Tampere University

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MANUFACTURING EXECUTION SYSTEM FUNCTIONALITIES IN AN INDUSTRY 4.0 ENVIRONMENT

Faculty of Information Technology and Communication Sciences
Master of Science Thesis
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ABSTRACT

Tommi Linnamaa: Manufacturing execution system functionalities in an Industry 4.0 environment
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The future of incoming industry 4.0 will have big impact on the manufacturing industry. Industry 4.0 brings heavily integrated systems that are autonomous and smart. This will have a huge impact on future factories. One of the core elements in a modern factory is the manufacturing executions system (MES). MES manages the factories production and industry 4.0 will bring new requirements and possibilities. It is important for future development to identify main features that will be used in a industry 4.0 environment. This thesis identifies industry 4.0 main concepts and technologies.

After this thesis has compiled a list of concepts and technologies in industry 4.0. This is done by comparing literature regarding industry 4.0. Technologies that are mentioned in multiple papers are then compiled to a list. The thesis will then compare which features are the most important to implement in a future MES. This will create easy to define areas in industry 4.0 that are then used as a tool to analyse a MES in development.

Pinja is a software company specialized in the manufacturing industry. They have a new MES software called iPES. This thesis describes how iPES implements the main functionalities and requirements of a MES. Then it start analysing the software using the list of technologies that was created.

Using concepts identified in thesis there will be a analysis on how well the new software handles future technologies used in a I4 environment. This way it is possible possible to identify future problems that will arise in a industry 4.0 environment. Also determines what are the main features to focus on.

Keywords: Industry 4.0, MES, Manufacturing industry

TIIVISTELMÄ

Tommi Linnamaa: Tuotannonohjausjärjestelmän ominaisuudet industry 4.0 ympäristössä
Diplomityö
Tampereen yliopisto
Tietotekniikka
Marraskuu 2020

Olemme siirtymässä teollisuuden uudelle ajalle nimeltä industry 4.0. Tämä on tulevaisuuden visio valmistavasta teollisuudesta. Se tuo tuo mukanaan vahvasti integroituja systeemejä, jotka ovat autonomisia ja älykkäitä. Näillä tulee olemaan suuri vaikutus tulevaisuuden tehtaisiin. Yksi ydin elementeistä nykypäivän tehtaassa on tuotannonohjausjärjestelmä. Tuotannonohjausjärjestelmän tehtäviin kuuluu tehtaan tuotannon hallinnointi. Industry 4.0 tuo mukanaan uusia vaatimuksia ja ominaisuuksia tuotannonohjausjärjestelmille. Tämän työn tarkoituksena on kartoittaa Industry 4.0 tärkeimmät elementit ja teknologiat.

Aluksi tämä työ kokoaa listan elementeistä ja teknologiaoista, joita esiintyy industry 4.0 ympäristössä. Tämä toteutetaan vertailemalla kirjallisuutta, joka käsittelee industry 4.0. Usein esiintyvät teknologiat kootaan listaksi. Listaa verrataan tuotannonohjausjärjestelmän päätehtäviin ja järjestetään lista sen mukaan, mitkä ovat kriittisimmät ominaisuudet toteutettavaksi. Näin saadaan yksinkertainen listaus tärkeimmistä osa-alueesta, jotka tulisi toteuttaa kun valmistetaan tulevaisuuden tuotannonohjausjärjestelmää.

Pinja on teollisuuteen keskittyvä yritys. Heillä on uusi tuotannonohjausjärjestelmä nimeltä iPES. Tämä työ kuvailee kuinka iPES toteuttaa tuotannonohjausjärjestelmän vaatimukset ja ominaisuudet. Tämän jälkeen analysoidaan ohjelmisto hyödyntäen työn tekemää listaa industry 4.0 teknologioista.

Lopuksi iPES kyky suoriutua industry 4.0 ympäristössä analysoidaan käyttäen teknologialistaa. Tämän avulla selvitetään mahdollisia ongelmia, joita voi esiintyä tulevaisuudessa. Saadaan myös listaus tärkeimmistä kehityskohdista, joihin tuotannon aikana tulisi keskittyä.

Avainsanat: Industry 4.0, MES, Valmistava teollisuus

PREFACE

First I want to thank Kari Systä for great guidance throughout this project. He helped me in coming up with the thesis topic and was fast to respond to my questions. Also thanks to Tampere University for giving the opportunity to study Information Technology.

Special thanks to my workplace Pinja. The idea for the thesis came from working there and I got to use their project as an example. They gave me the time I needed to complete this project.

I also want to thank for the years spent in Tampereen TietoTeekkarikilta, getting to know people and having fun together. Biggest thanks goes to Tupsula as it has been the best place to live in for the last couple of years. Especially Keke-team kitchen, which has the best open office space for writing a thesis.

At Tampere, 4th November 2020

Tommi Linnamaa

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LIST OF SYMBOLS AND ABBREVIATIONS

API	Application Programming Interface
AR	Augmented Reality
BOM	Bill of material
CAD	Computer Aided Design
ERP	Enterprise Resource Planning
EU	European Union
GDPR	General Data Protection Regulation
I4	Industry 4.0
IoT	Internet of things
ISA	International Society of Automation, non profit society of enginers. Develops standards for automation
MES	Manufacturing execution systems
RAMI4.0	Reference Architectural Model Industrie 4.0
REST	representational state transfer
TAU	Tampereen yliopisto (engl. Tampere University)
TUNI	Tampere Universities
URL	Uniform Resource Locator
VPN	Virtual Private Network

1 INTRODUCTION

Industry 4.0 is a commonly used term in manufacturing. Which is the idea of how manufacturing industry will work in the next decade. Industry 4.0 will bring a lot of automation and communication between devices. Knowing what is going to happen in the future will give a competitive edge to all organizations.

However, reading about Industry 4.0 can be confusing, as everything mostly focuses on the big picture. This thesis will narrow the focus and see how it will effect the manufacturing execution systems. This will be done by creating easily identifiable elements from industry 4.0 that can then be analysed in the context of a MES software.

This thesis will map out all the typical elements of Industry 4.0. After that, the elements will be compared to Pinja's iPES software. Using the industry 4.0 elements it is possible to identify future problems. This will help development of software to focus on elements that will be relevant in the future, and not waste time on unneeded features.

This thesis starts by going through the research methods. Then takes a look at manufacturing industry and what context industry 4.0 and manufacturing execution system have in relation to it. After that, this thesis will take a in-depth look on key elements that a manufacturing execution system can take advantage of in the industry 4.0 environment. When that is established, Pinja's iPES MES software features are introduced. Then iPES is compared with industry 4.0 key elements and seen how it takes advantage of them. Last is a summary of the results.

2 RESEARCH METHOD

This chapter will describe the research methods in this thesis and what is its general purpose. First is discussed the general problem. The different research methods and goals will be examined. Lastly, the benefits of this analysis will be discussed.

Industry 4.0 Is a term coined by a German research group [1]. It is meant to represent the next movement in the manufacturing industry. Which is the movement towards connected devices and people in manufacturing. Meaning usage of data and IoT connectivity. All equipment in a production line gather data and share it between them. This helps foresee possible problems and help users make decisions faster by taking advantage of the data.

This thesis is done by researching literary publications related to Industry 4.0 and manufacturing execution systems. Using publication research, a general idea of industry 4.0 and manufacturing executions system will be generated. This thesis will then combine these two and compare what there is to gain in this new, connected environment for manufacturing execution system. There will also be discussion of concepts in industry 4.0 that do not have an effect in the manufacturing execution system environment.

Industry 4.0 is not a definitive standard. So this thesis will try to simplify the confusion related to Industry 4.0. Aim is to get a better understanding what is Industry 4.0 and some core concepts for a software that is part of a bigger entity. There is also a focus on dividing Industry 4.0 into easy to understand technical entities. This will be done by comparing publications about Industry 4.0 and finding similarities between them.

Once the general functionalities of a manufacturing execution system in industry 4.0 has been mapped out. This thesis takes a MES software under development and compares how well it implements the functionalities. This will give insight for possible future development of the system.

As the Industry 4.0 is a idea aiming to show what future manufacturing process will be. There are papers defining what are the characteristics of Industry 4.0. The aim of this thesis is to look at how Industry 4.0 can be utilized to evaluate a MES. This will be done by taking Pinjas software and see how well it fills the Industry 4.0 characteristics.

Pinja develops products for the manufacturing industry. One of which is a MES software called iPES. It focuses on production lines orders and storage capacity. There is a new version of the product that is created for mobile tablets and computer browsers.

In the end, there will be a better understanding what Pinjas software does well and what are some possible improvements to be made. This will hopefully demonstrate what needs to be done to future proof the software.

3 BACKGROUND AND MATERIAL

This chapter handle all the core systems around Industry 4.0 and the Manufacturing Execution System. As these are two different systems, before analysing how they work together, there needs to be a understanding of both of them as a single entity.

This chapter starts by describing organizations operative branch and manufacturing industry. Once the core idea if manufacturing has been introduced, the thesis will describe the history of manufacturing and how it leads up to Industry 4.0. Then the thesis will go through what industry 4.0 is.

After the description of industry 4.0 the thesis will start describing the context of a manufacturing execution system. Starting with the whole structure of manufacturing, so that there is a understanding on what level the manufacturing execution system operates at. Last in this chapter is the description of manufacturing execution system main functionalities.

3.1 Operations

A organizations main objective is to fill the demand with supply. This is brought up in the book Operations management [2]. Organization should have balance of customer need and wants. By not fulfilling the demand, the organization is missing out on possible profits. On the other side, if organization is supplying more than there is demand, it is doing unnecessary work, as it is doing more than needed.

The book divides a organization in to three different parts. These are finance, operations and marketing, as is depicted in figure 3.1. The finances responsibility is to manage accusations. They acquire needed resources and distribute throughout the organization as is needed. Marketing keeps track of the needs. It keeps an eye on the market and tries to keep up with the needs of the customers. Also trying to effect the needs by marketing own services to customers. The last one, and most important for this thesis is operations.

Operations is the part in a organization that focuses on producing goods for the needs. Operations try and get its goods and services to the customer as optimally as possible and with the resources that it has to its own use.

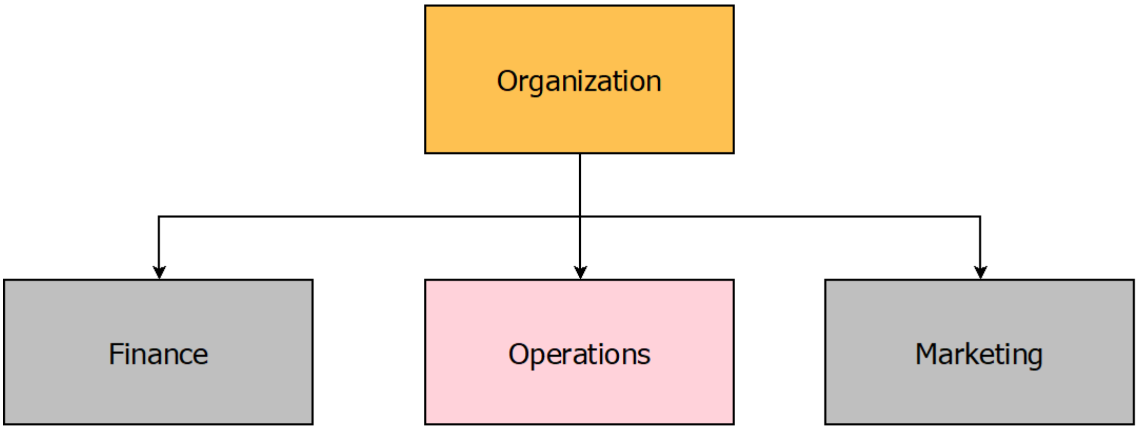

Figure 3.1. Organization is divided into three parts. This thesis will focus on the operational section.

It is also important to note, that there are two different outputs that operations can have. These are either goods or services. Goods use materials and turn them into something more valuable. While services focuses on giving customer something that is tailored to them specifically and their needs. It is also nothing physical, more, it is some type of combination of time, location, form and psychological values. This thesis will focus only on industry that produces goods. That is often some type of material or products that are processes. For example the production of a bicycle is a type of goods that is produces. It needs to be assembled, painted and packed. All these require their own materials that are then processed to its own product: a bike.

3.2 Manufacturing Industry

On this section we will define the current environment for manufacturing industry. What this thesis means when talking about industry and how it has evolved over the years. This will give us the basis for this thesis. Why it is important to look for changes in manufacturing industry.

Manufacturing industry is described as "An industry that produces goods rather than services, or these industries considered as a group" . The goal is to manufacture goods from material. Creating value by processing materials into something more valuable.

The focus will be on the manufacturing industry in this thesis. It is important to note, that here is also a own industry in producing services. The management of services is a bit different, as they do not focus much on the use of goods.

When discussing production, resources are a big part of it. Production is always limited by its resources. The book [3] divides resources into four main categories. The four categories are capital, work, materials and knowledge. Everything needed for producing products is included in one of these elements.

Capital is all the physical elements needed for production. This includes possession of real estate, factory floor and its machines, IT-infrastructure and other physical investments alike. Work is the possible contribution that each worker can give for the production of goods. Materials are all the goods used in the production of products. This varies a lot depending on the type of product in production. Lastly there is Knowledge. This includes all the non physical possessions in the production. Things like know-how of the workforce, owned licenses and patents. The acquisition and functionality of all of these elements works differently. But similarity is that all of these the company can either do them selves or get from somewhere else.

It is not realistically possible to produce exactly the needed amount in time. The good thing about producing goods, is that they can be stored for later use. This helps meet the needs in time. As it is possible to produce goods into storage before they are needed. Then use them when the need arises. The down side is that storing goods costs resources. For example, the food industry has high costs for storing food, as it needs to kept cold to avoid spoilage. So the aim is to minimize storage. But having enough in storage to meet the demand.

There should also be a separation of manufacturing and project. Project is something with a life cycle. It has a start and an end. Of course there can be projects within the manufacturing process. For example project to streamline or optimize the production line. Another example could be a project in renewing a machine inside the factory. These are both examples that can have an effect on the production. But, for this thesis we will be focusing on the continuous production of products. Project can be seen as a exception in production for the manufacturing process.

Throughout history, the manufacturing industry has had multiple revolutions. Meaning that there has been a drastic change in the way manufacturing is done. The change leads to a rapid increase in the volume of produced goods and at the same time the use of materials reduces. This is described in a paper by Popkova [4]. When a industrial revolution hits, it is because of a new technological advancement. The new technology also has its own needs. Revolution leads to changes in infrastructure and logistics.

There have been three different revolutions throughout history. First one happened in 18th century to beginning of 19th century [4]. It was the first movement to industrial manufacturing. Before that everything was done by manual labour. the first industrial revolution led to creation of the whole infrastructure and logistics. First production machines were created. Transportation was done by steam powered vehicles. To take advantage of the new technologies, it was required to meat all the requirements. When all was set up, the manufacturing machines connected with a steam transport. You could manufacture way more efficiently compared to a factory full of people making everything by hand.

Second industrial revolution came with the conveyer belt and it happened in the late 19 to early 20th century [4]. It allowed the manufacturing to become more systematic than before. Materials could be moved in a steady pace throughout the factory. At the same time it allowed the use of railways. Again, to keep up with competition and production investments into conveyer belts and railways had to be done. This sped up the manufacturing again.

Last industrial revolution was in the end of 20th century [4]. It was the rise of digitalization and globalization. To stay relevant in the industry. Manufacturing needed to move to digitalized equipment and global products. Logistics grew and transportation lengths were longer. Products move between continents. Use of computers become essential.

Now we are on the beginning of 21st century. Studies have spotted a movement towards a new trend. The use of big data and IoT equipment. As a plan for future, a German workgroup group coined the term Industry 4.0 at Hannover fest on 2011 [1]. This is what the next industrial revolution is called, and it is happening right now.

3.3 Industry 4.0

The world digitalizing fast and so is the industry. The Germans coined the term Industry 4.0 [1]. Figure 3.2 shows us the different revolution stages these were talked about in detail in the last section.

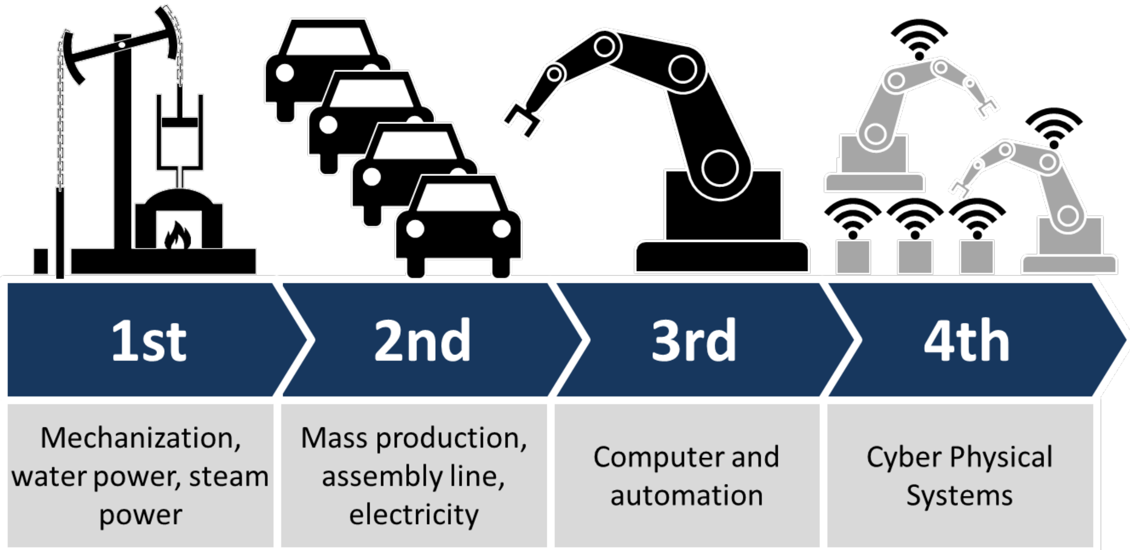

Figure 3.2. *Illustrates all the different industry periods [5].*

Industry 4.0, shortened as I4 in this thesis, is the concept of moving to a new Industrial revolution capitalizing on current new technologies. It will also make some of the structures and standards of today obsolete and require a new way of thinking. [6]

There are papers that summarize the technologies and concepts around I4. This thesis uses two papers for its basis of technologies. First one of them is a paper called How to Define Industry4.0: The Main Pillars Of Industry 4.0 [7]. The second paper is called Industry 4.0 [8]. Next the concepts and technologies described in these papers will be defined.

The usage of **big data** is a great value for a company. When producing goods there is a lot of data that can be utilized. Also when the amount of systems, sensors and smart machines increases, the amount of data available also increases by a huge margin. This can be used for example in quality control, analysing statistics on the probability of failure. Data is also used in forecasting trends and needs in production [2].

The increase in sensors and systems also lead to the so called **smart factory**. A smart factory can respond fluently to exceptions. Say a machine breaks down, the factory would get a signal from the machine and its sensors and be able to notify maintenance of the problem. Maybe even have a alternative production route to work around the broken machine.

Having a factory that acknowledges its own state will require some **autonomous robots** to function. This inhales that there are robots that can work independently without instructions. For example the autonomous robots in Amazon warehouses that are able to move packages by them selves [9].

All the produced goods and machines will also have a **virtual representation** of them selves. When production moves from one stage to another, its virtual counterpart will follow in the virtual factory. The whole process has a virtual copy of itself. this can then be used by software to, for example, predict the process and see if it is on time.

As virtualizing factories and their components becomes common, this also allows for use of **simulations**. No need to manually rearrange factory layouts for supposed optimization. Rather, this can first be simulated. Creating a virtual factory with new parameters. Then evaluating the data to current factory parameters. This allows for comparison between the current and possible new work conditions, without the risk of actually committing too much resources to implementation.

When the amount of systems and smart robots increase, the way they communicating with each other is called **integrated systems**. They need to be able to communicate with each other. They can not work in a vacuum. They need to be aware of the surrounding and the state of previous and next system. In other words. There needs to be a increase in vertical and horizontal integration. Meaning that machines need to be able to communicate between each other. Like two machines that operate one after another. When other has a task ready and is ready to move it forwards. It needs to be able to signal this to the next machine. This is the vertical integration part. There is also the horizontal direction. Meaning systems need to be able to communicate upwards and downwards in the abstraction levels. This is like a machine informing upwards to management that it has started a operation.

One of the main necessities is that all the communication is done through wireless network. This is because of the multitude of different apparatuses and **Internet of Things** (IoT) devices. IoT devices are devices made for collecting data and to be used without the need of a human. These also work wirelessly [10]. There is no need for central network infrastructure. The goal is to move all calculations and software to the cloud. Using cloud removes the need of upkeeping own networks and infrastructures. Managing all data is easier in the cloud. As it can scale in parallel with the amount of data.

I4 tries to capitalize on newest technologies. One of the main concepts in I4 is the possibility of mass producing highly customizable products. This can be seen with the adoption of 3d printers. When 3d modelling is utilized, changes can be made virtually and it can be used in production instantly with the use of 3d printing. Rapid prototyping and instantly customizable end products is called **additive manufacturing**.

As there is a multitude of available data, it can be processed and used to **visualize** the states and statuses of different operations and systems. As there are a multitude of systems in place, the importance of good visualization increases. Being able to instantly see the state of the factories production allows users to know what is happening in the system.

One way to visualize and support users is the use of **Augmented reality** (AR). AR allows user to interact with the real world through a virtualized visualization [11]. Moving through shop floor with AR technology and seeing through it the state of machines and their operations. This gives instant feedback from the real world to user. This requires accurate mapping and data of the whole factory.

Of course with all of this use of different networks arises the issue of security. Different cloud platforms can be attacked remotely and having access to critical parts of the software can stop the full production of the factory. This leads to **cyber security** having a big role in a I4 environment.

3.4 Manufacturing Structure

The manufacturing process can be a long and complicated procedure. There are multiple factors that make up the process. This thesis will concentrate on the production of products that are derived from materials and different intermediate products. Meaning that different materials are processed and combined into products that are then sold to customers. This will require good inventory and assembly management. This section will take a overview of the process as a whole. What the typical structure of manufacturing process looks like.

ISA95 ISA95 [12] divides manufacturing into 5 different levels. The levels go from 0 up to 4. This is depicted in the figure 3.3. At the lowest level, that is level 0, there is the process it self. This is where the actual transformation happens. Materials are processed and transformed. The lower we are in the levels, the smaller the examined time frame is. For lowest level we talk about milliseconds.

Level 1 include all possible data collection of the process. There are sensors and analysers controlling the process. Systems that make decisions based on the data collected by the sensors. At this level are the possible control panels for the current process. In the shop floor level where operator can see different statistics of the process. For example a monitor with the current temperature of a heating process. On level 1 the observed time frame is seconds.

Next we have level 2. This is again higher up abstraction level. This is a overall view of the current process. Not including much detail. Mainly for supervisors to see the current state of the process. This level will also include communication to other relevant processes. Like informing next process when it is done for it to be ready to receive new input. Level 2 handles everything by the minute.

Level 3 is the main focus for this thesis, this is the operation management level. Level 3 manages all the operations and their workflow. Factory needs to process its daily tasks in a optimized order. Level 3 is responsible for scheduling operations and seeing that they can be completed. Manages communication with other areas in factory. Keeps track of inventory and that it is sufficient and that all operations have the needed materials. For example when one process gets delayed. The level 3 will get this signal from the level 2 control systems. Then its the operation managements responsibility to manage other operation start time to compensate for the one delayed process. For managing the operations on level 3 there have been created multiple different Manufacturing execution systems. These are systems for controlling the responsibility in level 3 and communicating to levels 2 and 4. When managing operations we are managing them for about that current time. So managed time is about a hour instances.

Last there is level 4. This is the business logic of enterprises. System related to managing enterprises system logic is called Enterprise Resource Planning or ERP for short. It handles management, data and communication between all other systems. That is storage, sales, logistics, products, HR, production and multitude of other areas related to organization. For level 4 the time frame of interest is all the way from years to days.

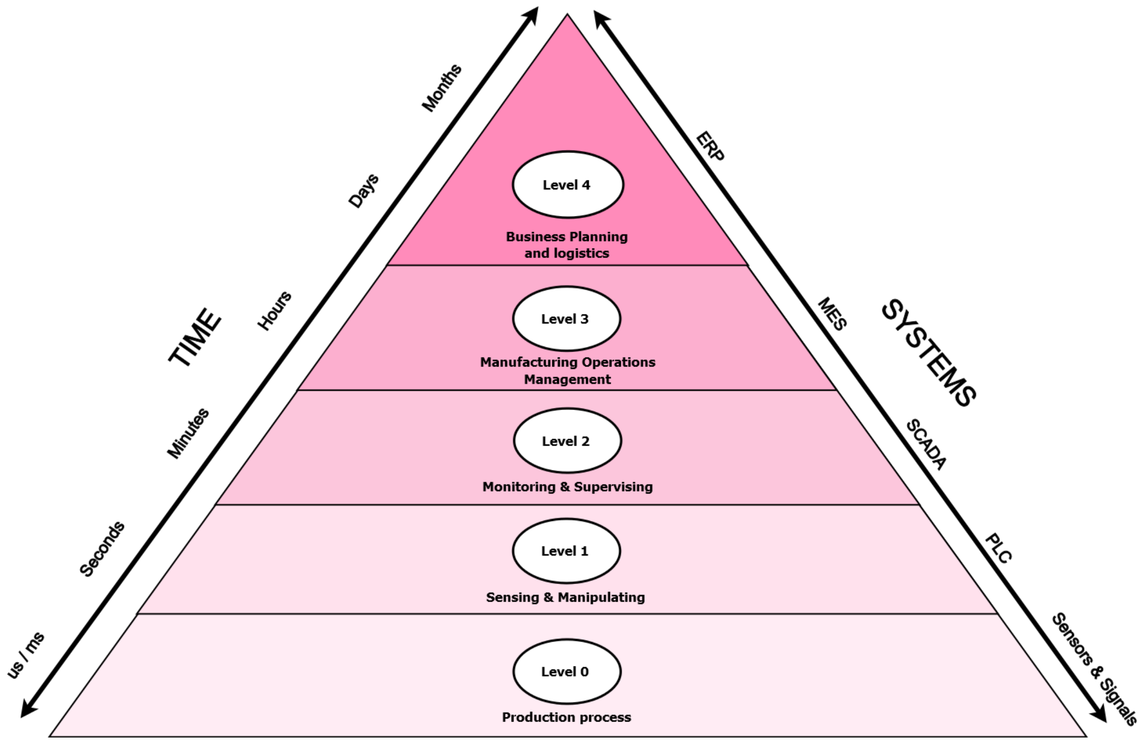

Figure 3.3. *All levels of ISA95 automation pyramid [12].*

Figure 3.3 visualizes the ISA95 defined levels as a automation pyramid. This helps visualize the concept. Each level needs to communicate the one above and under itself.

3.5 Manufacturing execution system

Manufacturing execution system, better known as MES. This section will take a look at what are the required inputs for MES and when should it be used. There will also be a list of possible outputs a MES system can produce.

As discussed in last section, MES works on the level 3 as defined by ISA95 standard [12]. Meaning it manages the work flow in a factory. This is calculating what is produced and when. Often times, factories produce multiple different end products. End product is a collection of different raw materials, sub assemblies and processes creating the end result that is called end product. All these different processes are often times done in parallel in multiple different locations in a factory. MES is what manages all these parts.

A working MES need couple of different inputs. In Stevenson and Williams book [2] there are three different inputs defined. These are called master schedule, bill of material and inventory. This is the minimum for a working MES. This are now described in detail.

Master schedule is the requirements of products for MES. The main questions master schedule answers are what is needed? When it is needed? How much of it is needed? For example when having a bike factory producing bikes, it includes what bikes should be produced. When should these bikes be ready for customer and how many each customer needs. This gives MES its basic data to use, it now has a requirement and goal.

Now that MES knows what it wants to produce. It needs to know how to produce it. That is why every end product should have a BOM - bill of material. This is a list of all materials needed to create the product. Example of a BOM can be seen in figure 3.4. It shows what parts are needed to create what products. There are also sub products. Like the bike frame. This is produced by welding together multiple bike frame parts. This will give us the total amount of material needed to produce a bike. One end product can have multiple sub products, which in part are made of other materials. Now creating one bike will need one frame and one frame is made from three frame parts. If there is a need for 100 bikes, it will require 300 frames.

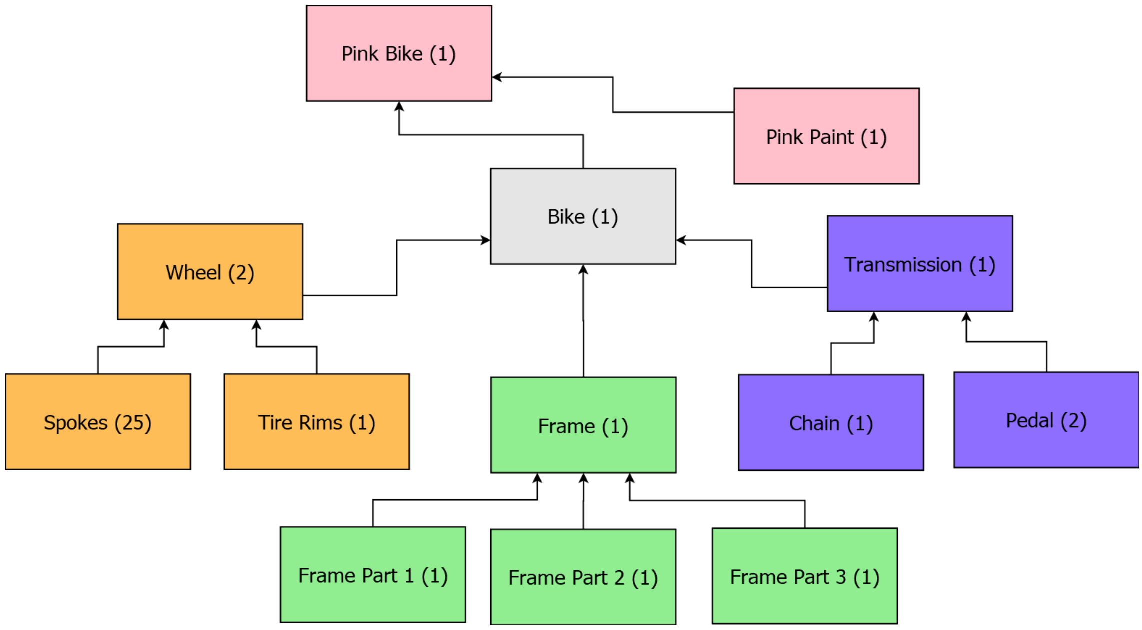

Figure 3.4. *Diagram of a BOM for a simple bike. Shows what materials are needed for each part.*

The third input that MES need is the inventory. This is knowledge of what products and materials are already ready to be used. If there are not enough materials for producing all the required goods, they are either needed to be produced or order more from subcontractor. This also will have a impact on the time producing end product. It might take longer for materials to be ready for use, meaning some operations will get delayed. This will push all operations forwards in time that have dependency for the delayed process.

After having all the needed inputs, MES is able to create multiple different outputs. The main outputs are a planned schedule, tasks for each process and possible updates in orders. They are used to manage whole work process. There are also some secondary outputs. Multiple different analytical measurements. MES is also able to update the inventory throughout the process.

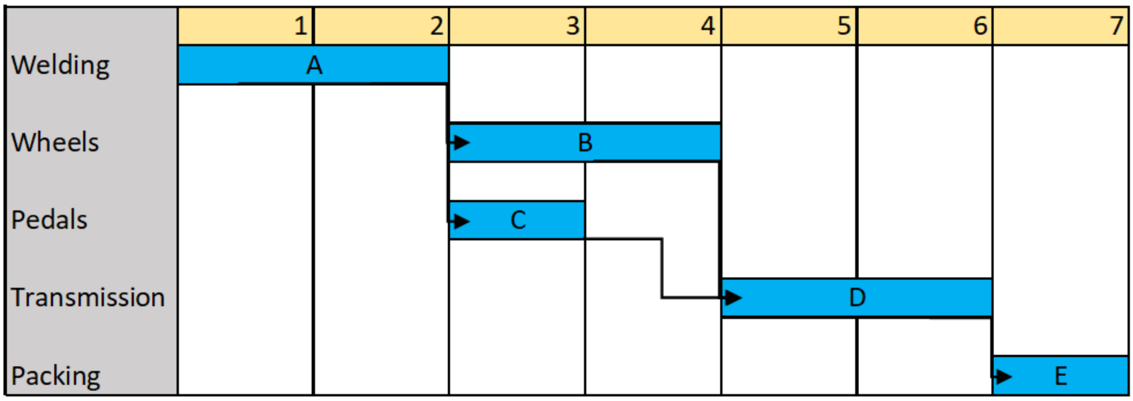

Figure 3.5. *A Gantt chart of production stages and how they are linked with each other.*

Knowing the material needs and when they are needed allows MES to calculate needs downwards. Creating a sub or end product takes time. Some processes needs to wait for others before they can start processing. This is visualized in figure 3.5. It shows relationships between different operations. Operations are when we take materials or sub product and process them to something else. For example in the figure the operation A represents the welding of frames together. On top is shown how long these operations take. It can also be noted, that operation B and C can not start, before operation A is done. Also, operation D has a dependency on B and C finishing. When calculating all requirement for different operations the end result will tell us when end product will be ready. For the example in the figure, bicycle will be ready for shipment for customer in seven timeframes.

The plan gives the processes their work schedule. Using the plan, all the different processes will have their daily schedule for the day. They can work according to the plan. If everything goes without exceptions, the upper level can work with the predicted completion times for products. This means, that the ERP level will have knowledge when products will be ready. So they can promise customers accurate shipping times.

The aim is to have as close to real-time data in MES as possible. This allows for possible exceptions to be handled as fast as possible. For example if a machine breaks down, this should be represented in the planned schedule. Taking one resource out of the plan will delay production. But with an accurate MES it is possible to notice problems and react in time. At least it is possible to notice possible delays and inform customers about them in time.

Throughout the production, MES processes huge amounts of data. This can be later used to get some analytical data from the manufacturing process. For example knowing what resource is being over used or bottle neck. Bottle neck meaning that there is a process that slows down all the other processes. Allows the factory to consider the acquisition of new equipment to increase production.

MES will use materials and produce goods. This will have a change in the organizations inventory. It is important for MES to keep the inventory up to date. As it will have an effect on future production. All materials that are used should be updated to inventory, and all created products that are stored in inventory should be added.

4 MES FUNCTIONALITIES IN INDUSTRY 4.0

This chapter will compare MES functionalities and how they can utilize the core concepts of Industry 4.0. In the end all the core concepts have been listed and marked as either be critical, major, minor, trivial or irrelevant for a MES in a i4 environment.

Even though all core concepts are important for implementing I4. This thesis focuses on the point of view for MES applications. Implementing I4 should be a strategy for the whole corporation and MES is only a small part of it. Thus not every I4 concept can be implemented in a MES. That is why it is important to separate the most important features to be implemented. The goal is not to find a solution or how to implement the core concepts of I4. The goal is to filter out what should be focused on and what is unimportant for a MES.

4.1 Big Data

In the manufacturing industry big data is used mostly in the production and planning areas. The use of big data is for accuracy in the predictions and forecasts [13]. As future scheduling is the area where MES operates at, it is safe to say, that MES should be able to manage big data.

It is already mentioned, that MES handles a lot of different data. There is all the data coming from processes. Possible data input layers are the level 2 and level 4 ISA95 levels. MES in itself also handles data, thus possible data sources are ERP, shop floor robots and MES own data.

For MES there is not much that ERP can give regarding big data. This is stated in 3.4 as one of the inputs is the planned schedule, which comes from ERP. MES only utilizes the planned schedule, it should not manage it. Generating the planned schedule should involve some type of machine learning and big data management. But this is the responsibility of ERP.

It has been stated that current problem with the robots on the shop floor, is that they have their own communication methods and there is no standardized protocol [14]. As the paper states, there could be a centralized big data module for shop floor data. This could process the data and send it to MES. So one requirement would be for MES to add another input. Which would be the updated process data transformed in another big data module. This MES input should be able to make adjustments to scheduling calculations and iterate them throughout the manufacturing.

Problem with MES is that every manufacturing process is different. There are many different scheduling methods to optimise the production process. Forward and backwards scheduling which schedule depending on the planned completion date. Its also possible to schedule by trying to optimize the use of the bottleneck operation [2]. The problem is hat there are multiple variants and parameters that like setup and wait times etc. There are already tries to implement the use of big data and machine learning for scheduling [15].

A advanced scheduling method is important for the success of MES. Often times there are implementations of simple scheduling like forward and backwards scheduling [2]. As these work, but having a scheduling utilizing big data can be a major selling point for a MES. Implementation of big data will be rated as major.

4.2 Smart factory

The concept of smart factory is larger that the MES itself. It incorporates the communication between all the moving pieces in a factory. MES is only a small part in this, but it still might play a big role in it. It is also argued that MES wont have a place in a fully autonomous smart factory [16]. Because everything is decentralized and everything works by cooperating with each other and there is no need for centralized system.

Because a fully autonomous shop floor is still a long time away, there will be a transition period before that. At that point, MES will have an important role. As all operations and shop floor equipment manages to communicate with each other, they need to have some type of control unit that sees the whole picture and can guides the work flow. Considering the inputs and MES responsibilities, it will be the perfect module to control movement within the shop floor.

As MES has the knowledge of all current operations and materials in the shop floor. It would only need a way to communicate with all the elements in shop floor. Thus it could be arguable for a I4 compatible MES to have a new output category, the operational output. This would include instructions for processes, logistical robots and maintenance. This needs to be a iterative process. All changes happening in real-time needs to be updated into MES by the same entities. So MES needs to be also able to receive data from the processes, logistical robots and maintenance.

Data sent to processes would be parameters as what are its next materials. Once the process has all the required materials, it can ask MES for permission to start the operation. Processes can send real-time information for when they will be ready. MES can take this into account and modify expected completion times to more accurate.

The job of logistical robots is to move material from process to process. They are also required to get needed materials from storages. MES will keep a list of all working logistical robots on its shop floor. It should know the state of all robots. What they are getting and where. This also requires for the logistical robots to have a communication platform with the MES software. For this MES will its own module that manages the swarm of logistical robots and handles the controls.

Maintenance is a big part of manufacturing industry. Equipment that can manage their maintenance needs by them selves, is a part of the smart factory idea. Malfunctioning equipment can have a effect on multiple different elements in production. For example lower quality, lower capacity or even safety concerns [2]. By utilizing the sensor data of equipment, MES can have a good knowledge of the status of equipment. Organization can set limits for when to repair certain equipment to optimize costs and time. The paper about smart MES [14] shows how there could be a system that when detecting a problem in a equipment, there would be a automatic alert for maintenance as soon as the problem is detected. All equipment maintenance will have a effect on the MES scheduling. Either MES need to handle equipment maintenance by itself, or be able to handle data that informs of the current and future state of equipment.

There is some discussion about the role of MES in the future [16]. As Factories get smarter the shop floor needs less management. In the future the goal is to have functioning hivemind of robots that does not need anyone organizing them. But before this happens, something needs to handle the workflow of the factory floor. As MES handles the scheduling, it is a prime candidate to organize it. Thus it can be argued that as long as autonomous robots can do everything by them selves, they need to be commanded by something. MES has all the knowledge to do this. To keep its value and do its task, the ability to manage a smart factory is critical. At minimum this is the created schedule for each resource, which is the main responsibility of MES anyway.

4.3 Autonomous robots

The concept of autonomous robots really important for I4 development. But as MES is a software solution, it has nothing to do with physical equipment and how they work. Of course MES utilizes these robots but this sections is about acquiring working automated robots. Thus it is easy to state, that for MES this concept is irrelevant.

4.4 Virtual representation

Because of the amount of data to be gathered in a I4 factory. The ability to create a virtual object of products and machines becomes possible. Gathering all the essential parameters of the production. Allows us to create a virtualized environment of the factory. As the operations in shop floor go from one stage to another. There will be a virtualized copy doing the same in the virtual world created.

As MES will have all the needed data by its inputs. It becomes natural to give MES the responsibility of creating the virtual representation of the factory. Most important thing to virtualize are the equipment, state of production, materials and products. All of the data should come from different sensors and IoT devices. There should be no need to manually insert any values to the system.

Virtualizing the equipment allows to keep an accurate description of the state of them without needing to go on-site to check them up. This could lead to more accurate calculations when MES is creating the planning schedule. As each equipment's efficiency can increase and decrease depending on its condition. If it is known, that a equipment works only at half the capacity, this can be taken in to account in the calculations.

When all the moving products have a virtual representation that is updated throughout the manufacturing process. It makes it possible to show in real-time the current state of production. When a equipment starts a new process. It can send a signal to MES that the operation has stated, continuously updating its progress. This allows for real-time representation and visualization. Also effecting next operations. As there comes updates of the current situations, these can be utilized to recalculate the planned schedule. Thus giving a more accurate prediction of the completion times. This is the main task of MES [2] so staying up-to-date of the current state of production is really important.

At the time when production moves forward. The current materials and products in inventory change. If a operation is tasked to melt gold into hundred gold bars. Throughout the process. MES should be updated with the amount of gold used and new gold bars created. The amount of available gold bars will increase at same rate as gold materials go down. This should be updated into the MES virtual representation of production.

Main objectives of MES is to create accurate data and predictions of manufacturing process, as stated earlier in the thesis. Having a accurate virtual representation of the factory is crucial. It allows for real-time visualization of the state of factory shop floor. It will also increase the accuracy of planning, when all data comes directly from the shop floor. Virtual representation effecting all the main functionalities of MES and improving the main MES functionalities, this concept is important to implements. Thus is ranked as critical.

4.5 Simulation

When all physical elements have their own virtual counterpart. It becomes easy to attach a 3D model to these virtual elements. This opens up the ability simulate factory conditions. Creating virtual factory running just like the physical factory.

For MES this opens the possibility of simulating the planning schedule. This is a alternative method of running MES scheduling. As scheduling is a way to organize the work flow of shop floor to meet product order target dates.

Simulation is just one way to schedule. As earlier in this thesis was mentioned, this could also be done using machine learning. These are just two different approaches to the same problem. Simulation is using a more controlled environment. Capitalizing on accurate models of all the factory equipment. With accurate date it can be possible to run simulations using different parameters and see what the end result would be. This works a bit differently compared to machine learning. Machine learning takes advantage of all data gathered throughout the manufacturing process. By tweaking inputs and comparing outputs, it can optimize the work flow. So machine learning is more of a black box operation, where users have little control of how it works. Simulation on the other hand relies on that users can insert accurate data into its object to allow for a better result. Both are valid options that can be used in different situations.

A example of scheduling using simulation is the Simio framework [17]. Here a whole factory has been modelled. The main idea is to not solve the problem of scheduling. Rather give all factory elements accurate logic work flow. Then running the planned orders into the system and seeing how it functions. If problems arise, it is easy to change some scheduling parameters and scheduling decision parameters. Maybe change the prioritise to maximise a particular resource capacity. Running the simulation again allows to see how this would effect the end result. Changing these different parameters is something that can be done by the machine automatically. Trying different parameter compositions and seeing witch has the best end result.

As MES main tasks is to create a valid schedule plan. Having a way to do the actual scheduling is a must. Now in a I4 environment the decision to use machine learning algorithms or simulations is a though question. The chosen solution mostly depends on the available data. If there is accurate data of all the equipment and resources in the factory simulation becomes a option. But if there is a abundance of historical data, machine learning becomes a option. Especially when there are no accurate factory data or when the work flow in the factory become so complicated that simulations have too much parameters to take into account. Here a black box machine learning algorithm can find a good schedule model. As it cares only for input values, and does not care how the factory's work flow works. But no matter which approach is chosen, in a I4 factory at least use of one of the solutions would be highly encouraged.

When looking at what simulations bring to the table and comparing that to MES. It can be said, that simulating the environment and thus creating a schedule plan is exactly what MES is supposed to do. Basically at this point, the idea is to simulate MES functionalities and pick the best ones. So it could be argued, that simulation is not something that would support MES but rather replace it. Simulations have the same inputs, main tasks and also outputs. The only difference is, that it can be ran virtually. This allows the user to try different methods and pick the one that works best. This is why simulation wont be considered as a MES functionality in this thesis. As it is an entity of its own. Simulations will be marked as irrelevant.

4.6 Integrated systems

At this point it should be clear that in the I4 world, there is a lot of communication happening between devices and systems. The communication is happening vertically and horizontally. As main idea of I4 is to have a fully autonomously working system, it becomes obvious that devices needs to be able to communicate with each other. This section defines where MES stands in a I4 factory and what components it will be communicating with.

Having all systems heavily integrated will also shift the decision making to be more dynamic. No longer will the manufacturing order go from top to bottom. ERP should not be solely responsible for the planning. MES can take more responsibility in the planning process. This is noted in a paper about key factors in I4 success [18]. Here is noted that business decisions can happen at lower level as there the process is better known.

The reference architecture model industrie 4.0, seen in figure 4.1, visualizes the communication between systems and layers. It has different integration layers horizontal, vertical and product lifecycle. The idea is to have all elements connected to each other and work together. RAMI4.0 is built using three axis's. There is the factory hierarchy, product life cycle and architecture.

First axis is the factory hierarchy. This could also be seen as the horizontal layer. In this, the connected world is the highest level. It is basically the cloud and internet. Where are computation and calculations are happening. It is a concept outside the factory. All the computing power that is not required inside the factory. The connected world will then be integrated to the factory through higher level factory elements. In the middle there is the factory floor. This is all the different equipment and resources used in manufacturing process. Also includes all the small IoT devices. This would be where MES also will be functioning. Last there is the smart products them selves. These are the end products.

Another axis of RAMI4.0 is the product life cycle. It starts with the planning of a product. This includes prototyping and modelling. Knowing what to produce will allow the calculations of needed materials and resources. Thus begins the construction planes. These includes the work flow in the factory, what processes needs to be done. Last there is the execution part of production. Creating the product and then planning its possible maintenance. These are the product and factory management instances.

The last axis is the horizontal layer. This is where all different systems communicate between each other. The highest one being the organization and its business process. It will go down all the way into physical elements. Last is the physical equipment inside the factory. MES is responsibilities are located in functional and informational layers. Functional layer manages the production. Information layer includes info of products, such as their products. As MES has a large are of responsibilities. It is natural it will be divided between layers.

Because of the heavy integration and communication between systems, it is important to have a solid documentation and keep different MES modules as modular as possible. As in the end plan of I4 is to decentralize all functionality [16]. If MES becomes obsolete, with modular components it can still be made into smaller working modules. In the future MES might not be one big centralized data source, but rather split into different working autonomous entities.

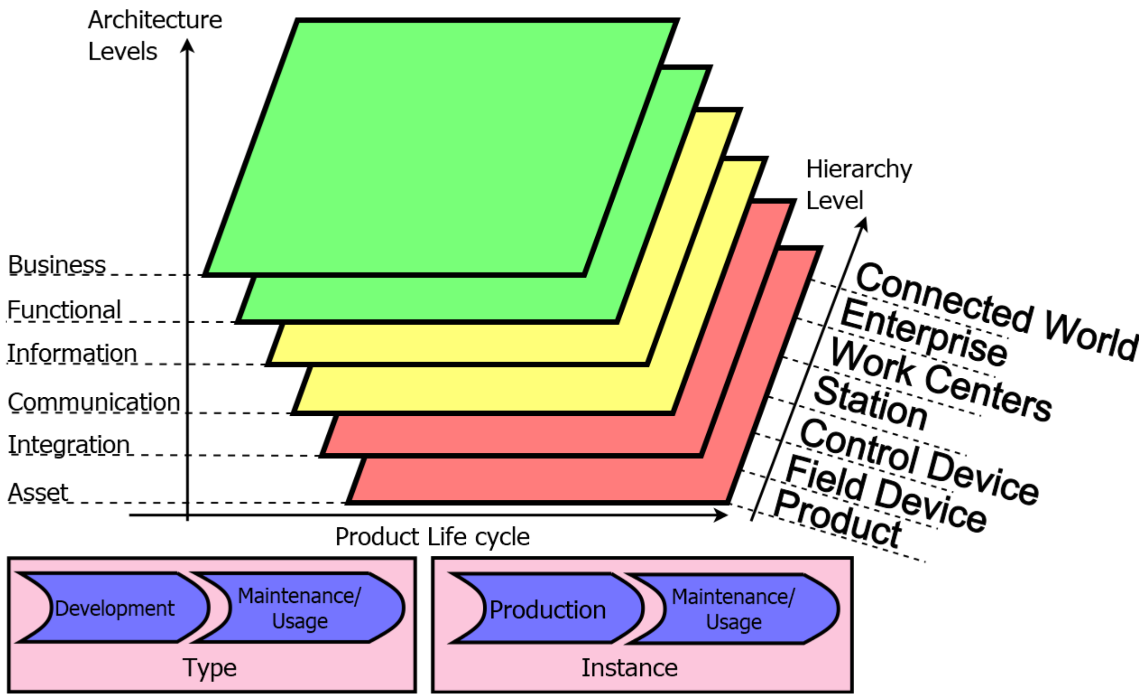

Figure 4.1. *Visualization of integration layers called RAMI4.0 [19].*

There has been discussion if MES has a place in a fully matured I4 environment [20]. As all the components are autonomous and can order them self. But before that, having a modular and self contained scheduling module is crucial for the functionality of a factory. Thus having a open system that can be connected to different inputs is important for the future of MES. Being able to communicate horizontally and vertically is important. Future MES should not be made to a closed big system. Focusing on easy to access data points is important for the future of MES in a I4 environment. Implementing good integration possibilities will be marked as critical.

4.7 Internet of Things

Internet of things is the concept of small devices with sensors that do not need human interaction to work. These are wireless devices providing specific data. In a factory these are in machines and equipment. Gathering data of equipment state and process progress.

This section is about acquisition and use of different IoT devices. MES is a software taking data from different systems, including IoT devices. But as this section is about incorporating IoT devices into a manufacturing factory. The section will be rated as irrelevant for the interest of this thesis. Throughout the thesis we can assume there are IoT devices and sensors in use and the are able to provide MES the required parameters.

4.8 Cloud Computing

In the factory hierarchy of RAMI4.0 the highest level had the connected world. One part of this is the cloud. There are multiple advantages in utilizing the cloud. MES can take advantage of the cloud in following areas: analytics, scalability, pay-per-use, mobile access and centralized data access [18].

Utilizing advanced analytics in the cloud means being able to see the usage and quality of the MES. This allows the organization to easier make decisions regarding software. Allows for the possibility to identify possible bottlenecks. Also if there are problems with the connection or uptime, these will be identified in the analytics.

One of the main features of cloud computing is the easy possibility of scaling. As cloud consists of clusters of servers that are interlinked. So when there becomes a increasing need of computation power, the organization can increase the available power easily.

Most of cloud platforms business model are by pay-per-use. Considering the organization does not have to invest in its own infrastructure this can save them in upkeep costs and initial investments. When all computing maintenance is taken care of off-site by a third party.

With the factory being able to communicate with the connected world, comes the ability to connect to the cloud from anywhere in the shop floor. For example allowing users on the shop floor instantly to see the schedule created by MES. Before, there were dedicated computers installed in a factory to manage MES. Now it can be accessed from anywhere. Operations can check from the cloud what are the next processes and required materials for them.

Cloud computing helps MES in its main functionalities. As discussed, there will be a lot of data to analyse from different systems and devices. All this data will be stored in to the cloud. The same cloud where MES will be running. Having all data stored in the same place, makes it so that MES can directly access them. This helps with the integration of systems and data availability and real time. The data stored in cloud is straight form all the systems in the factory, making it close to real-time.

To take advantage of cloud computing. The MES should be structured to be able to be run asynchronously in modular components. Otherwise it can not take advantage of the clustered computing power. This needs to be taken into account in early stages of MES development. How different components are going to communicate with each other.

At the moment, cloud seems to bee the future. Organizations are looking for cloud solutions. For MES developers to stay competitive. Their software needs to be cloud compatible. For the functionalities and to stay competitive, the development of cloud computing should be seen as major.

4.9 Additive manufacturing

The current manufacturing does not handle customization of products well. Production lines are created to efficiently produce specific products. Additive manufacturing is creating products using virtual models. This has been done for example in metal manufacturing [21].

When additive manufacturing was introduced, it was first used mainly for fast prototyping [22]. Quickly making up a 3d model and have it produced through a 3d printer soon after. As technologies have advanced the additive manufacturing has become more reliable and scale has been increasing. Main advantages compared to old manufacturing are increased lead time, savings in cost of production and ability to produce complex products.

Most of the advantages of additive manufacturing do not belong to MES. They are mainly material and process related issues. But, as one of MES inputs is the bill of material, which can change dynamically if additive manufacturing is used to implement customizable products. When implementing a MES solution it needs to be able to handle dynamically changing BOMs.

As the effects of additive manufacturing do not have a large impact on MES functionalities, the implementation of it in a MES will be rated as minor. Only requirement is that the materials in BOM values can be changed and this will be taken into account in MES inventory. So the MES values should be linked properly with MES inputs.

4.10 Visualization

Now a days the manufacturing process can be complicated. Knowing what is happening becomes harder. This is why good visualization is important. It helps users and managers to see and react to the state of the shop floor. With the data MES has available, it can visualize order and process progress, resource usage and capacity, inventory updates and possible exceptions in manufacturing.

One of the main views that MES can generate is a simple Gantt chart of manufacturing. It is a depiction with a timeline of how processes are related to each other. It visualizes when and where orders will be processed and completed. An example of a Gantt chat is depicted on figure 3.5. This allows manufacturing planners to get a quick overview of manufacturing process.

When looking for places to optimize in the manufacturing process. Knowing how resources are being used can be valuable for spotting bottlenecks. If a manufacturing process is always being loaded to over 100% capacity, it can be a sign of a bottleneck. Meaning the resource is needed more than what it can provide. Thus for example adding a another resource of the same type can increase the output of manufacturing. But It can be hard to see what resource is being overused. This is why some type of visualization of resources can be important. Showing how close to capacity each resource is being used. This can be a timeline showing how much a resource is needed throughout the process.

Another output that MES has is the inventory updates. Meaning how the inventory of materials and products fluctuate throughout the process. The manufacturing process uses materials to create products and these will change the inventory values. This can be important for noticing trends in use of materials. Another important visualization is to warn users when there are not enough materials to accomplish the production plan. If a material shortage is spotted. It allows planners to either order more materials from sub-contractors before they run out. Another fix would be to change the production schedule so, that products for witch there are materials are being produced.

Even though MES creates a scheduling plan for the shop floor. In reality, problems will arise. Some orders can get delayed and not be able to ship in time. Some resources can break down or become unusable. As MES has a good overview over the whole process. It is a good place to alert users of exceptions. MES should have clear ways to notify users of problems. Possibly have possible fixes to them. Especially manufacturing critical problems should be clearly highlighted to user.

Having a visual view of manufacturing process is important for many organizations. It might not have a effect on the scheduling. But a heavily visualized and smooth user experience in a MES software can be a strong selling point. Visualization is important to keep in mind when developing MES software. However, as it is not the main task of MES it wont be marked as a critical functionality. Rather is should be marked as major, being one of the main selling points and allowing more efficient use of MES.

4.11 Augmented reality

Augmented reality (AR) is the technology of projecting virtual objects into the real world. This requires some type of see-through display that can show user data mapped into real world objects. It also needs to be able to track user movements or gestures. This can be a simple tablet with camera. When using the camera the tablet can enhance the view with directions or information of the surroundings. For operations VR opens up the use of heads-up displays, digital product controls, augmented operator manuals and augmented interfaces [23].

As MES knows the state of manufacturing process. It could feed the data to different AR devices on the shop floor. Giving the possibility to show state of processes and tasks in a AR heads-up display. Looking at a resource and instantly seeing what it is working on and where it will go next. The shop floor layout can be mapped out and show guidelines to next process [24].

The concept of digital production is to project possible virtual modules onto a physical object [25]. Having a camera showing image of a car and then virtually changing the amount of doors or colour of the car in real-time. Idea is to visualize the end product before the assembly. This is valuable in prototyping or highly customizable products. For MES this would be a interface that can feed possible inputs and get the new designed output. When a products assembly or material need changes in production, the changes need to be transferred to MES planned schedule.

MES main objectives is to control the work flow in the factory. This means it has knowledge of all the manufacturing processes. Making MES to be a good place for gathering info on all the operation processes. This combined with AR allows assembly lines to get advanced instructions on how to assemble products with visual feedback. Assemblers can have AR devices on them that virtually guide them in the assembly. Handling all the process guidance might be too big of a entity for MES to handle. It should be implemented as its own module, MES might then forward the information to the processes that require them.

Lastly the use of equipment on shop floor can be enhanced with AR devices and displays. Rather that having buttons to press, there can be visualized function on the equipment and assembly line. Operating machines and equipment with guided AR. This does not belong to MES main tasks. MES handles the overall work flow, and AR guided machines are task specific operations and should not be controlled by MES.

A lot of the possibilities of AR in manufacturing is not in MES scope. Mainly visualizing different process states and forwarding data from other sources. Thus the implementation of AR is not one of the main issues for I4 and MES. It still should have the ability to communicate with possible AR devices so the importance of implementations will be rated as minor.

4.12 Cyber security

Once all the devices and equipment starts to be connected and a lot of the manufacturing is virtual. There becomes a concern of cyber security. As everything is in the cloud, it is possible to access it without being physically percent. Organizations needs to take cyber security seriously in as most of their assets become virtual. A paper on encrypting Computer Aided Design models lists different options on adding security for its data. Some of the methods can be implemented for MES. The methods are, Access controls, Multi-resolution approach, encryption [26].

Access controls is the ability to control who can see what. Requiring a authentication before gaining access to data or operations. When accessing a MES there should be a authentication of user. Use of different level user groups is highly encourages. As different access levels are required by different users. Those working at factory floor should not have access to factory scheduling controls.

When working with cloud and web applications. Multi-resolution approach becomes something to take into account when planning the security. As clients are talking with the server. They only need to send what is needed. For MES, the most valuable system is the server side calculations. This is where calculations and data handling is done. Client side should only be used for visualization of data. Because the implementation is split, it is harder to access all the functionalities. When client send only minimal data to server, it is hard for a middle-man to benefit of the data, as the context is missing. Server then only sends the end result. This will abstract the data connections and how the MES functions. The functionalities should not be on client side that is easier to get hands on.

Last there is the encryption. Scrambling sources so that a key and method is needed to unscramble it back to readable data. This is so that if organizations data gets to the wrong hands, it can not be used without extra knowledge. One typical example is the users passwords. When storing the passwords in a database, they should be encrypted. Thus, if someone gets access to database. They cannot instantly see the users password.

As MES has lots of control of factory data and functionalities. Cyber security should be a big concern. If someone manages to completely shut down MES it could make the whole factory go on a stand-still. Thus the implementation of security is seen as a major objective.

4.13 Summary

As MES has a specific part in the large scheme of manufacturing industry. I4 will effect only some parts of MES. Table 4.1 summarises this chapter. The table summarises different I4 concepts area, solution and importance.

Concept	Problem Area	Solution to Problem	Importance
Smart factory	shop floor, robots, process	Planned schedule, communication with equipment	Critical
Virtual representation	Production state, Materials, Products, Equipment	Real-time updates, Sensors, Models	Critical
Integrated systems	Horizontal, Vertical and Product lifecycle	Documentation, Standards	Critical
Big data	ERP, Shop floor, MES inputs	Computing power, Machine learning, sensors	Major
Cloud computing	Software hosting, Infrastructure, Shop floor, IoT	Cloud hosting platforms, Private cloud	Major
Visualization	MES progress, Resource usage, Capacity, Inventory, exceptions	Alerts, Notifications, Graphs, Highlights, Monitoring stations	Major
Cyber security	Data hiding, Data access, data encryption, Centralized functionalities	Access controls, Multi-resolution approach, Encryption	Major
Additive manufacturing	3D printers, BOM	Data access points, Dynamic data-links	Minor
Augmented reality	Displays, Product controls, Operator manuals, Interfaces	Data access-points, API documentation	Minor
Simulation	Shop floor, Scheduling, MES inputs and outputs	-	Irrelevant
Autonomous robots	Shop floor, Logistics	-	Irrelevant
Internet of things	Sensors, Devices, Cloud	-	Irrelevant

Table 4.1. *Summary of MES in I4 environment*

Problem area column describes the parts of MES and manufacturing where the I4 concept has an effect on. The solution to problem column are different technologies that needs to be applied to take advantage of the I4 environment. Last is the importance of the solution. This value is given in this chapter by comparing the area of the concept to the MES primary functionalities that were described in section 3.5.

There are three areas that should not be taken into account when developing MES for I4. These are simulation, autonomous robots and IoT devices. Others are ranked in the order of importance.

5 PRODUCT ANALYSIS

This chapter will take a look at pinja MES platform called iPES [27]. Which is a MES web application. This chapter will take look how PES handles the main functionalities of MES.

5.1 Pinja MES software - iPES

PES is a web platform meant to be used by tablets and other mobile devices. There have been other iterations of PES in the past. All of them have been software meant to run on a desktop computer. This is the first one to be developed for mobile devices. This is version 8 of PES also known as iPES. The data shown in this section, is from a imaginary bike factory. As the software is still under heavy development, a lot of visuals are bound to be changed.

As stated earlier, the main inputs for MES is a master schedule, BOM and Inventory records [2]. These are used in MES computing and produces a planned schedule which defines workflow of the factory floor. This also allows to produce different analytical data as a by-product. Statistics and visualizations on state of the manufacturing process. This chapter will see how iPES handles all of these aspects.

MES needs a master schedule to be able to function. This is a list of all the orders for products that factory produces. This includes their promised delivery dates. iPES is its own entity, and relies on a outside system to give it the master schedule. This is often times done through a separate ERP. There are different ERP on the market and they have different types of output data. Big part of iPES customer services is the integration of the system into the clients system.

iPES has its own interface for handling BOMs. This is where it is possible to set work phases an materials to a final product. Figure 5.1 shows how iPES visualizes the BOM structure. There are +-icons that opens ups the materials needed for producing its parent product. The figure is the default BOM that is used for a deluxe bike. IT consists of the bike itself. After bike comes the final assembly part. This is called default BOM at this point. Under that one are all the materials needed for the final assembly. This continues all the way until final materials. Each material can be opened up to reveal next set of material needed to create these products. These so called work phases are then linked with the required material input and outputs as well as the required resource to get the job done. This is Then used when MES does its scheduling.

The data for BOMs comes from iPES own database. This can be integrated through clients own systems. In the worst case, clients do not have full BOMs of their products. iPES has its own interface for configurating and creating BOMs. Meaning they can be done by hand through a user interface.

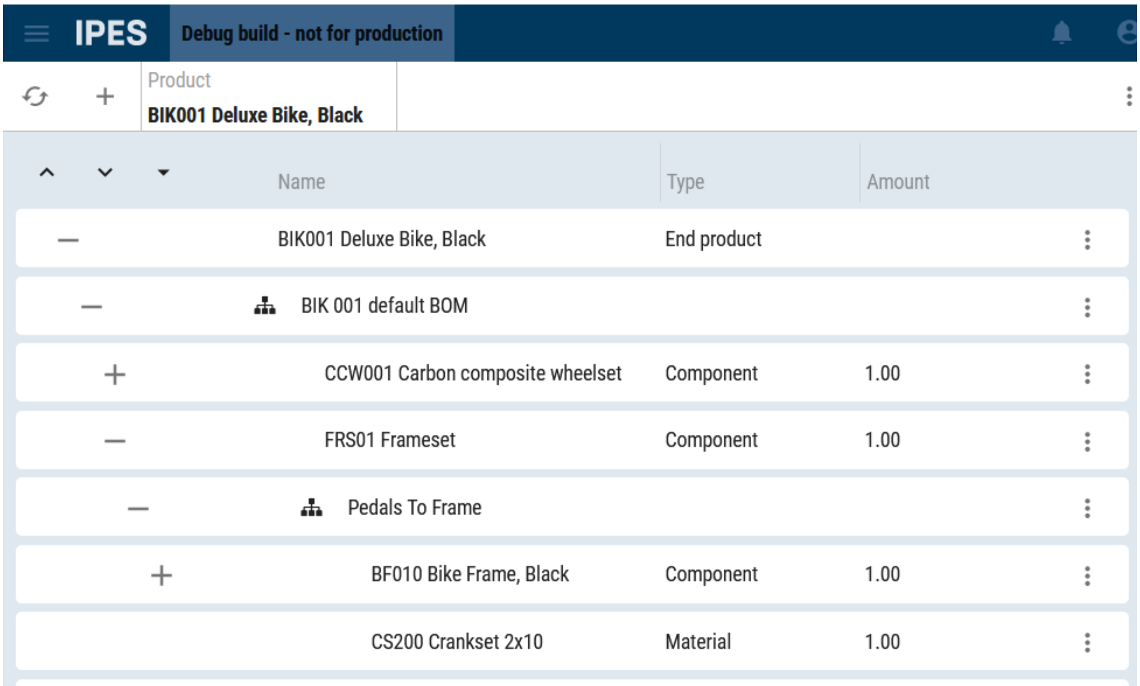

Figure 5.1. *How iPES shows the BOM of a bike.*

As iPES main objectives is to keep track of inventory fluctuations. It has knowledge of different warehouses and how much material and products are stored in them. This is important to know, as it allows to give user warnings when materials are so low, that some orders cannot be fulfilled. As for where the warehouse data comes from, it is again, from customers own databases. iPES handles changes, but can not automatically know how much material any customer has in its storages. Thus requiring the customer to provide the initial values of products and materials. They can either be integrated through customers systems or applying the amounts by hand.

Early on, it is possible to notice, that for iPES to work, it requires a lot of integration into customers systems. It is more of a analytics tool that is coupled into customers manufacturing systems. There is a lot of heavy lifting done at the start of the installation process. As all customers data have to be mapped out to support iPES. But once all data flows through the system. The software should work smoothly and be well integrated into customer manufacturing process.

Once iPES has all the data it needs. It can be used for scheduling product orders. The resources that iPES users are product orders, manufacturing processes, worktime calendars, product manufacturing process routes, products and their materials. Some of these are a bit modified inputs for a typical MES allowing for more accurate calculations. Worktime calendars are the days and hours when workers are working. For example, no process can move forwards at a assembly line if it requires a worker and its holidays when no one is working.

For scheduling iPES has forwards and backwards scheduling implemented. These are easy to implement as they work with a easy to understand algorithm. Queueing processes one by one, either from due date backwards or start time onwards. Once all processes are queued we see if they will be done in time. There is also a scheduling method called complete, this is a combination of the two. This is Pinjas own scheduling solution. The implementation of scheduling is fully modular and autonomous. Thus allowing to add different scheduling methods easily.

The output that is generated by iPES is the start and end time of all processes and on what manufacturing process they will be on. As there can be multiple processes that do the same thing, or a process capacity can be higher than one. Making it possible for tasks to be run in parallel.

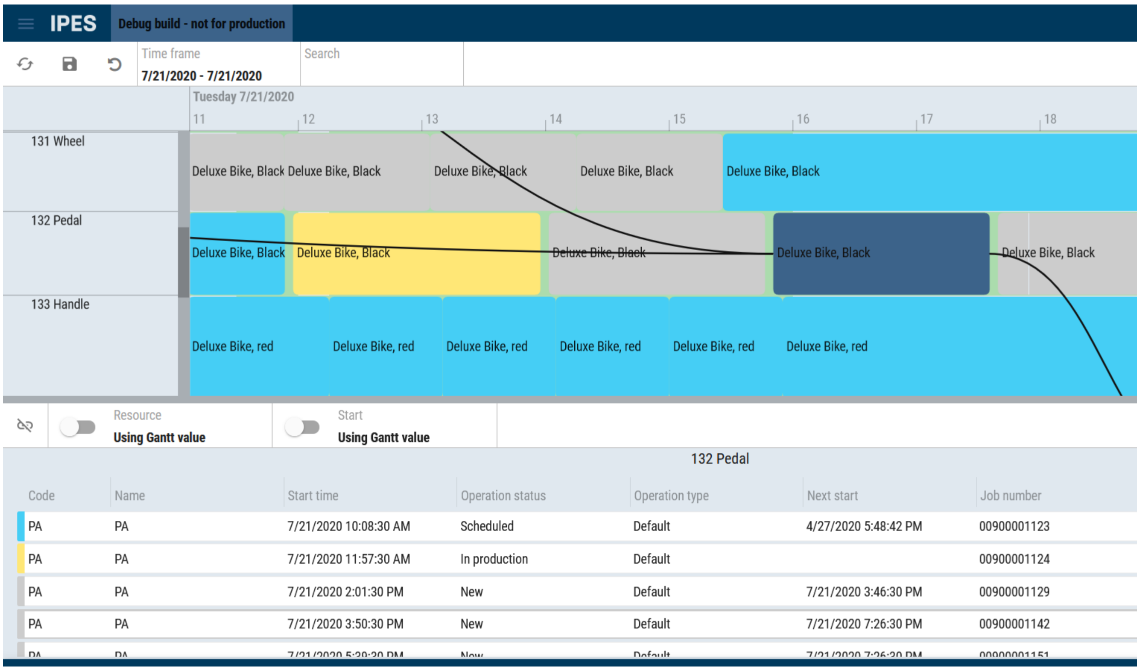

Figure 5.2. *Planned schedule in iPES.*

The end product that iPES creates can be seen in figure 5.2. The view in figure is called detailed planning view. It shows the schedule and work flow of the factory. On the left hand side are all resources listed. Depending on factory type, these can be people or process operations. Top of the view has different filters and time frame controls. Bottom is the support views. These are helper views that show detailed information. Now there is a list of operations for the 132 pedal resource. The same operation queue can be seen in the middle. When selecting a operation it will also highlight the operations before and after the selected one, this is done by drawing black lines from and to operations.

Even though the scheduling is automated, the schedule might some times need manual configuration. This can be because of need to prioritize some orders or changing the order of operations can make work flow easier. In the detailed planning view this can be done by dragging and dropping operations. Operations are configurated for their allowed resources, so they can be moved to another location. When operations are moved, iPES will automatically take into account their operation parameters and schedule the new order of operations by taking into account the changed location. This allows for fast on the fly editing of the schedule. iPES also saves the changes and only applies them to database if user saves the changes. This is to prevent accidental changes to factory work flow. The save icon can be seen in figure 5.2 top left corner.

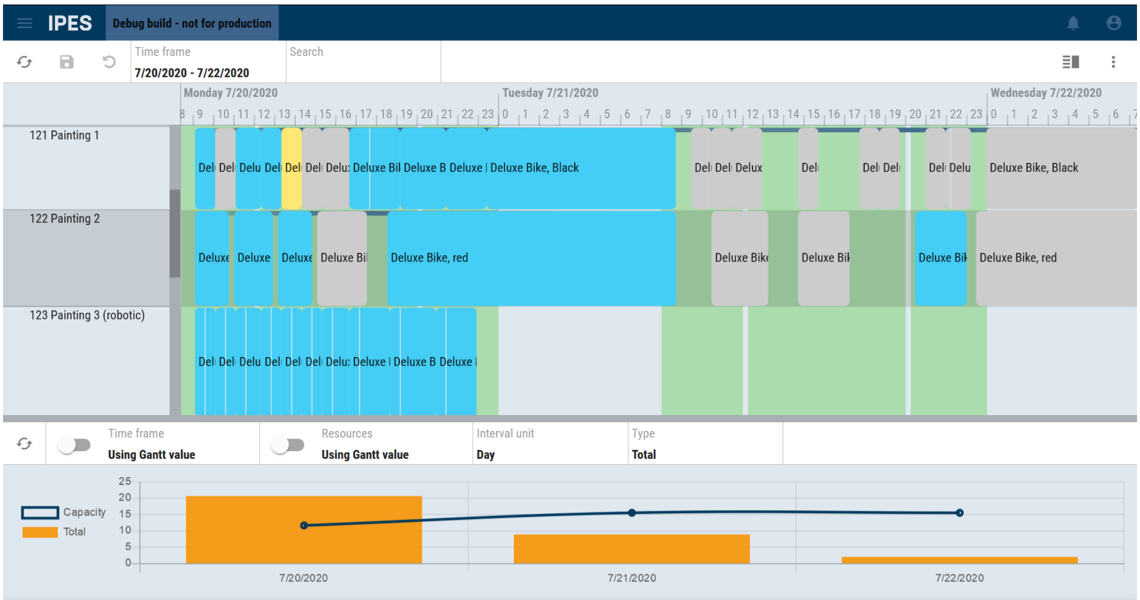

Figure 5.3. *Bottom sows the resource usage of resource '122 Painting 2'.*

iPES handles a lot of data and is able to create different analytical visualizations. Next are a couple of examples of iPES visualizations. First is the resource capacity view, seen in figure 5.3. This takes the selected resource and shows its current load throughout the selected time frame. In the bottom of the figure is a graph of how much the selected resource, 122 Painting 2, is being used within the next three days. Orange bars show total usage, and the blue line shows the maximum for the resource. We can quickly see that first day the resource is overloaded. While the following days it could be used more efficiently. Knowing this, the planner can do some modification to better balance the resource usage.

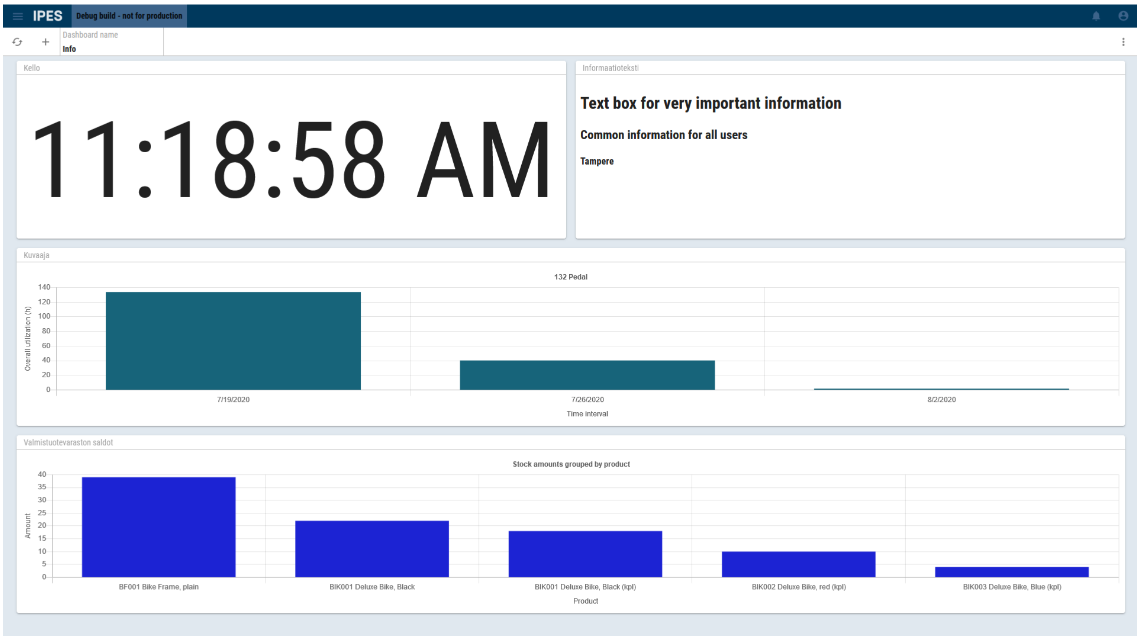

***Figure 5.4.** Customizable dashboard for fast overview.*

One of the main ideas of visualization is to quickly show the user the state of manufacturing. This is why iPES home view includes a configurable overview view. One example of this is in figure 5.4. Here is one type of configuration of the view. It includes current time, a box of possible current information, utilization of a single resource and production amount of different product. All of these view can be easily configurated for factory needs. Time frames and target resources and products can be changed.

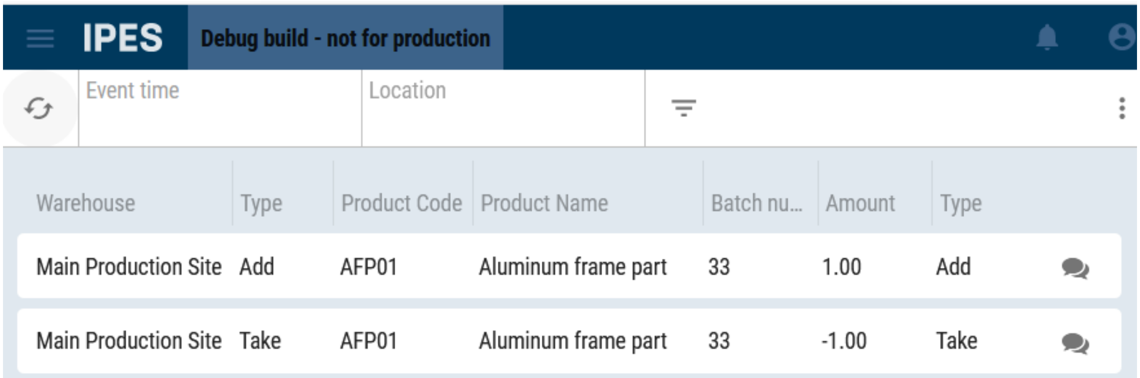

***Figure 5.5.** Visualization of inventory updates.*

The last output of MES are the implementation of inventory updates. As earlier stated, iPES know the amounts of materials and how much is used in each process. As it is known how much each process uses materials, it can be used to calculate the increase and decrease in products.

The main view for handling inventory events is the event view in iPES. A screenshot of the view can be seen in figure 5.5. There are detailed information of what product is changed and where. There is a warehouse column to tell the user in what storage the change has happened. Then there is the type of change, this will tell the user if products have been added or taken, increasing or decreasing the total amount. Then there are some detailed information that identify the product, such as its code and what batch it is from. This data is generated by iPES based on the data that is migrated from customers production data.

iPES has more functionalities that will not be addressed in this thesis. As these are not the responsibilities of a MES system. iPES is not just a MES but has some functionalities outside of its typical responsibilities. The rest of the thesis will only take into account the functionalities discussed in this section. That is the main inputs and outputs of a MES. Meaning the visualization and calculation of the work flow in shop floor and the updates to inventory.

6 RESULTS

This chapter compares PES to I4 main concepts. Comparing how well it implements each idea. Hopefully, in the end, there will be a better understanding what PES does well and what could be developed further.

PES is a MES software under development. As it is still in development it is crucial to detect possible issues early on. It is meant to solve clients future problems, so it is a prime candidate for analysing using I4 method.

6.1 Critical implementations

This section will look at implementation of all the critical concepts for MES in I4 environment. These are smart factory, virtual representation and integrated systems.

6.1.1 Smart Factory

One of the requirements for I4 smart factory was for MES to be able to process data from the shop floor. This includes all the robots, maintenance and logistic robots. iPES hold information of current equipment and users on the factory floor.

When handling processes iPES has the ability to transform operations. It knows the state of each operation and product order. The operation management is detailed. Which is important seeing managing the work flow is main objectives of a MES.

iPES can change the operations statuses through a simple user interface. This is done manually by a factory floor worker. When a operation start, worker selects operation from his worklist and signals iPES that operation has started. Same happens when the operation ends. Most of the time this is done manually. iPES has the ability to do operation changes automatically, but this requires integration with customers systems. This integration needs to be done separately for each customer. This is because of the lack of common practises when communicating with shop floor equipment. This is something that the industry needs to fix as the systems start to integrate with each others even more.

Once a operations starts. Its status changes from scheduled to started and once it finishes, its status changes to completed. This information is updated in real-time to incorporated systems. Allowing upper management to easily follow the current situation inside the shop floor in real time.

As earlier noted, iPES has no way to detect equipment failure or even manage that type of incoming data. There is no interface implemented for factory equipment data. This can be seen as a major fault regarding the future. As equipment getting maintained have a impact on work output of factory machines. Only way to take equipment functionality into account for now, is to decrease the resource efficiency coefficient. This can be done in resource management view, but has to be done manually. A automated system would help create more accurate estimations in scheduling. It should be noted, that while writing this thesis, the ability to manage factory equipment is under development and close to done.

6.1.2 Virtual representation

iPES has most of the required data to maintain a factory mapped out. Although, there is no fully virtualized factory floor. All of the factory visualization is done by the Gantt view shown in figure 5.2. This is a well known way to illustrate the state of production.

The operations shown in the Gantt view are updated depending on their current state. When factory workers start a process. The state of the operation changes. Changes in the real world will have a corresponding change happen in the virtual iPES environment. Materials are being used throughout the process and operations move forward. Meaning the iPES virtual visualization should be well in sync with the real world state.

Although virtual representation has not been fully implemented for the factory floor. It has been implemented for updates in a warehouse containing factory's inventory. Example of the view can be seen in figure 6.1. All different shelves have been mapped out and drawn. once the shelves have been mapped out, they are colour coded depending of the state and material stored in them. Each cell in the column represents a place for materials to be stored.

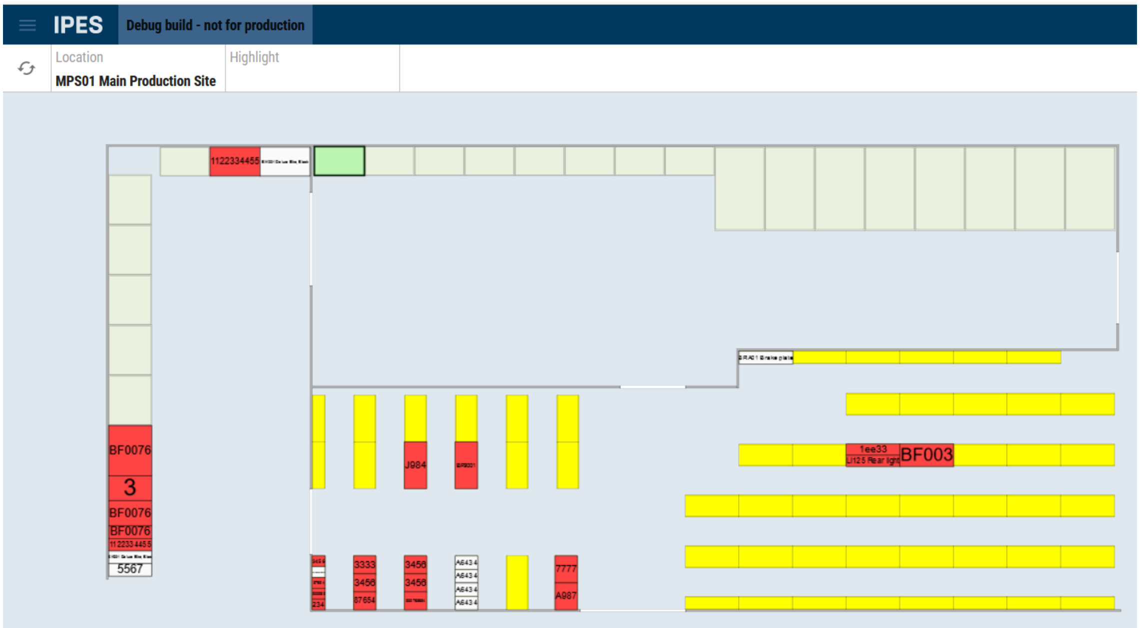

Figure 6.1. *Real-time updates of inventory changes.*

The real-time storage system is done utilizing websockets allowing for instant updates. The view is used to show factory workers the state of warehouse instantly. Where materials are stored and if they can be used. For example, after painting materials, they might need to dry before use. Thus could be marked red until they are dried and ready to use. This allows users to quickly see the status of the warehouse. This can be seen as a example of smart factory functionalities. As the warehouse by itself knows its own status and updates it accordingly.

iPES has a good support for simple virtual representation. When real world events happen, these event are transferred to the virtual environment. All the main requirements for virtual representation have been implemented.

6.1.3 Integrated Systems

This section compares iPES integrations to the different layers of communication depicted in RAMI 4.0 [19]. These are the horizontal, Vertical and product lifecycle layers.

Having a good integration consists of having working migrations between different system layers. The communication also needs to work with product lifecycle and hierarchy levels throughout the process. As iPES is divided into a client and server. In the future, it could be possible for outer systems to couple with iPES through its servers representational state transfer (REST) application programming interface (API).

MES function is in between the ERP and production equipment. In iPES this works with having data coming from ERP and then planning the working order of tasks in the shop floor. This works once all the required data from factory floor has been configurated. iPES only need the orders from ERP, after that, it can handle calculations by itself. iPES will keep ERP updated on planned completion times for orders and update their state throughout the process. So ERP should have the latest information of the order completion progress. This satisfies one need in the horizontal integration layer as depicted in RAMI 4.0 [19].

Some issues arise with communication between factory floor equipment. This is mostly because of no standardized communication methods, as mentioned before. For iPES to be I4 compatible, it needs to have a API for factory floor equipment communication. This would be the communication layer between level 3 and level 2 in the automation pyramid [12]. Unfortunately this is different for each factory, and requires a lot of manual labour. This is mostly a issue that factories have to solve.

When looking at handling of product life cycle. iPES can handle the product from start of the process all the way to the end. It even is able to handle different production routes for the same product. Meaning, that if there is a alternative way to produce the same end product, iPES know how both of these production methods can be manufactured.

One possible fix for integrating low level equipment with the iPES system is the use of server API. Most of the functionalities and data of iPES can be accessed through its REST API. This is a HTTP interface for which systems can make call to get information and input data.

All MES primary tasks are working in iPES. iPES is good at utilizing input data. Unfortunately Lower level communication is very limited. But this is to be expected, as there are no communication standards or libraries for low level equipment communication. Getting most out of the iPES system still awaits for the lower level systems to incorporate some standards or easy to use libraries for equipment handling.

6.2 Major implementations

This section will look at implementation of all the major concepts for MES in I4 environment. These are big data, cloud computing, visualization and Cyber security.

6.2.1 Big data

In iPES development the use of possible big data has been taken into account but there is only one instance where it has been applied. The architectural structure of the iPES server side is built in a way, that it can handle possible big data critical calculations. Also there is a view that utilizes big data called volume planning that has a big data implementation.

iPES has been built with the idea to be utilizing a so called microservice architecture. In short, this is the idea of creating small concentrated modules with specific tasks. Giving each module a specific task, streamlines the interactions and makes smaller and easier to handle components. As in the end, each service gives its data to client which then compiles them to something of value to the user.

All the services work in a vacuum. Then there is one main component which task is to handle the communication between services. It allows for the services to contact each other. The software has been built in a way, that each service can be ran on its own server. Then the main module keeps track of where each service is. This for example will allow the use of a big data handling service. It can be spread into multiple server clusters for heavy calculations. As this is built in, implementing something like this is easy. There is the structure to support big data.

Most of the development time has gone into creating functionalities that handle main tasks of MES. For now, the basic scheduling methods have been implemented in iPES, there has not been a need for a more complicated machine learning centred scheduling system. It has been noted, that for the current environment, the basic scheduling methods have been enough for customers. However, iPES have been built in a way, that adding a machine learning scheduling system is easy to add into the system.

6.2.2 Cloud computing

As iPES was created with web technologies in mind. The use of cloud computing comes naturally. This gives a platform independent environment that can be accessed from anywhere with the correct access and internet. This requires a cloud hosting platform and working continuous integrations. The software infrastructure needs to take into account possible struggles that cloud platform brings.

Throughout the development the iPES platform is being hosted on Microsoft cloud platform Azure [28]. It is a cloud platform which hosts data online. iPES uses Azure for its databases and application hosting. Later it can be expanded to take advantage of azures ability to host server clusters to allow for parallel calculations when applying big data functionalities.

The development of iPES takes advantage of azure by having its continuous integration deploy a development versions into a test environment hosted by azure. Continuous integration, CI in short, is the automatic testing and deployment of new source code. The CI is done using Microsoft DevOps service [29]. New code is directly compiled and tested. Then pushed into the test environment. This allows for instantly seeing changes in the product and for a more agile development cycles. The CI pipeline can be expanded to customers platforms. Allowing for instant updates when they become available for customers. This still require some development and problem solving from customers. As most of the customers have their own infrastructure and require a secure connection.

The deployment of iPES has been parameterized for faster and flexible deployment. By changing a couple of parameters and deployment targets, the software can be easily be deployed to different customer environments. The configuration file has been parametrized so, that in the project build process the parameters are updated and the software is able to connect to customers own services. This takes advantage of the cloud environment by automating everything and having the whole process fully in the cloud. This allows for rapid deployment remotely.

There is one issue regarding data when using cloud platforms. The customer data will be in the hands of a third-party. Possibly in a different country even. This should be considered and informed to the customer. If they would have a problem with a outside party handling their data, there needs to be a another possible solution. Thankfully, the iPES client is not required to run on azure. It can be installed on any website hosting server that has all prerequisite software installed. If customers would require this, it should be their responsibility to setup the infrastructure for the software.

6.2.3 Visualization

iPES takes advantage of visualization for the current state of factory floor. It manages to use different visualization methods for all the main MES features.

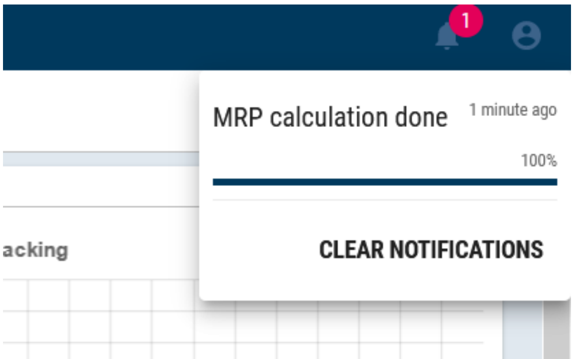

Figure 6.2. *Screencap of iPES notification system.*

There is a basic notification system working on iPES already. It can be seen on figure 6.2. There is a small number with red background showing how many notification there are for the user. Once the alert button is clicked, it opens up all the notifications sent. Notifications are also able to track task progression. This is mainly for calculations that take so long, that user has to wait for them to finish.

iPES has multiple ways to highlight data. When something is selected, it is often times highlighted in some way. This can be seen for example in figure 5.2. There dark blue operation is highlighted as selected. As all the highlight have the same colour scheme, its easy for users to identify states throughout the software.

A alert system is also implemented. It highlight possible issues in the production. If a production order would be late or materials are lacking, there will be a highlight on the screen that informs the user of the problem. This allows the user to quickly see what the problems are, rather than having to analyse all the data.

6.2.4 Cyber security

Last of the major implementations is the cyber security of iPES. Next is a analysis of how iPES implements the different security solutions. These are use of watermarks, access controls, multi-resolution approach and encryption.

Authentication is a major part of iPES security functionality. There are a couple of different authentications required for whole iPES system. There are the users that have their own account and accesses. There are different authentications needed for the chosen hosting platform. For example azure accounts if the software is hosted there. Lastly, authentications are needed for database access. These can be integrated to a single domain account, this is depending on the customer infrastructure.

To help the user management, iPES uses different user groups. User groups can be configurated to have specific accesses. Then a user can be linked to a group to get all the access that the group has. This makes it so that it is not required to setup each user, but rather include in a group.

There is authentication on client and server side. First user log in to identify them selves. After that, they can use the software features they have access to. The client also has its own authentication. When user logs in, they get a identification string stored in cookies. This will be sent to the client on every request. Client identifies the user with this token and check if they have access to the request. This also prevents outsiders to straight access the APIs interface. As every request requires you to be authenticated.

As earlier stated, iPES is divided to client and server. Client is mostly controls related to managing data and visualizing the calculations and effects of scheduled plan. If a outsider would get his hand on the data between client and server. There is not much harm that could be done. The data that is sent between client and server is context sensitive. Thus cannot be made to anything value without the context of iPES.

Biggest problem would be, if a outsider gets access to the database. As this is where all the crucial data is stored. But this is not the scope of iPES. It is the customers responsibility to secure their infrastructure. iPES should take all the possible countermeasures that its own data is being stores securely.

There are couple of locations where iPES used encryption for security. One is the user password. It is encrypted when stored to database. Another one is the client side code that is minified. This is done to obscure the code that is being executed. This makes it harder to reverse engineer the code of iPES. Minifying takes the original source code and makes it unreadable but functional. This is important as the client can see this code. A lot of resources goes to creating the source code, thus obscuring the code is important. This makes it harder for others to copy the implementation.

6.3 Minor implementations

This section will look at implementation of all the minor concepts for MES in I4 environment. These are additive manufacturing and augmented reality.

6.3.1 Additive manufacturing

As stated earlier in this thesis. MES software should be able to dynamically handle changes in BOM structure and have some access points for changing BOM data. This should include automatic material and inventory changes when BOMs are changed.

iPES API has all the basics for managing BOMs. There is a basic CRUD, which is short for Create, Read, Update, and Delete. Meaning through the iPES API it is possible to do all actions for managing and changing BOMs. This also means, that outside systems can call the API, given that they have the required access clearances.

Because of the functionalities of the API it is possible to couple a outside module for fast prototyping of products. This system can then output the new customized BOMs and send them to iPES. This way the customized BOMs can be sent to iPES and will be a part of the production. iPES can then handle the customized product in its scheduling.

6.3.2 Augmented reality

As Augmented Reality technology will most likely be a outside system that uses iPES data. There needs to be usable API access points. This will allow for outside AR systems to visualize the data created by iPES.

There is a multitude of different data that can be read from the iPES API. Some notable data points would be the state of production operation and resources. This can be used to visualize and manage state of production through AR devices.

7 CONCLUSION

This thesis manages to summarize the manufacturing industry and how the technologies have developed in manufacturing. Taking a look to future of manufacturing by discussing what is industry 4.0 and then categorizing all relevant technologies. After analysing the manufacturing industry the thesis identifies the context of a manufacturing execution system. Allowing the reader to understand the whole picture and how all the topics relate to each other.

Once the I4 technologies are listed and MES main functionalities are clear, the thesis goes through how the I4 items will effect MES. Each of the technologies were listed as either critical, major, minor, trivial or irrelevant depending on how relevant they are for a MES. For MES the most most critical elements are Smart factory, Virtual representation and integrated systems. This have the biggest effect when implementing MES main functionalities. Three technologies were deemed as irrelevant, as they have no effect wen implementing a MES. These are Simulation, autonomous robots and internet of things. It needs to be remembered, that they are irrelevant for MES development, they still play a major role in the industry 4.0 vision. For I4 all the different elements are just as important.

Next the thesis presents the Pinjas software called iPES. This is a MES software created for future applications. The thesis goes through how iPES handles all the mentioned main functionalities of a MES. This gives a better understanding of how typical MES software's work.

With the listed technologies and information of how iPES works, the thesis compares how iPES could benefit from the i4 technologies. The thesis describes how iPES implements each element and if there are some aspects missing. Giving a better understanding what could be improved for the future. The analysis works as a example how the I4 elements can be used.

This thesis gives simple tools for analysing MES in a industry 4.0 environment. As the I4 concepts are very broad it does not allow for any focused analysis. Rather, the tools given in this theses are only major guidelines that should be looked in to when developing a MES software. They wont give any straight solutions to problems. Rather tries to give a direction for development.

For this thesis. The listed technologies and how they interact with a MES software could be seen as a success. They manage to break I4 to smaller pieces and focus on a specific area. As for the later part of this research. When trying to identify and analyse these elements in a working MES software, there were some difficulties. This is because of the broad nature of the technologies and MES. Both can be used and implemented in many different ways, and there are no correct answers. The results of iPES analysis end up being shallow without real focus.

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