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ENHANCING PRODUCTION LINE EFFICIENCY IN ASSEMBLE-TO-ORDER PRODUCT ENVIRONMENT

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ABSTRACT

Aura Nieminen: Enhancing production line efficiency in assemble-to-order product environment
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The efficiency of production lines is one of the key factors to remain competitive in ever-tightening market conditions. The importance of production efficiency is further emphasized on production lines that focus on manual work in high-wage countries such as Finland. The target company for this thesis is General Electric (GE) Healthcare, a health technology manufacturer which operations found on lean philosophy. The targets of this research are two assemble-to-order production lines that manufacture hospital monitor Carescape One and its by-product F0 dock station.

In lean production, efficiency improvements are achieved by simultaneously optimizing production flow and resource efficiency. To achieve high flow and resource efficiency, production work must be standardized, with work sequencing, WIP, and takt time always tailored to situational specs. The precondition for standardization eliminating variability and waste caused by variation. The aim of this work was to achieve sustainable efficiency improvements for the target lines by eliminating waste using the single/double loop learning -framework and by creating an optimal standard work for the production lines.

The efficiency waste was identified based on already existing and observed, qualitative and quantitative data. Root cause analyzes were performed for the most complex, double loop learning -issues. The solutions for the identified root causes and for the simpler, single loop problems were evaluated based on the solution durability and how well the solution serves the entire plant. The target was to achieve measurable efficiency improvements already during the research, so the simplicity of the solution and its short-term feasibility affected choosing best solutions. The best solutions were then implemented, their success was monitored, and the changes were iterated based on single/double loop learning.

The research successfully eliminated several types of waste from waiting to unnecessary walking and overprocessing. The resource efficiency of the line was improved by 11 %, the throughput time of a device was reduced by 93 % and the walking distances within the standard work were reduced by 54 %. As a by-product of the throughput improvements, a faster feedback loop was achieved for quality issues, as well as significant space savings as the Work-In-Process (WIP) of the subassembly was reduced from 100 subassemblies to 5 and the WIP of untested devices was reduced from 50 devices to 5.

In addition to the actual efficiency improvements, the takeaways of the research are the key factors of lasting change. The most important factors contributing to the change were the active involvement of employees through the change process and the perseverance of the management in implementing the change. Employees were involved in problem definition, root cause analysis, solution generation and further development of the change. Full-time focus on the improvement projects in this research enabled the change agent to become sufficiently familiar with the problem and carry out the necessary follow-up. However, the research situation is rare for the research target company, where many improvement projects are carried out, but with very limited schedules. The biggest obstacle for the target company in achieving lasting improvements is the lack of follow-up. The change process is therefore perceived as a linear, momentary event instead of a learning loop where change is iterated and properly rooted.

Keywords: production line efficiency, flow efficiency, resource efficiency, change management, standardized work, Kaizen, single loop learning, double loop learning

TIIVISTELMÄ

Aura Nieminen: Tuotantolinjan tehokkuuden parantaminen assemble-to-order ympäristössä
Diplomityö
Tampereen yliopisto
Tuotantotalouden koulutusohjelma
Toukokuu 2022

Tuotantolinjojen tehokkuus on yksi tuotantolaitoksen keskeisimmistä tekijöistä kilpailukyvyn säilyttämiseksi kiristyvässä markkinatilanteessa. Tuotannon tehostaminen korostuu entisestään manuaaliseen työhön painottuvilla tuotantolinjoilla Suomen kaltaisissa korkean palkkakustannuksen maissa. Tämän diplomityön kohdeyritys on lean-filosofiaan nojautuva General Electric (GE) Healthcare, ja tutkimuksen kohteina ovat sairaalamonitoreja ja sen oheistuottetta assemble-to-order logiikalla valmistavat Carescape One ja F0 dock station tuotantolinjat.

Lean-tuotannossa tehokkuusparannukset saavutetaan optimoimalla samanaikaisesti tuotannon virtaus- ja resurssitehokkuus. Korkean virtaus- ja resurssitehokkuden aikaansaamiseksi tuotannon työn tulee olla standardoitua, jossa työn sekvensointi, WIP ja takt time on räätälöity aina tilannesidonnaisten speksien mukaisesti. Standardoinnin edellytyksenä on vaihtelun ja vaihtelusta koituvan hukan eliminoiminen. Tämän työn tavoitteena oli saada kohdelinjoille aikaan pysyviä tehokkuusparannuksia poistamalla linjalla havaittuja hukkia yksi-/kaksisilmukkaisen oppimisen viitekehystä hyödyntäen sekä luomalla linjalle optimaalinen standardityö.

Tehokkuushäiriöt tunnistettiin olemassa olevan sekä havainnoidun, kvalitatiivisen ja kvantitatiivisen datan pohjalta. Kompleksisimmille, kaksisilmukkaisen oppimisen häiriöille suoritettiin juurisyyanalyysit. Selvitettyjen juurisyiden sekä yksinkertaisimpien, yksisilmukkaisen oppimisen ongelmien ratkaisuvaihtoehtoja arvioitiin. Arvioinnin kriteereinä olivat muutoksen kestävyys sekä ratkaisun kyky palvella koko tehdasta. Työssä tuli aikaansaada tehokkuusparannuksia jo tutkimuksen aikana, joten ratkaisuvaihtoehtojen arvioinnissa huomioitiin myös ratkaisun yksinkertaisuus sekä sen toteutettavuus lyhyellä tähtäimellä. Parhaaksi arvioidut ratkaisuvaihtoehdot implementoitiin, muutosten onnistuneisuutta seurattiin ja muutoksia iteroitiin yksi-/kaksisilmukkaiseen oppimiseen pohjautuen.

Työssä onnistuttiin poistamaan tehokkuushukkia linjojen epätasapainosta aiheutuvasta odottelusta turhaan liikkeeseen sekä laitteiden yliprosessointiin. Linjan resurssitehokkuutta onnistuttiin parantamaan työn aikana 11 %, laitteen läpimenoaikaa vähentämään 93 % ja standardityön sisällyttämiä kävelymatkoja vähentämään 54 %. Läpimenoaikaparannukset minimoivat oheistuotteenaan laatuongelmien reagointiaikaa ja vähensivät linjan vaatimaa pinta-alaa alikokoonpanopisteen Work-In-Process varaston (WIP):n laskiessa 100 kokoonpanosta viiteen ja testaamattomien laitteiden WIP:n laskiessa 50:stä laitteesta viiteen.

Varsinaisten tehokkuusparannusten lisäksi työn keskeiset opit liittyvät pysyvän muutoksen avaintekijöihin. Keskeisimmiksi muutosta edesauttaviksi tekijöiksi havaittiin työntekijöiden aktiivinen osallistaminen läpi muutosprosessin sekä johdon pitkäjänteisyys muutoksen läpiviemisessä. Työssä osallistettiin työntekijöitä ongelmanmäärittelyyn, juurisyyanalyysiin, ratkaisuvaihtoehtojen muodostamiseen sekä muutoksen jatkokehittämiseen. Täyspäiväinen parannusprojekteihin keskittyminen mahdollisti muutoksen läpiviejän riittävän perehtymisen ongelmaan sekä tarvittavan jatkoseurannan. Tutkimustilanne on kuitenkin harvinaislaatuinen tutkimuksen kohdeyritykselle, jossa parannusprojekteja suoritetaan paljon, mutta hyvin rajallisilla aikatauluilla. Kohdeyrityksen suurimmaksi esteeksi pysyvien parannusten aikaansaamisessa tunnistettiinkin seurannan laiminlyönti sekä muutosprosessien mieltäminen lineaarisiksi, kertaluontoisiksi tapauksiksi muutosta iteroivan kehän sijaan.

Avainsanat: tuotannon tehokkuus, virtaustehokkuus, resurssitehokkuus, muutosjohtaminen, standardityö, Kaizen, yksisilmukkainen oppiminen, kaksisilmukkainen oppiminen

CONTENTS

LIST OF FIGURES AND TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

ATO	Assemble-to-Order
eDHR	Electronic Device History Record
ERP	Enterprise Resource Planning
GE	General Electric
KBB	KanbanBox, a web software for implementing Kanban system
KPI	Key Performance Indicator
NVA	Non-value Added
OPP	Order Penetration Point
PDSA	Plan-Do-Study-Act
VA	Value Added
WIP	Work-In-Process

1. INTRODUCTION

This section discusses the background of the target company and the production lines under investigation, progressing to the research problem and research questions. The research is narrowed down in terms of the objects of observation, the phenomena of interest and timeline. Finally, this section discusses the choices made in the design of the study utilizing Saunders' research onion.

1.1 Company background

General Electric (GE) Healthcare is a subsidiary of an American based conglomerate General Electric. GE Healthcare operates in over 100 countries in the fields of medical technology, pharmaceutical diagnostics, and digital solutions. The focus of GE Healthcare Helsinki is manufacturing and product development of patient monitoring and anesthesia systems. This study focuses on the manufacturing process of Carescape One patient monitor and its supplement F0 dock station.

Production performance at GE Healthcare is measured with six Key Performance Indicators (KPIs): safety, quality, delivery, cost, inventory, and people. This study focuses to improve the cost KPI through enhanced line efficiency. High production line efficiency is a prerequisite for remaining competitive in a high-wage country. As competition in the market intensifies, efficiency targets must be constantly raised. Additionally, the Carescape One production line almost completely relies on manual work which further emphasizes payroll costs. Although this study puts less emphasis on the remaining five KPIs, the key element of the study is that no measures are taken on the cost of any other KPI. For example, quality, which is an uncompromisable necessity in the field of hospital electronics, is never compromised.

Production processes at the Helsinki plant are shaped by fluctuating demand, assemble-to-order -production model (ATO), high level of manual work and lean philosophy. The fluctuating nature of demand and lack of demand management pose challenges to production. Firstly, devices should be produced within short lead times to ensure customer satisfaction. Although lead times can be reduced by increasing capacity, resource efficiency should be guaranteed also at times of low demand. Secondly, resource efficiency cannot be achieved by stocking up semi-finished products as it contradicts the basic principles of lean. Thirdly, fluctuating demand not only complicates production planning but also favors hiring short-term employees. Training employees for several workstations and production lines to increase flexibility might be unprofitable when employee turnover is high. This thesis investigates the main factors that impair the resource and flow efficiency of the production lines and seeks to develop permanent solutions for them based on root cause analysis and literature on lean change management.

1.2 Research problem, scope, and schedule

This research aims to solve the problem of insufficient resource efficiency and lack of one-piece flow. Research questions of the thesis are:

1. What are the main factors decreasing efficiency on the studied production lines?

2. Based on root cause analyses, what are the justified measures to improve efficiency?

3. What are the overall effects of the implemented measures on efficiency?

Efficiency is improved by reducing variance and the waste it generates. Current standard works of line employees and their responsibility areas are updated and monitored to support changes made during the research. An intrinsic part of the solution evaluation and change management process is to pursue a sustainable change. To achieve change sustainability, implemented changes are monitored and iterated to ensure desired results. This will be executed based on single/double loop learning framework presented in chapter 2.2.3.

In this thesis, the production process of Carescape One is considered to start in the temporary in-house material storage (supermarket) and end when a line operator has delivered a ready order to the area where orders from all production lines are gathered (pick & pull area). Due to the ATO production of the monitor, Work-In-Process (WIP) inventory must be maintained at the Order Penetration Point (OPP) between testing and configuration. The lead time of the *entire* production process will be ignored, as the storage at OPP is intentional and determined by external factors. Instead, this thesis aims to optimize the production process in two parts: from supermarket to testing and from device configuration to the pick & pull area.

The starting and ending points of the production process are same for F0 production. However, in the beginning of this project, F0 production material was stored directly at the production line. Therefore, the root cause analysis and solution evaluation parts of

Carescape One issues (chapters 4 and 5) discuss transferring F0 material to the supermarket, although in the F0 observation data (chapter 3) the material is already located there. Observations, root cause analyses and solution implementations of the stations were conducted in a logical order for each production line but not simultaneously for both of them. This causes such slight inconsistencies between the chapters.

1.3 Research layers

This section discusses the research choices made in the study from research philosophy to data collection. The selections are shown in the Saunders onion model in figure 1.

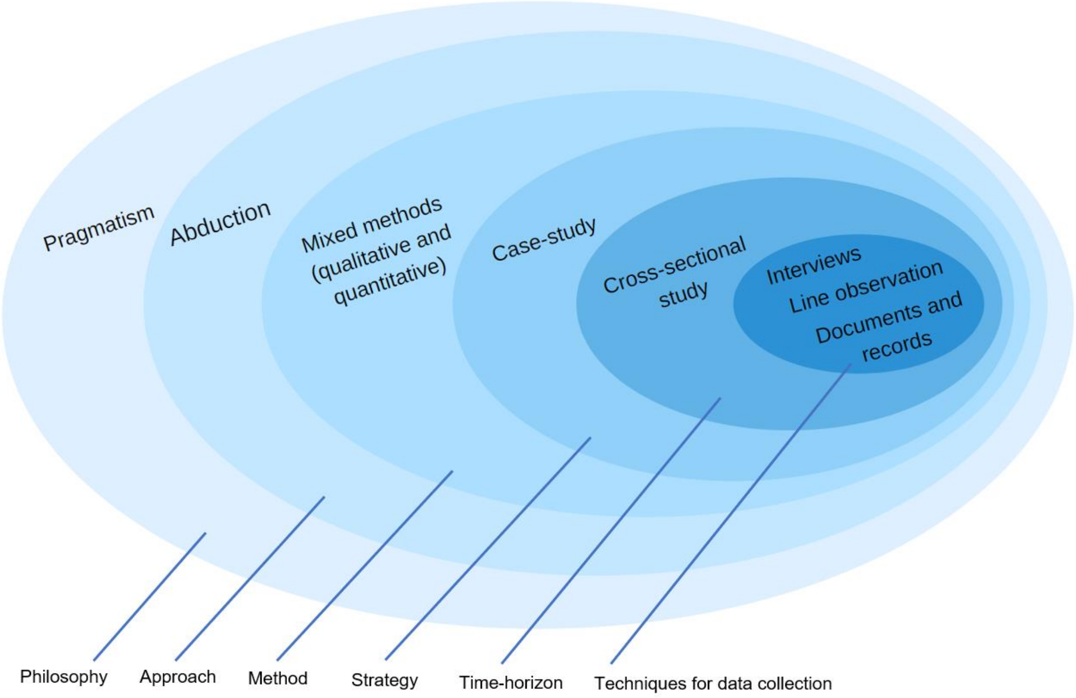


Figure 1. *Research onion of this research. (Saunders et al. 2019, p. 130, modified)*

The fundamental idea of the research is to solve practical problems and develop future practices of the production lines. Therefore, the research is based on a pragmatic research philosophy. The area of interest are all phenomena that affect the operations of GE Healthcare. Reality is constructed and justified through experimentation and observations rather than through social constructs. A successful change achieved during the project is thus measured improvements, not experienced improvements. This research aims to bring tangible benefits for the company, so philosophizing and theorization on an abstract level is kept to a minimum.

The chosen research approach is abduction. There is no existing theory as to where inefficiencies arise, so it must be built on observations. Such generalizations are justified by as many observations as possible. In case the desired efficiency improvements are not achieved, the created theory is modified, and corrective actions are taken. In other words, the known premises (observations) create conclusions (root causes for efficiency problems) that are tested (solution implementation and monitoring of the change).

This research utilizes mixed research methods. Qualitative data gives weight to different issues and increases the objectivity of the study. Although qualitative data is also collected through observations and interviews, “reality” is not built on subjective experiences. For example, qualitative data is used as a base for the interviews. Qualitative data is used to create deeper understanding of the problem and cause-and-effect relationships. The deeper understanding helps root cause analyses and solution generation. In addition, qualitative data is collected to obtain information that may not appear during line observations.

The chosen research strategy is a case study, as the study intensively examines a target production line in the target company. As a typical case study, this study provides an in-depth description of the production line and relevant results that benefit the case company (Jääskeläinen 2020). However, the results of this study strive to be at least partially generalizable for production lines with similar elements as efficiency improvements are achieved through a combination of different sub-solutions.

Within case studies, this is an action research as it suits particularly well for studies with a practical approach. The research occurs in iterative Plan-Do-Study-Act (PDSA) cycles, in which the author influences the outcome of the research by acting as a change agent within the company. The challenge of the study are ongoing changes. Controlling the subject of the research is difficult as well as planning and scheduling activities in advance. (Jääskeläinen 2020) It is impossible to know in advance how the problems and solutions of one station affect the remaining three stations. Additionally, the research environment is non-static. The production area cannot be frozen for this research - development projects and changes outside the scope of this work are implemented on the line. This complicates drawing the line between before and after -situations and obscures causal relationships.

The study is conducted as a cross-sectional study. Current data from the line (observations and interviews) are emphasized over past data in root cause analyses. However, the study includes features of longitudinal research, as the line and the development of efficiency are still observed after the implementation of the change. As the study iterates actions to achieve best efficiency improvements and observes the line in PDSA-cycles, it is not sensible to study the development of just one unaltered phenomenon.

The data is collected from multiple sources. Data sources are presented in the matrix in figure 2.

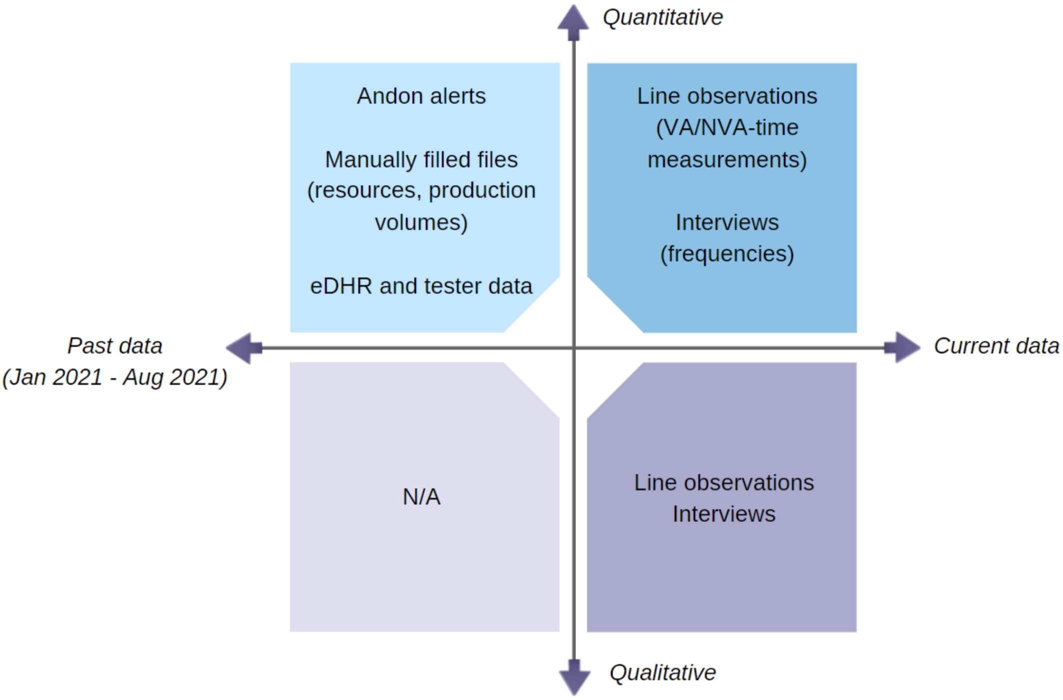


Figure 2. *Data sources used in this research.*

As per figure 2, the data consists of already available past data and self-gathered data. The past data is collected from January 2021 to August 2021, and it consists of disturbance alarms generated directly from the production line (andon alerts), resource files, production volumes files, automatic electrical Decive History Record (eDHR) data and data recorded by testers. The self-gathered data is quantitative and qualitative. The quantitative data consists of the timing results obtained from line observations and frequency intervals of the disturbances specified in the interviews with line operators. Qualitative data is collected through line observations and interviews. The objects of the line observations are employees and tools, single operations, and even entire processes.

The interviews are conducted as informal, unstructured thematic interviews. Themes chosen for the interviews are based on already identified issues in line observations. This eliminates conflicting sources and directs the research away from perceived reality. Additionally, it limits responses to regard efficiency issues only. On the other hand, unstructured thematic interview leaves room for comprehensive description of the issues.

2. THEORETICAL BACKGROUND

This chapter explores the theoretical background around production line efficiency. The first part of this chapter focuses on the basic principles of lean production and the elements of standard work. The second part focuses on lean change management discussing two recurring themes in the literature for a successful organizational change: leadership commitment and employee participation. Additionally, the second part presents single/double loop learning model which is used as the framework for change management in this research.

2.1 Efficiency in lean production

Lean is simultaneously a philosophy, principle, and collection of tools designed to maximize value-creating activities. Lean is strongly connected with quality and productivity improvements by eradicating unnecessary operations. Lean is also strongly related to continuous improvement. (Sundar et. al 2014) Problems should be solved continuously, and sub-optimization should be avoided. To detect problems in real time, lean principles are often associated with pull production.

Lean production highlights flow efficiency. Instead of simply monitoring the efficient use of resources, unnecessary operations and queues must be minimized. This streamlines the flow of units that go through the process. The relationship between resource efficiency and flow efficiency is illustrated in the matrix of figure 3.

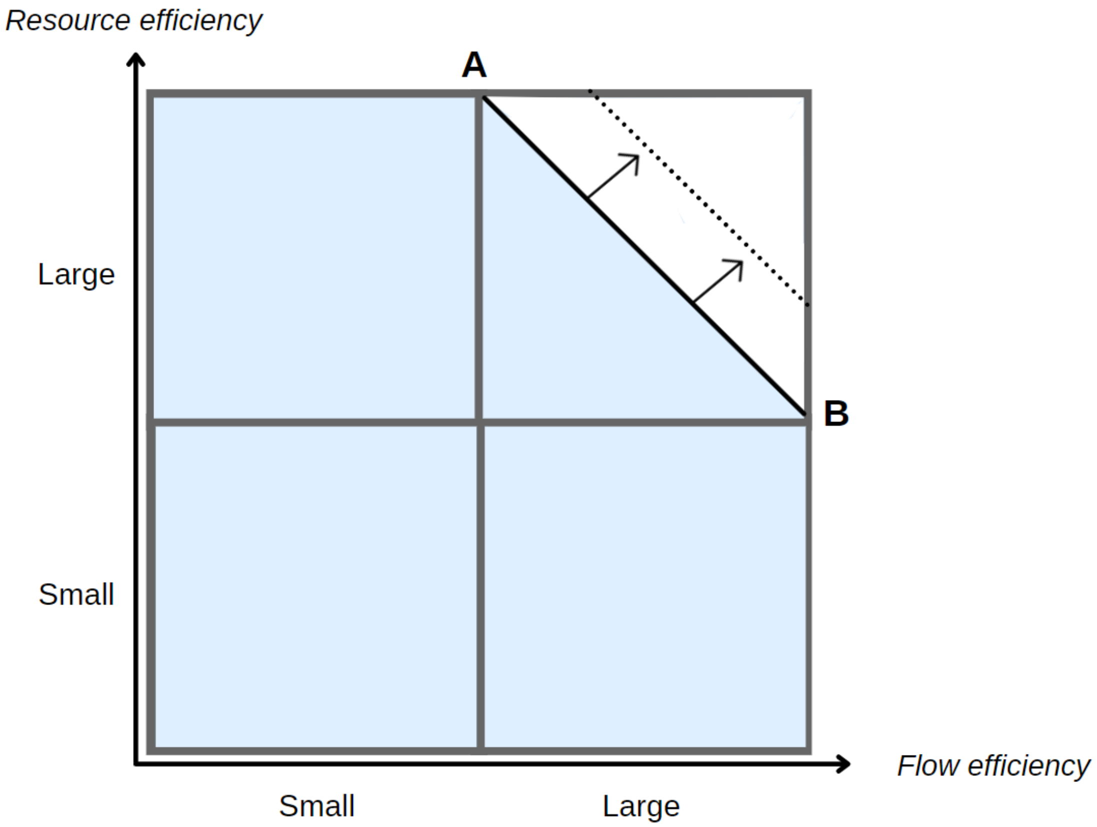


Figure 3. *Efficiency matrix. (Modig & Åhlström 2013, p. 105-106, modified)*

The blue area in the matrix is the feasible efficiency area. According to the matrix, it is possible to reach the maximum utilization rate or the flow efficiency, but it is impossible to achieve them simultaneously. The diagonal line indicates the maximum combined efficiency that can be achieved in a certain production environment. The environment consists of elements such as employees available, tools, and the way operations are organized. Organizations can then aim for point A or B, or any point on the line connecting them depending on for example the cost of resources, production approach or importance of a short lead time. The maxima can be improved by removing variability from the operational environment (Modig & Åhlström 2013, p. 106). This is illustrated by the dashed line. This chapter discusses these two types of efficiency, waste caused by variation, and standard work as a mean to reduce variability.

2.1.1 Resource utilization

Resource utilization is the traditional outlook on production efficiency. Utilization measures how long a resource or a resource group creates value over a certain time period. (Modig & Åhlström 2013, p. 10) For instance, an assembly machine in a 3-shift production that runs without defects 9 hours a day is being used at a 37,5 % utilization rate. Factors such as breaks, setup times, machine malfunctions, material shortages and uneven task allocation all affect production line utilization.

Utilization is closely connected with opportunity costs. Resources tie capital either as one-time investments or ongoing expenses. Every second a resource is not creating value can be translated into an expense that could have been invested elsewhere. Therefore, companies traditionally view maximized resource utilization as a prerequisite for "getting one's money's worth". (Modig & Åhlström 2013, p. 11)

In simple terms, maximizing resource utilization means always keeping everyone and everything busy (Novkov 2018). Such a complex environment as a production facility often bears limitations to 100% resource efficiency. For example, product demand might fluctuate, employees have fixed working times and cannot be sent home when tasks run out, and operations are rarely divided in equally long bits. In practice, keeping everyone occupied at all times would require starting new tasks in advance (Novkov 2018), creating in-process storages or under-resourcing production to guarantee endless workload for everyone. Resource efficiency can also be enhanced by bundling up smaller operations to bigger ones (Modig & Åhlström 2013, p. 9) for example by increasing production batch sizes to minimize setup times or repeating same tasks in one production unit.

Though storages and piled up work tasks might be the answer to optimized *production costs*, there are other variables production planners need to consider. Bundling up operations and creating in-process storages might increase lead times which often reflects to customer satisfaction. In addition, completing work well in advance ties up money to inventory and increases risks for rework or scrapping as order backlog and product specifications might change.

Utilization is a suitable metric in case there are bottlenecks in the production as it is crucial to ensure maximum usage rate of the bottleneck workstation. In turn, maximizing resource utilization in a lean production might create unnecessary storages just for the sake of improved resource utilization. (Jani 2019) All in all, resource utilization is a suitable outlook on efficiency in a push system, for example in a make-to-stock production, where products are produced based on demand forecasts rather than actual demand. In turn, lean-like pull system, i.e., producing for actual customer demand requires an outlook that optimizes production flow and lead times.

2.1.2 Flow efficiency

Flow efficiency is a fairly new efficiency indicator. Where resource efficiency focuses on the production resources, such as production equipment, people, materials and software licenses, flow efficiency focuses on the production unit. (Modig & Åhlström 2013, p. 13)

In efficient process cycles, the product is viewed as a unit that *flows* through production process. Production process consists of the interactive network of transforming and transformed resources (Slack & Lewis 2019). Interaction of these resources can be categorized as either value added (VA) activities or non-value added (NVA) activities. NVA activities are also known as waste or *muda*. Optimizing flow efficiency is ensuring there is always at least one resource that is adding value to the product. Flow efficiency measures the portion of VA activities of a production process in relation to the total time the product spends in the process (Modig & Åhlström 2013, p. 13).

Flow efficiency is determined by two factors; VA activities and process lead time. Lead time is defined as the time it takes for a unit to flow from the beginning of a process to its end. Therefore, lead time depends heavily on the scope of a production process. Processes can be defined on various levels of abstraction – there is no official rule for where a process starts and ends. For example, production process can be perceived to start where customer need is detected or where raw material is collected. (Modig & Åhlström 2013, p. 30).

The second factor of flow efficiency is the summed-up duration of all VA activities within the chosen process scope. Value stems from customer need. Whether or an activity adds value or not is determined from the product’s point of view. VA activities always process the product to fill customer need. They are necessary steps to achieve the final form of the product. Processing can also be a NVA activity if it does not result in increased customer value of the product. (Modig & Åhlström 2013, p. 23-25)

Customer needs consist of direct and indirect needs. Direct need is the concrete, primary outcome expected from the product. Indirect needs relate to customer experience which makes them more intrinsic to the service sector. (Modig & Åhlström 2013, p. 23-25) Production activities often lack the presence of customer experience which reduces the importance of indirect needs.

Organizing resources to optimize process cycle instead of their own utilization does increase mere production costs as resources are not used at their maximal capacity. The benefit of flowing production lies within short lead times and responsivity that create customer satisfaction. Short lead times improve customer satisfaction especially in environments where direct needs are significant compared to indirect needs as in manufacturing. (Modig & Åhlström 2013, p. 26)

Companies must balance production cycle efficiency and resource utilization to achieve both customer satisfaction and minimized production costs. It requires a specific way to organize production processes (Modig & Åhlström 2013, p. 16). One tool to organize and maintain these processes is standardized work. However, before standardized work can guide towards efficient production, variance and consequent waste must be removed from the process.

2.1.3 Muda

Muda, or waste, is a common concept of lean ideology. Its definition varies in studies. The concept can be understood for example as NVA activity (Sundar et. al 2014), or it can be grasped through the seven categories of waste as identified by the Toyota production system.

Activities of production workers can be divided to work and waste. This dichotomy defines waste as apparent needless activities such as waiting. Work in turn constitutes of VA work where material is processed towards the end product as well as necessary NVA work such as machine setup times. (Thürer et al. 2016) Thus, not all NVA can be eliminated from the production process. Value is defined as the end product qualities that the customer is ready to pay for. Therefore, waste comprehends all efforts that consume resources yet add no value from the customer point of view. (Poornashree & Ramakrishna 2019) In order to enhance production efficiency, NVA activities should be eliminated or reduced to minimum.

The seven categories of waste are:

- Overproduction
- Inventory
- Motion
- Transport
- Defects
- Overprocessing

- Waiting

Overproduction refers to producing products well in advance or just in case - without realized orders. Overproduction is strongly connected with inventories. Inventories tie up capital, take up space and increase risks for example when rework is needed. Inventory as a waste covers additionally all in-progress work. (Torkkola 2019, p. 25-26) As opposed to production to stock, just-in-time production is a way to minimize inventories and lead times. The main principle is to produce only the amount that is needed when it is needed as determined by realized orders.

Motion as a waste covers the movement of employees and machinery. Principles of lean manufacturing highlight that employees should do and move as little as possible to complete their tasks. For an efficient work, production workers should operate like surgeons. Tools and materials should be in their reach and all tasks outside the actual production process, for example troubleshooting or material pick up should be externalized to other employees. In addition to clearly defined work tasks one of the key factors to eliminate movement is employing an efficient layout.

Layout also affects material and product transportation needs. Unnecessary transportation might require machinery and cause waiting, as other workstations are waiting for the material or product to arrive. Transportation can also be reduced with changes in the production process, for example changing the order of work stages.

Defects refer to the need to rework a product that does not fulfil the standards set to meet customer expectations. Defects stem from machine malfunctions, misunderstandings, and workmanship errors. It is crucial defects are noticed as soon as possible as they have a cumulative effect on variation and cost as the production process progresses (Torkkola 2019, p. 27). Defects also cover claimed products which, in addition to the manufacturing rework accrue expenses during claim clarification, investigation, documentation and communication.

Waiting refers to the time an employee cannot continue a task before a previous task is finished. Waiting is caused by imbalanced workstations, malfunctions, or other waste categories such as material transportation. Additionally, waiting includes such tasks that are not part of the employee’s job. For example, when an employee carries out tasks that belong to another role, the employee is not using work time for processing the product, thus causing the product waiting.

Some sources bring up eighth waste category: unutilized talent. The potential of employees is wasted when they are carrying out tasks below their talent level, for example when a highly trained employee continually completes tasks that require no training. Another form of wasted potential are excluding production workers from processes such as idea generation and problem mapping. Collecting knowledge straight from the production line via Gemba walks and interviews is one of the foundations of lean.

Removing waste should not be a goal itself. It is rather a way to achieve wanted outcomes. As stated above, different types of waste are connected to each other which motivates a systematic approach to waste elimination (Torkkola 2019). One way to detect areas of improvement is conducting a value stream analysis. It is created by walking through the steps a product flows through from customer request to its fulfillment and analyzing waste connected to each step. (Koenigsaecker 2013) Companies should investigate the key waste types and their cause-and-effect relationships to improve the efficiency of production. Waste stems from overload which stems from variation (Torkkola 2019). Standardized work is a tool to decrease variation and clarify priorities.

2.1.4 Standardized work

Standardized work is a Toyota-founded lean method which aims to stabilize performance. It is the only way to grasp current production performance and highlight production problem areas. In addition to creating a basis for comparison, standardized work is a tool for increased production efficiency and quality. (Brunt 2021) It is important that standardized work represents undisrupted production or detecting waste and malfunctions becomes extremely difficult. This means that waste should be recognized and eliminated before creating standard work. Waste that cannot be removed, for example necessary NVA work, is incorporated in standard work. Whenever processes change or waste is eliminated, standard work should be renewed to match improved production setting (Tulip n.d.). Standardized work consists of three elements: takt time, precise work sequence and standard in-process inventory.

Takt time is the time slot for producing a unit in order to meet customer demand. It can be perceived as the rhythm which defines the rate of production at an assembly line or even at an individual workstation. Customer demand cannot be met if any process within the production line exceeds takt time. Takt time is calculated based on production demand rate and available working time (excluding breaks, start-up processes, shut-down processes, and clean-up times):

Takt time = $\frac{Available\ working\ time\ per\ day}{Production\ demand\ rate\ by\ day}$.

As takt time is directly defined by customer demand, it is a tool of JIT production. In an environment where production demand fluctuates, takt time needs to be reviewed frequently. Falling behind defined takt will result in inadequate production rates and on-time delivery hits. Faster production pace than takt time will result in excess inventory. One of the most intrinsic goals of standardized production is to stay in takt at all times. It is to be noted that even a precisely on-takt production does not guarantee production efficiency if required pace is obtained through over-resourcing.

Lead time is the time it takes to fulfil customer need from the order date to delivery. In addition to production times, it includes for example pre-processing and transportation. Lead time also reveals inventories between operations.

Whereas takt time is a theoretical pace defined by customer demand and lead time is process duration from customer order to delivery, cycle time is the actual pace finished units are produced. It is independent from customer demand. Cycle time can be decreased by adding more operators to the production line. Running the line faster than takt time creates leeway to meet customer demand even if the line encounters problems.

# of Operators needed to meet takt time = $\frac{\sum Cycle\ times}{Takt\ time}$.

Only with a fitting number of operators the production line can stay in takt efficiently. Efficient allocation of production tasks between operators and elimination of wasted production time is enabled through the second element of standardized work: precise work sequence.

Work sequence is the optimum order of tasks each production worker performs within takt time. This sequence of tasks is repeated at each cycle. The optimal work sequence can vary depending on how many employees are working at the production line. Standard work sequence ensures that deviations in the production process are noticed as the job is otherwise performed the same way on each cycle. (Malavasi 2017)

Third element of standardized work is standard in process inventory. It is defined as the minimum amount of stock within the production process needed to minimize waiting time while fulfilling takt time. (Brunt 2021) For example, the waiting caused by unbalanced workstations can be eliminated by having a stock between the stations. Adequate WIP is determined by capacity of resources and demand. Excessive WIP in turn complicates spotting defects in processes and increases risks. Limiting WIP by reducing overproduction also reduces other types of waste such as waiting and transport. (Hemalatha et al 2020).

All three elements of standardized work are situational. They serve a setting with certain work steps, cycle times and customer demand. For example, improving production processes by decreasing their duration might change efficient work sequence and required inventories between stations. Therefore, it is important to actively review and update the elements of standardized work.

2.2 Lean change management

This section is about lean change management as a factor that enables sustainable efficiency improvement. First two subchapters discuss the basic pillars of sustainable change, leadership commitment and employee participation, at a pragmatic level. Last subchapter introduces single loop and double loop learning as a tool to categorize change management approaches and achieving sustainable change.

2.2.1 Leadership commitment

As technical constraints diminish by evolving information systems, organizational behavior is playing an increasingly central role in driving successful change processes. Organizational behavior consists of the attitudes and actions of leaders and employees, as well as their team dynamics and interpersonal relationships. (Lorenzi & Riley 2000) Much of the organizational behavior associated with a change process is built on leadership. This section discusses the impact of leadership in driving successful change through three different categories 1) understanding the need and targets 2) communication 3) consistency.

The first area of leadership commitment is understanding the need for a change and its targets. As per multiple change management models such as Kotter’s 8-step change model, ADKAR, Lewin’s 3-Stage Model of Change Theory, change processes begin in understanding the need for the change (Kotter 1995, Goyal & Patwardhan 2018, Cummings et al. 2016). Management must comprehend the issue and feel a sense of urgency towards it before creating a shared vision. In other words, changes should not be implemented for the sake of changing. Uninternalized need for a change complicates change communication and might lead to insufficient resourcing and monitoring of the change.

Burning platform is a metaphor for a situation where an organization is absolutely forced to undertake some major organizational change to survive. It stems from an oil rig fire accident where few employees, against instructions, jumped from the platform to freezing North Sea instead of waiting for a rescue party – and survived. In a burning platform situation, it is typical that the change involves risks and none of the available options is ideal. Unacceptable status quo however motivates to take action. (Serrat 2017, p. 367-374) Although the concept of a burning pier is extreme and mainly applies to groundbreaking organizational changes, the idea of unacceptable status quo can be applied to minor changes. Nevertheless, it should be noted that the model is for awakening people. Bringing up horror scenarios is inappropriate in a situation where the staff is already aware of the problems. (Mattila 2007, p. 143).

Leadership is essentially about leading a team from the current situation to the desired end point. It is thus important to understand the current situation (burning platform), but also the desired outcome. (Mattila 2007, p. 148-149) As the ultimate mission of a leader is to influence people to achieve a particular goal, leadership does not exist without a vision (Abbas & Asghar 2010). Similarly, change leadership does not exist without a vision for a change. A clear change vision also creates mutual responsibility for its success (Kotter 1995).

A good vision should be clearly distinct from the current state (Stouten et. al 2018). A concrete gap between the current and future state also eases forming right actions. It must be considered that goals of an individual change must align with the strategy of the entire organization. Hierarchically built goals of a change ensure their consistency. In an operational level, targets are concrete, measurable, and understandable to everyone. The team-level and organizational-level goals of a change can therefore built on the operational level. (Mattila 2007, p. 148-149) Linking operative targets to higher hierarchical levels also prevents sub-optimization in the goals of a change.

The second area of leadership commitment is communication. Vision communication complements the vision but on the other hand requires that the leader has already successfully defined the need and goals for change. The shared vision must be argued plausibly. (Mattila 2007, p. 140-143) The ease of vision communication should already be considered when the vision is formed (Stouten et. al 2018).

The theory of change models argues that the vision of a change should be communicated using multiple channels, such as newsletters, workshops, and social media (Stouten et. al 2018). When communicating a vision across multiple channels and by multiple people, it must be ensured that all communication about the vision is consistent (Kotter 1995). For example, discussion in informal channels should be in line with formal channels (Hasanaj & Manxhari 2017). The consistency of verbal and non-verbal communication calls for particular attention. Especially formal leaders should practice what they peach as example setting is one of the most important ways to communicate (Stouten et al. 2018).

The three conditions associated with a vision and its successful communication are clarity of the vision, its attractiveness, and its ambition yet realism. Clarity of vision is a stumbling block. Vision is often created to sound impressive and convincing to external stakeholders. However, even more important is that the vision is clear to its implementers. Verbiage is unconvincing if it is not understood. Secondly, leaders must be able to translate the expected benefits of the change to the members of the organization. Practical understanding of the benefits eradicates change resistance and makes the change attractive for employees. The third point of a successful vision communication is the ambition yet realism of a change vision. Typically, visions tend to be ambitious, but their realism might be dismissed. The enthusiasm of vision implementers fades if the vision is perceived as unreachable utopia. (Mattila 2007, p. 140-143) Therefore, a good vision should come across feasible for change recipients but not be specific enough to determine the specific measures of the change. Vision formation and communication are successful when its recipients understand it, accept it, and are committed to realize it (Strouten et al. 2018).

Although crucial, vision communication is only a fraction of the communication needed in driving a change process: leaders must maintain active communication throughout the whole process. Those affected by the change want to know when and how the change will be implemented. They want to know what is expected of them and how the change will change their work. The team responsible of the change can build trust within the organization by informing employees transparently what is happening, when and why. Although there is a consensus that communication clarity is essential, some studies show that large amounts of information can cause negative reactions (Riehl et. al 2019). Therefore leaders should still leave out information that is irrelevant to their target audience.

Whether positive or negative, leaders’ own attitudes toward change influence the attitudes of their staff. This is particularly important remark for frontline leaders, as frontline employees are often the ones who need to make the biggest changes to their work in change implementation, although their attitudes tend to be dismissed in management-initiated changes. Leaders’ own attitudes to change are conveyed through verbal cues so leaders must be aware of the way in which they discuss change and its progress. (Farahnak et. al 2020, p. 100-102) Working intensively with the change may also blur the team’s perception of what is clear to members outside the team and what is not. Therefore, in addition to planning the contents of the change, the team should plan associated communication as well. An effective communication strategy includes what is said and when, to who and how and through which communication channels.

In addition to passing information, communication plays an important role in integrating employees into the change process (Riehl et. al 2019). Thus, communication covers discussion that arises at the initiative of the employee. Leaders should prepare to answer any questions regarding the change (Hasanaj & Manxhari 2017) and create a culture of dialogue between employees themselves. Sharing knowledge is also a way to learn about the organization; what its employees know about its processes and products and how they position themselves in the organization (Haghi et. al 2021).

The last element of leadership commitment is consistency in driving the change. Consistency refers to perseverance, change monitoring, evaluating, and learning, and possible corrective actions to achieve the set targets. Consistency is also linked to the previous areas of leadership commitment; if management does not understand the need for change, it is unlikely to sacrifice resources for its successful completion. On the other hand, if the goals pursued by the change are unclear, the success of the change cannot be assessed even when wanted.

Completing a project action list does not automatically mean a successful and complete change. The outcome of the change must be regularized to prevent incipient benefits from disappearing. (Mattila 2007, p. 192) For example, everyday work may reveal development needs that had not been considered during the design phase of the change. The implementation, monitoring and further development of the change must therefore also be considered as a part of the change.

In addition to regularization, a successful completion of a change covers the follow-up work and reflection of the change. Paused and failed projects are also worth exploring, as they provide valuable lessons. Project might also generate ideas that are not directly related to the assignment that can be utilized outside the project. (Mattila 2007, p. 199) Change agents should also collect feedback from employees about change processes that they perceive successful themselves (Riehl et. al 2019).

2.2.2 Employee participation

In addition to leadership commitment, employee participation is a recurring theme in the literature on change management. Employee participation covers involvement of all those affected by change, from middle management to supervisors and line workers. It covers the entire change process, not just the planning or implementation phase. First this section discusses employee participation in making change initiatives; how idea generation can be enhanced, and Kaizen culture maintained. The section then focuses on employee participation throughout the change process when the change is initiated by management.

Trusting employees is a characteristic linked with transformational leadership style. Transformational leaders are also known to empower employees and increase their confidence. (Abbas & Asghar 2020) The more employees are empowered in authority the more effective employee involvement is in initiating and driving successful changes (Haghi et. al 2021). Transformational leadership also associated with organizational commitment (Farahnak et. al 2020) and ability to learn (Abbas & Asghar 2020). The employee motivating behavior of transformational leaders is especially relevant during organizational changes (Farahnak et. al 2020).

Trusting employees is a key contributor to Kaizen culture, which is a human-centric problem solving in its essence. Kaizen drives continuous improvement. It is based on the idea that production efficiency arises from the joint effort of its individuals and not necessarily from an invincible production system itself. Improvements in efficiency and other areas is therefore achieved when people improve their own work. (Miller et. al 2014) Kaizen-based organizational culture creates an important foundation for all changes in the organization. Instead of involving employees only in individual change projects, they should be constantly involved in the activities of the organization. This means management's openness to bottom-up change; their overall confidence that employees can make important decisions yielding positive results. (Wilkinson et al 2010)

In addition to trusting and appreciating employees, organizations must place value on standards. The only way to understand current performance, the starting point for Kaizen, is to have standardized work. Kaizen is fundamentally about improving these standards and linking individual actions with long-term objectives of the organization. (Miller et. al 2014) Standardized work defines the best way to perform tasks reducing variation and errors and improving quality. (Mĺkva et. al 2016)

Kaizen does not happen by itself. It requires specifically organized time and management for evaluating decisions, reflecting them, and learning from them. For example, creating a standard work alone is not enough as it must be constantly improved (MÍkva 2016), its implementation must be monitored, and deviations recorded. Leaders should communicate changes and monitor the sustainability of implemented actions. Additionally, they have an intrinsic role in encouraging idea generation. (Foran & Ryan 2017)

Creating an idea that leads to innovation stems from four factors: knowledge, creative thinking, motivation and work environment. Firstly, employees must have knowledge to generate ideas. This knowledge is technical knowledge as well as ability to identify opportunities and combine information. Sharing information within a team is crucial. Knowledge-attribute can be reinforced in employees by creating heterogenous, multidisciplinary teams and rotating work. (Doran & Ryan 2017)

Secondly, employees need to think creatively. Creative thinking can be strengthened through brainstorming, as well as other exercises that specifically aim to stimulate creative thinking. (Doran & Ryan 2017) The sharing process stimulates the generation of ideas, as ideas can build on top of each other. However, group brainstorming sessions must consider the size of the group. Individuals may feel their efforts are redundant in large groups. Additionally, in face-to-face brainstorming sessions, only one employee can share ideas at a time which makes it difficult to process ideas together comprehensively. It is also more difficult for a large group to reach a full consensus on the ideas presented. However, brainstorming groups should big enough to accommodate diversity. (Paulus et. al 2018)

The third attribute is the external and internal motivation of employees to create ideas for improvement. External motivation refers to stick and carrot, and internal motivation refers to employee’s own desire, interest, and excitement to improve. (Doran & Ryan 2017) Underperforming employees may discourage the rest of the group, making incentives necessary. Challenging goals and competitions are a way to maintain motivation and employees’ desire to improve. (Paulus et. al 2018) Another way to increase employee motivation are financial incentives, but their use can have unintended consequences. For example, generating incentives might stop right when the target is reached. Financial incentives might also unmotivated internally motivated employees. More important than financial incentives are sufficiently frequent verbal feedback, recognition of effort, and the attention of the leader. (Doran & Ryan 2017)

The last attribute associated with the generation of ideas is the work environment that encourages towards it. Such environments may be, for example, an organization that promotes a culture of experimentation by treating failures in a positive and learning manner. (Doran & Ryan 2017) This is supported by Osborn's approach, which seeks to produce as many ideas as possible without regard to their quality (Osborn 1957). Quality over quantity creates a demanding atmosphere, which limits the emergence of ideas. Although the Osborn rule is widely used in brainstorming sessions, it should be applied at various occasions within an organization, such as meetings. Employees should always feel welcome to present their ideas without condemnation. (Paulus et. al 2018) Another way a work environment can encourage new ideas is emphasizing teamwork, as best ideas often emerge as a fusion of individual ideas. Lack of bureaucracy can also stimulate idea generation, as well as a compartmented company where information flows freely. (Doran & Ryan 2017)

In addition to promoting the above attributes, it is important that appropriate channels exist for expressing ideas. These channels can be for example face-to-face time with leaders or a mailbox for submitting handwritten notes. Organizations can also utilize electronic idea exchange tools where employees can both contribute an idea when it occurs as well as interact with each other’s contributions (Paulus et. al 2018). Expressing ideas should not require much effort. Moreover, it is important to actively monitor and implement ideas so that enthusiasm for idea generation persists.

In addition to ideas initiated by employees themselves, employees are often involved in top-down changes. As stated in chapter 2.2.1 the first step of a change process is identifying the need for the change and setting targets as well as communicating them clearly to all affected parties. Change resistance might arise in the introduction phase of the change. Although employees react differently to change, eradicating possible change resistance is the first step in involving all employees in the change process.

Change resistance is the behavior and underlying attitude of individuals and groups which counters the purpose of a change. (Damawan & Azizah 2019). It is to be noted that not all change resistance is visible. For example, younger employees with relatively strong bargaining position in the labor market might have lower threshold to change jobs when facing a disagreeable organizational change. Long-term employees in turn might make noise in the power of the same feeling. Regardless of the approach, change resistance often arises from care towards the organization. (Mattila 2007)

Change resistance can be experienced at any level of the organization. According to a study conducted by Lean Enterprise Institute (LEI) in 2000, 36 % of failed ideas are failed due to supervisor resistance. (Langstrand & Elg 2012) However, largest part of change resistance stems from grass roots as it rarely participates in the preparation of a change (Mattila 2007). Understanding the reasons behind change resistance requires understanding the behavior of both individuals and groups. Additionally, change resistance is fueled by different factors depending on the level of the organization. For example, change resistance could stem from the fear of unknown, misunderstandings, rooted habits, lack of rewards, fear of losing one’s status or unconvincing need for the change. (Mattila 2007)

Change resistance constitutes of multiple layers. Unwillingness to go through a change is only the tip of the iceberg. Less visible, yet fundamental factors are the lack of information and right skills to go through the change. (Protzman et al. 2018) Employees resist a change if they are unable to picture themselves moving towards the vision. (Stouten et. al 2018) Therefore, it is crucial to justify the need and urgency of the change, communicate the expected improvements as well as guide through the concrete steps needed to implement the change to achieve positive reception. (Protzman et al. 2018)

Opposing change is not necessarily about its vision. Employees may view the vision as good and believe in the long-term benefits of the change, but simultaneously worry about its implementation or the disadvantages it brings in the near future. (Lorenzi & Riley 2000) Therefore, it is good to also communicate the specifics of the change to employees. The benefits experienced by employees are a good start to get support for the change. However, companies often fail to communicate and explain the negative effects the change causes to employees. Adequate explanations for inconveniencies have been studied to eliminate change resistance. (Stouten et al. 2018) Despite the benefits of transparency, the need for a change and its benefits should always be experienced stronger as the efforts the change takes. (Protzman et al. 2018)

Resistance to change is also affected by how employees view their managers and change agents. Top-down changes will be resisted if employees do not trust the management and consider all management's intentions bad by default. (Lorenzi & Riley 2000) In order for top-down changes to be received favorably, employees must trust both their direct manager and top management. The decisions of the direct manager affect the daily life of the employee. On the other hand, top management decisions affect the company’s culture as well as financial survival, which might make the employee worry about the future of their workplace. Trust in management also affects how fully an employee can focus their energy on their actual productive work rather than self-preserving activities. (Mayer & Gavin 2005)

Once the vision and its concreteness has convinced employees, the next step is to maintain the plausibility of the vision and employees' enthusiasm to move towards it. An extensive change project can be started from a pilot project that introduces the change to employees. Pilot projects allow making mistakes in a good spirit. Another way to strengthen the faith of employees is to ensure fast results. This means leaving more critical areas to a later stage of the project and starting with easier but more visible measures. (Mattila 2007, pp. 158-159) The measures to achieve the vision can be modified during the process, but they must be clearly communicated and justified for the project to remain credible.

The next step in involving employees in the change process is to invest in training employees during the implementation phase of the change. If the change is implemented and employees do not know how to change their day-to-day operations, there is a risk that employees will return to their old habits. As noted, resistance to change is not always based solely on the old desire to hold on, but on the lack of knowledge and skills associated with change. For example, implementing a new tool often requires guidance. Adequate training can be ensured by monitoring change and creating an active feedback loop to gather feedback on both the actual change and its implementation process.

2.2.3 Single and double loop learning

Leadership commitment and the active participation of employees throughout the change process create a strong foundation for successful change. Both of these factors also play a role in achieving sustainable change, where the success of a change is assessed, and corrective action is taken. There are also various theoretical frameworks for implementing sustainable change. The model chosen for this research is single and double loop learning. Single and double loop learning incorporates the idea that a successful change does not happen merely by designing a plan of action and implementing it as such. Effective change requires that continuous cycle of improvement, Kaizen, is applied to the change process itself.

Single and double loop model and, more broadly, organizational learning as a driver of sustainable change was chosen as an approach for this research as it fits the surrounding Kaizen culture of GE Healthcare. Additionally, the unstable operating environment of GE Healthcare supports the view that a cyclical change is the most effective approach to achieve results that best benefit the company. It is unwise to assume that an action plan effective at baseline would still apply months later in an organization that is constantly changing as it is. Lastly, since the efficiency issues raised during the study are diverse and require different approaches, single/double loop classification enables a comprehensive processing of problems, while still giving greater weight to deeper, more complex problems.

Single and double loop learning is illustrated in figure 4. The key difference between the loops is that in single loop learning, the organization learns how to carry out existing tasks better to achieve targets (i.e., having a match between reached and expected outcomes, and therefore exiting the loop). (Tissari & Heikkilä 2001) In double loop learning, organization questions underlying politics and targets. Existing actions are not taken for granted; they are constantly rebuilt to support best perceived targets. (Basten & Haamann 2018)

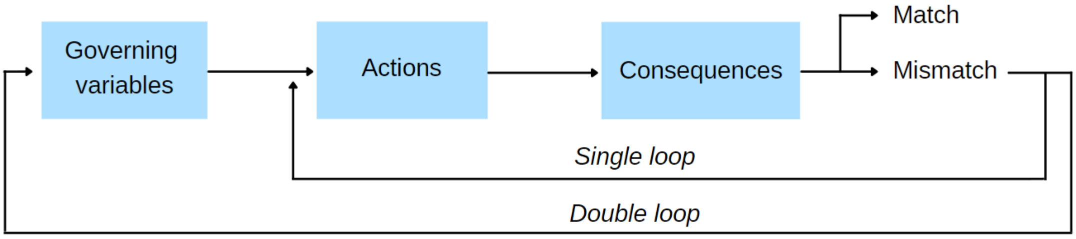


Figure 4. *Single and double loop learning. (Tissari & Heikkilä 2001, modified)*

The learning loops are suitable for different situations, and they are both needed. Single loop learning is suitable for routine situations where some disruption or inconsistency occurs. (Tissari & Heikkilä 2001) Reality is matched with expected outcomes with small changes in procedures and filings without questioning why what is being done. Single loop learning can be seen as eliminating the symptom of an issue.

Single loop learning answers the question “Are we doing things right?”. The learning process begins in finding out problem areas in the current process. These problem areas can be for example bottlenecks, defective tools, or untrained employees. These problems then define relatively straightforward measures that improve the process. For example, a defective tool is repaired without questioning its maintenance process nor the need to use the tool in the first place.

Double loop learning is suitable for solving more complex problems (Tissari & Heikkilä 2001). When targets are not reached, the organization questions factors behind the issue, such as norms, assumptions, and ways of working, and even the target itself. Instead of merely eliminating a symptom, a root cause analysis of the problem is conducted. This kind of learning loop challenges the organization more as it requires self-awareness and humility towards known ways of doing things. Double loop learning answers the question “Are we doing the right things?”.

The model provides a good basis for classifying different types of issues. However, as mentioned, the model will not work without leadership commitment and employee participation. Without a sense of urgency towards the change and its communication to others, it is unmotivating to follow the success of change and improve it until desired results. Without communication and a feedback loop, information about the mismatch and development areas will not pass to the party driving the change. Without a creative organizational culture that encourages brainstorming, the most effective ways to get out of the loop will not be invented. When combined, leadership commitment, employee participation and the single and double loop learning can bring about a lasting change in which problems are approached in ways that suit them.

3. RESEARCH DATA

This chapter focuses to present the data collected from Carescape One production area. The chapter also includes evaluation of validity and reliability of the data sources.

Each subchapter first presents the historical performance data between January 2021 and August 2021. This data is collected from various manually filled files, eDHR database and andon alerts. Andon alerts are organized with pareto principle and only the key issues are addressed. Second data source are interviews with line operators and value stream team members conducted either as separate events or in the context of line observation. Thirdly, each subchapter focuses on the current state of the line through qualitative and quantitative line observation results. The observation data is collected through time measurements, personal hands-on production line experience and other qualitative remarks of the author. Lastly, each subchapter summarizes issues arisen through each data source to create a basis for data analysis.

3.1 Carescape One assembly

Carescape One assembly consists of a subassembly station, assembly line with four workstations and a testing station with four testers. The standard work sheet of the line is presented at appendix A. Movements of the subassembler are marked with red, assembler with the blue and the tester with purple. Movements within current standard work, repeated in every cycle, are marked with solid line. Irregular movements, such as movements needed once per order and waste that is not incorporated in current standard work, are marked with dashed line. Appendix A illustrates a scenario where the assembly line is run with one assembler in order to highlight unnecessary detours.

The production process of a Carescape One monitor starts at the subassembly station. All material needed in subassembly is gathered next to the station in a small market-like setting filled by line spider. Due to drying, the subassemblies are left to wait for overnight which creates a WIP between subassembly station and the assembly line.

Assembler at the first station of the assembly line begins work with grabbing a kit behind the line and adding a subassembly to it from the subassembly station. A kit is a platform that has all the material needed to assemble one device. Kits are brought to the line from the supermarket by a spider. Material is brought to supermarket from larger warehouses by superspiders.

Operators have to log in to a device record system at each station of the assembly line like at the subassembly station. Producing the device with one operator requires moving from one station to another because the tools and material at stations vary. The assembler transports the material kit manually when changing from an assembly station to another. The whole assembly line consists of manual work and the workload is divided to the four stations as equally as possible – within the constraints of tools and space.

When line runs at a full capacity the testing station becomes a bottleneck which creates a WIP between assembly line and testing station. On the other hand, one assembler is unable to produce enough devices to create a continuous input flow to testing station. This usually leads to sequencing resources so that an employee is testing devices at only some of the days that the assembly line is running. WIP between assembly line and testing station vanishes which such approach approximately weekly. Though the production process eventually evens out, the two WIPs of the assembly indicate a lack of one-piece flow.

3.1.1 Historical performance data

Looking at the data from January 2021 to August 2021, the line efficiency of Carescape One assembly (including subassembly, assembly line and testing) fluctuates heavily from week to week. The cause for fluctuation is the lack of single unit flow: WIP is generated between subassembly station and assembly line as well as between assembly line and testing. As the efficiency indicator *Units / Operator* is measured from tested devices, a testing-intensive week generates an efficiency spike. Similarly, a week when devices are assembled but not tested appears as an inefficient week. Average daily efficiency of Carescape One from January to August has been 7,3 units / operator.

The main reasons for line stops and the lack of one piece flow have been poor material availability and tester issues. Additionally, when the assembly line runs at low capacity, devices are not assembled at adequate pace to create a continuous input for testing station. Therefore, testing has been knowingly excluded from resource plans so employees can be allocated to workstations for whole days.

Even when there are no technical tester issues, the tester station is a bottleneck when the assembly line runs at full capacity. The imbalance is further reinforced due to tester unreliability. Because of inconsistent test results, employees have been advised to reject a device only after three fail results from the same test. Log data from the first tester shows that this practice causes 22 % efficiency loss compared to when a device would be passed or rejected based on the first test result.

Figure 5 illustrates the causal connection between line operator quantity and line efficiency, including only the 4-seated assembly line. Partial days are marked in the graph with decimals. As seen in the graph, NVA time increases with operators, implying the assembly line is unbalanced. However, it is to be noted, that the line is configurated to full capacity at times of high demand. Hurry to fulfil orders increases the frequency of workmanship errors and thus defects per unit. Devices with failed test results are not included in the figure which polarizes the graph.

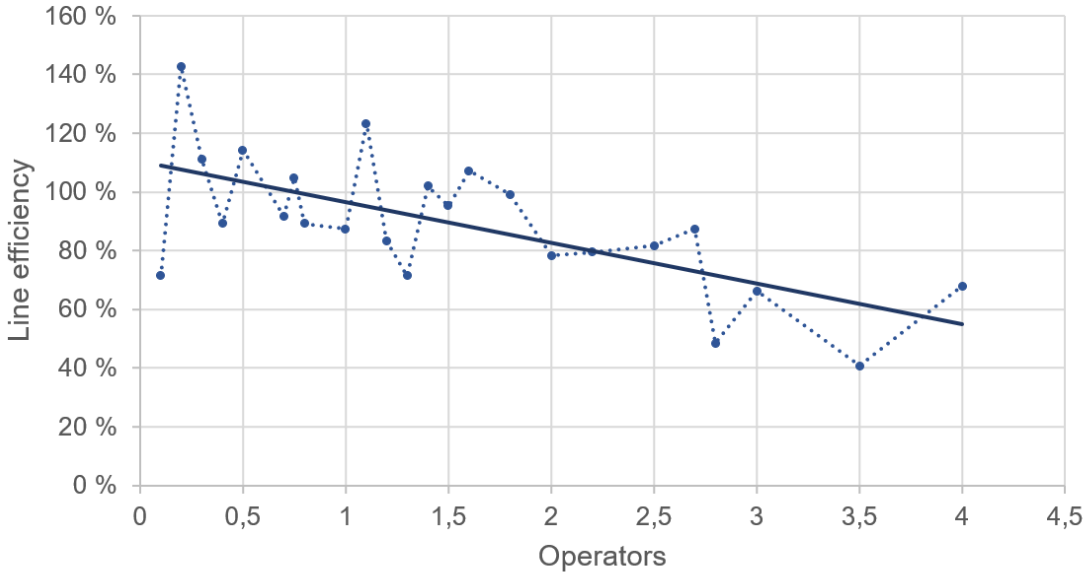


Figure 5. *Connection between line operator quantity and resource efficiency in Carescape One assembly line.*

Andon alerts initiated at Carescape One subassembly station, assembly line and testing station between January 2021 to August 2021 are presented in a pareto chart on figure 6. Andon alerts were brought into active use in April 2021, distorting the absolute amounts of alerts over the studied period.

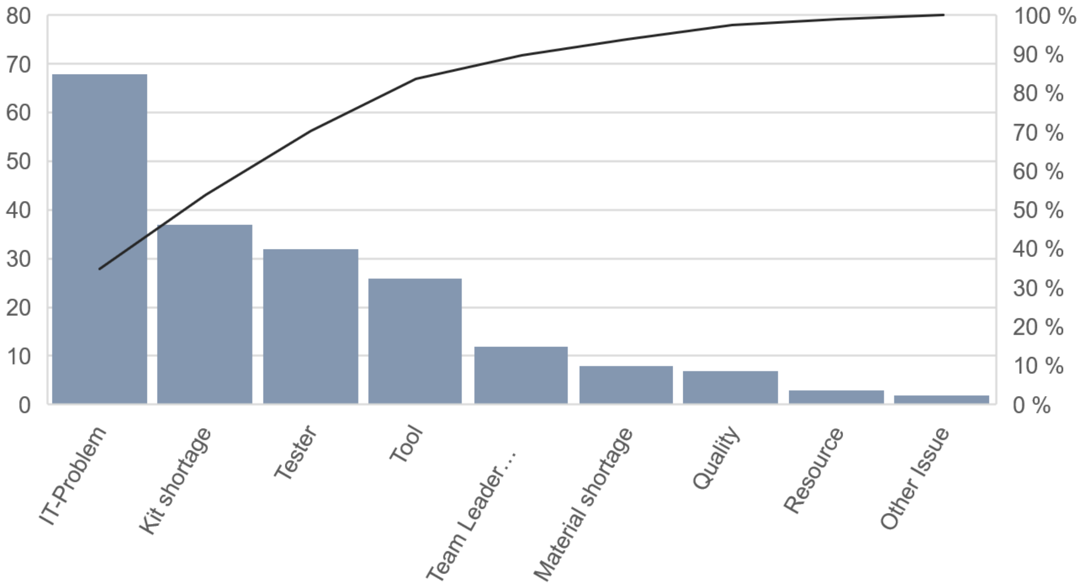


Figure 6. *Andon alerts initiated at the subassembly station, assembly line and testing station of Carescape One.*

With 68 andon alerts, distinctly most frequent issue were IT-Problems which consist of camera connectivity issues, eDHR issues, label printing issues and other IT-issues. IT-issues are usually solved with the help of manufacturing engineers. At times global updates to production applications cause line stops or slowness which cannot be solved on-site.

Second most common issue were kit shortages with 37 alerts, affecting only the assembly line. Kit shortage alerts inform line spider to bring more kits to the line. Unlike other alert types in figure 6, kit shortage inevitably leads to line stop. Therefore, the response time to kit shortage alerts is critical. In idealistic situation the line spider checks the kit situation of the line frequently enough spot impending kit shortage. Kit shortage alert is also sometimes created as a sign of self-spidering. Alert about self-spidering requires no action and is immediately solved by the creator of the alert. Therefore, the alert is created for the sake of efficiency records.

Third most common issue are tester malfunctions at the tester station. Tester issues include interrupted tests and inconsistent test results that result in re-testing. Unreliability of the first tester alone caused 69 h 20 min unnecessary machine time over the studied period. When line operates at full capacity, the first tester becomes bottleneck which causes 1 minute and 20 seconds of waiting for both operators at configuration. However, as soon the line operates at 95,1 % or lower capacity, the bottleneck shifts elsewhere and waiting disappears.

Tester problems also consume manual work of the tester, manufacturing engineers, mechanics, device repairers and employees who transport devices between the production line and repair station. Additionally, the problem with the first tester cause occasional line stops which, in an idealistic one-piece-flow production where WIP is between the testing station and configuration station is eliminated, always prevents completion of orders.

3.1.2 Line observation and interview

The subassembly station was observed individually 15 times consisting of two different employees. Figure 7 portrays different types of waste per each subassembly produced at the station.

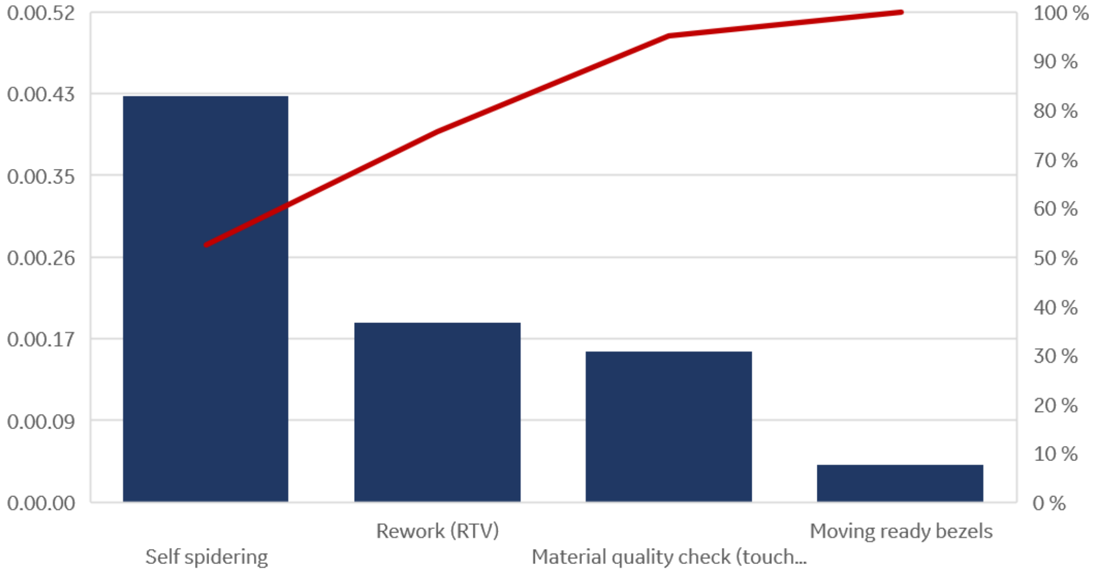


Figure 7. *Non-value added time per device at Carescape One subassembly station.*

The most prominent issue was self-spidering. It is to be noted that the subassembly station was observed rather few times and for two days which makes the issue stand out. However, past data of the station shows that the subassembly station is often operated at different times than the production line, implying that intentional self-spidering does occur on the line.

Second frequent issue was rework due to supplier material issues. Due to rather few observation times, the frequency veracity of this issue was confirmed with the estimations of line employees. Third issue at the subassembly station was the time a line employee spent checking material quality.

The assembly line was observed for the duration of 25 device assemblies, assembled by five different employees. All configurations of the assembly line were studied to spot both line imbalances and waste in changing stations. Figure 8 portrays different types of waste per each device produced at the assembly line. The duration of each waste is based purely on line observations. Frequencies of each waste are based on both line observation and interviews with employees for more accurate estimations.

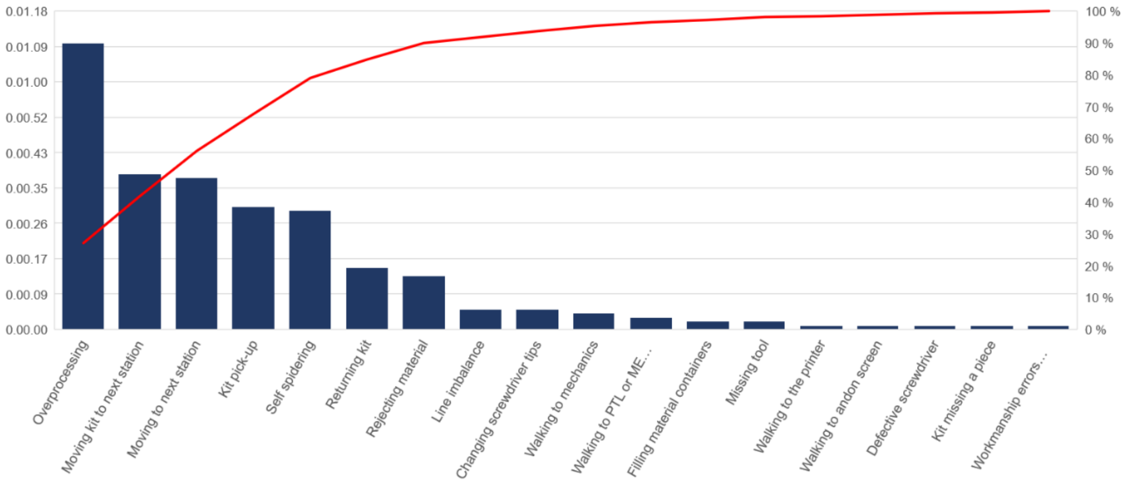


Figure 8. *Non-value added time per device at Carescape One assembly line.*

As shown above, overprocessing of products is the single most significant type of waste, generating as much as 1 minute and 10 seconds of NVA time in the production of one Carescape One. Overprocessing consist of generating "too good quality" i.e., perfecting the product even past accepted specs as well as checking material quality at the line.

The three next waste categories; moving a kit to next station, moving to next station and kit pick-up have to do with the physical setting of the line. When there are two to four operators at the line, operators must move material kits to the next station without changing the station self. Because the kit line is unconnected, this requires effort from two operators; one who is passing a kit and one receiving and adjusting it. This is referred as "moving a kit to next station".

Moving to next station and logging in to the device record system in turn takes in average 37 seconds per device. The average considers all station changes (which occur inevitable every time there are one to three employees working at the line) and the frequency of operating the line at capacity. It also constitutes the kit-pick up which occurs simultaneously with station change if there are less than four operators at the line. Moving to the next station requires a detour as there are side tables between the stations.

Additionally, setting up the computer at the end of station change causes a notable delay on production, especially when another employee is logged in.

Kit pick-up refers to the very first activity an employee performs to begin the production; lifting a kit from a trolley to the first assembly station and adding a subassembly from the subassembly station to it. Kit pick-up is an activity that is repeated at each cycle. Kit return is the activity the last person at the assembly line does at the end of producing a device, respectively. In this activity the employee returns an empty kit nearby the same place full kits are left to wait.

Self-spidering refers to the situations where there is no line spider assigned for the production line. This is considered as a waste as the assembly work is interrupted every time the assembly worker walks to the supermarket to fill in kits and to carry them to the production line. Sometimes demand is low and only a few employees are allocated to the production line. Such situations lead to unnecessary waiting of the line-spider and therefore intentional self-spidering might come into question.

To gain more insight in the observed issues, their frequency and causal connections, line employees were interviewed. The interviews were conducted in connection with the line observation (frequencies) as well as at separate root cause analysis sessions. Root cause analysis interviews focused on two main issues: overprocessing and ineffective line spidering. Insights of the interview and root cause analysis of the said issues can be found at chapter 4.

3.2 Carescape One configuration and packing line

The configuration and packing line is a separate line from the assembly line. It capacity for two employees. The line consists of a configuration station and a packing station. Assembled and tested devices are allocated to certain orders at configuration where language and other setting are added to the devices based on orders. All devices must be configurated before packing. Devices cannot be configurated in advance because a storage with unfitting configurations is a notable risk for on-time delivery. In the packing station, the device is packed in a cardboard box along with accessories. Ready packages are placed on a pallet or a trolley waiting for the order to be completed. Complete orders are brought to a pick & pull area. Employees at the pick & pull area gather devices produced at different production lines and bundle them up according to customer orders.

Movements of Carescape One configurator and packer are illustrated on figure A on green. To highlight unnecessary detours, appendix A illustrates a scenario where the configuration and packing station is run with only one employee.

3.2.1 Historical performance data

The resource efficiency in Carescape One configuration and packing station is measured as the configurated and packed devices per operator per day. The 4 week's moving average of resource efficiency from January 2021 to August 2021 varies between 157 % and 50 %. The overall trend is slightly decreasing regardless of the efforts for continuous improvement.

The efficiency data has relatively low validity and reliability. Although the same principle in daily goal formation (based on the output ratio of the two devices) applies every week, the resource file entries are inconsistent. For example, in certain weeks the eDHR data shows a significant number of packed devices, yet the manually filled resource file claims zero operators were allocated at the line. With more comprehensive research, multiple discrepancies between eDHR user timestamps and resource files arise. Additionally, the manually filled resource files do not specify whether an employee has been packing Carescape One -devices or F0s or both. Tracking efficiency with such combined data is complicated as productivity targets (packed devices per day per operator) vary between these two products.

Secondly, the resource files only allow allocating complete man-days. An employee who works 60 % of the workday at the line is regarded as a 100 % resource, yet an employee who works 40 % of the day at the line is fully ignored in efficiency calculations. Though random variation evens out on a large scale, rounding inputs to full man-days distorts weekly efficiencies and makes causal connections more difficult to detect in day-to-day management. Additionally, moderate order backlog leads to *constant* allocation of < 50 % man-days on the line as even the few orders need to be fulfilled on time, yet devices cannot be configured and packed well in advance. Lastly, employees that train a new workstation are not calculated as a resource for approximately two weeks. However, the output trainees create is taken into account in efficiency calculations which either increases the efficiency rate of the line or leaves a mark of an output that, on paper, is produced by nobody.

In addition to inconsistent base data (low reliability), the efficiency data is invalid due to vague efficiency targets. The efficiency targets are evaluations of actual performance of the line as the targets are primarily used to map resource needs. It is justified that the targets incorporate non-idealities such as tool malfunctions and employee trainings when they support recruitment decisions. To validate the efficiency data and to detect improvement areas on the line, however, the efficiency targets should base on current standard work observations rather than on actualized performance.

In May 2021 the production team leader and operators of Carescape One line started collecting more specific data of daily production volumes. Though the problem of invalid efficiency targets remains, this file allows fractional allocation of resources and specifies whether an employee configured and packed Carescape Ones or F0s. Additionally, this file allows an operator to log potential disruptions which eases data analyzation and problem solving. Table 1 portrays the average efficiencies of Carescape One configuration and packing line from May 2021 to the end of August 2021 based on the new file.

Table 1. *Average resource efficiencies of Carescape One configuration & packing line during weeks 20-35 of 2021.*

	Average resource efficiency	Sample size (days)
One or less operators	75,3 %	25
More than one operator	66,1 %	16

As the file is new, the sample sizes are relatively small. Additionally, the efficiency data presented above has been collected during summer months when new employees are hired to fill in regular employees during their summer holidays. New employees decrease efficiency rates during their official training period which also requires work time from regular employees. Even after a completed training the new employees might affect efficiency rates through slower working pace and workmanship errors. Summer employees of 2021 were always trained and assigned to configurate and pack both products, so their presence reflects equally on table 1.

As mentioned, the validity of table 1 is somewhat questionable due to performance-based efficiency targets. However, data entries are consistent which allows efficiency comparisons between different resource quantities. Table 1 portrays a 9,2-percentage point decrease in average resource efficiency between when the line is operated by more than operator compared to one or less operators. This indicates an imbalance between the two stations.

Figure 9 portrays the andon alert data from the configuration and packing line of Carescape One and F0 demonstrate that the most common reasons for operation disruptions are material shortages (51 % of alerts) and IT-problems (24 % of alerts). Nearly all the alerts were opened by line operators. Fig 9 portrays a pareto chart of the alert categories of configuration and packing line of Carescape One and F0.

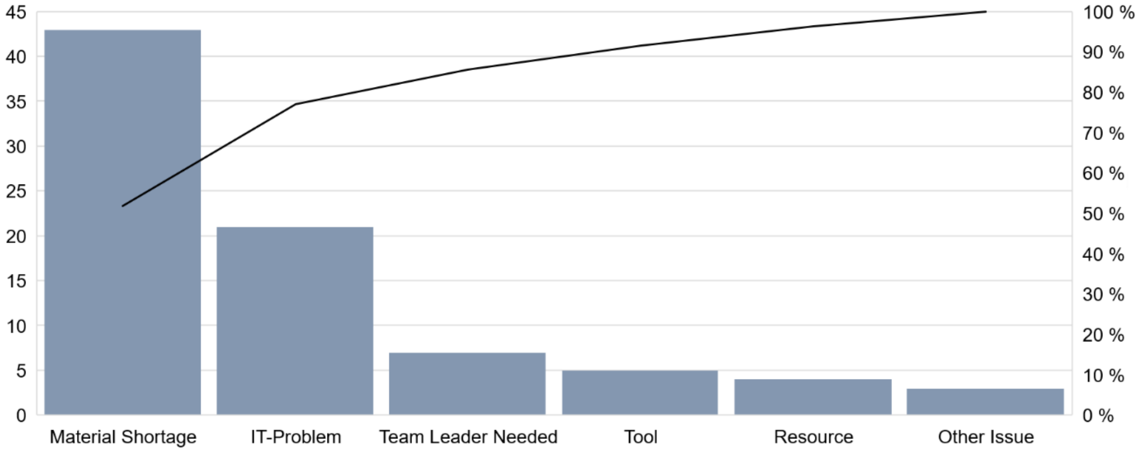


Figure 9. *Andon alerts initiated at the configuration and packing line of Carescape One and F0.*

Andon alerts for material shortages consist of both current and anticipatory shortages. The alerts are mainly targeted at internal logistics workers that bring material to the production line, but some are signals to buyers. Material shortages between April 2021 and August 2021 have affected various items from manuals to package filling material. The time it takes to resolve a material shortage interruption depends on whether the material is already stocked in-house, whether it just arrived or whether the shortage concerns the whole factory or even parts of the supply chain. Since factory-wide material shortages are out of the scope of this research, the following paragraphs focus on the line shortage alerts – cases where material exists in a storage but has or is about to run out from the line.

Among alerts described above, the average alert duration from its initiation to its resolution was 1 hour and 5 minutes. As these alerts include actual shortages as well as impending shortages, it is difficult to determine average line downtime. Nevertheless, all material shortage alerts initiated by a line operator indicate an imprecise standard work of the line spider. In an idealistic process the line spider performs routine line checks to track up-to-date material situation. In case of an impending material shortage (i.e., an empty box in a two-box system), they either refill material from the market if available or request super spider to bring more material to the market first and then bring it to the production line themselves.

Second most common reason for andon alerts in Carescape One & F0 configuration and packing line were IT-problems. 50 % of them relate to eDHR, 20 % to printers and 15 % to cameras, which are used in quality assurance documentation. Alerts concerning IT-problems are targeted at and solved by on-site engineers. At times the IT-problems are global which limits in-house problem solving and increases troubleshooting times.

Realistically, andon data presented on figure 9 only demonstrates a partial truth. For example, sometimes employees might open multiple andons about the same issue if the first one is not noticed fast enough. Even if the duplicates are eventually deleted, it is still difficult to estimate actual troubleshooting times. Additionally, as per observations and interviews, employees rather fix an easy-fix issue themselves than wait for the according person to react to an andon alert. For instance, employees often go get material instead of alerting the line spider to bring it to them. Operators might also walk up to andon owners and describe problems face-to-face instead of creating an andon alert about the issue. Furthermore, operators admit to sometimes create and immediately close an andon after the issue was solved to leave a proof of the issue. Problems with andon usage are examined in more detail at chapter 3.2.4.

3.2.2 Line observation and interview

The purpose of the line observation was to find grey areas (work steps that can be performed at multiple workstations) between the configuration and packing stations to level out line imbalance. In addition to measuring the duration of each step, the observation aimed to gather information about NVA activities. The line was observed for three days including four different employees and multiple different configurations. Only fully trained employees were included in the time measurements. However, a new employee was included in the interview when finding out the most challenging steps of the station. The eventual sample size of configured and packed devices observed was 25.

The interviews included two employees with multiple years of experience in the configuration and packing line, a new employee as well as the shift manager and production team leader. Each interviewee volunteered for the interview, viewing the research as an opportunity to improve their own working conditions and pass on information to the management.

The interview was conducted as a theme interview covering the areas of observed issues: working methods, workstation balance, layout and tools as well as training. The first interview aimed to gather information about causal-connections and frequencies of issues. Later on operators were included in the root cause analysis presented at chapter 4.

First issue brought up by operators was waiting. Due to changes in the packaging process, configuration has become a new bottleneck of the line. As the configuration stage lasts significantly longer than packing, the packer must wait for the next configured device before continuing work. To fill in the waiting time, the packer can carry out some tasks such as assemble the cardboard box for the next device, fill raw material stock or transport ready orders away from the line.

As interviews and past data of the line suggest, configuration is a bottleneck at the line, lasting 1 minute 47 seconds longer than packing. Packers used the waiting time either prepping cardboard boxes in advance or completing other contributory tasks such as filling the material stocks of the line or tidying up the workstation. The longest work step of the line is the machine-run configuration of the device. It requires special equipment which makes the task impossible to do at both stations which makes balancing the stations difficult. Grey areas between the stations are limited because packing requires an already configurated device, which can be opened on eDHR one station at a time.

The varying sources of muda and their duration per device are presented in a pareto chart in figure 10. Operators were once again interviewed to verify the frequencies of different muda to reduce distortions. For instance, a lengthy IT-problem was reduced from observation as none of the operators had faced such problem before.

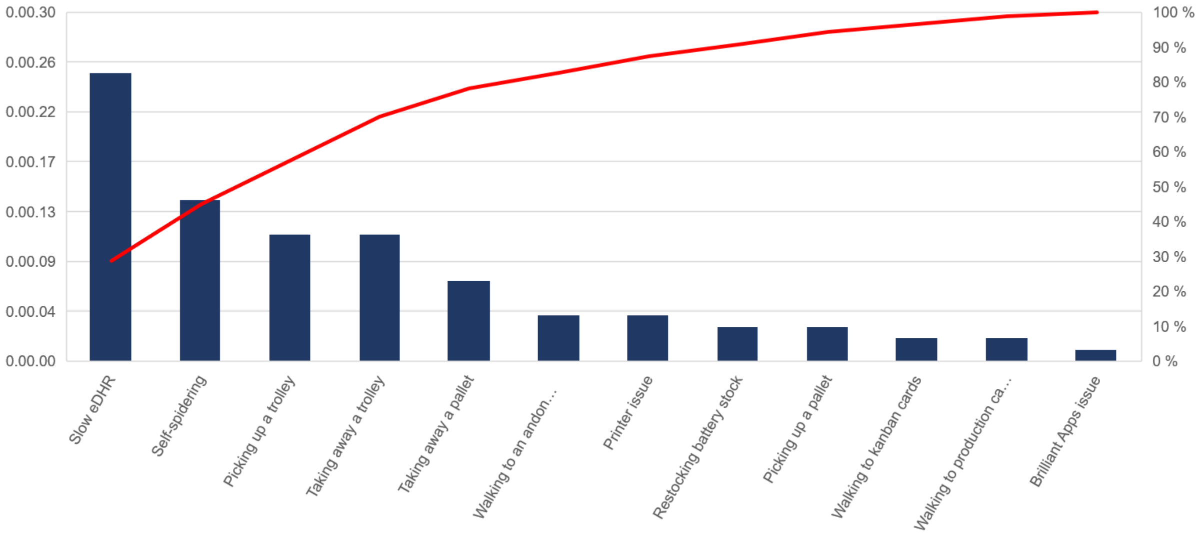


Figure 10. *Non-value added time per device at the configuration and packing line of Carescape One and F0.*

Slow eDHR was the most significant issue adding 25 seconds NVA time to each cycle. Operators do not open an andon alert for system slowness as it was described “everyday slowness” that occurs between 10 to 12. The device history record system might freeze and require signing in again. The system also takes long to process requests and might buffer for multiple seconds before the operator can fill in the next step. As operators use the system frequently, after every single completed task, individually short delays accumulate.

The second most significant muda was caused by self-spidering. During the observations, material often ran out and operators either waited the line spider to react to an andon alert or went to get the material themselves. Self-spidering also includes the time operators use when figuring out material availability and location. As employees described, inaccurate material balances lead to unnecessary investigation and search, further prolonging the disruption.

The three next forms of waste concern transportation of finished orders. As seen in appendix A, the longest routes of configurator/packer occur when the operator brings the ready order to Pick & pull -area and gets a new pallet for the next order. The issue is considered a waste and not a lengthy work step as it is not a part of the standard work of the line worker, and it does not occur in each cycle.

Lastly operators were observed to walk to andon owners instead of creating electronic andon alerts. Operators walk especially to the manufacturing engineer to get a quick response on an urgent issue. NVA time increases if the andon owner is occupied and operators check their availability multiple times.

In addition to observed forms of waste, interviewees brought up issues in the layout of the line. Narrow walkways, bulky packing material and limited workspace lead to zigzagging. The workstation feels especially cramped when the F0 configuration and packing station is in use simultaneously with Carescape One stations. Additionally, the area lacks space for pallets and trolleys which leads to material overflow every time both F0s and Carescape Ones are configurated.

Last issue brought up in the interview regarded excessive camera usage at the configuration station. Especially new employees find it difficult to get a good picture with the camera because photographed surfaces reflect light from the ceiling lamps and the camera needs to be operated with steady hands for a focused picture. Operators learn to get focused pictures through experience, which is why the issue is not reflected in figure 10.

3.3 F0 assembly and testing

The F0 dock station is the add-on battery-charging product for Carescape One monitor. The F0 dock station assembly line consists of one assembly station and two testing stations. Each F0 dock station is tested in connection with the assembly. The movement of the operator is very straightforward and optimal as the stations are next to each other and material is brought to the line in kits just as for Carescape One.

3.3.1 Historical performance data

The resource efficiency of F0 assembly line was 88 % between January and August 2021. The assembly line is always running on one operator so imbalance between testing and assembly duration is insignificant for line efficiency.

During summer 2021, there was a two-week line stop due to rework. The rework was needed because of revision change of a label which was not anticipated when producing an all-time high inventory at the OPP. Due to the exceptionally large inventory, the rework required 12 man-days and stopped the line completely. Resources needed for the rework were assigned under “supporting work”. As a result, the impact of the rework was not recorded in line efficiency.

Fig 11 portrays andon alerts created at the F0 assembly line between January and August 2021. The andon data reveals that more than 80 % of the issues on the line are caused by either IT-related problems or the testers.

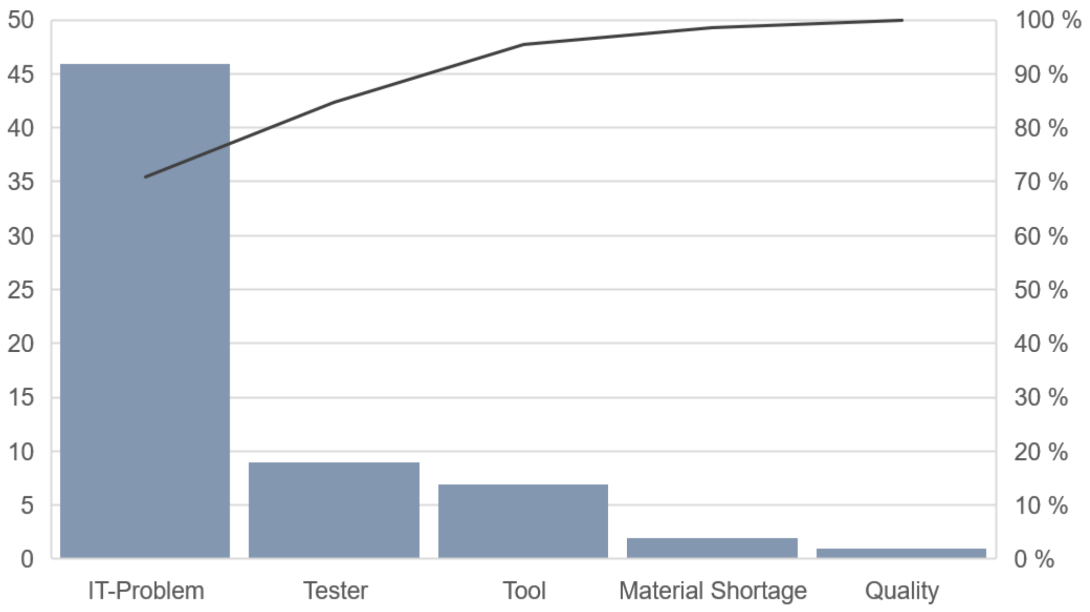


Figure 11. *Andon alerts initiated at the F0 assembly line.*

Over 90 % of the IT-problems at the line regard the same issue; an operator cannot complete the assembly of the first device of the day. The issue exists due to the dual-make of the device. During the studied period, solving the issue required the help and access rights of the manufacturing engineer. However, since August 2021 operators were able work around the problem on their own. The eDHR related detour adds an additional 15 seconds to each cycle which, in otherwise idealistic productions adds up to 8 minutes 30 seconds per day.

Tester alerts are equally divided between the two testers of the line. There were only nine alerts created during the eight months. All alerts were created because of a IT-problems of the tester, and they were all resolved in less than an hour.

3.3.2 Line observation and interview

The F0 dock station assembly and testing line was observed for 22 cycles, including four different operators. Cycle time results varied significantly between the operators, shortest cycle time being 8 minutes and 55 seconds and longest 18 minutes 18 seconds. Work pace differences between operators strongly affect the outcome of the production line, because unlike in the Carescape One assembly line, it is not possible to accelerate production utilizing grey areas. The outcome and cycle time depends on one operator only. Apart from varying working paces, apparent waste per product is presented in a pareto chart in figure 12.

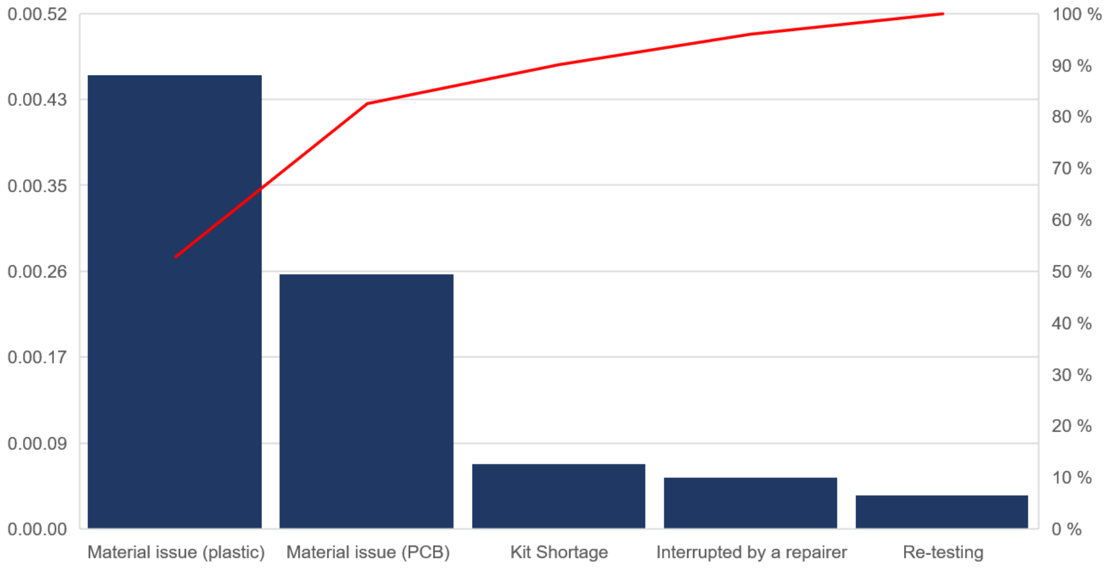


Figure 12. *Non-value added time per device at the F0 assembly line.*

The most significant issues observed at the line were material issues. During observations, an operator noticed a new quality issue on a plastic part in an almost assembled device. In such cases the material kit and device are transported to repairers as-is. However, the rejection process requires the operator to suspend eDHR session, file a rejection report, open an andon alert and transport the device to the area of rejected items. In some cases, the help of another operator or manufacturing engineer is needed which further prolongs the seemingly simple and quick rejection. For example, operators use time troubleshooting if the quality issue is caused by a tool, assembling technique or faulty material.

Second issue was an over 40-minute kit shortage at the production line. The frequency of the issue was altered with the help of opened andon alerts. Kits were introduced to F0 assembly line in January 2022, and andon alerts revealed that the observed kit shortage was the only kit shortage experienced since then. Nevertheless, the root cause for kit shortages and inefficient spidering is addressed in chapter 4 as the issue is relevant for Carescape One assembly line as well.

The last two types of waste are less significant in the sense of additional manual work but distort cycle time. Few of the observed times the workflow of a line operator was interrupted by a repairer as there is a shared testing station. In other words, the testing station was occupied as the line operator finished assembling a product causing unnecessary waiting. Re-testing in turn refers to tester unreliability. Especially one of the two testers rejects devices that on second testing round pass the test. The tester requires only 25 seconds of manual work, yet at every re-testing the line skips a takt and accumulates WIP.

3.4 F0 packing

F0 packing consists of one station. The device is not configurated, but the packing process requires reading barcodes and recording data of accessories to eDHR before the actual packing. F0 dock station orders are set to trolleys or pallets and brought to the pick & pull area. F0 orders are supposed to be completed at the same time as Carescape One order as they are ordered in pairs. However, different cycle times of the packing stations have prevented hand in hand -packing. The movements of F0 packer contain the same movements as a Carescape One packer, illustrated on green in appendix A.

3.4.1 Historical performance data

Looking at the data between May 2021 and August 2021 the resource efficiency of F0 dock station packing station was 78 % between May 2021 and August 2021. Just like for Carescape One, the studied period is only from the summer months as previous resource data has combined Carescape One and F0 dock station packing. Additionally, the target of 25 packed devices per operator per day is not based on an official measurement and therefore the validity of the 78 % efficiency is losing its relevance. As the maximum capacity of the station is one operator, there is no imbalance at the workstation.

Andon alert data of the F0 packing station from January 2021 to August 2021 is already presented at chapter 3.2.1. Most of the alerts created from the combined andon location regard both products. For example, the stations share the same spider and overall logic for material flow and material transfers which means spidering issues and balance discrepancies affect both stations. Only configuration issues (under “IT-problem” andon category) affect Carescape One station.

3.4.2 Line observation and interview

The F0 packing line was observed for 15 cycles, including three different operators. Although the packing line consists of only one workstation, it was also observed in a very urgent order situation where two employees worked at the station. One employee tracked accessory data to eDHR and the other packaged the product. There were distinct differences in working paces. The longest duration of data tracking was 3 minutes 19 seconds and the shortest only 1 minute 30 seconds. The duration of the packing phase varied from 1 minute 22 seconds to 2 minutes 42 seconds. The observer waste as NVA time per device is presented in figure 13.

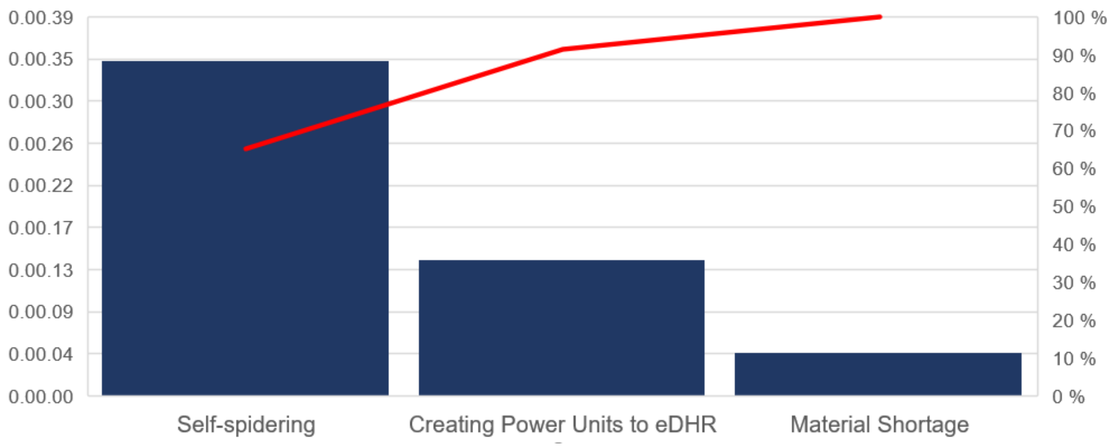


Figure 13. *Non-value added time per device at the F0 packing station.*

The observed waste related to spidering in one way or another. Three of the observed cycles included self-spidering, as no spider was allocated to the area. The second most significant waste, creating power units in eDHR, is a required step in the production process, but it is an outsourceable support task and should be performed by a spider. The power unit is needed in every package, and it should be always created to eDHR before packing. The third significant waste are material shortages where line operators stay at the line and wait for a spider to deliver needed material. It is a sign that anticipatory material ordering, or material checks of spiders are not working.

In addition to these issues, the 15 observation cycles included a disruption of more than 20 minutes, during which 5 operators from across the Carescape One area investigated a quality defect in the F0 dock stationing devices. The operators went through the entire stock of assembled devices to find a usable device to be configured. Although the search was very time-consuming and caused a significant delay, employees estimated it to be so rare that it was completely removed from the waste pareto. The repeated work error caused by negligence was immediately cleared up, as the responsible, newly hired worker was present. It was also decided that this work mistake should be highlighted in future training sessions of the assembly station.

Interviews with employees did not reveal any new problems to the waste pareto. The interviewed employees only further emphasized the ineffectiveness of spidering and the ambiguity of the related activities.

4. ROOT CAUSE ANALYSIS

The main issues of Carescape One production and F0 dock station production from observed and past data are collected to appendix B and C as simplified value stream maps. The blue boxes represent work steps in the production process, the triangles represent WIP, turquoise boxes represent databases and purple boxes represent waste or other issues.

Majority of the observed and discovered issues occur in the production process of both products. The issues vary in their technicality and complexity. As described in chapter 2.3.3, actions addressing different issues require respectively different learning loops. Issues classified to fit double loop learning are analyzes and discussed in this chapter. Issues classified to fit single loop learning are discussed directly in chapter 5 which focuses on solution evaluation. The categorization of all issues is presented in table 2.

Table 2. *Single/double loop learning classification of discovered issues.*

Issue	Learning loop applied
Inefficient spidering (kit shortages, material shortages)	Double loop
Physical limitations of the production area (layout issues, unconnected kit line, line imbalance)	Single loop
Rework (RTV)	Single loop
Material quality issues	Single loop
Overprocessing	Double loop
Order unclarities	Double loop
Material unclarities	Double loop
Walking to andon owners / andon use	Single loop
A non-cyclic task, assigned to nobody	Single loop
Tester unreliability	Single loop (addressed cursorily)
System slowness	Not addressed
Repairers disturbing workflow	Single loop

Material quality problems call for a double loop review. Instead of only eliminating material inspections from the production line, it is important to understand why defective material arrives to the plant in the first place. However, such analysis enters into sourcing and contractual matters which go beyond the scope of this research. For this reason, the issue is viewed from a more superficial perspective where single loop learning and “symptom eliminating” actions are applied.

Another allowance in the thesis was made for tester unreliability issues. Multiple factors suggest that single loop learning is a suitable approach when solving tester unreliability: testing is an essential part of production processes, quality is an unquestionable value of GE Healthcare and tester issues are very technical in nature. However, tester unreliability is an already known issue which has been under investigation for over a year. Investment calculations and large-scale technical mapping of the issue go beyond the ultimate purpose of this research which is why this study does not aim to eliminate tester issues but one of their symptoms (re-testing).

Lastly, system slowness is identified as an efficiency problem, but it is completely eliminated from solution evaluation and implementation. The use of information systems cannot be circumvented or reduced. In addition, the problems are known to be related to software used throughout GE’s global organization. As buffering and system updates are beyond control, the issue is not addressed in this thesis.

4.1.1 Inefficient spidering

Inefficient spidering causes unnecessary waiting and walking. Operators must either wait long for a reaction to an andon alert or leave the line to go get material themselves. In some cases, replacement material is available near the line, for example in full kits. This occurs in cases when a kit is missing a piece, when there is a wrong piece in the kit or when a piece gets broken during production work. In more severe cases, the kits are completely missing. Operators then have to leave the line to either spider the line themselves (spider not allocated to the line for that day) or go find the line spider who has left the area or floor to do other tasks (spider not aware of line capacity and kit needs of the day). Interviews also showed the line spider is not necessarily aware of the tasks which are expected from them. That is, the current standard work of the line spider is a formality rather than a guideline which the employee can actively rely on. Root cause analysis of inefficient spidering is presented in appendix F. The key findings of the analysis are:

1. Inadequate standard work of line spider
2. Spider is not included in resource plans
3. Inadequate training process of line spider

It is important that the line spider is aware of the capacity of the production line each day. The capacity varies from day to day due to employee absences and higher resource needs at other production lines. The standard work of line spider does not include checking the line capacity at the beginning of the shift. The daily capacity indicates how frequently the spider needs to visit the line and bring in kits. Additionally, the standard work only serves a situation when the line is run at high capacity and kits need to be constantly filled. Slow consumption of kits has led to situations where line spider has left to do secondary tasks (not defined in the standard work) elsewhere in the plant without a clue when to check the line again. Inadequate standard work also refers to its inadequate utilization. Even a well-defined standard work is useless as a theoretical document. The research revealed the existing standard work was never introduced to line spider.

Second root cause of inefficient spidering was excluding spider from short- and long-term resource plans. The production team leader of Carescape One production line allocates employees to different workstations of the production line on a daily basis. In this context, the availability of line spider is disregarded as there might be a more urgent need for the employee at other areas of the production. Deliberate or not, the absence of a line spider interrupts the work of line operators. When the line spider is needed more at another production line, impaired line efficiency is justified in the light of overall benefits. In daily tracking, the performance of the line does not cause concerns as the benefits can be concretely seen during the same review. However, day-to-day explanations for impaired efficiency get lost when reviewing the long-term data. Long-term reviews of the production line lack a benchmark (e.g., on-time orders of the helped line), and therefore the trade-off appears unfavorable.

Another issue is the poor tracking of the efficiency of spiders and other assisting roles. Without efficiency targets or performance tracking, long-term resource needs cannot be tracked either. This means that even when production plans double and production worker requirements rise respectively, the effect on assisting roles is ignored or guessed.

Third root cause for inefficient line spidering is the inadequate training process of line spider. Firstly, there is no assigned trainer for this role. Carescape One spider role differs from other spider roles of the plant which limits employee variability and the pool of trainers. Secondly, the standard work (document) is not made available and present enough in the work of the spider. The document states all of the responsibilities of the line spider, and guides through workday and -week. Without a proper guidance which states responsibilities and their required frequencies, important tasks might get skipped whilst the spider keeps themselves busy with inessential tasks. Lastly, it is crucial to update the standard work and give proper training to every new task that is added to it. For example, Kanban system was implemented to Carescape One material storage during fall 2021. Training spiders to use related tools and familiarizing them with Kanban principles was unorganized and lacked ownership. Employees were left confused and their requests for practical training were dismissed as the team responsible for Kanban implementation considered publishing an instruction manual as sufficient training.

4.1.2 Overprocessing

In the broader sense, waiting can be understood as wasting the time on hand. It covers all interruptions in production. The most recognizable waiting is the time an operator spends at workstation waiting for an input from previous workstation. This type of waiting is often caused by unbalanced production line, or disruptions. Time spent for troubleshooting, clearing up unclarities and prolonged breaks are all considered waiting even when an employee is actively doing *something.* Even when a line operator is performing a VA task, the task is considered waiting if it is not a part of the standard work of the line operator.

Overprocessing is one of the most oblivious forms of waiting as it easily blends into regular work steps. Though overprocessing is wasting time on hand and therefore it is included to waiting in its broader sense, a separate root cause analysis was conducted on overprocessing. The analysis can be found in appendix D.

Overprocessing appears as overly precise work and continuous quality checks. As constant quality checks are a symptom of bad material quality (caused by supplier), it is excluded from root cause analysis and discussed directly in chapter 5. This analysis focuses on overprocessing in the sense of producing unnecessarily flawless devices which is an issue of workmanship quality.

Interviews with operators revealed operators have an inner urge to produce “best possible quality”. Concretely, this means removing all quality defects found whether they are accepted by specs or not. Operators find it hard to pass on a device with minor quality error especially when it can be removed by redoing a step. Subjective outlooks and guidelines also advocate producing flawless quality as another operator might reject the device later in the process due to the same defect. Operators have to take decisions into their own hands when a quality-oriented party instructs to produce highest quality possible no matter what and another party highlights line efficiency and defined specs.

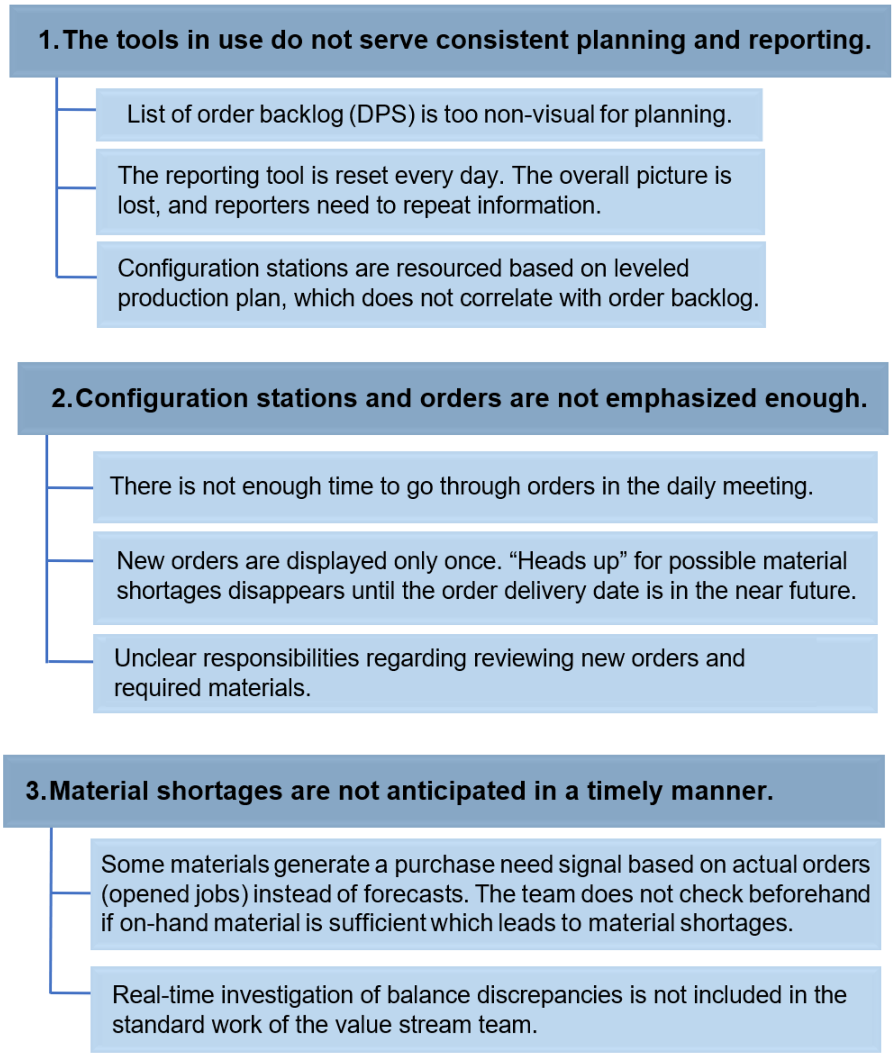
4.1.3 Resolving order unclarities

Another example of a non-value adding activity observed at the configuration stations is when operators resolve order unclarities. This occurs when operators have started configurating an order and material runs out abruptly. Another example is when operators anticipate that material is running out and they need confirmation which orders to prioritize. Third example is when operators are allocated to the configuration station even when there are no jobs open. Order unclarities are analyzed in appendix E.

In an ideal situation, the value stream team takes considers material availability, takes care of order prioritization, and allocates resources accordingly. The line operator is not intended to debate which orders or tasks to complete next, especially since the line operator has insufficient visibility into the different functions of the value stream. The thought process should be done as a team. The team exists and holds daily meetings, yet observations reveal that the value stream team is not functioning up to its full potential and purpose.

The main problem in the functionality of the team is its silo mentality. The team consists of different functions: team lead, procurement, engineering, and production planning. Each member represents their own area of expertise but views it with a tunnel vision. There is a review on each area in the daily meeting of the value stream team, yet as separate sections which complicates connecting all pieces together.

Problems of the daily meeting and other operations of the team were analyzed with members of the team. The issues concern widely different tools and working methods, and they are grouped under three main problems in figure 14.



1. The tools in use do not serve consistent planning and reporting.

- List of order backlog (DPS) is too non-visual for planning.
- The reporting tool is reset every day. The overall picture is lost, and reporters need to repeat information.
- Configuration stations are resourced based on leveled production plan, which does not correlate with order backlog.

2. Configuration stations and orders are not emphasized enough.

- There is not enough time to go through orders in the daily meeting.
- New orders are displayed only once. “Heads up” for possible material shortages disappears until the order delivery date is in the near future.
- Unclear responsibilities regarding reviewing new orders and required materials.

3. Material shortages are not anticipated in a timely manner.

- Some materials generate a purchase need signal based on actual orders (opened jobs) instead of forecasts. The team does not check beforehand if on-hand material is sufficient which leads to material shortages.
- Real-time investigation of balance discrepancies is not included in the standard work of the value stream team.

Figure 14. *Issues in the operation of the value stream team that cause order unclarities for line operators.*

One of the main issues are the tools used for planning and reporting the line. Firstly, the tool that operators follow when configurating orders is also used as a planning tool. The view is a simplified list which was perceived too non-visual for planning purposes. For example, it is difficult to detect from a list how the orders are divided into different days within a week, and how many operators should be allocated to the configuration line on each day. In addition to complicated resourcing, the list does not visualize material needs. The order rows must be opened one at a time for monitoring material consumption and availability. Such manual work and verification is required for low consumption items which purchase signal is not generated based on forecast but on realized orders.

Another issue regards the reporting tool the production team leader uses in production team meetings, value stream meetings and factory level -meetings. The excel-based tool is always reset to reflect the events of the previous day. Such snapshot-like view on the production befogs cause-and-effect relationships. The production result of the week may come as a surprise on Friday as meeting attendees have difficulties remembering the problems of Monday, let alone connecting their effect to the result of the week. Defending outcomes by repeating same problems, in turn, frustrates team leaders and is a waste of everyone’s time. Daily variations also cause unnecessary concern and justification as they often level off within a week. For example, team leaders must explain lagging behind the daily production target at the end of the week, even if the target was exceeded in the beginning of the week.

Last issue concerning tools in use has to do with leveled production plans of configuration lines. The leveled supply plan does not correlate with the actual order backlog as Carescape One and F0 demand fluctuates. Resourcing the line according to the leveled configuration plan is problematic because orders must be completed on time, yet they cannot be completed too much in advance. As a result, operators are sometimes allocated to the line even though there are no orders available, or on the other hand, the configuration line might be unmanned even if employees are needed there. Resource allocation is done by the leveled plan because real-time resource needs, dictated by the order backlog, are not visible anywhere.

The next major problem is that daily meetings prioritize assembly line output and problems far more than orders and configuration. As a result, there is not enough time left to review upcoming and just received orders. In addition to the production planner, this also affects buyers, as the "heads up" for exceptional orders disappears after a quick glance. Therefore, impending material shortages of rarer materials (which purchase signal is only generated when the job is opened) might go unnoticed. The interview with the buyers also revealed that it is unclear whether going through new orders and required materials is the responsibility of the buyers or the planner.

The third main issue causing order unclarities for configurators and packers are material shortages which have not been anticipated in a timely manner. These material shortages mainly concern low consumption that generate a purchase signal according to a realized need. Material shortages arise if the opened job is bigger than threshold defined for the part. Such shortages may take days to weeks to respond to. On the configuration and packing line, this shows as prior investigation of material availability or as half-done orders laying the station.

Another reason for material shortages are balance discrepancies. In this case, purchase signals based on forecasts do not work, as they are based on an incorrect balance in the system. Balance discrepancies are discussed in-depth in chapter 4.1.4, but they also have a connection to the value stream team. When a balance discrepancy comes up, the value stream team should determine the root cause in real time. In the context of an annual inventory, it is extremely laborious if not impossible to find out the reasons for the balance discrepancies retrospectively. Therefore, it should be integrated into the ongoing activities of the value stream team.

4.1.4 Resolving material unclarities

Third form of waiting in the sense of a NVA activity occurs when operators resolve material unclarities. This includes cases where material is physically at different location than Enterprise Resource Planning (ERP) system shows, or physical on-hand quantity differs from system quantity. However, resolving material unclarities brings up another problem – dysfunctional spidering. Improving spidering would completely remove the time that line operators spend resolving material unclarities. As inaccurate system data would still remain an issue for spiders, the root cause for material unclarities is analyzed in this research.

Balance discrepancies come up in multiple ways. Spiders might notice material is missing when getting material from the warehouse to the production line. “Positive” balance discrepancies come up when tested devices do not appear in ERP. This occurs when an item in the bill of material has zero balance in the ERP system when in reality it is available and being used. Balance discrepancies also come up as a by-product when items are examined in ERP for any reason.

The issue with discrepancies in on-hand quantity is more severe than inaccurate locations as inaccurate balances might lead to line stops. However, inaccurate system locations have a connection with inaccurate quantities. It is a mere impossibility to go through all locations to secure item balance. Therefore, item balance may be decreased when operators perform cycle counts and cannot find item at its assigned location. Though inaccurate item balances are more harmful, inaccurate storage locations require a significant amount of search and investigation work.

Interviews with line operators and spiders showed there are multiple reasons why material transfers are not concluded. First, lack of pokayoke allows operators move material without transfers in the first place. Anybody in the house can move material physically without transfers, including subcontractor employees. Employees might not understand the importance of transfers and therefore neglect transfers. Newer employees might be completely oblivious to material transfers. Humane errors such as calculation errors and forgetfulness also play a role even when employees are aware of and trained for material transfers. In addition to humane factors, there are other sources for material discrepancies. For example, tools used for inventories, varying logic used in bill of materials and different units in material quantities (pieces, feet…) could lead to incorrect material balance entries.

To determine root causes of Carescape One and F0 material discrepancies, most significant discrepancies (in quantity) of Q4/2021 were listed. However, retrospective investigation of balance discrepancies turned out to be too challenging as the only lead in the root cause analysis were cycle count adjustment entries made to ERP. Despite interviewing the employees who had made the entries, only one root cause of the ten codes was found out.

The significance of double loop learning got emphasized when the 5 whys root cause analysis for individual balance discrepancies was ineffective. Even if it was possible to track down the root causes of the balance discrepancies retrospectively, eliminating individual issues still seems too superficial. For this reason, the problem is approached by questioning the underlying policies and assumptions regarding material storage.

1. Why is material available for anybody to move?

The factory layout poses challenges for material storing which is why its storage is spread over several different locations. However, controlling material availability with locked storage locations is mainly protested due to blind adherence to traditions. The senior staff of the plant are rooted in the norms and customs of the company. Restrictions on the availability of material have been previously proposed by an outside hire but it was dismissed without proper justification.

2. Why is there an inventory only once a year?

Daily inventory is already built into the ERP system, which appoints few codes every day. The inventory frequency of an item depends on its value. Daily inventory is working at the receipt of the goods, as it is possible to stop material reception during the inventory. However, daily inventory causes resistance in the supermarket and in production lines because the items are stored in multiple storage locations and material flow is not interrupted for the duration of the inventory. For example, when the quantity found in the supermarket does not match the system quantity, the supermarket employee should search up to five different locations to be certain of the actual on-hand quantity. Absence of material in one location most likely means material is marked to incorrect storage locations instead of actual material shortage. On-going material flow during the inventory in turn cause confusion and chaos.

3. Who gets informed of balance discrepancies and how do they react to them?

Balance discrepancies are communicated to the production team leader and to production planner if it affects the completion of orders. The priority in that moment is to figure out the truthful balance. Material is stored at multiple locations, so the item must be fully inventoried before correcting its balance. Buyer is informed in case the item is actually out of stock.

The aim is to also find out the causes of the balance discrepancies when they occur, but there is no existing process for it. The causes for discrepancies are left unrecorded which leads to case-by-case problem solving. The responsibilities for root cause analyses are unclear, and the time and competence of value stream team members is limited.

Eventually material unclarities can be tracked down to two major deep-rooted problems:

1) Material is available for anybody to take
2) Daily inventory is not working as material is stored all over the factory

Additionally, simpler problems arose for which single loop learning can be applied:

1) Real-time analysis for balance discrepancies is missing
2) E-trainings for material transfers are not in Finnish
3) Inventory lacks guidance for special cases:
    a. Checking the unit used for the material
    b. Checking if barcode reader reads the whole serial number to excel
4) Kit codes, where one code includes multiple items
5) Unclear responsibilities of material transfers when material is brought to manufacturing engineers

6) Lack of instructions and a substitute when superspider is absent and cannot do material transfers

For the simplicity of the above issues, they are not further discussed in solution evaluation.

4.1.5 Walking to andon owners

One of the longest walking routes operators take are walks to andon owners such as manufacturing engineer, production team leader and mechanics. In the analysis, the focus is precisely on why operators prefer leaving workstation to get andon owner instead of creating an alert from the line computer. Issues that require the alert in the first place are discussed in their own paragraphs.

Operators shared that often reaction times for urgent issues are significantly shorter when an operator meets the andon owner face-to-face. Some issue categories are owned by employees whose primary task is to constantly “serve the line” and solve acute issues occurring at production lines. These alert owners are for example mechanics and spiders. Other issues, for example those that require the attention of manufacturing engineers and production team leaders, have longer reaction times as their owners are often occupied by another workload such as meetings, development projects or issues of other production lines. Line operators specified, that they walk to andon owners only when the issue is severe enough to stop the production flow. Less severe issues withstand longer reaction times.

According to the guidelines of the plant, production flow should be prioritized over everything. For example, line stop alert should justify leaving a meeting, provided that andon owners follow alerts (text messages) constantly. In reality, andon owners are often focused on their in-progress work, and they complete a task or a meeting before checking andon alerts. However, when a line operator comes by and explains the issue briefly, andon owners go resolve the issue with lower threshold.

Face-to-face interaction is efficient because forces out a reaction of the andon owner. The issue is much more difficult to postpone when there is an employee standing by. The bigger issue however is to grasp the severity of an issue via text message. The constant stream of alarms makes it impossible to familiarize oneself with each alarm. Andon alerts lack an indicator that let the owner know – with a brief look – how severe the issue is.

5. SOLUTION GENERATION AND ANALYSIS

This chapter includes solution generation and their analysis to the efficiency problems observed on the line. The first part presents solutions to simpler, single loop learning problems which did not require a root cause analysis. The second part presents solutions to double loop learning problems, i.e., those that were analyzed in chapter 4. Ready solution packages are not necessarily compared with each other, but different solution elements are generated, evaluated, and justified. The solutions chosen for the implementation are summarized at the end of the evaluation section of each problem.

5.1 Changes requiring single loop learning

This section discusses the more obvious problems encountered during data collection. Though the problems are clear, their solutions are still evaluated because as there may be multiple ways to address them. For example, the inefficiencies caused by a layout were easy to trace to the layout, but building a functional layout requires consideration. In accordance with the framework, the following single loop learning -improvements do not question familiar operating logics or their underlying assumptions, but they aim to improve current operating models.

5.1.1 Physical limitations of the production area

Much of the waste at the assembly and configuration lines are an issue of material placement, tool availability and line design. Due to “obvious” solutions, physical limitations are addressed under single loop learning without in-depth analysis. Observed issues and their causes are summed up in table 3.

Table 3. *Issues due to physical limitations.*

Issue	Physical limitation
Waiting due to lifting kits from a workstation to another and returning kits manually	Unconnected kit line with no return system.
Detouring when changing a workstation at assembly line	Tables between workstations
Waiting due to production line imbalance	Workstations do not have enough tools to realize the potential of grey areas
Imbalance between packing and configuration station due to long machine time of configuration	Only one configuration station is in use as there is not enough room for the second station at the configuration line.
Unnecessary walking when getting packing material.	Illogical material placement at the packing station

The physical shortcomings of the line have been brought to the attention of the management long before this research. However, their effects on productivity became concrete with the findings of this research. For example, though unconnected kit line was originally considered an insignificant factor yet lifting a kit and returning it manually turned out to be a surprisingly large efficiency problem

GE Healthcare already decided to arrange a Kaizen event for Carescape One efficiency in November 2021. The observational results justified the event should focus on the physical limitations of the area. The company also considered a Kaizen event focusing on standard work improvements and line balancing. Waiting due to line imbalances turned out to be less significant issue than anticipated. Although such Kaizen event would require less resources and investments, it would only improve line efficiency when the line is run on full capacity. Layout change and line reconstruction in turn improves efficiency no matter how many operators are allocated on the line.

The observed issues on table 3 decrease resource efficiency of the line. In addition, there are other areas for development that are within the scope of the Kaizen event and therefore define criteria for a successful change.

One of the issues are the massive amounts of WIP in the line. WIP is mainly accumulated between subassembly station and assembly line, between assembly line and testing station and between testing station and configuration line. The WIP is accumulated by working methods (such as not testing assembled devices right away) and enabled by physical settings (such as a multi-level carts available for assembled devices). This Kaizen event aims to design a line and standard work that minimizes WIP and creates a one-piece-flow. In terms of the physical setting, this means placing workstations side by side and eliminating storage space.

Another issue on the line is the material stored directly at the line. For example, before the Kaizen event, Carescape one subassembly station and F0 assembly station were not in the scope of spidering, and all the material was stored at the stations and nearby them. Storing material at the line takes up space and confuses the general appearance of the line. In addition, picking up material and filling their containers consumes time. Another aim of the event is to transfer as much material as possible from the line to the supermarket.

Although the decision of a layout change and line reconstruction is clear without further evaluation, it is necessary evaluate *how* the layout and assembly line are changed. Objectives for an ideal solution are:

1. The workstations are arranged in an order that supports a streamlined material flow.
2. The workstations are close to each other.
3. Minimum material stored at the line.
4. Improved assembly line: connected kit line, no need for additional tables between workstations & comprehensive range of tools at workstations.
5. Packing material is placed by the packing station.

In addition to the listed objectives, there are other constraints and aspects affecting the solution planning. For example, the employees of the moonshine shop are available for the project for one week only. Secondly, investments on new material should be minimized. Thirdly, the space available limits workstation placement. Two of the first layout ideas are presented on figure 15.

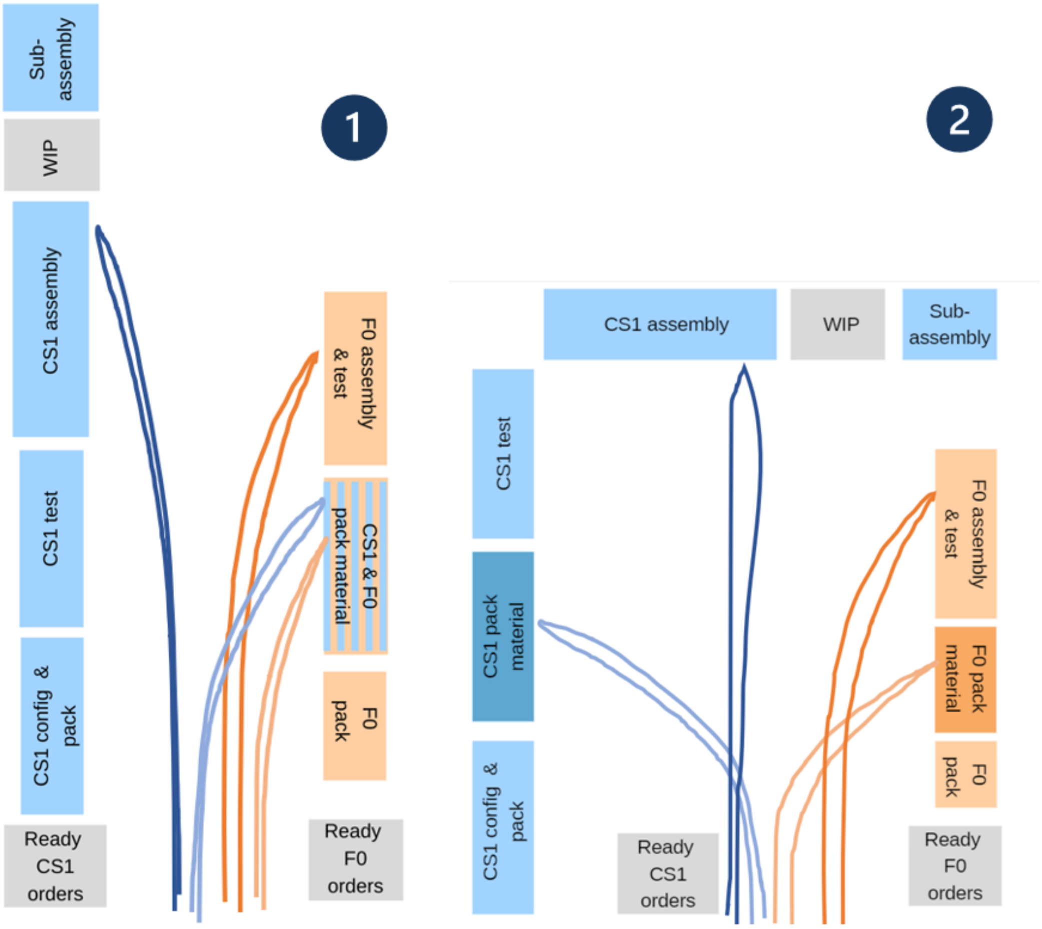


Figure 15. *Rejected layout options and spider routes.*

Both layout options have clearer material flow. The workstations are located in a logical order and travel distances of operators are minimized (objectives 2 & 5). In both options, F0 material is moved from the line to the supermarket (objective 3). Carescape One and F0 configuration and packing station is split into individual stations as an extension for their assembly and test lines. The only issue is that the products should be packed simultaneously as they are always ordered together. Combined station clarifies the simultaneous completion of orders. However, separated workstations support streamlined material flow (objective 1). To achieve simultaneous packing, separate "playbooks" with various sequencings must be created for all configurations of the stations.

One of the issues in the first layout option was the inconveniently long row of Carescape One stations. It is impossible to arrange passageways between stations due to space constraints. Secondly, packing materials of Carescape One and F0 should be combined in one area, weakening objective 5. Thirdly, all spidering is carried out through from a single passageway. Kits must be transported through the entire line which chaotizes the area and poses a collision risk.

Layout 2 optimizes space utilization through a L-shaped line. This arrangement also allows the packaging material to be placed close to each packing stations (objective 5). Although the flow of material within the line is straightforward, the problem of spidering remains. In addition, production management was reluctant to implement an L-shaped line without further elaboration.

Inoperative layout options motivated to reduce the overall need of space. The most effective way to reduce needed area was to integrate subassembly station to the assembly line. This frees up the space needed for the subassembly material as well as finished subassemblies (objective 3). The only obstacle was drying time which, depending on the source, was instructed to last from 5 minutes to 24 hours. Prototypes revealed the drying time is unnecessary which enabled merging subassembly station to the assembly line. As a result, third layout option was formed. It is presented in figure 16.

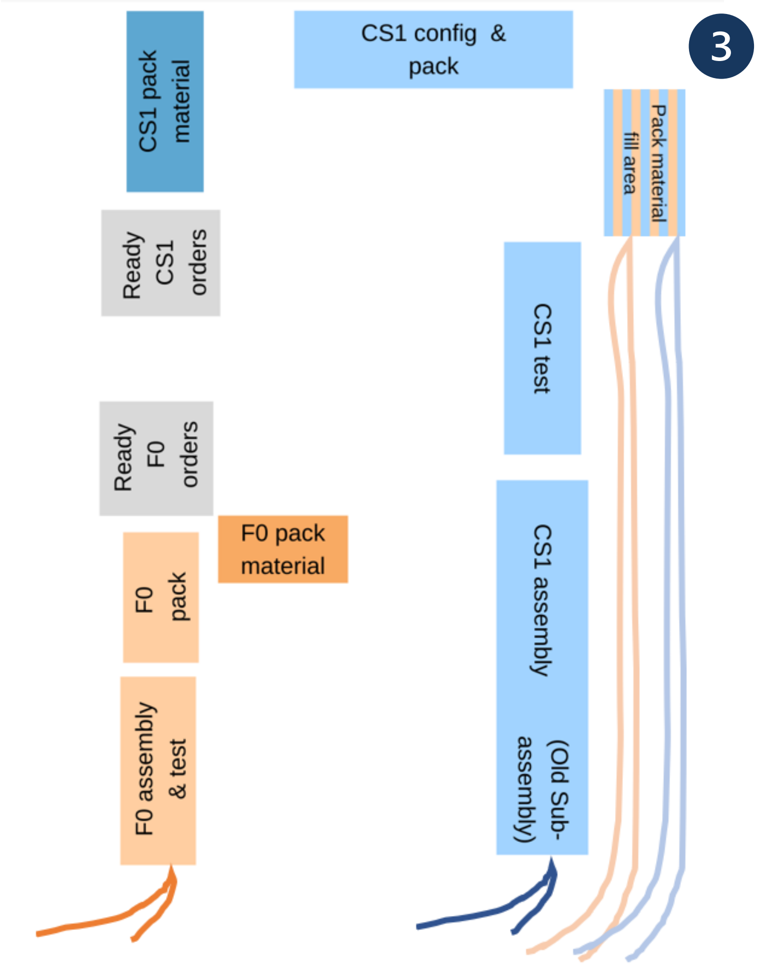


Figure 16. *Final plan for the new layout.*

In the final option, one additional route was created through which orders can be transported out and from which operators can enter. The workstations are close to each other (objective 2) and are arranged according to the streamlined material flow (objective 1). Objective 3 is best achieved from the alternatives because both F0 material and subassembly material are transferred to the supermarket and brought to the line in kits. The kits are brought to the edge of the production area, removing the need to enter in.

The material of each packing point is stored in the immediate vicinity of the packing stations (objective 5). This is possible as only a necessary batch is stored by the station. Additional material is stored at a separate fill area which is stocked in accordance with 2-box system. With a separate fill area, the spiders' route can also be arranged to not interfere with routes of line operators. The space reserved for the Carescape One configuration and packing station also allows setting up the second configuration station. The assembly line is built completely anew (objective 4).

Eliminating WIP between the assembly line and testing means that testing is not considered an individual station anymore but a part of the assembly line. Employees are not allocated just to the testing station anymore as all devices are tested directly after assembly.

The changed division of work requires instructions, training and monitoring so that workstation balance is guaranteed. In addition, the chosen layout requires improvements to the 2-box system, new rules for ordering material, and clear instructions for spiders.

Solutions:

1. Reorganizing the layout (layout option 3).
2. Improving the assembly line (connected kit line, tools to increase grey areas in production).

5.1.2 Rework (RTV) and inadequate material quality

One of the most significant issues observed at the subassembly station was rework operations had to do for reasons beyond their control; operators had to reapply material on a part which supplier quality varies. Operators had already internalized the rework as an inevitable step in the workstation. Due to acceptance of the problem, the production team leader and other members of the value stream team were unaware of the issue. Therefore, the issue has not been communicated to the supplier either. The primary solution for the issue seems simple:

1. Checking existing specs defined for the part.
    a. Giving feedback to supplier if existing specs are not followed.
    b. Defining specs and communicating them to supplier if required quality is not specified for the part.

Insufficient material quality is also a central issue on the assembly line. Operators spend a significant amount of time evaluating blemishes and bumps of material brought to the line. Due to subjective quality criteria, operators must evaluate whether to accept a piece or not. For reassurance, operators ask multiple opinions before deciding, which multiplies the wasted time.

Supplier quality issues have troubled the line operations from the outset. The production of Carescape One in Helsinki was launched in a hurry in 2019. As a result, item specs and suppliers were still forming and evolving after the launch. Soon after the production began, the demand for the product skyrocketed due to Covid-19 pandemic. Quality specs had no time to standardize before the massive capacity increases. The desperate times of material availability also drove the company to prioritize quantity over quality. Current terms of supplier contracts are still unclear to all in-house operators involved in the manufacture of the product. As there is no official quality checkpoint for the parts before the assembly line, the task has landed to the production workers.

Preferrable solution is to remove material quality assessment completely through better material quality. Short-term efficiency gains can also be achieved by moving material inspection upstream. While shifting responsibility from one employee to another does not improve the resource efficiency of the plant, it does improve line performance and production flow. The task of the assembly worker is to assemble products and all activities outside of it are waste. If the waste cannot be eliminated, it should be allocated to support roles so that the actual revenue-generating function of the plant remains as efficient as possible.

Solutions in the preferrable order:

1. Reviewing quality criteria defined in supplier contracts.
    a. Giving feedback to supplier if existing specs are not followed.
    b. Defining new quality criteria and communicating them to supplier if required quality is not specified
2. Moving inspections up-stream to material reception.
3. Moving inspections up-stream to line spiders.

5.1.3 Transporting ready orders

A significant waste in both packaging stations was the time it took for operators to transport finished orders and to pick up new pallets and carts to the packing stations. The smaller the order batches, the more frequently the operators must transport the order to pick & pull area. In addition to wasted time, the transporting of the pallets was an ergonomic load. Operators have resorted to carrying empty pallets without a hand forklift to save time. Transporting ready orders is also problematic because it occurs on an order-by-order basis. The task disturbs workstation balance as it is a non-cyclic task that cannot be scheduled. Transportation of orders can also be seen as a waste of employee potential. Orders can be transported with short training by anyone, but training employees for assembly line and configuration station is much more complex.

Means to include non-cyclical work steps to standard work are ineffective in a situation where transports cannot be scheduled for example in connection with breaks. For this reason, outsourcing the task to another role, a spider, is the optimal and only option to preserve cyclic standard work of the packer. As current spiders lack the time to transport orders, there should be a new spider role for transporting orders of all production lines. Redefined spider roles are a partial solution to inefficient spidering. Therefore, the new role is discussed more in chapter 5.2.3.

Solution:

1. Introducing a new spider role for transporting finished orders.

5.1.4 Tester unreliability

Unreliability of the testers caused extra work at both the Carescape One and F0 testing stations. Devices were re-tested if operators suspected the rejection was due to the tester. This generates unnecessary manual work and prolongs the cycle time of the device. Tester issues have been under discussion for months before this project. Solving the issues is beyond the expertise of in-house engineers which means the issue had to be escalated to higher organizational levels.

Testing cannot be bypassed and there are no additional testers to use. One solution is investing to new testers, but investment calculations require in-depth calculations familiarization of demand forecasts. Instead, this thesis approaches the problem through working methods. The objective of the solution is to gather more information about the issues to support the escalation and make tester issues a visible part of the process.

Re-testing devices is the most effective way to hide the problem. Instead, operators should discard the device after the first rejection, even when they suspect the test failed because of the tester. This increases the workload of repairers, who record the status of each device in an information system. These records give the problem the weight and urgency it deserves and might justify possible investments in the future. In addition, this method protects the flow of the production line. Failed tests last as long as passed tests so each cycle will be same in duration when operators stop re-testing devices.

Solution:

1. Collecting data from tester issues by rejecting a device after first fail result.

5.1.5 Disturbed workflow

A device is brought to repairers when it is discarded from the assembly line. Repairers will investigate the fault and take the necessary action. When repairers want to ensure the fault is gone, they must re-test the device at the assembly line as there is only one tester available in-house. Line operators will have to wait for their turn after assembly if the tester is used by a repairer. In an ultimate ideal scenario repairers have their own tester to save production from such interruptions. However, a new tester is an investment of over a hundred thousand euros, which is not addressed in this thesis.

Remaining options are that repairers either leave repaired devices for line operators to test or test repaired devices themselves during the breaks of line operators. The unfinished work of repairers and repair lead time increases if devices are left for line operators to test. Additionally, this procedure increases the workload of line operators. Thirdly, storing devices in different states requires constant alertness and communication to avoid mix-ups.

Testing only during breaks limits testing time. Repairers also accumulate some equipment waiting to be tested during the day. Devices also accumulate in repair stations. In other words, one-piece-flow of the production line is prioritized over repair one-piece-flow. Testing during breaks is still preferable as repairers will receive feedback on the repaired device relatively quickly. For this method to work, it must be ensured that line operators take breaks at the same time and that their breaks do not overlap with the breaks of repairers.

Solution:

1. Testing repaired devices only during the breaks of production workers.

5.1.6 Malfunctioning andon usage

One of the longest walking routes operators take are walks to andon owners such as manufacturing engineer, production team leader and mechanics. The focus is precisely on why operators prefer leaving workstation to get andon owner instead of creating an alert from the line computer. Issues that require the alert in the first place are discussed in their own paragraphs.

There are two reasons for andon malfunction. The first reason is that the andons lack an indicator of their urgency. Andons are used to gather information on problems as well as to call a person to the production line. Both alert types appear same to andon owners. It is important for andon owners to see at a first glance what the problem is, who is affected and whether there is an actual need for help. As such, andon alerts do not awake a sense of urgency in the andon owner, in which case employees feel that they are getting the required attention by walking to andon owner. On the other hand, this teaches andon owners that if the problem is urgent enough, the line operator would come to discuss the problem face-to-face.

Another problem identified is the under-resourcing of andon owners, especially manufacturing engineers. When an andon alert is received, the owner of the andon often has a meeting or some other task in progress and cannot be on call for alarms in the same way as, for example, mechanics or spiders. The constant interruption of work is already stressful in itself, but additionally it puts the andon owner in front of prioritization decision.

Another problem with andons is that even if the employee can solve the problem on their own, they will still create an andon alert to record information about the disturbance. This increases the number of andons, and the recipient of the andon alarm cannot see at first glance whether they are needed and, if so, how urgently.

One solution to the problem is to create an own channel for recording issues that have already been resolved and keeping andon alerts only for alerting help. However, this requires extra work, as andon alerts should also be stored in a separate system afterwards. On the other hand, this would significantly limit the number of alerts and emphasize that every andon alert is urgent.

Better option is to use andon system for both alerting and record problems, but to add an indicator for the priority of the problem. For example, a “line stop” -note at the beginning of an alarm indicates that the immediate attention of the andon owner is needed. Although the number of andons remains the same, extra storage work is saved and andon owners can delay responding to uncritical andons.

Priority indicator of andon alerts is a good start but it is crucial that the whole plant has a shared understanding of product line prioritization. It is easy to state that the operation of the production line is the top priority for the entire plant. This requires allowances and understanding that the recipient of an alert, for example, leaves a meeting or interrupts a task in order to serve the line. Additionally, andon owners should check andon alerts constantly to provide required reaction times for the production line.

Solutions:

1. Adding a severity indicator to andon alerts.
2. Concentrating the responsibilities and time of existing resources to day-to-day production or hiring more production team leaders and manufacturing engineers.

5.2 Changes requiring double loop learning

This section includes analysis of solution options for more complex problems. The solutions aim to eliminate the root cause of the problems, which were all identified in chapter 4, with the exception of material unclarities. Some assumptions and company policies were questioned in the solution generation, and they should be questioned again until actions yield desired efficiency results.

5.2.1 Overprocessing

The root cause analysis revealed that the overprocessing of devices, i.e., producing unnecessarily good quality, arises from the extremely strong quality culture of the organization. Quality is prioritized over cost KPI so line employees ignore efficiency targets if it is possible to achieve better quality by redoing a work step. Additionally, production workers never unlearned extreme precision even when supplier material issues reduced from the early days of the production line. Quality is merely perceived as an objective so training employees to lower their quality standards was not a priority.

Quality culture is also internalized by other parties such as manufacturing engineers. They convey to the line workers quality-related work instructions that comply with their own agenda. The tradeoff between perfect quality and line efficiency becomes clear only when the management reviews the comprehensive performance of the production line. The factory management cannot encourage producing perfect quality on the expense of efficiency as they must guarantee great performance on all KPIs.

Management must not alienate from daily activities and demand perfection in every area without concrete instructions and tools to achieve it. They must understand and accept the trade-off between perfecting a device and working efficiently. In practice, this means passing a consistent message to the line’s value stream team, who can pass it on to employees on that line. In this way, the line avoids conflicting instructions, uncertainty and the pressure that arises when they have to choose between quality and efficiency themselves. This consistent message is, for example, an instruction that all quality accepted by the customer should also be accepted on the production line. Alternatively, the instruction can be that the production worker must correct any correctable errors, even if they are accepted by the customer. Whatever the message is, it must be internalized throughout the entire value stream team before it can be followed on production floor.

Solution:

1. Plant management must convey a clear and consistent message to guide quality related behavior.
    a. If customer-set specs direct line workers in the future, the specs must be unambiguous, understandable, and available for line workers.
    b. If devices need to be perfected beyond customer-set specs, plant management and the value stream team must comprehend and accept its effect on line efficiency.

5.2.2 Material unclarities

Root cause analysis of balance discrepancies were too challenging to conduct retrospectively. Therefore, this chapter includes a comparison of closed and open material storages. There is also an evaluation what a continuous inventory of an open material storage would require. The solution alternatives considered are therefore closed material storage with an annual inventory and an open material storage (current approach) but with a continuous inventory.

Figure 17 illustrates closed material storage in its simplicity. The blue areas represent locked or restricted areas to which only certain people would have access, for example spiders who would have access to a maximum of two locations.

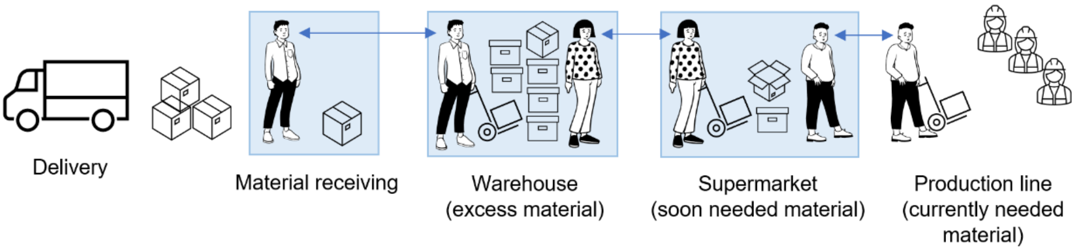


Figure 17. *Ideal controlled material availability system.*

The key message of the graph is that the line worker has no access inside any storage location, and all material travels to them through the spiders. Spiders are trained to make material transfers. They have a clear division of responsibilities over storage locations. Once the material arrives at the house, it would be taken directly to a warehouse. The material will be kept there until the supermarket requires refilling. The material remains in the supermarket until the production line indicates the need for more kits. The supermarket also works as a kiosk operated by line spiders when employees have other occasional material needs. Whenever material leaves the closed area, line spider has the responsibility to make an entry in the ERP system.

The concept of a closed material storage seems simple, but the current storage space of the company imposes limitations. For example, there are multiple warehouses around the factory and some material must be transported directly from the warehouse to the production area as there is not enough space in the supermarket for packaging material. Because of this, three types of spiders are needed; one that fills the supermarket from warehouses, one that fills the assembly line from the supermarket, and one that brings packing materials to packing stations directly from the warehouse. The material flow is illustrated in figure 18.

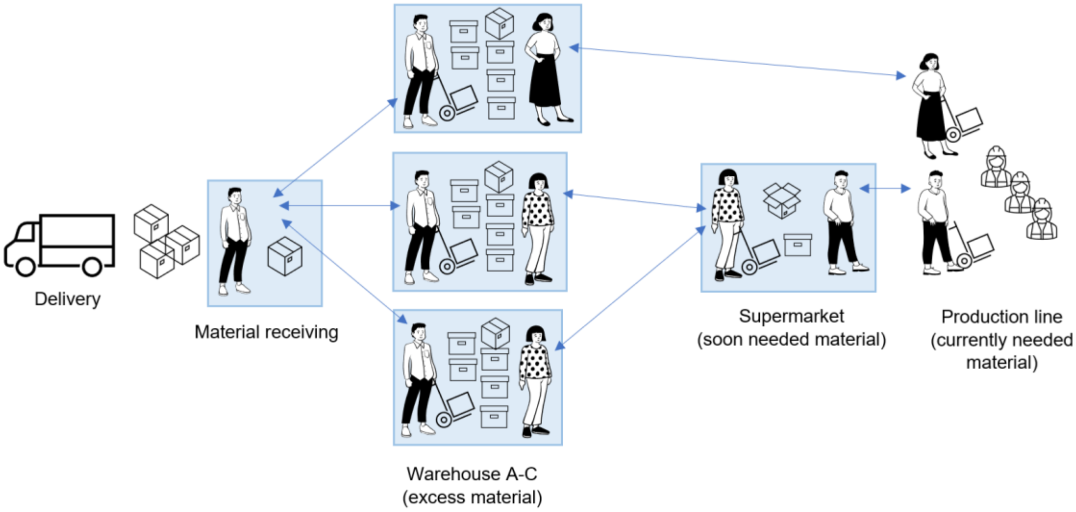


Figure 18. *Controlled material availability system for currently available space.*

It is notable that the spider roles in the image can be implemented with the current, open storage system, although spiders do have access to every location. The spider roles are discussed in more detail in section 5.2.3.

The advantage of a closed storage system compared to an open system is that it clarifies the division of responsibilities for material transfers in ERP. The storage location itself reminds that it is indeed a storage location for which certain materials are marked in ERP. Spiders’ ownership and responsibility over inventory transfers in a particular area are clear, whereas in an open system, the responsible person for a balance throw is impossible to find. The impossibility of tracking balance discrepancies allows forgetfulness and ignorance of marking material transfers to ERP.

The transition to closed material storage will require changes to access rights as well as physical structures around the currently open supermarket. In addition, switching to a closed storage system requires a complete inventory of each code and changed logic in storing. Items used in the same production area should be stored at the same place and not put in whichever warehouse there happens to be space. Deploying the closed storage system also requires extremely clear spider roles and sufficient resources to implement them. There must also be a smoothly functioning system for ordering material to production lines as production workers cannot go get it themselves. This means for example large enough bin-sizes in two-box system so that material never completely runs out from the line.

The advantage of open material storage is its ease - the material can be obtained quickly if necessary. For example, a line operator can, if necessary, retrieve material independently from the supermarket instead of waiting for a spider. Open material storage also meets space constraints as material can be placed anywhere, where there is room for it. It does not need additional infrastructure and provides backup-plans when systematic material flow gets disturbed.

The problem with open material storage is that it obscures responsibilities for marking material transfers. Open material storage also makes inventory more difficult, as the flow of material cannot be monitored. The lack of walls and well-defined storage areas makes material accumulate here and there, even in areas that are not defined storage locations at the ERP system.

However, open material storage is the only option until an inventory of the entire plant is carried out and the infrastructure required for it is built. Improving current storage logic can be seen as a single loop type solution until an inventory of the entire plant is completed. A key remedy to alleviate the symptom of balance discrepancies is implementing continuous inventory in the current storage system. Closed storage system should be strongly considered if balance discrepancies still occur after intensified inventory intervals and other single loop measures implemented and proposed in this thesis.

In essence, the problem with current daily inventory is that team leaders and the planners of the inventory are unaware how it should be conducted it in practice. Respectfully, the idea and need behind daily inventory has not been communicated to its implementers. Leaders have failed to provide concrete guidance to the inventory implementers and just added the functionality to the ERP system. The ignored practical challenges are for example the spread-out material storing which requires simultaneous inventory in all storing locations. Implementers also feel resentment because daily inventory is perceived as a minor chore to do on the side of other workload. There is no specific slot reserved for it in the working day or week. If production lines require spidering all day and material flows from a storage location to another accordingly, it is simply impossible to conduct an inventory. Lastly, the team leader of the supermarket does not monitor the daily inventory or bring up the issues associated with it as there is no place or platform for it.

The ERP system selects inventoriable codes based on their value. As they are not sorted by production lines, each production line should be stopped every day for the inventory. However, in terms of line stops and time spent searching for material, the value of the item is irrelevant. Optimizing line efficiency, it makes sense to inventory the codes with biggest balance discrepancies in quantity, regardless of their value.

Continuous inventory can be (re)started by a pilot project. It is unnecessary to directly start a daily inventory as lower inventory frequency also lowers the threshold to start the process. If balance discrepancies still cause problems, the inventory interval, and the number of codes to be inventoried can be altered. A list of the most crucial codes should be available to the market, so that also unintentional line stops can be used effectively for spontaneous inventories.

Once the result of the inventory is found out, the balances are corrected in the system and the reason for balance discrepancies are recorded. The results of continuous inventory and the process itself should be monitored. The inventory team should also actively identify the root causes for the balance discrepancies and address them, possibly through escalation. There should be a separate meeting for root cause analyses and action plans to support systematic and sufficient review. Thus, the pilot project aims to eliminate the root causes of the largest balance discrepancies by either improving the existing continuous inventory process or by creating it anew.

Solution:

1) Implementing a pilot project for continuous inventory.

5.2.3 Inefficient spidering

Main issues of inefficient spidering were lack of standard work, ignoring spidering in resource plans, and inadequate training of the line spider of Carescape One area. Additionally, methods for ordering more material were unclear; material was ordered via andon alerts, Kanban cards, face-to-face requests, and a 2-box-system. Spiders and line workers were unaware which method to use for which parts.

Creating standard work for spiders is one of the most critical steps in streamlining spidering. The standard work expresses the responsibilities of different roles and the sufficient frequency of material checks. Standard work also clearly clarifies how material should be ordered to the line. This means that andon alerts are fully dedicated to recording disturbances, and all pre-ordering of material happens either with kanban card or a two-box system. Creating standard work for spiders is so crucial that it is chosen as a partial solution without further evaluation.

The next solution is to connect the Carescape One spider to a pool of all spiders in the factory. When the line does not have its own spider, spidering does not need to be considered separately in resource plans either. In addition, learning material and a training process already exists for other spiders so there is no need to create an individual training for the Carescape One area spider. This option requires that the Carescape One supermarket is combined with the factory supermarket. The distance to the supermarket will increase significantly, but a combined supermarket will streamline operations and level out workload of spiders. Combined pool of spiders also eases substituting. Due to the equal spidering of the lines, a combined spider pool is seen as the best option.

The next solution is to introduce two new spider roles. Currently, there is a line spider serving the assembly line and a superspider serving packing stations. In addition to these, there is a need for a spider who fills the supermarket from a warehouse and a spider who transport finished orders to the pick & pull area. Currently, the supermarket is filled by line spiders on the side of their other work. This can cause delays in line spidering, as there is no defined process or interval for fills. The transport of finished orders is handled by line workers which consumes time available for production.

An alternative solution is to incorporate these tasks for existing roles. This is challenging, as filling of the supermarket should happen without interrupting line spidering. Spider should only restock material when no production line in the factory needs more kits. For the resource efficiency of the entire plant, it does not matter whether finished orders are transported by the line operator or a separate spider. However, the idea of a production line as a core function in the factory advocates that all supporting work should outsourced for non-assembly workers. The support work does not require special training, so it should be outsourced to achieve a high utilization rate on the production line.

The team leaders should start tracking the resource needs of supporting work the same way as the resource needs of the production employees. Tracking resource needs of spiders supports possible recruitment decisions during the busiest times and, on the other hand, frees up spiders for production work during more quiet periods.

Solutions:

1) Specifying standard work of all spiders
2) Adding Carescape One spider to the pool of spiders
3) Clarifying the logic in ordering material and providing needed tools (2-boxes, Kanban cards…)
4) Introducing new spider roles for filling supermarket and transporting orders
5) Tracking spider resource needs and aligning spider resourcing with up-to-date spider capacities

5.2.4 Order unclarities

The causes for order unclarities were traced to the activities of the value stream team. The problems of the value stream team fall into two areas: the planning tool and the agenda for the daily meeting. The tools used in the meeting are non-visual and they fail to provide a comprehensive view that covers all needed areas (resources, material, orders, and quality issues). In addition, the reporting tool relies on manual typing, which dedicates the daily meetings for data collection rather than problem solving and planning. Additionally, there is no systematic way to allocate tasks or go through project statuses which creates information gaps and ambiguity.

Production planning requires a tool that shows available resources in one week window and the estimated production volumes based on them. Therefore, over- and under-resourcing of workstations become apparent. Realized volumes should update to the tool during the week so that any corrections can still be made to resourcing towards the end of the week. On the other hand, the tool also shows clearly if the leveled production plan was already reached in the beginning of the week so there is no need to constantly justify low production volumes towards the end of the week. Buyers can also see from the graph if estimated production volumes are more than the leveled production plan, allowing them to anticipate possible material shortages.

The planning tool can also be used in reporting, but then it needs to include other company KPIs, such as quality and cost. Data on line efficiency and faulty devices can be extracted into the reporting tool directly from a file updated daily by production workers, minimizing manual typing for supervisors. Only information about on time delivery needs to be updated manually from order backlog.

In addition to the reporting tool, discussion flow and agenda of the value stream team daily meeting has room for improvements. All six KPIs of multiple production lines are extensively reviewed in the meeting. Instead of reporting everything, the meeting should be spent reviewing problematic areas to use time more efficiently. There are also special forums and meetings where repetitive quality and cost issues are analyzed. This makes it unmotivating to report daily about individual tester rejections or efficiency-deteriorating occurrences. Instead, the focus of value stream team daily meetings should be on issues related to everyday work - material availability, absences, order backlog and technical changes affecting the line. The main goal of the meeting is to combine the latest knowledge of these areas and to make short-term decisions based on it. This is facilitated by visualizing of the situation with a graph included in the new reporting and planning tool. The graph includes the production plan based on the quarterly forecast, the resourcing plans, and the realized production volumes for the current week. To achieve the holistic approach in plans, the value stream team should ask the following questions whilst reviewing the graph:

1. Are there enough orders in the backlog to fulfill the plan?
2. If so, do they include orders which material availability should be checked (i.e., manuals of rare language configurations)?

With these two simple questions, the production area avoids over-resourcing and situations where operators start configurating an order but runs out of material unexpectedly. The production planner will also see immediately if the weekly forecast is less than the actual order backlog and there are thus too few operators allocated to the configuration station.

Going through new orders is included in the current agenda of the value stream team meeting but the production planner may have already scheduled some of the orders before the meeting. In this case, buyers might miss required actions to ensure material supply for such orders. For this reason, it is suggested that the planner takes a picture of the new orders at the beginning of the day before starting to schedule them. This picture of all new orders can be reviewed at the daily meeting so that all members of the value chain team are informed about all new orders.

The team leaders also highlighted the need for more systematic problem solving and solution monitoring. For this reason, there should be an action list that is reviewed at the end of the meeting. Recording the measures taken to overcome issues also enhances escalation of difficult tasks.

The agenda of the meeting is:

1. Going through records from previous day with the help of the new automatized reporting tool, only bringing up deviations from expected results.
2. Reviewing current day and the rest of the week with the same tool. Confirming that the plan is aligned with order backlog and material availability.
3. Going through new orders (using a picture).
4. Going through the action list and possible escalations.

Solutions:

1) Creating an automatized reporting and planning tool that provides compares realized results to plan.

2) Introducing a meeting agenda for the value stream team daily meeting that utilizes the reporting tool and includes a task list to track problem resolution.

6. IMPLEMENTATION AND FUTURE ACTION PLAN

This section reviews the implementation of two example changes and the learning process during change, based on the theory discussed in chapter 2. Of the measures selected in the previous chapter, single loop learning example is the layout & assembly line improvement and double loop learning example is the implementation of new spider roles and their standard work. Additionally, a concrete proposal and action plan for the continuous inventory pilot project presented in section 5.2.2 is presented at the end of this chapter.

6.1 Layout change and assembly line improvement

The layout change and the reconstruction of the assembly line were performed as a Kaizen event action workout. The goals of the action workout were achieving a one-piece flow on the line, streamlining the material flow and improving resource efficiency. The Kaizen project team was diverse and multidisciplinary; in addition to the author of this theses is consisted of the line team leader (project lead), a production worker, a lean specialist, a manufacturing engineer, a mechanic, and moonshine shop employees.

The Kaizen event was set to finish in one work week, although demolition of the old production line started the previous weekend. During this week, the team built a new production line, designed a new layout, moved existing workstations to their places, set up the second configuration station to the configuration station, formed a new standard job for line employees and tested the functionality of the area. Another action workout team took care of transferring all Carescape One and F0 material to the combined supermarket of the plant.

The first prerequisite for leadership commitment, understanding the need for a change, was achieved through the measurements performed in this thesis. The measurement data brought up how the unconnected kit line consumes time, how the layout provokes unnecessary walking and how the packing and configuration station are unbalanced – a problem which could be solved with another configuration station if only there was more space available for it. Clear data of the problems gained the support of the leaders that approve the theme for the Kaizen event.

In addition to the need, concrete goals were set for the project. For example, the goal was to reduce walking distance from 46 meters / cycle to 15 meters / cycle, reduce decive throughput time from > 24 hours to 3 hours and to increase resource efficiency from 7,3 devices / day / operator to 8,4 devices / day / operator.

Although the Kaizen project lead was the line team leader and not the factory management, the vision for the change came fundamentally from the general directions and values set by the factory management. The organizational vision which all GE Healthcare Helsinki operations pursue is communicated for the organization as briefings. It is also presented as a physical map on the company premises, and it is highlighted in the day-to-day operations and meetings where lean is implemented. The project lead of the Kaizen project communicated the vision and steps of the project to the Kaizen team a week before the event, as well as to the line workers at a daily meeting. With a pre-communicated vision and goals, it was possible to ensure consensus among team members. Eliminating ambiguities beforehand also enabled effective implementation of tasks during the limited time of one week.

In addition to communicating the vision, there was continuous communication during the change. Every morning the Kaizen team went through the agenda for the day and divided responsibilities. After each day of the Kaizen week, the project lead briefed the factory management what had been achieved and what challenges were encountered. The plant manager was the process owner of the Kaizen even and thereby acted as an external advisor for the Kaizen team.

After the week the line was monitored and further developed to reach the project targets. The Kaizen team formed a to-do list from remining tasks and assigned owner and a schedule for each task. The to-do list was monitored with weekly meetings until the list was empty. The line operators were informed about the follow-up tasks of the Kaizen event during the daily meetings. The line operators were also informed of the efficiency improvement results which were used to justify the new efficiency target of the line.

The second key element driving sustainable change was employee involvement. The employees of the line were involved in the change process already in the problem identification phase, i.e., in the data collection of this research. Interviews revealed that operators recognize the impact of layout and assembly line and encourage the change themselves. Representatives from the line staff were also included in both Kaizen event teams to bring a practical perspective to idea generation. Line operators were also involved in the concrete change; dismantling the line and reorganizing material and workstations. Line employees were also interviewed during the post Kaizen event monitoring phase to find out areas for further development.

During the Kaizen week a new assembly line was built where the subassembly station is integrated into the rest of the assembly line. The new kit line is connected, and it has a kit return mechanism. Tables between workstations were removed and screws were positioned for better ergonomics. Tools and materials such as screwdrivers, screws and a camera were also to workstations, increasing grey areas and therefore balancing out different speeds of workers. However, the limited space of the workstations proved to be a challenge. A comprehensive set of tools generate grey areas, but too many tools make a workstation cramped. As a result, side tables were re-added between the desks to store the tools shared between two workstations. However, the new tables can be moved, so they do not cause detours when moving from a workstation to another.

The test station was placed directly after the assembly line. The new standard work advises operators to test assembled devices immediately. Employees are no longer allocated to the testing station only, but the last employee at the assembly line switches between assembly and testing. Connecting the testing station to the assembly line generated one of the single loop learnings of this research. It is illustrated in Figure 19.

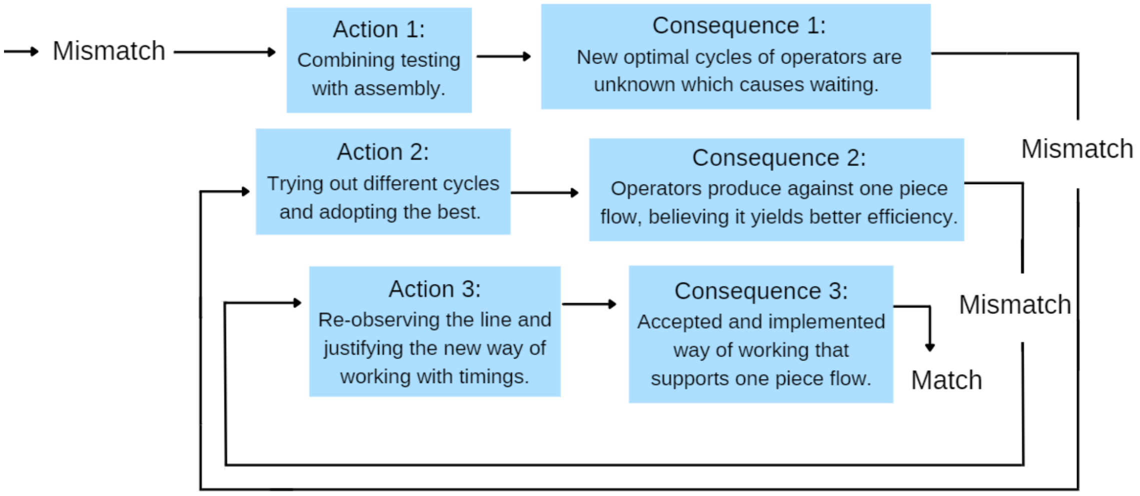


Figure 19. *Single loop learning process of combining testing and assembly line.*

The first observed issues had to do with ambiguities regarding when employees leave a kit to the next assembler and start a new one and when do they continue with a kit to the next station. For example, employee had moved to the testing station with an assembled device but had nothing to do after the testing was done. The employee could not return to the last assembly station because it was already occupied by another assembler who had produced a kit “too far”. Because of increased waiting times, different production methods and workstation divisions were tested with each number of operators until the most optimal workstation divisions were found.

However, this only partially improved the situation. Some production workers expressed concern that it was impossible to achieve the desired one-piece flow at the testing station. According to them, the raised efficiency target could be reached only if operators work “their own way” contradicting one piece flow. This problem was identified as a matter of belief, as the efficiency target was initially based on one piece flow time measurements. The working method that supports one piece flow fought against employees’ intuition which made them ignore the agreed production method. To justify the new approach and realism of the goal, different methods were compared. The revised one-piece flow working method showed best time results which led to the approval of employees.

Another example of single loop learning that took place during the project and its follow-up was caused by reconstruction of the assembly line. The loop is shown in Figure 20.

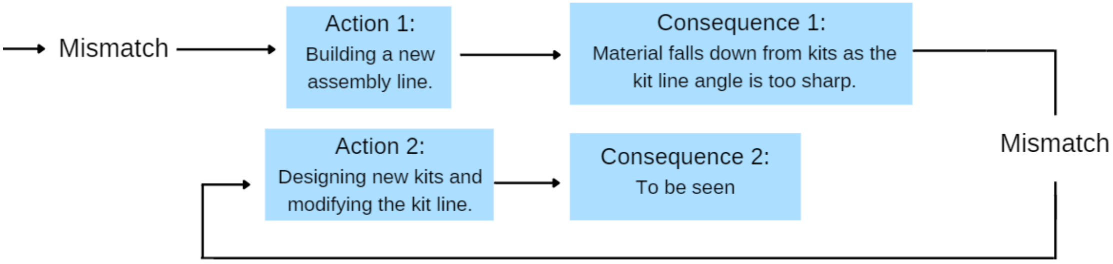


Figure 20. *Single loop learning process of building a new assembly line.*

When the new kit line was tested, it was found that the materials were dropping from the kits. The problem is that the new kit line has a steeper tilt angle than the old one. It also takes a long time to lift a kit from the kit trolley to the kit line as operators have to move extremely carefully to not drop parts. The new kit line also prevented operators from raising worktops to support standing work. Therefore, the kit line angle and position had to be altered which required a new kit shape. New kits were designed for the line which also allowed better placement for the old subassembly station material.

The Kaizen week had both immediate benefits and those that did not materialize until months later. In the end, the walking distance shortened from 46 meters per cycle to 21 meters per cycle through the improved placement of workstations and material. The throughput time of the device was reduced from >24 hours to only 40 minutes by eliminating the subassembly WIP. The resource efficiency of the production and testing was increased from 7.3 devices per operator to 8.1 devices per operator through the new standard work, connected kit line, as well as increased grey areas of the assembly line.

6.2 New spider roles and their standard works

Observations of the assembly line and configuration line revealed several situations when material was not at the production line when needed. The root cause analysis tracked the problem to inadequate standard work by spiders. The solution evaluation also found that the work of spiders is most efficiently divided for four spider roles. This chapter reviews the process of creating and deploying the new roles and their standard works. The process involves more significant changes deploying double loop learning as well as minor modifications to existing practices deploying single loop learning. The learning loops are presented in Figure 21. The grey boxes represent the profound realizations in double loop learning.

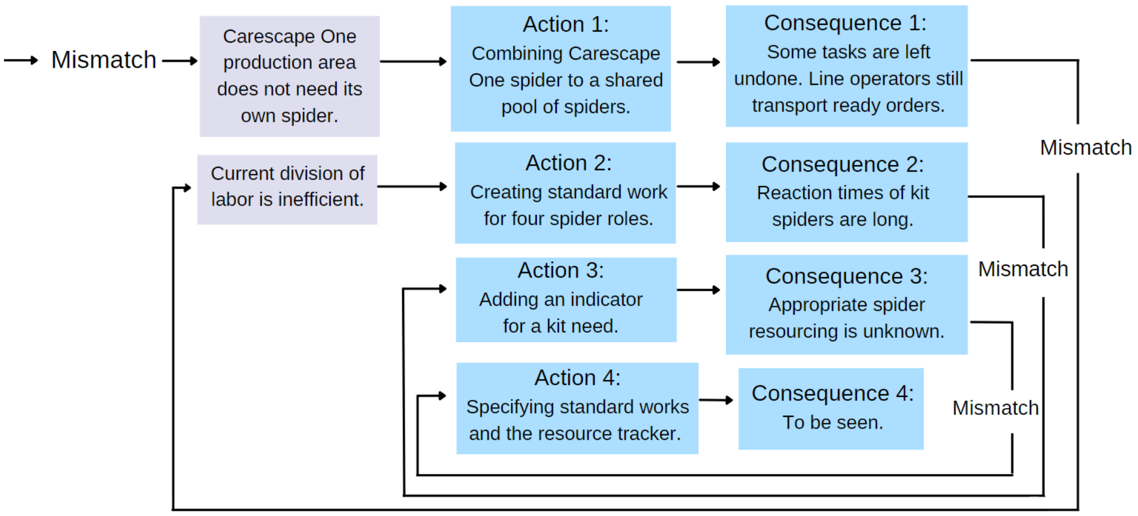


Figure 21. *Double and single loop learning process of spider role and standard work improvements.*

The Kaizen event, which focused on rebuilding the assembly line and changing the layout, questioned the need to keep a separate Carescape One/F0 supermarket. Only the isolated location of the production area supported having an own supermarket and an own spider. However, both Kaizen event teams saw it most efficient joining the Carescape One/F0 supermarket with the main supermarket of the factory. At the same time, it was decided that the line would be spidered evenly by a joint pool of line spiders.

When the new line was observed after the Kaizen event, spidering issues remained. The responsibilities for certain tasks were unclear, as one spider used to be responsible for both the assembly and configuration line of the area. Some tasks were left undone as the new spiders of the area did not have the skills or access to handle them. The line operators also continued to transport finished orders to the pick & pull area. Therefore, it was suitable to create standard works for the four spider roles presented in section 5.2.3. Initially the pilot version of the standard work only covered the tasks of each role and their approximated frequency. The pilot standard work was accompanied with an excel tool that let spiders see which lines are running and on which capacity in a two-week window. The idea was to specify the standard works driven by practical experience so that eventually it could determine walking routes and exact times for the tasks.

After the introduction of the pilot standard work, it was soon noticed that the reaction times of the line spiders were longer than before. The kits run out all the time, and in the worst-case scenario the entire assembly line could wait up to 40 minutes to receive more of them. The problem was partially alleviated by improving the distribution of andon alert notifications as well as adding a far-visible flag to the line to indicate kit needs.

However, the most significant issue seemed to be intermittent under-resourcing of spiders – especially spiders that deliver packing material. Spider resource needs were not monitored in the same way as production line resources. As order forecasts increase and short-term recruitment decisions are made, the increase in line capacity is ignored in support roles. Therefore, the supermarket had the same number of spiders regardless of if the production lines were run at full or low capacity.

The standard work of Carescape One spidering was specified with a schedule to quantify spidering needs. Additionally, kit fill, and configuration material fill cycles were measured of each production line. The durations work as a basis for a schedule that is feasible in an undisturbed situation. New andon categories were also created for spiders to record factors that interfere with their work, such as incorrect storage locations or difficult placement of material. In addition, a support role section was added to the resource tracking tool. As the required spiders per line worker -ratio becomes more precise, the tool can be utilized for appropriate spider allocation. This frees up spiders for production work at quieter times and, on the other hand, supports possible recruitment decisions during periods of higher demand.

One of the most important prerequisites for leadership commitment, understanding the need for a change, materialized well in spidering improvements. The management, team leaders and employees understand the impact of spidering, as it affects every line of the factory. Defunct spidering is prone to line downtime, which in worst cases stops the work of line employees. The vision of the change was already shared at every organizational level, as problems related to spidering have long been present in daily meetings and other occasions. Required communication concerned the methods of achieving the vision rather than the vision itself. For example, implementing a new spider role for order transportation, was accepted by plant manager only when other options (such as transporting orders during breaks) were found to be infeasible. The standard work was also presented to the lean team before its implementation. This ensured that the standard work built from an operational point of view did not quarrel with the strategical directions or other operational divisions of the company.

Setting concrete efficiency targets for the new standard work and spider roles was difficult, as standard work itself does not eliminate spidering disruptions. These disruptions that remain regardless of organized and scheduled spidering tasks are for example balance discrepancies, incorrect storage locations and under-resourcing. The target of the change was to clarify the division of labor and harmonize the way spiders operate. In this way, at least ignorance or ambiguities of spiders no longer cause inefficient spidering.

Although standard work does not eliminate disturbances independent from spiders, the standard work is a prerequisite for identifying and monitoring disturbances. If the spiders cannot stick to the schedule assigned to them, it immediately indicates an external disturbance. These disturbances have so far remained at an abstract level, as spiders do not know the response times expected of them to begin with. On the other hand, disturbances that spiders bring up informally are not recorded or monitored. The new andon categories allow management and team leaders to systematically monitor these disturbances in the future.

The change was implemented persistently, although the process took a surprising amount of time and energy. The setbacks were caused by differences of opinion between different teams, difficult reconciling of theory and practice, as well as new issues that arose after actions were taken. However, clear prioritization of spidering, and an understanding of the importance of the problem, facilitated perseverance. Although the problem was clear in this research, its urgency still had to be highlighted for other parties to gain needed commitment and help.

Employees were involved in the change throughout the iteration process. Employees were interviewed about problems related to spidering already at the problem definition stage. After the Kaizen event, they were interviewed once again about the functionality of the combined spider pool. The interviews revealed for example that line workers had to take over some of the old spider’s tasks, as they do not automatically fit for any of the new spider roles. In addition to collecting information of problems, employees were involved in solution generation. A draft of the new spider roles was presented to the spiders, and adjustments were made based on their suggestions. Additionally, line employees were trained for the new spider roles and andon categories.

6.3 Proposal for continuous inventory pilot project

The main problem with the existing continuous inventory is that its practical implementation and process ownership were left unconsidered. Unclear instructions and a lack of monitoring led employees to boycott inventory. Employees throughout the organization are unaware whether the daily inventory was in operation or not. Due to its ambiguous and fragmented nature, continuous inventory has become an avoided concept that no one promotes or has time to launch.

This section intents to provide a pragmatic proposal for launching continuous inventory. The main goal of the proposal is to provide a plan that can be implemented with a low threshold. The attributes can and should be adjusted along the experiment, utilizing single and/or double loop learning presented in this research. This section also introduces the thought process behind the proposal. The thought process and options considered is thought to ease the upcoming development of the continuous inventory process.

There are three starting points for the pilot project; improving the current inventory process to meet production floor needs better, creating a new, informal process based on production floor needs, or combining continuous inventory with another existing inventory process. These options are compared in Table 4.

Table 4. *Options for continuous inventory pilot project.*

1. Improving current continuous inventory process	2. Creating a completely new process for continuous inventory	3. Combining continuous inventory with another inventory process
+ Already existing, official platform (ERP) for the process	+ The codes to be inventoried can be chosen freely	+ Easy to add to an existing and working process with existing resources + Eliminates unnecessary repetition

- Bureaucratic, is organized by an external party **- High frequency of inventory creates a high threshold from the beginning**	- Requires building an inventory logic and new tools - Unofficial	- Requires adjustment in how inventoriable codes are chosen

While improving the current continuous inventory process intuitively seems the most effortless option, its challenges lie in the bureaucracy of the process. The continuous inventory facilitated by the ERP system mainly aims to synchronize the actual inventory value and the system inventory value. The inventoriable codes are selected by their monetary value, which is irrelevant logic for the production operations that are disturbed by balance discrepancies of any value. In addition, the system appoints inventoriable codes daily, which makes inventory time consuming and thus raises the threshold for moving to continuous inventory in the first place. It is difficult to change the logic of the inventoriable codes, as the logic has been built by a team outside the plant.

Creating an entirely new process, in turn, enables to freely choose the codes to be inventoried. For example, the pilot project could only inventory such codes that repeatedly have balance discrepancies. However, the new process will be informal and manual, as there is no ready-made tool for it, and it is not included in the ERP system. Additionally, such repetitive balance discrepancies must first be determined before launching the project.

The best starting point for the pilot project is therefore to combine it with existing Kanban inventory. Updating the list of codes used in the Kanban inventory is externalized outside the plant and the inventory is done three times a week. There is an employee specifically allocated for this inventory (neither a spider nor a production line worker), who already visits the same storage locations that should be visited in continuous inventory. Combining continuous inventory with the Kanban inventory eliminates duplication of work. Codes with high consumption have been selected for the Kanban system. Through their high consumption, they are sensitive to balance throws and therefore suitable for the continuous inventory. According to the current inventor, the ongoing flow of material is not a notable issue when inventorying, so there is no need to stop production lines during the continuous inventory.

The current Kanban inventory process requires some adjustment so that continuous inventory can be added to it. Currently only the codes which balance is different in the ERP system and KanbanBox (KBB) are inventoried. Such discrepancies occur when employees forget to read Kanban cards empty. Codes which KBB balance matches ERP balance are not inventoried though the system balance might differ from the actual on-hand quantity. For this reason, the logic should be altered so that the remaining codes also get inventoried.

There could be a standard number of inventoriable codes, for example three codes per inventory day. The highest inventory priority are those codes which KBB balance differs from ERP system balance. In case there are less than three KBB discrepancies, remaining codes are randomly selected until three codes have been inventoried in total. Inventoried codes should be marked in a list so that during the next random selection a new code is selected until all Kanban codes have been inventoried.

One of the key parts of the continuous inventory project is recording and eliminating the causes of balance discrepancies. It is important to remember that a frequent inventory does not eliminate the balance discrepancies per se but gives a better visibility into the causes. Because the inventory is performed several times a week, balance discrepancies can be tracked in real time. When a balance discrepancy occurs, the correct balance must be corrected to the ERP system immediately. In addition, the reason for the balance discrepancy must be determined by the inventory team. The inventory team could consist by, for example, the process owner, inventors, material specialists, the production planner, and the production team leader. A suitable process owner could be the manufacturing program leader, who is responsible for KBB implementation and has strong knowledge of the features of the ERP system.

Once the cause of the balance discrepancy has been determined, it should be categorized and recorded. In addition, it is proposed that the team responsible for the continuous inventory process have a separate meeting every other week to review most common causes with the help of a problem-solving report. Alternatively, the meeting can be added to current KBB weekly meeting if its duration is extended by 15 minutes. The categories recorded for balance discrepancies help to structure the most crucial problem areas, as well as to develop an efficient action plan based on them. The summed-up proposal for the continuous inventory and the related responsibilities are presented in appendix G.

7. DISCUSSION AND CONCLUSION

This section examines the research from three perspectives. First it examines the success of the research by the extent to which it achieved its objectives. The second section examines possible sources of error and estimates the reliability, validity, and generalizability of the research. Finally, the chapter evaluates potential themes for future research that aims to improve production line efficiency.

7.1 Reaching objectives

The objective of this research was to achieve permanent efficiency improvements for the Carescape One and F0 production lines, first by eliminating variability and waste and then by determining the optimal standard work. The study sought to find 1) the main factors decreasing efficiency, 2) justified measures to eliminate them and 3) overall effects of the implemented measures. To achieve lasting change, the change processes implemented during the study followed a single or double loop learning framework, depending on their complexity. In addition, the processes sought to emphasize the two key factors to successful change highlighted in the change management literature: employee involvement and leadership commitment.

The first goal to find main factors decreasing line efficiency was fully achieved. Versatile data collection, especially interviews, exposed even the hidden types of waste. Long-term monitoring of the line revealed the frequency of disturbances, which allowed their prioritization. Prioritizing issues was the key to the success, as eliminating even the waste lessened by pareto selection was challenging.

The second goal to find justified measures to eliminate emerged waste was achieved relatively well. Categorizing issues into single loop and double loop issues proved to be effective, as it was unnecessary to perform a root cause analysis for all problems. This helped achieving simple and quick efficiency improvements. However, deeper familiarization was indeed needed for the more entrenched efficiency problems to call proposed solutions justified. For example, running out of material on the line could have been due to several different factors, so it was necessary to perform root cause analyses for it in diverse teams. The goal was achieved in the sense that a justified solution was found for all the main waste detected (excluding tester issues).

Although the requirement to implement the proposed solutions was not defined in the research questions of the work, it was partly built into the tacit expectations of the research as well as in the third research question “What are the overall effects of the implemented measures on efficiency?”. The implementation, monitoring and evaluation of the proposed solutions proved to be the most challenging part of the research for multiple reasons.

The first factor hindering implementation was the scale of the problems. For example, some of the problems were rooted in the processes of the entire plant which makes their solution much more bureaucratic. Solving large-scale problems also required active help from the value stream team members whose time for this study was limited. Even when the processes are rearranged on the production lines under investigation, the implementation phase becomes complicated as soon as it considers the entire plant as a whole. For example, the standard work of spiders had to be created thinking of the spidering of the entire factory. This made the task time consuming and complicated for example creating schedules and dividing responsibilities.

Another factor that made it difficult to implement the proposed solutions was the iterative nature of the implementation. The number of implemented solutions in itself is not a functional value, as new problems arise in the process. With the comprehensive monitoring the double loop learning requires, it took several months to eliminate some of the issues. The change processes took time also because no numerical targets were set for the changes which would have indicated when the loop was “complete”. Mismatch in the learning loop was always caused by an unsuccessful practice, which motivated the iteration of change again and again. However, the loop approach to change processes proved to be an extremely useful way to move towards *sustainable* efficiency improvements. No problem categorized in the double loop learning category was solved by the predetermined solution alone.

The benefits of the implemented changes were partially quantified. The benefits were best defined in physical changes, as they enabled identifying clear before-after moments. With one-off changes, it is also possible to be sure that the change has been fully completed and that it affects at the time of the after-measurements. However, not all benefits achieved during the research could be measured as some of the measures implemented will yield results only after the new processes and working methods are fully adopted by the organization or when other delays have disappeared. For example, improvements in training material will materialize when new employees train the assembly line, and improvements in supplier quality eliminate rework only when the current stock in-house has been used up.

All in all, the three research questions set for the study were answered and the work provided concrete efficiency gains. In addition to the research questions and pre-defined objectives, the work provided additional benefits. The most obvious benefit is presentation of the non-verbal information prevailing in the organization. Such insights in a written form will support the future development projects of GE Healthcare. In addition to this, the actual research process and strong collaboration with production workers strengthened the Kaizen’s culture in the organization and overall belief in development projects.

The most important additional benefit are the lessons that come from the theoretical part of this study. The importance of leadership commitment and employee participation, as well as the iteration of change processes, was tested during the study, and the study fully confirms the theory. For example, piloting the changes and generating quick profits succeeded in creating employees’ trust in the change. They also provided a valuable feedback loop for further development. Additionally, the learning loops revealed that targets are rarely achieved with sole pre-designed plans, which in turn highlights the importance of persistent monitoring of changes.

7.2 The validity, reliability, and generalizability of the research

The validity of the study is good, as the research approach and the methods used supported the investigated phenomenon. The phenomenon under investigation was specific - the inefficiency of GE Healthcare's two production lines. Therefore, case study was an appropriate research strategy. Quantitative and qualitative base data supported both the discovery of efficiency waste and the understanding of the underlying phenomena behind them. The selected indicators also measured the desired phenomenon comprehensively enough, as efficiency was determined through both flow and resource efficiency.

The reliability of the quantitative data presented in the work can be estimated as good enough for the needed accuracy. Quantitative data were mainly used to identify roughly the most important efficiency losses - the exact durations of the waste per device is not an object of interest per se. Therefore, possible slight errors in the time measurements deteriorate reliability insignificantly.

The most significant factor in observing the waste and their frequency was the limited number of observations. The fewer iterations are performed the more exceptional situations affect overall measurement results. For example, when the F0 assembly station was observed, an exceptional situation occurred where multiple operators had to solve a quality problem for over 20 minutes. Since the line was observed only 22 times, the significance of the situation was considerable when calculated directly as a wasted time per device. Therefore, the study relied on employee estimates to refine frequencies. Such employee estimates on the other hand depend on subjective experience. For example, issues that are perceived as annoying may get estimated as more common and less disturbing as less common.

The reliability of quantitative measurement data is also affected by the fact that the observable employees were always aware of the measurement situation and could affect the before-after results, intentionally or unintentionally. For example, it is possible that an employee highlighted disturbances they perceived as annoying by acting slowly when they occurred. On the other hand, for example after the Kaizen week, employees could have worked particularly fast in the hopes of achieving efficiency targets set for the week.

The relatively small number of interviewees could have been a source of error in qualitative research data. All interviewees were selected based on volunteering, and typically longer-term employees were more willing to share their thoughts on the effectiveness of the line than newer employees. In addition, time measurements were performed only for fully trained employees. As a result, improvement areas in the new employee training/learning process were mainly ignored, although training employees always decreases line efficiency at least temporarily.

It was also noticeable during the interviews that interviewees found it difficult to talk about efficiency losses caused by to human factors. Interviewees were careful not to talk about the actions of their colleagues in a negative tone to protect the work atmosphere. There was always a desire to find a fault in the process instead of a person or even type of person to blame. The protection of the work community was emphasized by the fact that the author of this thesis had previously acted as a production team leader for the interviewees and was thus not a completely impartial, external researcher.

The work can be generalized to some extent to similar production companies. The work did not seek to find one single truth but consisted of elimination of several different inefficiencies. Due to the modularity of the research, its parts can be applied to production companies that are similar for example in terms of material transport or production process. The analysis of some efficiency losses applies regardless of the type of production or the product to be produced - for example, overprocessing due to conflicting guidelines.

The suitability of single and double loop learning used in this study depends on the firm and the organizational level at which change is implemented. For example, the policies and standards of large organizations limit what can be questioned in double loop learning process at least when the change is implemented bottom-up. Many of the assumptions, defaults and underlying policies might not be open to debate whereas smaller or newer companies might be more flexible for change. Therefore, size and flexibility of the company has an intrinsic role in how much the change agent can “think outside of the box” when solving individual problems.

In this study, the employees’ resistance to change was close to nonexistent. Employee involvement was an intrinsic part of the study, as all changes were initially built from line observations as bottom-up manner. Therefore, the research already had a favorable starting point to confirm the theory about minimizing change resistance. The level of employee involvement appears to be at a great level at GE Healthcare and in the production lines studied. Employees were always ready to share their views on their own work, which speaks of the open atmosphere and the realization of Kaizen culture. The theory may be reflected differently in companies where Kaizen culture is less strong and in situations where change is implemented from top-down.

This study was also characterized by a change agent who was virtually an outsider, not a leader. Full devotion to the study created a deep understanding of the problems. This and narrowed down targets provided sufficient motivation for monitoring and development of the changes. However, it is usual that the change agent is an employee at the company. The typical change agents at GE Healthcare carry out development projects on a strictly limited schedule with full calendars and numerous priorities. Therefore, they lack the opportunity to get deeply acquainted with the problems or to ensure that the implemented measures work on long-term. Therefore, leadership (or change agent) commitment is seen as the most crucial obstacle in achieving lasting and successful changes at GE Healthcare as well as in similar companies to which this study is intended to be generalized.

7.3 Future research

Improving production line efficiency is a broad area of research, and this research covers only a fraction of the related aspects. The choices and delimitations made in this thesis, as well as the new themes that emerged during it, left room for future research on the subject.

As assessed in chapter 7.1, employee involvement was one of the key factors in achieving successful changes during this research. Additionally, as discussed in section 7.2, the changes in this research were bottom-up changes which substantially decreased change resistance and fueled enthusiasm of line employees. Thus, involving employees in the entire change process came naturally in this research. In chapter 2, it was discussed that in a sustainable change, employees should be involved in the whole change process, not just the deployment phase for example. This study left unexamined, how employees can be effectively involved in top-down changes and what are the effects in doing so. In other words, what are the ways to motivate employees to create, improve, and sustain change that is initiated from high organizational levels.

Second theme for future research regards potential tradeoffs between lean theory and employee autonomy. Although emphasized, change monitoring in this study remained relatively limited to confirm that the changed processes and practices have been fully embraced within the organization. Carefully developed standard work adds no value to the company if it is not followed. During the change monitoring in this study, it was already observed that employees have a desire to shape their own work instead of directly following the instructions given. Non-compliance with standard work is therefore not always due to insubordination or lack of motivation, but it sometimes comes from a good place. Employees' experience of their own work and the opportunity to influence it affect work motivation and thus efficiency. Future research could examine what kind of tradeoffs may occur between lean-complied standard work and employee-experienced work meaningfulness, and how organizations can balance between them.

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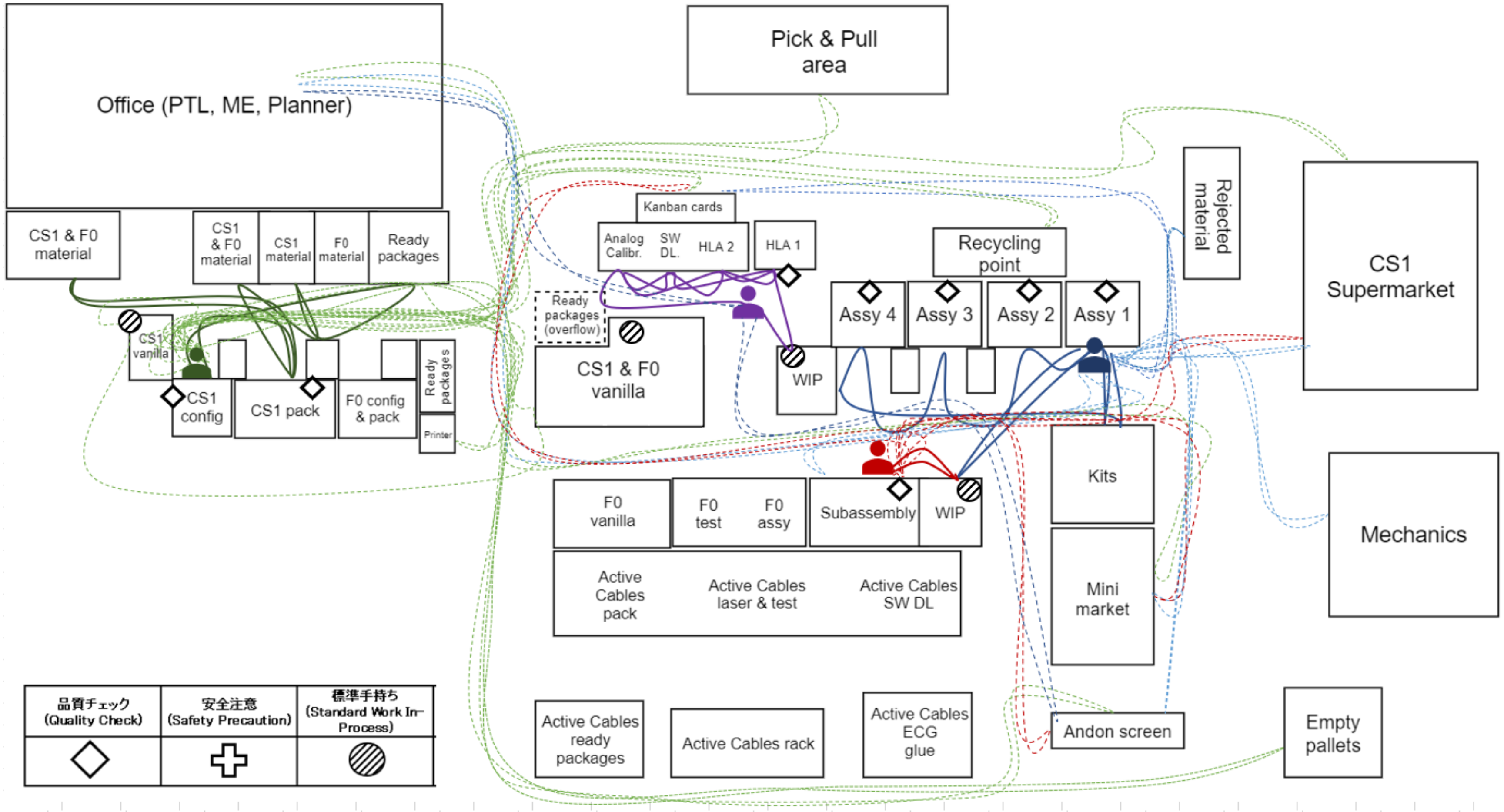
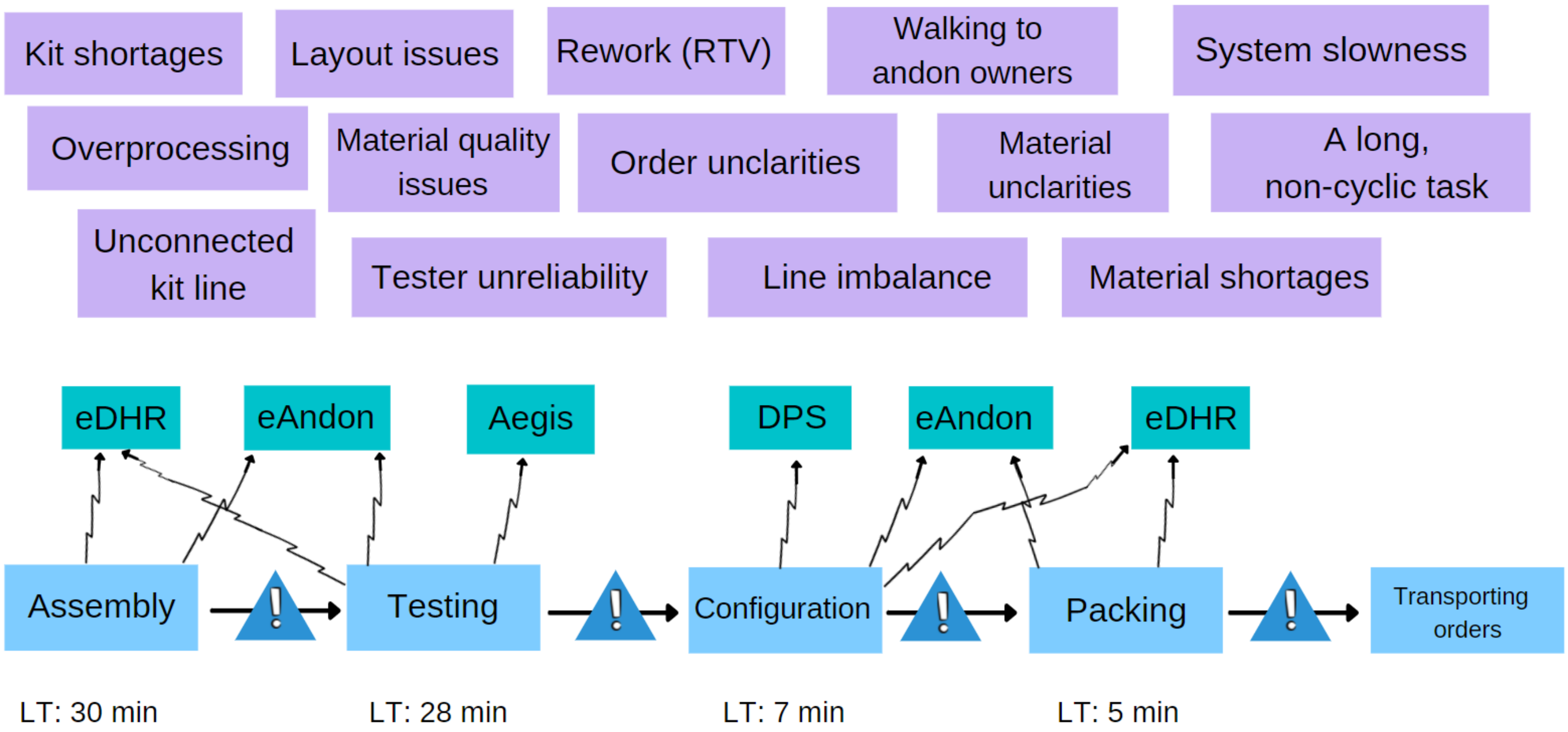
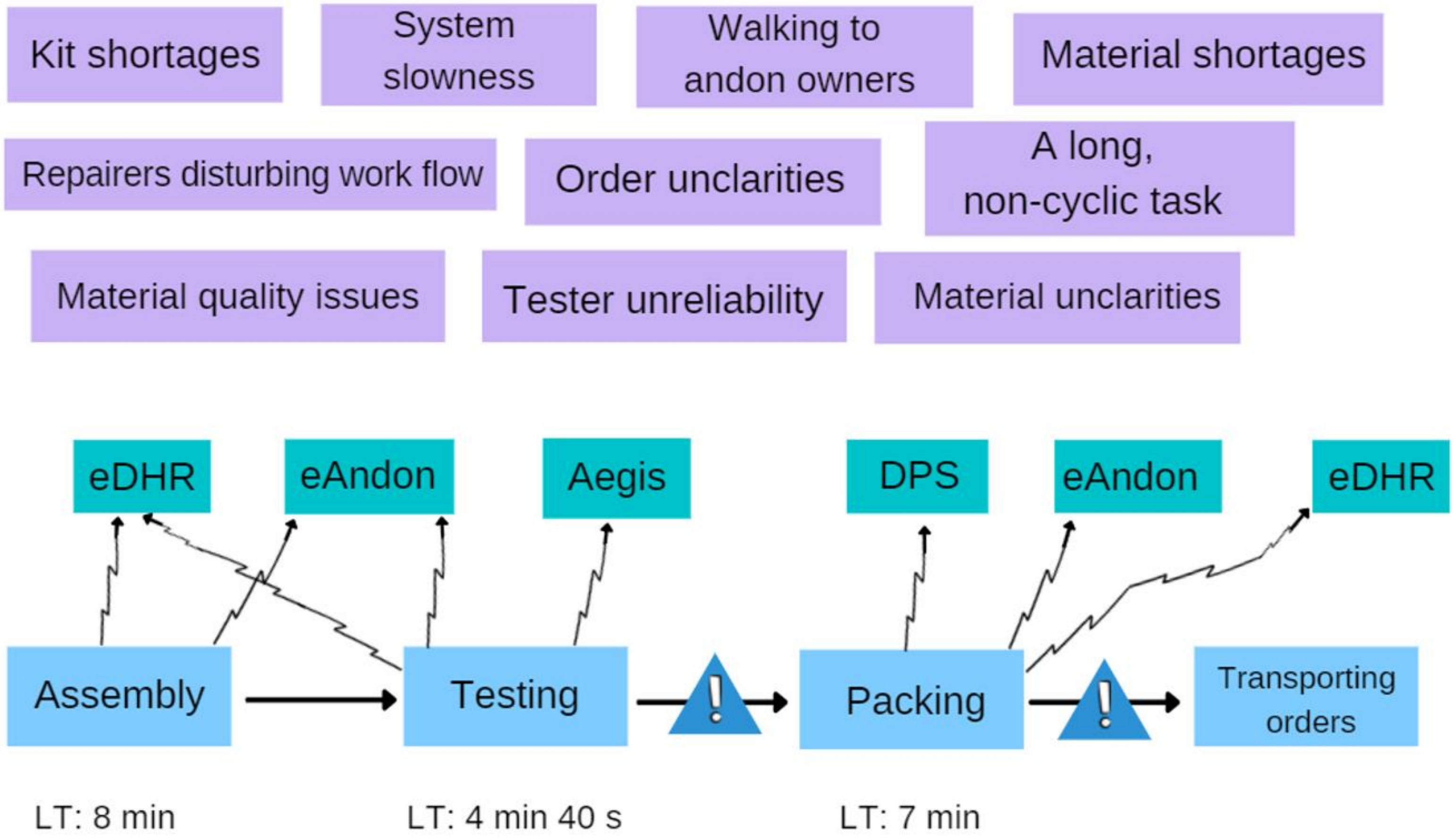
APPENDIX A: STANDARD WORK SHEET (BEFORE)



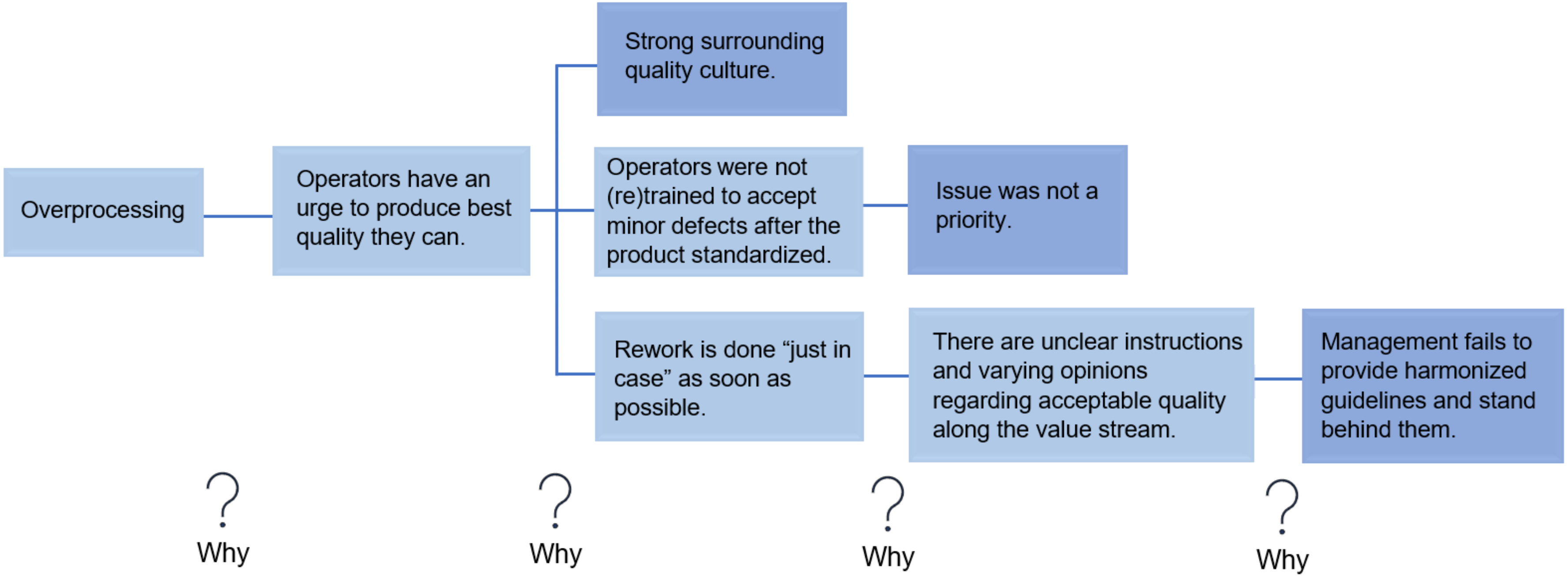
APPENDIX B: SIMPLIFIED VALUE STREAM MAP OF CARESCAPE ONE



APPENDIX C: SIMPLIFIED VALUE STREAM MAP OF F0 DOCK STATION



APPENDIX D: ROOT CAUSE ANALYSIS FOR OVERPROCESSING



Overprocessing

Operators have an urge to produce best quality they can.

Strong surrounding quality culture.

Operators were not (re)trained to accept minor defects after the product standardized.

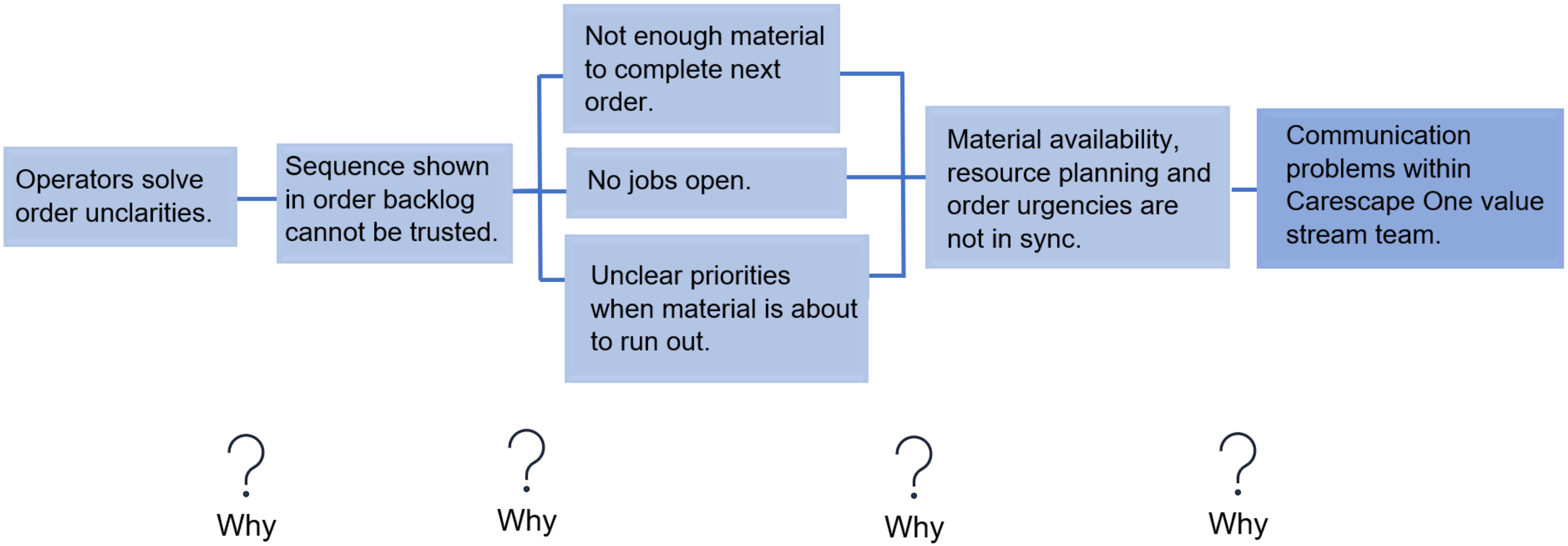
Issue was not a priority.

Rework is done “just in case” as soon as possible.

There are unclear instructions and varying opinions regarding acceptable quality along the value stream.

Management fails to provide harmonized guidelines and stand behind them.

APPENDIX E: ROOT CAUSE ANALYSIS FOR ORDER UNCLARITIES



Operators solve order unclarities.

Sequence shown in order backlog cannot be trusted.

Not enough material to complete next order.

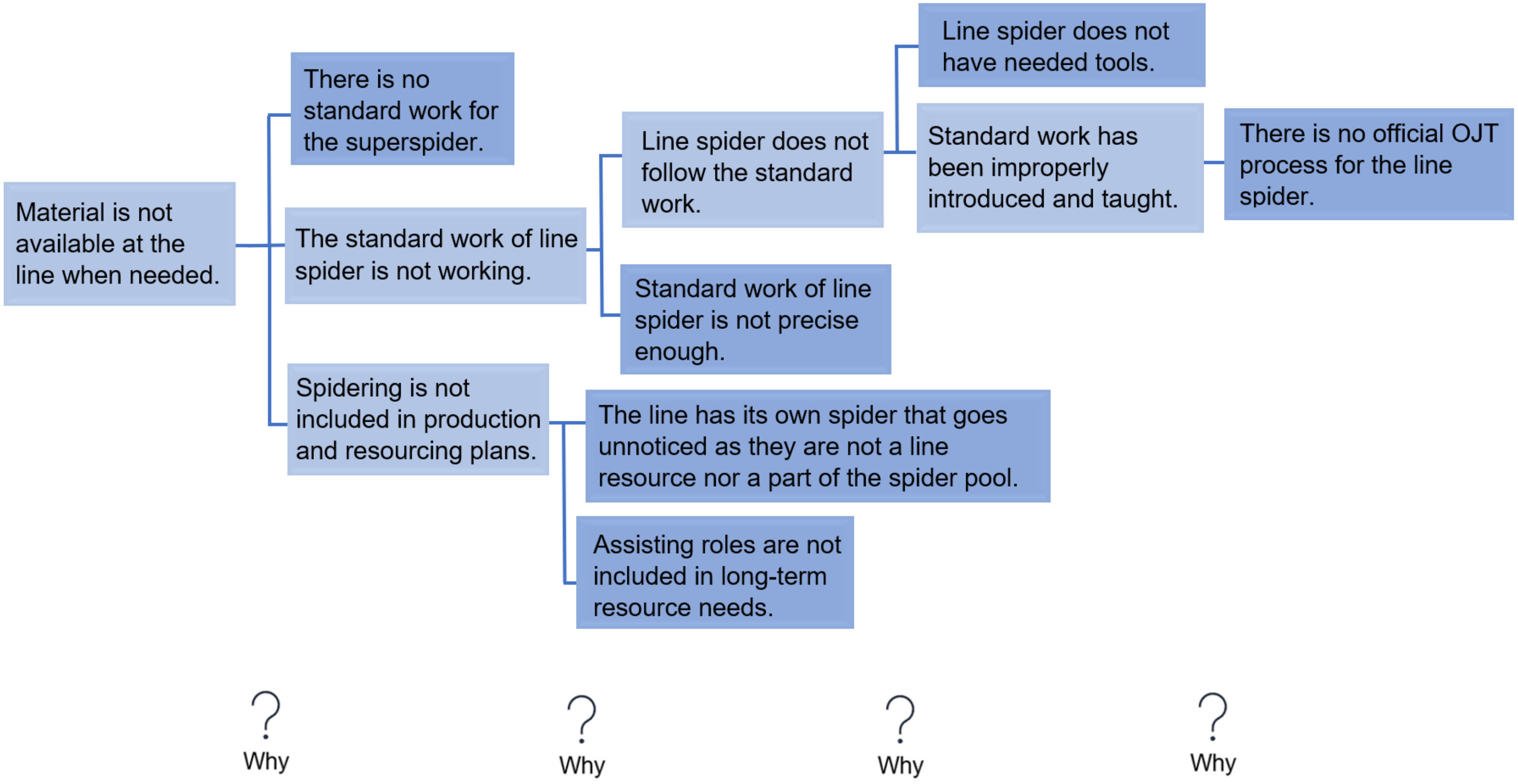
No jobs open.

Unclear priorities when material is about to run out.

Material availability, resource planning and order urgencies are not in sync.

Communication problems within Carescape One value stream team.

APPENDIX F: ROOT CAUSE ANALYSIS FOR INEFFICIENT SPIDERING



APPENDIX G: PROPOSAL FOR A CONTINUOUS INVENTORY PROJECT

WHY IS THE PROJECT NECESSARY?

Continuous inventory is needed to reduce production-stopping balance discrepancies, and to enable real-time root cause analysis of balance discrepancies. Balance discrepancies cause constantly investigation work for spiders and line workers. The current continuous inventory does not work as it lacks ownership, monitoring process and guidelines for its practical implementation. With the help of a low-threshold pilot project, GEHC can kickstart continuous inventory and gather lessons learned for its improvement.

OBJECTIVES

A better understanding of the causes of balance discrepancies, and thereby the possibility of eliminating their root causes. Further objectives are correct inventory balances and thereby savings in value-adding working time.

IMPLEMENTATION

Continuous inventory is carried out in connection with the KanbanBox inventory three times a week. At least three codes are always inventoried from the updated KBB code list, prioritizing codes that have different KBB and ERP balances. The remaining time allotted for inventory is used to inventory randomly selected codes among the KBB code list. The inventory team performs root cause analyzes for balance discrepancies and records the reasons in the ERP system. The inventory team meets every two weeks to review the root causes of balance discrepancies, to develop an action plan to eradicate the most recurring root causes, and to monitor the progress of the plan.

MONITORING AND MEASUREMENTS OF SUCCESS

The process owner is responsible for the functionality of the inventory process. The inventory process is developed on the basis of practical lessons. For example, the inventory team can alter the number of codes to be inventoried. Success of the project can be measured by reduced balance discrepancy -andon alerts.

DIVISION OF RESPONSIBILITIES AND ESTIMATION OF REQUIRED TIME

- Process Owner (Manufacturing Program Leader) - 1,5 h / week
    - 0,25 h meeting lead
- Physical Inventory Responsible (Line Assistant) - 3,25 h / week
    - 3 h inventory (20 min / code, 9 codes / week)
    - 0,25 h meeting
- Remaining Inventory Team (Material Specialists, Production Planner) - 1,25 h / week each
    - 0,25 h meeting
    - 0,5 h root cause analysis (each Material Specialist is responsible for codes of their own area)
    - 0,5 h solution implementation

+ Ad Hoc Inventory Team Member (Production Team Leader) - 0,25 h / week for root cause analysis / solution implementation