OULUN AMMATTIKORKEAKOULU

Antti Hautamäki

AUTOMATION OF PRODUCT YIELD MONITORING AND PRODUCTION TRACEABILITY

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Antti Hautamäki
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ABSTRACT

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Author: Antti Hautamäki
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The goal of this thesis was to create a template for an automated yield monitoring system with Microsoft Excel. Microsoft Excel was chosen for this because it is already in use in the case company and it is capable of doing this. The thesis began with reading through theoretical material followed by designing the layout for the Excel, writing functional formulas and macros to minimize manual input from the operators and linking workbooks to one another.

The production in the case company was prototype based so it is followed very closely, since prototypes usually have flaws, mismatching parts, and are not as reliable as a finished product would be. Yield monitoring was used to follow this. All passes, fails and the reason for the fails are marked so the possible questions can be worked on.

The finished product was a Microsoft Excel template that eliminates paperwork from the assembly line since everything is marked straight to Microsoft Excel. The finished product will improve efficiency and save time in the assembly line as well as the office side of things.

In this thesis theory and the importance of production monitoring and production traceability are explained first, followed by system development, piloting and summary.

Keywords: yield, monitoring, automation, production, traceability

CONTENTS

1 INTRODUCTION

The thesis was carried out in Oulu, between September and December of 2021 at iLOQ which is a Finnish growth company from which provides self-powered digital locking and immensely secure digital access management. iLOQ was founded in 2003 and the first product came out in 2007. (1.)

The subject of this thesis is automation of production yield monitoring and production traceability. It is also explained how important these are for any company that is producing any product. It allows the company to make decisions based on raw data, numbers. It also helps to see which part of the process is struggling. For example, if a product is divided into five different phases and one phase is struggling this is easy to confirm this with the numbers from yield monitoring. That way the company can make necessary changes to the design or assembly phase. Production traceability is also discussed in this thesis since yield monitoring is part of traceability.

The main goal of this thesis was to automate yield monitoring and secondary goal was to improve product traceability. During this thesis time was running out alas, traceability could not be improved and is only theoretical. At the beginning of this thesis, all assembly phases were marked on a yield paper, which is very time-consuming, error-prone, and inefficient. This is a step that needs to be streamlined for more efficiency. Streamlining this step means that the person previously collecting the papers now has more time for other tasks and the assembly line operators don't have to write as much. The steps to achieve this are:

1. Find out the requirements for the system
2. Create the template for the system
3. Write formulas, macros and link the files to one another
4. Test how it functions in the assembly line

2 PRODUCTION MONITORING

Production monitoring allows the companies to keep track of the number of products produced and it also helps to keep the inventory up to date. This process works by collecting data at different areas of the production line.

Production monitoring allows companies to measure the time required for raw materials to pass through the manufacturing process and become finished goods. It consists of processing time, inspection time, move time, and queue time. Processing time means the time spent to process the material to finished goods. Inspection time means time spent inspecting and or testing materials and finished goods. Move time means time spent moving the goods, for example, logistics. Queue time means time spent waiting for other activities. (2.) For example, operator 2 cannot work on the product until operator 1 has finished inspecting the goods. Takt time is an important part of production monitoring as well. Takt time means the amount of time to complete a task (2). Takt time is important for optimizing the capacity, reducing waste, and maintaining a continuous flow of work (2).

3 PRODUCTION PLANNING AND CONTROL

3.1 Production planning

Production planning can be defined as a technique of foreseeing every step in a long series of separate operations, each step to be taken at the right in the right place (3). Production planning is dynamic because plans may change quickly due to changes in circumstances (4). Production planning is determined by four factors, quantity, quality, cost, and time. Production planning starts with the analysis of data for example, how much there is demand. On that basis, the production is planned most economically. The goal of production planning and control is to produce the right quality, quantity, and shape for the consumer at the desired time. (5.)

3.2 Production control

Production control regulates the orderly flow of materials in the manufacturing process from the raw material stage to the finished product. French mining engineer Henry Fayol defined production control as the art and science of ensuring that all which occurs is following the rules established and the instructions issued. A proper production control system requires 4 different things to work properly: information, sound organization structure, standardization, and trainer personnel. The goal of production control is to achieve production targets, use resources in the most optimum way. (6.)

The objective of production control is to regulate and control the different operations of the production process such that the items are produced of the right quality, in the right quantity, at the right time with minimum efforts and cost (6).

4 PRODUCT TRACEABILITY AND ITS BENEFITS

Traceability is a broad concept that refers to the practice of identifying an object or work item and accessing any or all information about it (7). This is achieved by giving an object a unique tag, for example, a serial number. According to Töyrylä (8), customers are demanding more information about the origin of the product.

Smart manufacturing and traceability are the first steps towards complete, end-to-end visibility over supply chains. As products are tracked, the resulting data gives products their pedigree and provides a wealth of information that companies and consumers can use to inform better decisions. (9.)

Traceability is described as "the ability to trace the history, application or location of an entity through recorded identifications." Product traceability consists of two functions: tracking and tracing, see figure one. below. (10.) Tracking means following the path of the product as it moves through the supply chain. Tracing refers to defining the history and the materials used to make the specific item (10).

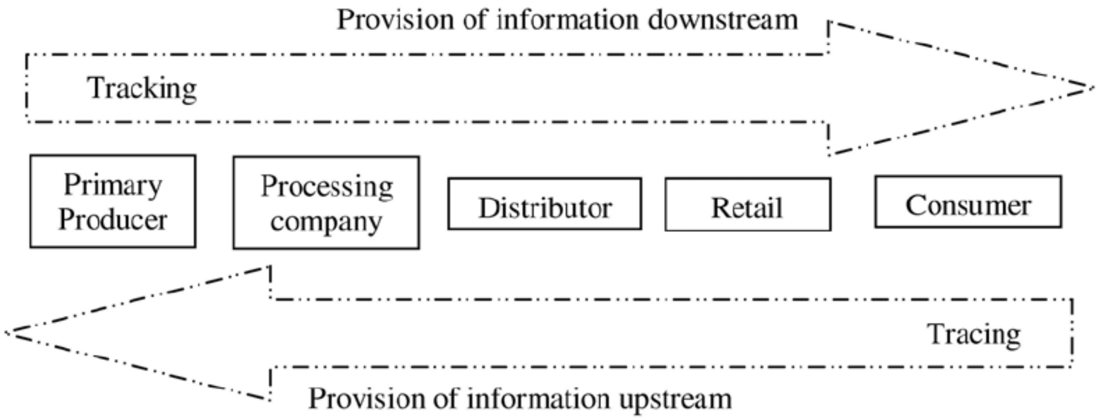


FIGURE 1. A simplified view of information flow in traceability (Schwägele 2005) (10)

Product traceability is required in certain industries, such as food production, automotive, and aerospace. In food production, it is enforced by law in European Union to ensure food safety. In aerospace, everything is recorded while in automotive only the most important components are traced. (11.)

Product traceability has many benefits for manufacturers as seen in figure two. below. Traceability allows increased insight and control over their products, which benefits manufacturing, warehousing, and inventory management. Product traceability will also improve distribution in the company. Implementing a traceability system can reduce delivery errors, transportation times, and refunds. (12.)

Traceability can also be used for continuous improvement because it allows for quick and precise error detection (12). Product traceability is needed to minimize financial exposure and efficient recalls concerning unfit products. Affected products can be traced to distributors and retailers and removed from the shelves. (13.)

FIGURE 2. Benefits of Traceability, Tulip (14)

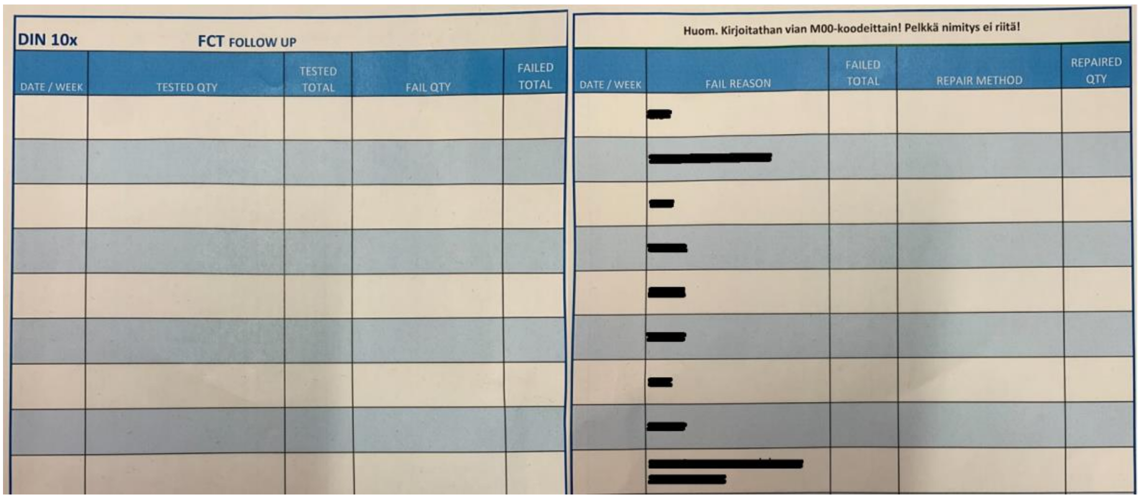
According to Tulip having data on the products' paths allows the manufacturers to find the root of the problem much easier while also minimizing negative impacts. Traceability also allows value stream mapping, letting the manufacturer know where and when there are bottlenecks and delays. (14.)

Since traceability monitors how products move through the process, it helps with value stream mapping - which gives manufacturers a more granular picture of their operations' value stream. Traceability can also help to find key points in a production line where quality checks should be added. (14.)

5 CHALLENGES SEEN AT THE CASE COMPANY

5.1 Production monitoring in the case company

In this case company production is monitored by using a yield-list in which employees write by hand how much have they done and at which assembly phase are they on. It is error-prone and inefficient because the results are put into Excel by another employee in the office.


DIN 10x FCT FOLLOW UP

DATE / WEEK	TESTED QTY	TESTED TOTAL	FAIL QTY	FAILED TOTAL

Huom. Kirjoitathan vian M00-koodeittain! Pelkkä nimitys ei riitä!

DATE / WEEK	FAIL REASON	FAILED TOTAL	REPAIR METHOD	REPAIRED QTY
	[redacted]			
	[redacted]			
	[redacted]			
	[redacted]			
	[redacted]			
	[redacted]			
	[redacted]			
	[redacted]			
	[redacted]			

FIGURE 3. Yield monitoring-paper

The goal was to get rid of the papers and put the results straight to Microsoft Excel to eliminate unnecessary work and make the process less error-prone. The Excel sheets and workbooks should be minimalistic and simple for ease of use and automated as much as possible so there would not be too much time spent marking up the results.

DATE / WEEK	SERIAL NUMBERS	ASSEMBLY QTY	ASSY TOTAL	FAIL QTY	DEFECT CODE	M0x-CODE OF THE PART / DESCRIPTION	M0x-CODE OF THE PART / DESCRIPTION OF REWORK METHOD	QTY
18.11.2021		50	49	1	S07 - Bended Part	M011989A		
19.11.2021		50	50					

FIGURE 4. Production yield monitoring base in Excel

5.2 Production Traceability

Production traceability is not in a bad state in the case company but there is always something to improve. Microsoft Excel, Microsoft Nav, InControl, and M-Files are used to follow the production and inventory which is not ideal because you need to work between four different programs, although Microsoft Excel and Microsoft Nav work quite well together.

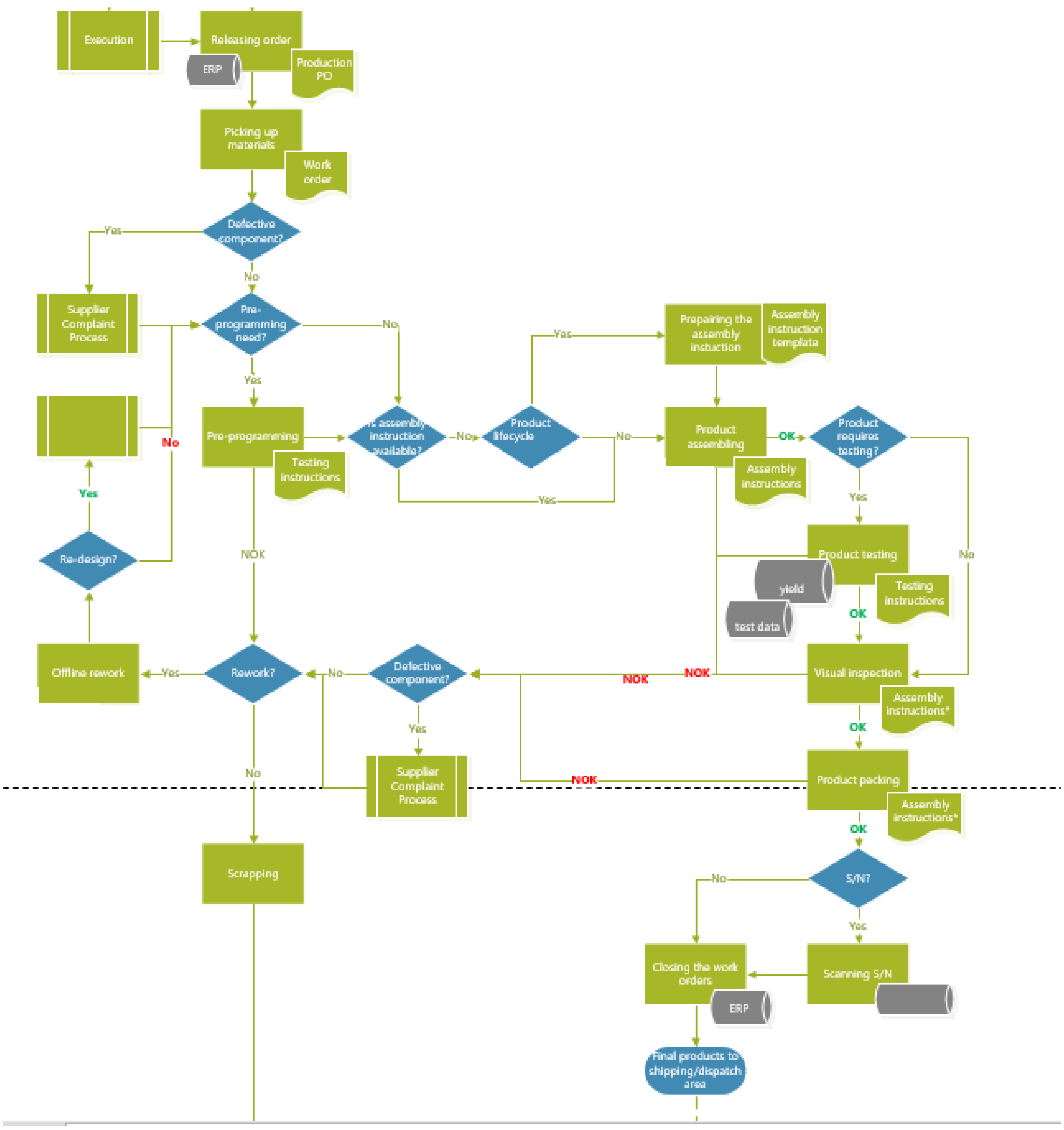


FIGURE 5. Process chart, iLOQ

The process chart as imaged in figure five above at seems quite messy at the first glance. It starts with an execution of an order which leads to a work order. After that, the materials are picked up from the logistics center where most of the materials are stored and handled logistically. After the parts have been sorted and programmed (if needed) they are sent to the production center for assembly. After assembling and yield monitoring, products are given serial numbers for the final tests, and after that serial numbers are scanned into the system and packaged for shipping.

Initially, the thought was to move the serial number to the top of the chart for increased traceability. However, after consultation from the NPI team leader, it does not make sense to move it because it is already easy enough to identify bad parts and finished products which fail in tests have serial numbers. On top of that, there is no rational or easy way to keep the serial numbers intact with unfinished products and parts.

6 NEW PRODUCTION MONITORING SYSTEM

6.1 Microsoft Excel

Excel is a spreadsheet program that organizes and analyses data. Excel is developed by Microsoft. It has a lot of useful different features, which makes it a very capable program to use. It has features such as calculations, graphs, pivot tables, and a macro programming language called visual basic for applications or VBA to name a few. (15.)

Excel was chosen for this project because it is relatively easy to use, and it was already used in the case company so there should not be a too big learning curve when operators are using the system.

6.2 M-Files

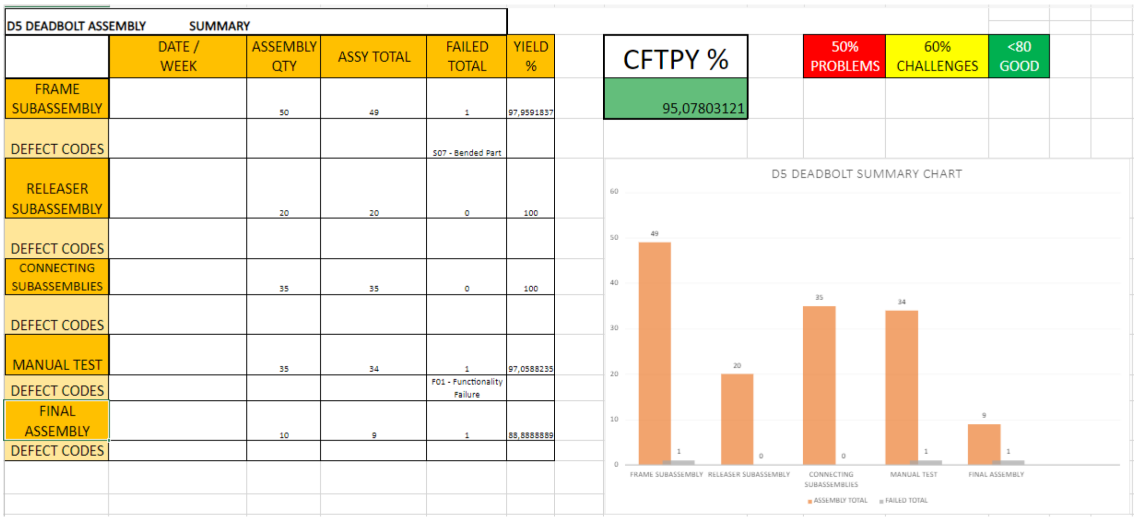
M-files is a Finnish technology company that develops and sells data management software. It automatically classifies different files by using artificial intelligence (16) and it also enables users to preview files within the program. M-Files is used in the case company to store different kinds of documents, for example, Excel files, 3D models of products or parts, instructions for assembly, et cetera. It also works as an automatic backup for files.

6.3 Features

The new yield monitoring system should replace all paperwork in the production line. It should display clearly what product operators have been assembling and the quantity produced.
Requirements for the new system are that it should show the date or the week the product was assembled, serial number, fail reason with the fault code, assembly quantity, fail quantity, total amount, yield percentage, and CFTPY (overall yield percentage).

The new yield monitoring system should also be visual, meaning graphs implemented to help with understanding the overall situation without looking at the numbers too much.

To ease the manual input of operators QR codes are also a requirement for fault codes. This means that there is no need to write the code manually.



D5 DEADBOLT ASSEMBLY SUMMARY					
	DATE / WEEK	ASSEMBLY QTY	ASSY TOTAL	FAILED TOTAL	YIELD %
FRAME SUBASSEMBLY		50	49	1	97,9591837
DEFECT CODES				S07 - Bended Part	
RELEASER SUBASSEMBLY		20	20	0	100
DEFECT CODES					
CONNECTING SUBASSEMBLIES		35	35	0	100
DEFECT CODES					
MANUAL TEST		35	34	1	97,0588235
DEFECT CODES				F01 - Functionality Failure	
FINAL ASSEMBLY		10	9	1	88,8888889
DEFECT CODES					

FIGURE 6. Summary table for the production yield monitoring

6.4 Creating the yield-monitoring system

The Excel workbook contains macros to ease use. Although macros make working easier there are also downsides to the use of macros in Excel. The biggest concern is the security risks that come with the use of macros since macros can be programmed to do almost anything, such as corrupt files or spread viruses quickly. No one should ever enable macros on an unknown document because of this.

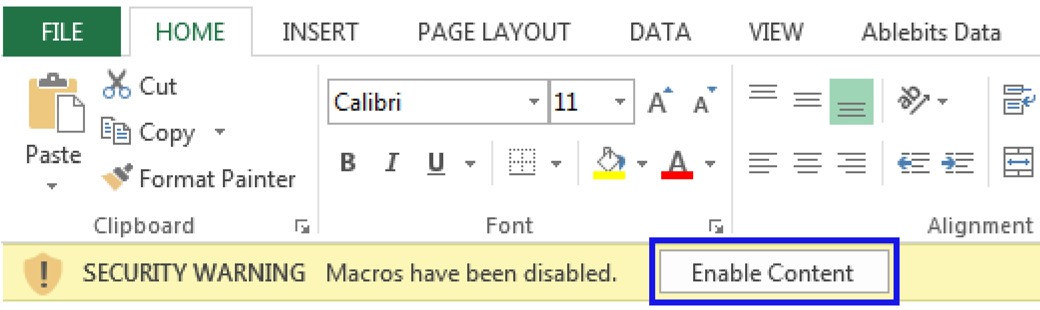


FIGURE 7. Microsoft Excel, a Security warning when opening a file with macros.

The layout of the sheets is based on the paper version because it is clean and there is all mandatory information. It might also be better for the employees because the layout on the excel looks the same as before.

The challenge that occurred with Excel was that the summary workbook which contains all the data from other workbooks sometimes had some issues fetching the data. The source of the data cannot be changed or otherwise, Excel won’t update the data in the summary workbook. For example, if the file location is changed, or the file is renamed, Excel won’t be able to fetch the data. However, there occurred no issues when setting up the files in M-Files.

In October the case company started using defect codes, which was a good thing regarding this thesis. The defect codes allow the operators to quickly describe the faults they see at the production line. To make things even smoother QR-codes were created for each defect code.

Defect code A	Assembly defects, iLOQ	Add M0-code of the part / extra discription can be added, if needed	QR CODE
A01	Wrong work method	Assembly/work phase not done according to specifications/instructions	

FIGURE 8. and example of an Defect code

The operators can scan the QR code to the yield-excel file, which means it is not always necessary to write anything which means that there is less time spent on marking the result which should increase productivity.

6.5 Maintenance of the yield monitoring system

The maintenance of the file/system is relatively easy. It can be divided into two main steps.
The first step is to update information and the second step is to make sure saving and backup are working.

The first step is quite self-explanatory, if information or link sources change inside the company it is necessary to change them to the system to keep the system up to date and running. This is a step that is done manually in the “main” file. After that, it should update the other files and workbooks as well.

The yield monitoring file is stored in M-Files, which means there is no need to create a backing up method via Excel. Only a few people have access to the file properties, which includes deleting it, restoring it in case of a crash, or accessing an older version of the file in case somebody accidentally deletes something important in the file. However, an automatic saving method is crucial to get rid of the chance that the file crashes and there has not been made a save in a couple of hours.

6.6 Traceability system

Traceability can be improved via a more sophisticated yield monitoring system and adding more information to the packages coming from the logistics center. At the start of this project, packages came with QR- or barcodes. This is a good way to track down when the package arrives at the destination.
During this thesis, time was running out to figure out how to properly improve the traceability system because improving traceability proved to be a lot harder than expected and a lot broader area as well.

7 DEMO OF THE SYSTEM

To find the strengths and weaknesses of the system, a demo station was made to see how it would perform in real life. The main purpose of the demo is to see firsthand how it is like to work with the new system and QR-codes.

The demo was successful over two days of testing in the assembly line. There were some suggestions to make it easier to use, but no big issues were found during the testing. Probably the biggest issue was that the defect codes need to be on paper to scan them since toggling between two different Excel files and scanning the QR-code to a certain cell did not work.

7.1 Cost of the system

The system itself is not too expensive. However, let's assume there are ten assembly stations and each one needs laptops, barcode readers, et cetera. it will become expensive. However, in the long run, it should pay itself back with increased productivity and no need to buy so much paper and ink for the printers.

Each workstation needs a laptop or even a tablet with a barcode reader for the QR fault codes. Mouse and keyboard are quality of life improvements, meaning not necessary but over time will prove more efficient use.

Price quotation for yield monitoring system

(1 workstation, assuming chair, table and cables exist already)

	Item	Price €
Necessary	Laptop	599,9
	Barcode reader	39,99
total €		639,89
Optional items, for ease of use	Keyboard	14,9
	Mouse	9,9
total €		24,8
both total €		**664,69**

FIGURE 9. Price quotation for the system

7.2 Designing the layout

The layout of the overall system should be at least as good as the previous system in the case company. This means that the layout should be designed so that takt time is not affected and Lean philosophy inside the company is easy to apply.

In figure five above the mandatory and optional items for the system are listed. The main purpose of the optional items is to make inputting the data easier.

FIGURE 10. An image from an assembly line, rework process. Yield-monitoring papers in the red pocket

As seen in figure 6, the laptop could sit on the rack or on the table to be easy to reach. Additionally, a wireless keyboard and mouse could sit in the back or side of the table if the laptop is on the rack.

To create the layout for the workstation sketching is quite useful since it helps to see what different ideas would look like. For this, a UX-designing program called Figma was used. In the figure 11 below tools, assembly parts, laptop, fault codes and manuals are shown on the assembly table.

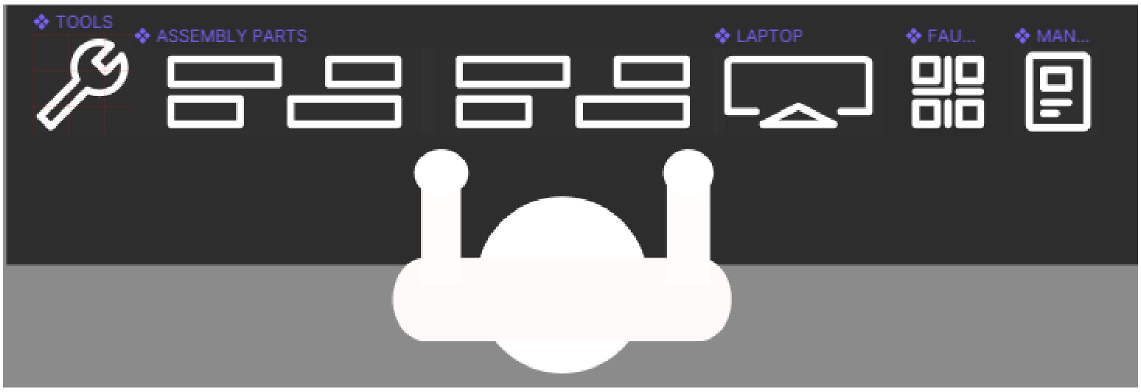


FIGURE 11. Example of an assembly table.

7.3 Work instruction for assembly line

A well-written work instruction helps operators in the assembly line to use the system efficiently and avoid mistakes when using it.
Work instructions are written in both Finnish and English, because are the operators are Finnish, but the official language of the company is English.

The work instructions can be found in the appendixes.

7.4 Visualization

Data visualization positively affects an organization's decision-making process with interactive visual representations of data. Businesses can now recognize patterns more quickly because they can interpret data in graphical or pictorial forms (17). The chart in figure 12 made by Young Hae Lee visualizes how traceability affects the cost of recalls and has visualized this very well.
Data visualization allows companies to recognize correlations between different variables, trends, markets, and risks and rewards.
Data can be visualized in many ways, such as all kinds of charts, histograms, and heat maps (17).

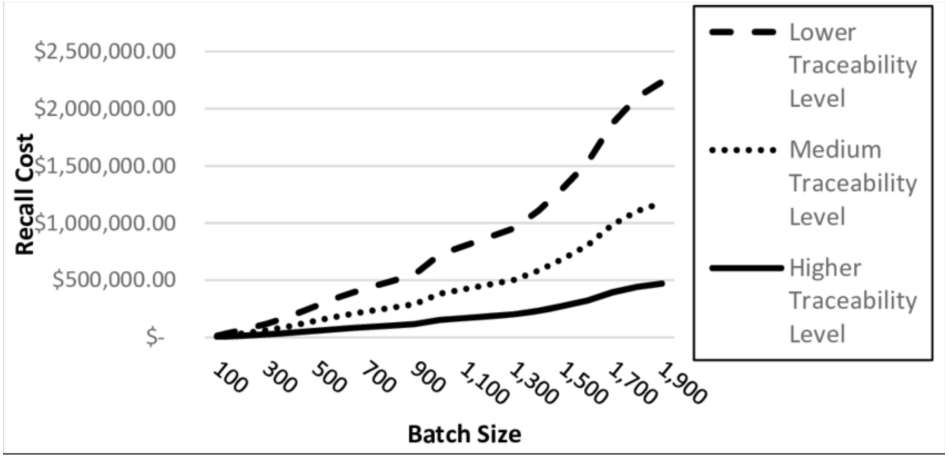


FIGURE 12. Recall cost under different cases. Young Hae Lee 2014.

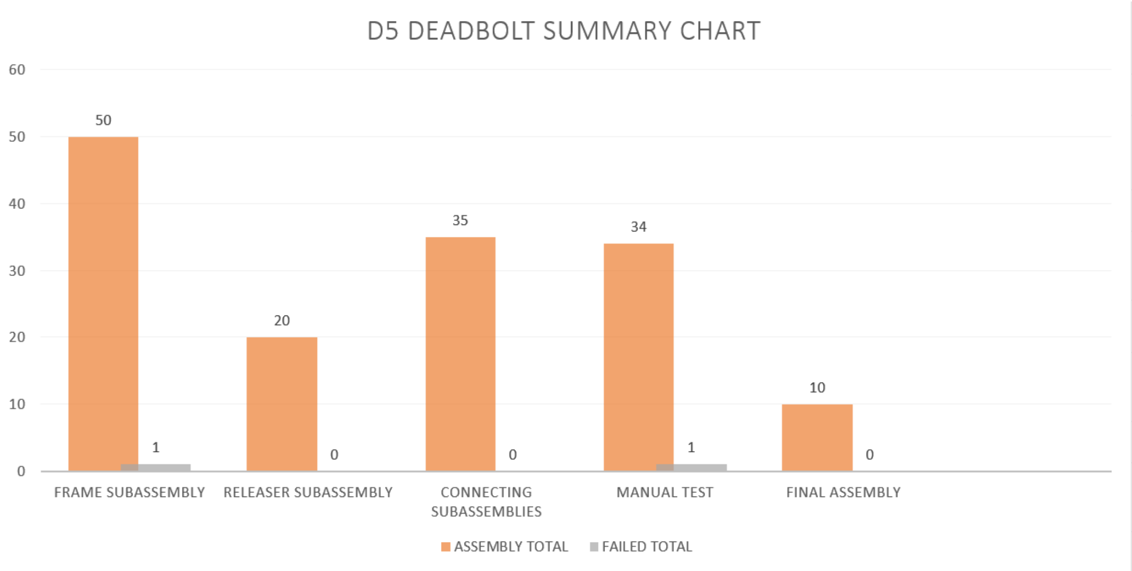


FIGURE 13. Summary chart from Excel

The summary chart above (figure 13) simply displays the number of assembled products and failed products in each phase. This chart is the result of the first day of testing the system in the assembly line.

A summary chart of quantity and reason of the fails was created with Microsoft PowerBi since it is a tool intended for data visualization/presentation. With PowerBi it is easier to display the amount of assembled and failed products but also the defect codes of the failed products.

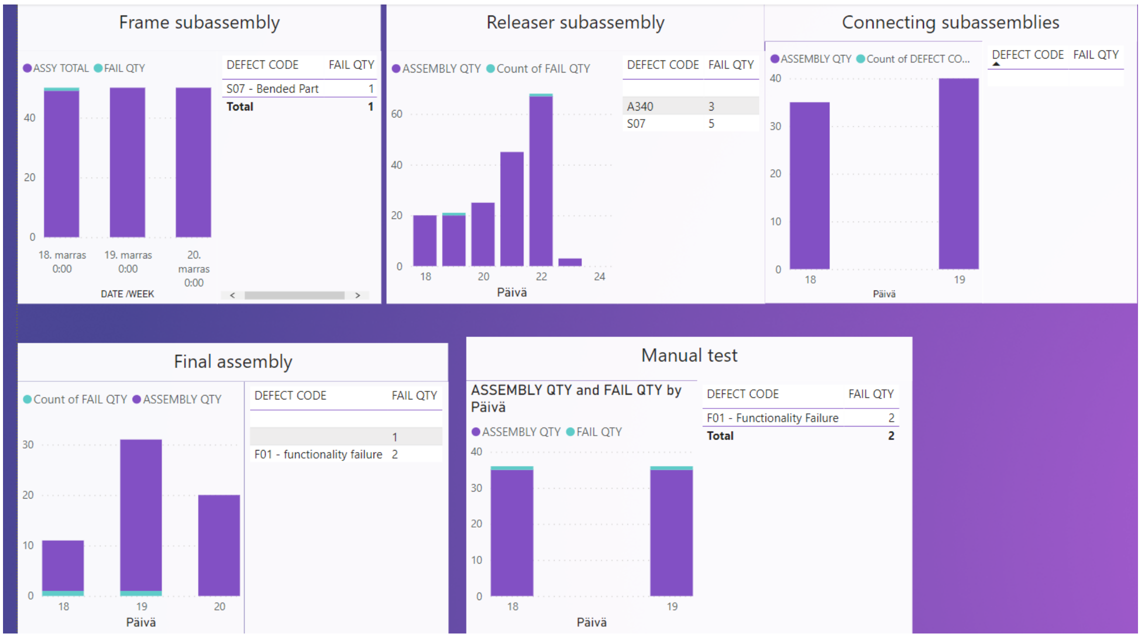


FIGURE 14. Charts from PowerBi

7.5 Deployment of the system

System deployment is a critical activity to make sure that the system is developed operationally acceptable, and that it is effective and safe for operation. System deployment involves the transition to the ultimate end-user, as well as the transition of support and maintenance responsibilities to the support organization or organizations. Demonstration or piloting is done before releasing the system. (18.)

The waterfall model in figure 15 below shows the process as a whole and it is divided into smaller separate phases.

- Requirement analysis, all possible requirements for the system
- System design, specify hardware and requirements, helps to define the overall system architecture
- Implementation, first testing with the input from outside
- Integration and testing, test the system, and look for any faults and failures.
- Deployment of the system, once testing is done, the product/system is released into market/use
- Maintenance: fix any occurring issues, update, enhance. (19.)

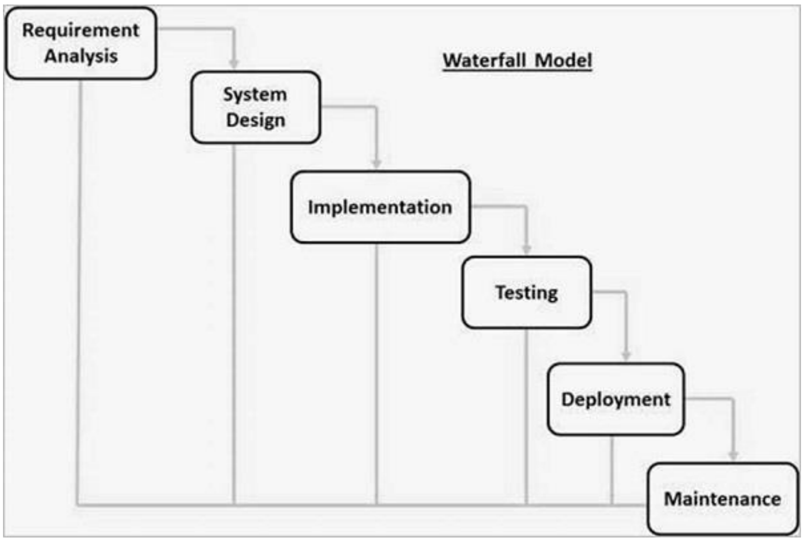


FIGURE 15. Linear-sequential life cycle model, SDLC (19)

8 CONCLUSION

8.1 Results

The main objective of this thesis was to create a base for a yield-monitoring system with Microsoft Excel to replace the paperwork used in the case company. This goal was met, and the base was created successfully which met all the requirements. On top of that, the excel file is “clean” enough to be imported into PowerBi for proper graphs.

8.2 Expectations

At the beginning of this thesis, everything about creating a yield-monitoring system and improving traceability did not seem a too hard task. However, it was a lot more work than I initially thought so traceability is only going to be theoretical in this thesis.

In the future, the yield-monitoring system could be developed even further, maybe even with a proper program intended for this purpose. Also, traceability could be considered as an independent project in the future.

In summary, developing a system that replaces paperwork is a lot more work than I thought, however, this was an amazing learning experience. This thesis was challenging and made me learn more about overall planning, scheduling, Microsoft Excel and PowerBi

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Work instruction, Excel yield-monitoring

1. Line setup time

Line setup time-välilehteen merkataan milloin linjan valmistelu on aloitettu (start time) sekä milloin lopetettu (end time) ja henkilömäärä (concurred capacity). Line work time -kohtaan merkataan päivämäärä, työn aloitus- ja lopetusaika sekä henkilömäärä. Myös kappaleemäärän voi halutessaan merkata.

LINE SETUP TIME			
DATE	START TIME	END TIME	CONCURRED CAPACITY
18.11.2021	7.15	7.45	1

LINE WORK TIME				
DATE	START TIME	END TIME	CONCURRED CAPACITY	PCS
18.11.2021	7.50	9.45	1	

2. Koonta ja testaus

Jokaisella työvaiheella on oma välilehti johon merkataan päivämäärä/viikko, koottujen määrä (assembly qty), viallisten määrä (fail qty) sekä vikakoodit (defect code) vian kuvauksen kanssa. Muistakaa M0-koodit!

DATE / WEEK	SERIAL NUMBERS	ASSEMBLY QTY	ASSY TOTAL	FAIL QTY	DEFECT CODE	M0x-CODE OF THE PART / DESCRIPTION	M0x-CODE OF THE PART / DESCRIPTION OF REWORK METHOD	QTY
[illegible]		50	49	1	S07 : Bended Part	[illegible]		

3. Sarjanumerot

Loppupään vaihella on omat sarakkeet sarjanumeroille johon ne merkataan, jos tuotteelle on annettu jo sarjanumerot. Jos sarjanumeroita ei ole, voi jättää tyhjäksi.

4. InControl

Summary-välilehdellä on suorat linkit Incontrolliin.

Incontrol links	
Production Tool Set	Proto Production
SN All Data	Dynamic production
Special Events, Returns	Manufacturing Tracking
	SN All Data
	Special Events, Returns

Work instruction, Excel yield-monitoring

1. Line setup time

Line setup time –tab is used to write when the assembly line was set up and the working time on the line.

LINE SETUP TIME			
DATE	START TIME	END TIME	CONCURRED CAPACITY
18.11.2021	7.15	7.45	1

LINE WORK TIME				
DATE	START TIME	END TIME	CONCURRED CAPACITY	PCS
18.11.2021	7.50	9.45	1	

2. Assembly and testing

Assembly and testing tabs are used to keep track of the quantity of each phase. Defect codes can be scanned from defect code list. Write down the date/week, assembly quantity, fail quantity and if necessary, defect codes with the description of the fault. Remember the M0-codes of the faulty part(s)!

DATE / WEEK	SERIAL NUMBERS	ASSEMBLY QTY	ASSY TOTAL	FAIL QTY	DEFECT CODE	M0x-CODE OF THE PART / DESCRIPTION	M0x-CODE OF THE PART / DESCRIPTION OF REWORK METHOD	QTY
18.11.2021		50	49	1	S07 - Bended Part	[illegible]		

3. Serial numbers

Serial numbers are marked in the last phases of the assembly, if the product has been assigned with serial number. If serial number has not assigned yet, ignore this step.

4. InControl

Finally, information about the products is inputted to InControl. The excel file has hyperlinks to InControl.

Incontrol links	
Production Tool Set	Proto Production
SN All Data	Dynamic production
Special Events, Returns	Manufacturing Tracking
	SN All Data
	Special Events, Returns