the production order starts but as the takt time for each operation is around 15 minutes, it is close to the real start time of the production order. The determination of the first item's first production order operation confirmation is calculated with following DAX formula to create a calculated column.

```
PreviousDate =
CALCULATE (
    MAX ( V_TS_AFRU[CnfTimeDate] ),
    FILTER (
        V_TS_AFRU,
                 EARLIER    (    V_TS_AFRU[CnfTimeDate]    )    >
V_TS_AFRU[CnfTimeDate]
            && EARLIER ( V_TS_AFRU[ProdOrder] ) = [ProdOrder]
    )
)
```

Once the column is created for the production order start date and time, then it is possible to calculate the difference in minutes between the start and when the whole production order has been finished. Below DAX formula creates a calculated column for that purpose. Once that is created it is possible to calculate the average time in minutes it takes per one item to be completed by dividing it by V_TS_AFRU table's SMENG column, which includes the information on the quantity of items per operation. By dividing the minutes by sixty an hourly number is received for better viewability in the dashboard.

```
DifferencetoPreviousDate (Min) = DATEDIFF([PreviousDate],V_TS_AFRU[CnfTimeDate],MINUTE)

CycleTimePerPiece(Min) = V_TS_AFRU[DifferencetoPreviousDate (Min)] / V_TS_AFRU[SMENG]

CycleTimePerPiece (H) = V_TS_AFRU[CycleTimePerPiece(Min)] / 60
```

The dashboard displays average cycle time per item for each production order. The visual is currently in a table form and worth future development to improve the visualisation. Currently the cycle times per piece have a lot of variances. This is explained by two reasons, first there are no weekend or night shifts thus it increases the cycle time for example if production order is not finished before the weekend and second there are certain bugs in the assembly line logic where it may create a false first confirmations in some cases. In a future development once the bugs in the assembly line have been solved a logic needs to be developed to ignore the times in a week when the assembly line is not working to achieve a more accurate cycle time measurement.

The dashboard also utilizes card visuals for certain KPIs. One utilisation is to display the current number work-in-progress (WIP) items of the released production orders. To calculate the WIP it is based on the V_TS_AFKO table and it is the difference of column GAMNG (total order quantity) and IGMNG (production order confirmed yield). This gives a number how many items there are currently not release but not confirmed thus it displays the current WIP and it is done with below DAX formula. There is also one card visual displaying the number of production orders in WIP. It is done by filtering in the visual those production orders which do not have confirmed production order status.

```
CylindersinProgress = V_TS_AFKO[GAMNG] - V_TS_AFKO[IGMNG]
```

There are also two card visuals displaying the sums of ready-made items, one for the last week and one for this week so far. They are based on the V_TS_AFRU table’s GMNGA column which has the information of confirmed yield for each operation. One card has also been created to display the last refresh date of the report for the users to see how up to date the current data in the dashboard is. It is done by creating a new table with the following code `= DateTime.LocalNow()`. Once the report is refreshed it takes the current local time and displays it in the card visual.

Once all the visuals were created those needed to be arranged in the dashboard. This was done keeping the target audience in mind in relation to their wanted period while keeping the report simple and easily readable. A short introduction presentation will be created for the users to explain the different elements of the dashboard. It will be printed out and stored next to the screen where the dashboard is located to cater also for the needs of visitors who want to understand the status and performance of the assembly line. The dashboard will be uploaded to Power BI online and the dashboard will be set up on a screen at the factory floor from where the screen can display the Power BI online web page. It will be set to update on regular intervals, first in the beginning once per day before the morning meeting.

The dashboard still has few longer-term improvements which could be made in the future but are out of the scope of this thesis work. One useful improvement to the dashboard is increasing the update frequency to once per hour. This can be done once a new table is ready on the case company’s data platform related to production order operations and their confirmations, it is currently in development pipeline. Another improvement possibility could be to predict the needed start date of the module as the dashboard displays only now that the worker should start do certain production order now. This could be achieved by utilizing historical data and it would create better possibilities on planning the next production orders to work on. The figure below represents a snapshot of the dashboard which was taken on 14.4.2023.

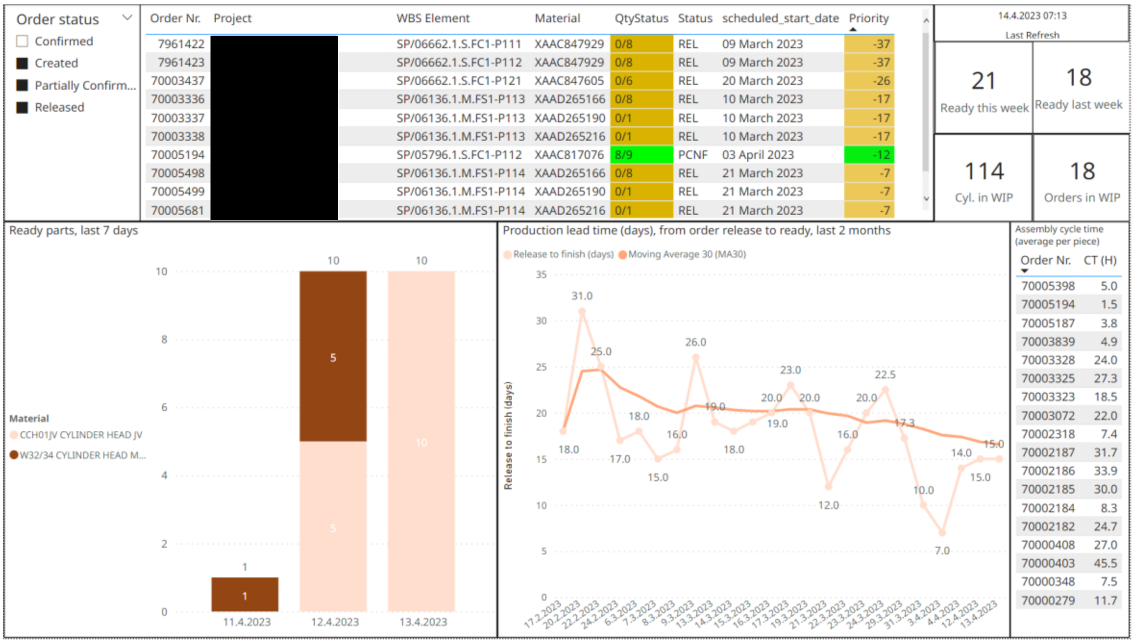



**Figure 10.** Dashboard snapshot on 14.4.2023

The following picture represents the dashboard displayed on a screen which is set at the factory floor. The dashboard is currently utilizing a laptop to run it and is set on a table, but in the future some improvements will be made to run the dashboard on a mini-pc and the screen will be attached to a wall to make the setup cleaner. Minor modifications were made to the dashboard after the above snapshot, such as changing the language of the dashboard to Finnish as most shop floor workers have limited English skills.

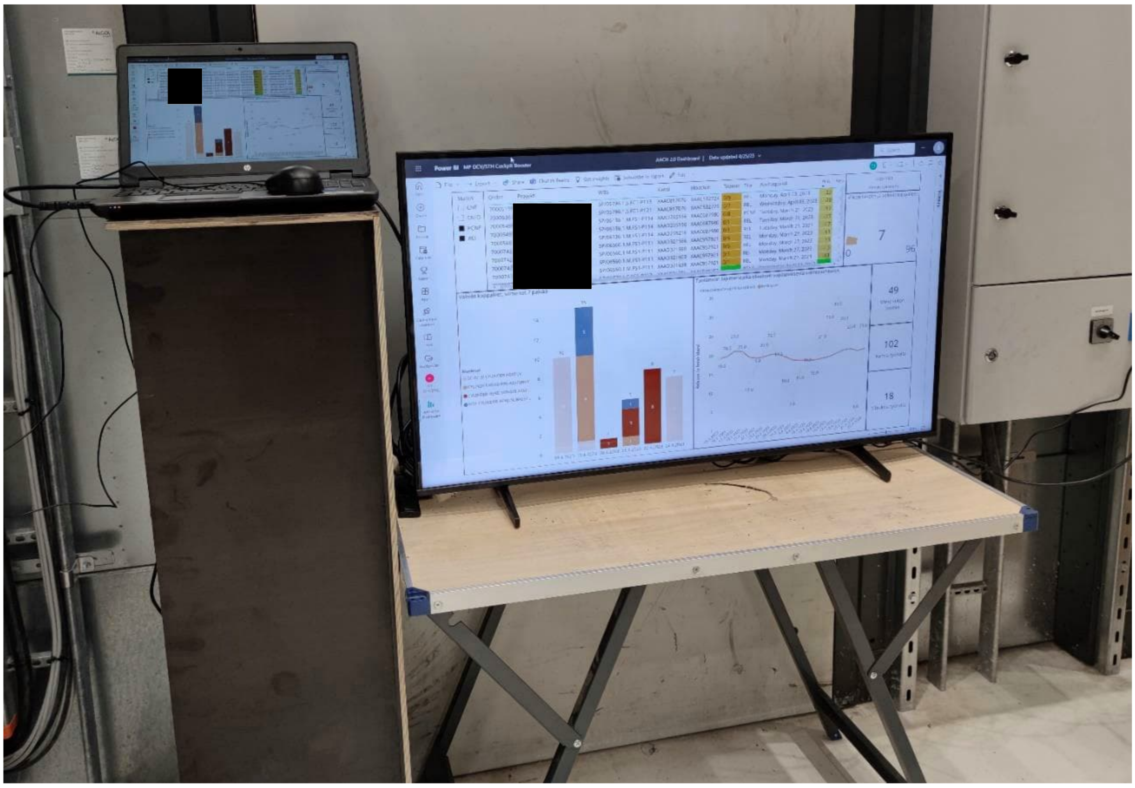


**Figure 11.** Dashboard on the factory floor

# 5 Conclusion

The thesis work utilized design science research framework to design and implement a digital dashboard solution to improve visibility and transparency of the factory's operations and production planning & control. The problem was at first identified resulting in the need to develop a solution in a form of a thesis work. The problem was formulated that there is a need to increase the visibility related to production planning and operations in the case company's new factory, where there does not yet exist any dashboards or visual management tools as the factory is still partially in ramp-up phase. This business issue was solved by utilizing design science research methodology to produce an artefact in the form of a digital dashboard. Next the research questions are presented along with their findings.

Research question 1: *What are the key user requirements for creating the dashboard system?*

The solution included various user requirements which were implemented in the form of a digital dashboard to fulfil the user needs. The user requirements for the dashboard were identified to come from three different user groups which are daily in connection with each other. These groups are the shop floor workers, production planning and control, and production management. The basis for understanding the user groups and their requirements were in first understanding the problem context and the type of solution to be developed for the problem.

The requirements from the shop floor workers were that it is critical for them to know the priority and the assembly sequency of the upcoming production orders. Having a visual dashboard would also cut the need for having to manually confirm the production priorities. The second user group was the production planning and control team to whom it was important to understand the up-to-date status of the production and adherence to the production plan. Another requirement was to be able to  improve the production flow by having better visibility on the WIP and lead times in production. The third user group is the production management. Their requirements were to be able to follow the past performance in the form of completed assemblies and better understand the targets for the upcoming week in order to take needed actions if needed.

Research question 2: *How does the dashboard system improve factory's production planning and control?*

For the factory's production planning and control team the dashboard solution brings visibility on what is the current level of WIP and the lead time trend over time. The dashboard can be utilized as a test platform when trying to increase production flow by reducing WIP and seeing in practice how the lead time is developing over time. Based on Little's Law as WIP is reduced the lead times should be reduced as well. It also helps by giving a glance on the adherence of the production plan on what has been the performance of the assembly line during previous week and this week. That in turn helps on understanding the capability of the assembly line which helps in planning the production plan for the upcoming weeks.

Another benefit is that the dashboard displays up-to-date performance information, which is also available to view at the office, thus reducing the need to walk to the shop floor to understand the production status. It also removes the need to constantly give instructions to the shop floor workers on what jobs to focus on next, as they can see the priority of each production order from the dashboard. Both of these benefits save time and allow the stakeholders to work on more value adding work tasks.

Research question 3: *How does the dashboard system improve the efficiency of production operations?*

From the view of the shop floor workers a new system to prioritize jobs was introduced which displays the job priority based on actual demand. The actual demand of the cylinder head subassembly may vary in the new factory where ramp-up operations are still on-going. This will help in preparing the required components for the upcoming assemblies and in turn improves the production flow and cycle times as work is prepared, and it is being performed on correct assemblies. The priority system similarly also cuts the time needed to make sure what jobs to produce next as it is clearly visible on the dashboard.

Dashboard also included visualisation of the current week's production performance and the production targets for the current week as well. Introduction of production targets is a motivator for the employees as it is a goal to work towards every week. Actions can then be initialized based on the dashboards performance indicators for example to work over-time if based on the dashboard it is clear that the production targets will not be met for the week. A morning meeting was also agreed based on the dashboard. Users can also see the status of production orders including how many quantities are completed compared to the needed amount.

The dashboard has received appraisals from the stakeholders, especially related to the information being more visible now directly at the workplace without needing to dig data from the systems. All of the user requirements were not fully possible to met during time of the thesis, either due to lack of data, insufficient data refresh time or simply out of scope of the dashboard. The case company will need further dashboards to be developed for different parts of the organisation with different functions, such as tactical and strategical dashboards with longer time horizons.

In dashboard design it is of great importance that either the designer understands the context and what is important, or the designer frequently asks guidance related to the topic if not familiar with it. Importance of dashboard being fully automatic without manual inputs was realized as the users inputting the data can make mistakes or forget to. Another matter to consider is that users appreciate up-to-date data, thus the data refresh rate should strive to be as frequent as possible especially in operational dashboard cases.

There are still many possibilities how it can be further developed. Some future improvement initiatives include to reduce the update frequency even further to one hour or less. One improvement is that by utilizing the routings based on historical data a more accurate and feasible production plan could be created. Another improvement possibility could be to predict the needed start date for the cylinder head module assembly based on the real demand so that it would be known beforehand. The dashboard development process should be iterative in the future as well when adding new functionalities and it should be continuously developed to best suit the requirements of different users and their use cases.

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