OPTIMIZING THE SEMI-AUTOMATED PRODUCTION PROCESS AT ARVATO SCS

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Management Summary

Arvato Supply Chain Solutions is a global provider specializing in supply chain management and logistic solutions. Arvato SCS operates under the Bertelsmann group, and the company has 4 site locations in the Netherlands. This research is conducted at the site in Amsterdam, located at the Schiphol-Rijk area. At the Schiphol-Rijk site, Arvato operates the assembly and packaging of CPU units for its confidential client, referred to in this thesis as "Hi-Tech Co.". The prevailing issue at Arvato lies in the outdated production process that it operates. As the production process has not been upgraded since 2008, the equipment has degraded significantly, leading to a decrease in efficiency and an increase in production stoppages. The company considers two options to address this problem: reinvestment in advanced machinery or an optimized redesign of the current semi-automated production process. The *"high frequency of production stoppages"* is the action problem at hand, and the core problem that leads to it is that the *"current design of the production process is not optimal"*. Therefore, this research provides interventions for the core problem that leads to the action problem for Arvato. The main research question that this research aims to answer is: *"How can the packaging production process at on the semi-automated lines at Arvato Supply Chain Solutions be optimized to reduce production stoppages?"*.

Arvato runs the current production process through 3 manual lines and 5 semi-automated lines. The focus of this research lies on the 5 semi-automated lines. The stations of each semi- automated line are the Folded Carton Erector, FHS Placement Station, Clamshell Station, Building Station, Folded Carton Closer & Label Printer, Inpakker Station, DistiBox Closer, and DistiBox Label Printer. Through these stations, the process combines different components from a Hi-Tech Co. product into one compact package. These components consist of a Central Processing Unit, a heat-sink fan (FHS) unit to cool down integrated circuits in the CPU, and an instruction manual. When these components are assembled into a package, the package is placed in a larger box that is ready for shipping. Once the larger box is filled with CPU packages, it is placed onto a palette that is handed over to the logistics team after an order is finished. The main problems with the current production process are the high frequency of changeovers, the FHS Placement Station, and the DistiBox Label Printer. The high frequency of changeovers occurs as a result of the way production planning is currently set up at Arvato. Furthermore, the company currently fulfills demand for its 5 product types using only 2 or 3 of the lines, which is another reason for the high changeover frequency. At the FHS Placement Station, the operator's only task is to place FHS components from the palette onto the conveyor belt leading to the Building Station. The operator at the FHS Placement Station is tied to this station and must redundantly pick-and-place FHS components from palette to belt to ensure continuous flow. If the operator is away from the conveyor belt for long enough, the flow of FHS components to the Building Station is interrupted and the Building Station remains waiting for FHS components. Having the operator stand in place for a full production period to perform one task is a non-value-added activity that needs to be eliminated. At the DistiBox Label Printer, the output of the printer is too low such that it leads to heavy congestion. Congestion gets so heavy that boxes start falling off the conveyor belt in front of the printer as it gets blocked. An operator is then required to remove the overflowing boxes, place them on a palette, wait for the current order to complete, and place them back onto the conveyor belt. When the order at hand is completed, production stops as it waits for the removed DistiBoxes to be reprocessed. Furthermore, the Clamshell Station and the Building Station are two stations that can be automated to achieve better performance.

The thesis includes a literature review on methods of performance measurement & KPI tracking, bottleneck identification & optimization, lean management, and process automation. The concepts learned from this literature review assist in generating possible interventions to optimize the current production process at Arvato. The proposed interventions for the problems with Arvato's current production process are as follows:

Intervention #1	Benefits
• Decrease the number of production lines from 5 to 3. • Set up production planning such that the frequency of changeovers decreases.	• More efficient utilization of the company's resources. • Increase in the availability KPI. • Increase in spacing. • Decrease in costs.

Intervention #2	Benefits
• Upgrade the DistiBox Label Printer.	• Increase in capacity. • Decrease in production stoppage frequency. • Decrease in wastes according to Lean Philosophy.

Intervention #3	Benefits
• Automate the FHS Placement Station using pick-and-place robot. • Automate the Clamshell Station & Building Station using robotics and machine learning.	• Optimization of the FHS Placement Station bottleneck. • Improved process performance and efficiency. • Decrease in human errors. • Decrease in headcount required to operate a single line.

The columns on the left for each table include the changes proposed by each intervention, while the columns on the right provide the benefits of implementing these changes.

Contents

Chapter 1: Introduction

This BSc Thesis is conducted at the company Arvato Benelux B.V. at the company's site at Schiphol-Rijk, Amsterdam. This chapter focuses on introducing the company Arvato Supply Chain Solutions (SCS) and identifying the goals this research aims to achieve. Section 1.1 provides a description of the company. Section 1.2 provides an explanation of the action problem and core problems. Section 1.3 provides an overview of the research design and objectives.

1.1 - Company Description

Arvato Supply Chain Solutions is a leading global logistics provider specializing in warehousing and value- added services. It is a subsidiary of the Bertelsmann Group, one of the most renowned media companies worldwide. Arvato SCS operates in over 20 countries and has over 18,000 employees. The company provides a diverse selection of services, such as warehousing and distribution, transportation management, and supply chain consulting to customers from various industries including healthcare, consumer goods, and high-tech firms. There are four site locations of Arvato in the Netherlands, namely in Gennep, Venlo, Oostrum, and Schiphol-Rijk. Company headquarters are based in the site at Gennep, but this research is conducted at the site in Schiphol-Rijk.

Figure 1 - Site Locations

The site in Schiphol-Rijk is dedicated to one of Arvato's clients in the hi-tech industry. Throughout this research paper, the client will be referred to as "*Hi-Tech Co.*", as information regarding the customer shall remain confidential. At Schiphol-Rijk, the company offers an additional value-added service to its client, and that is assembly. More specifically, Arvato operates the packaging process for Hi-Tech Co.'s products. These products consist of Central Processing Units (CPUs) for mobile and desktop devices. Packaging refers to the process of enclosing a product in a container or a material that protects it from damage and prepares it for shipment or storage. In the case of Arvato, this means receiving different components of Hi-Tech Co.'s products and assembling them into a single package that is ready for distribution to customers.

1.2 - Problem Description

The company operates the packaging process through 5 semi-automated lines and 3 manual lines, and it has been managed that way since 2008, with limited to no advancements. With competitors in the industry constantly evolving and the rapid development of technology, the current layout of the production process operated by Arvato has become outdated, and so has the equipment. The overall performance of the production process has declined, its efficiency has decreased, and the equipment has degraded significantly. This led to an increase in the frequency of production stoppages and downtime. The production team is therefore exploring two main options to solve the problem at hand:

- **Option 1** - To *re-invest* in the semi-automated production lines such that all outdated equipment is replaced for new, more advanced equipment.
- **Option 2** - To *re-design* the semi-automated production process in a modernized, efficient way such that the process is optimized and stoppages are minimized.

The focus throughout this research is only on the 5 semi-automated lines, as they handle the majority of production within the company. The 3 manual lines are assigned to orders with special requirements, and thus produce in significantly less amounts when compared to the 5 semi-automated lines. The manual process is also much simpler than the semi-automated process and does not require remarkable improvements. Furthermore, the main problems with Arvato's production process is in the 5 semi-automated lines and not the 3 manual lines. For the rest of this report, the terms "lines", "production lines", & "production process" refer explicitly to the 5 semi-automated lines.

1.2.1 - Action Problem

As the production lines and the equipment used for production have not been upgraded in 15 years, the team at Arvato aims to explore ways to re-design the production process and analyze the benefits of investing in newer, more advanced machinery. Several problems and bottlenecks exist throughout the production process, resulting in congestion at several stations on each line and a high frequency of stoppages in production. Furthermore, the machinery being used int the production process often fails, as it has degraded significantly over time.

The goal for Arvato is to optimize the packaging production process at Schiphol-Rijk. This is done by making the stages within the process more efficient and minimizing stoppages and downtime. Therefore, the action problem is identified as:

"High Frequency of Production Stoppages."

1.2.2 – Core Problem Selection

In the book *Solving Managerial Problems Systematically,* Heerkens (2017) defines a core problem as the fundamental issue or "root cause" of a complex problem, or the cause that is not an effect of another cause. Figure 2 provides the problem cluster that identifies the root causes for the action problem at hand.

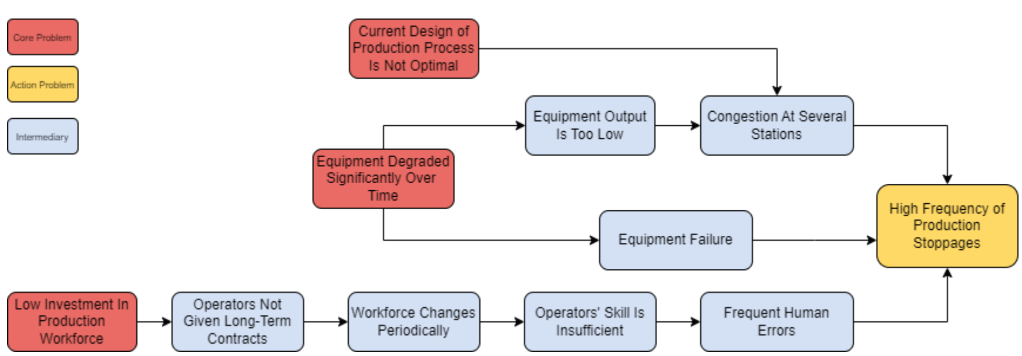

Figure 2 - Problem Cluster

The problem cluster highlights the action problem (in yellow), which is *"frequent production stoppages"*. Tracing backwards from the action problem highlights three root causes (in red) for the high frequency of production stoppages. The core problem that is selected to solve with this research is as follows:

"Current Design of Production Process is Not Optimal."

The term "design" in this context refers the general layout of the production facility, the process flows and sequence of each workstation on the line, the tasks performed in each workstation, and the equipment and machinery required. Therefore, the aim of this research is to optimize the 5 semi- automated lines by redesigning the current process and gaining insight into which equipment is crucial to reinvest in. The reasoning behind this selection is that addressing this core problem will indirectly solve another core problem, which is that *"equipment degraded significantly over time"*. Redesigning the lines will also require investing in new machinery to maximize the efficiency of the redesigned production process. Some bottlenecks in the process exist solely because the outdated equipment is not performing sufficiently, regardless of the improvements made in other parts of the line. Certain equipment is thus crucial to reinvest in. Furthermore, spare parts for some of the equipment are no longer available on the market, and it is expensive and time-consuming to fix failures for this equipment should they require new parts. Therefore, focusing on redesigning the way the current production process works does include reinvesting in certain machinery. Another reason for selecting this core problem is that neither "*equipment degradation"* nor *"low investment in production workforce"* is a broad enough problem on its own to be the main focus of this research. Solving these two problems alone will not achieve the goal Arvato has set with this project. On the other hand, solving the problem with the current design of the production process is both broad enough to be the main focus of this research and is more aligned with the company's goals.

1.3 - Research Design

This section discusses the research design formulated to conduct this research effectively. This section also states the main research question and research sub-questions this thesis aims to solve. Each research sub-question corresponds to a knowledge problem that should be solved to provide a complete answer to the main research question.

1.3.1 - Main Research Question

The main research question this research aims to solve is:

"How can the packaging production process on the semi-automated lines at Arvato Supply Chain Solutions be optimized such that production stoppage decreases?"

1.3.2 – Research Sub-Questions

The research sub-questions highlighted here correspond to the knowledge problems encountered throughout this research. The chapters of this report address each sub-question. Furthermore, each sub-question is dissected into smaller questions for further simplification.

Chapter 2 - *"How is the packaging process designed and what is the current situation at the company?"*

a) What is the current layout of the facility?
b) What are the stages of the current semi-automated production process?
c) What are the recent production volumes for the semi-automated lines?

d) What product types are the lines required to produce?

Chapter 3 - *"What literature is available to formulate possible interventions for the problems with the current process?"*

a) According to the literature, what KPIs can be monitored to effectively measure and evaluate the performance of a production process?
b) What are effective strategies and methods to optimize the bottlenecks in a production process?
c) Which methods of process automation can be implemented within a production process?

Chapter 4 – "*What are possible interventions for the problems within the current process?"*

a) What are the system's main problems & bottlenecks and how are they identified?
b) How can the production process be redesigned to increase its efficiency and performance?
c) Which pieces of equipment are crucial to re-invest in?
d) How can process automation be implemented within the production process to improve its performance?

Chapter 5 - *"Which of the proposed interventions are best to implement for Arvato?"*

a) What are the effects of each proposed solution on the performance of the production process?
b) How expensive is it to implement the proposed interventions?
c) How feasible are the proposed interventions?

Chapter 2: Current Situation Analysis

This chapter focuses on analyzing the current production process at Arvato SCS. This analysis is a result of direct observations and discussions with team members that are experts on the current production process. Section 2.1 describes the current layout of the facility. It is important to visualize the layout of the facility as the proposed interventions in Chapter 4 suggest a change in the layout of the production process. Section 2.2 explains how the 5 semi-automated lines operate, including the stages, production volumes, and product types produced on the lines. Section 2.3 provides the conclusion on the current situation analysis, stating the initial observations on the current process.

2.1 – Current Layout of the Facility

This section describes the current layout of the facility. Figure 2 first provides an illustration of the facility and is followed by a verbal explanation of the illustration.

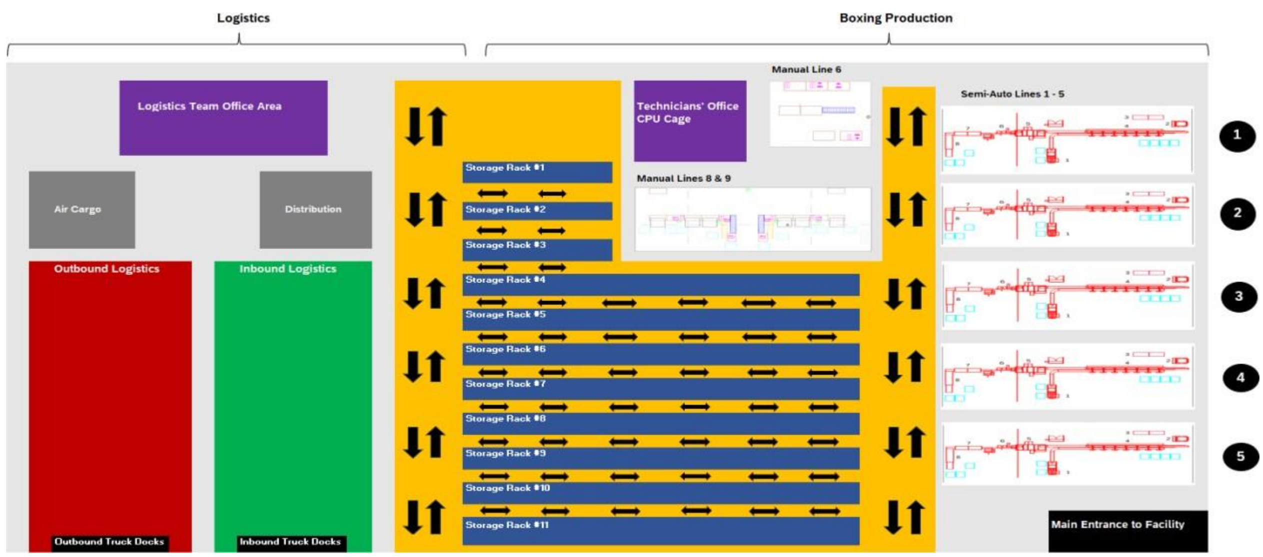

Figure 2 - Current Layout of Facility

The facility is divided into two areas, an area for logistics (left side in Figure 2) and an area for production (right side). In between both areas are 11 storage racks (blue) that separate each area from the another. Both areas are connected through a lane (yellow) between each storage rack, where forklifts and people can move. The logistics area, which is referred to by the company as the warehouse, is divided into inbound logistics (green) and outbound logistics (red). It includes a space for handling air cargo and a space for dividing products received from inbound logistics according to their end destinations (grey). Additionally, the offices for the logistics team are also located in the warehouse (purple). On the opposite side of the facility is the production area, where the 5 semi-automated lines, numbered 1 through 5, and 3 manual lines, numbered 6, 8, & 9, are located. The office where technicians stay is located in the production area (purple). Next to the office is what the company calls the "CPU Cage", where the CPUs received from Hi-Tech Co. are stored. This is a separate storage space for the CPUs as they are valuable, highly sensitive components that need to be stored carefully. The layout of especially the production area is important to visualize as possible solutions will suggest that the layout of the area changes.

While the layout of the warehouse is also shown in the illustration, it will not be an area of focus throughout this research. This is because this research does not address the logistics activities within the company; it only addresses the problems with the 5 semi-automated production lines, including their layout and current way of working.

2.2 – Current Semi-Automated Production Process

This section explains the process that runs on an individual semi-automated line. In short, the process entails combining different components from a Hi-Tech Co. product into one compact package. These components consist of a Central Processing Unit, a heat-sink fan (FHS) unit to cool down integrated circuits in the CPU, and an instruction manual. When these components are assembled into a package, the package is placed in a larger box that is ready for shipping. Once the larger box is filled with CPU packages, it is placed onto a palette that is handed over to the logistics team after an order is finished. Section 2.2.1 explains each stage of the production process in more detail.

2.2.1 – Stages of the Packaging Production Process

Figure 3 is a visual representation of one semi-automated line. There are 8 main stages within each line, and they are numbered in Figure 3 accordingly. The rest of this subsection explains the functions of each stage individually. Appendix C.1 contains the process flowchart for the current production process.

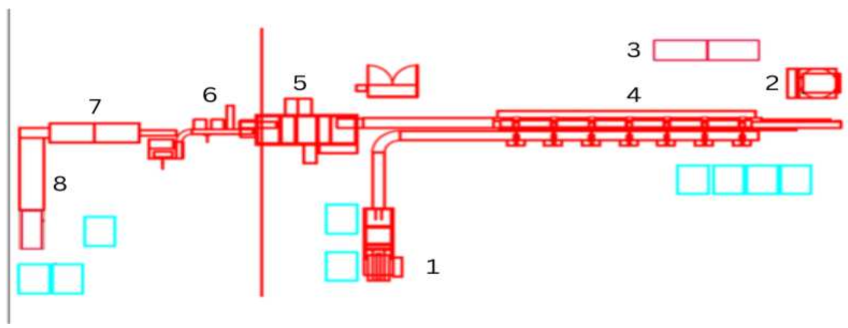

Figure 3 - Semi-Automated Production Line

- **Stage 1 - Folded Carton Erector:** The Folded Carton Erector folds flat sheets of cardboard into compact boxes in which the CPU and its components are assembled. The flat cardboard sheets are placed on the belt by an operator. The sheets then move through the belt into the erector and are folded into a box one-by-one. These folded cartons then exit the erector and move to station 4, the Building Station, where the components are assembled.

- **Stage 2 - FHS Placement Station:** The second station consists of a conveyor belt on which the FHS components are placed. An operator places the FHS components one-by-one from the palette and onto the belt. The FHS components are held in a cardboard box that has one slot for CPU units and another slot for the instruction manuals (see Stage 4 – Building Station for more details). The belt moves the FHS components to the Building Station.

- **Stage 3 - Clamshell Station:** The Clamshell Station is a table positioned beside the production line, directly in front of the Building Station, in which CPU units are placed into plastic clamshells. Placing the CPUs into the plastic clamshells is required to protect them from damages. When all the processors are in place, they are picked up by the operators at the Building Station to prepare for the assembly process.

- **Stage 4 - Building Station:** The Building Station is the point where all the components from the previous stations are assembled. At the Building Station, the folded cartons arrive through a top-level conveyor belt, while the FHS components arrive on the lower conveyor belt. The protected CPU units arrive from the Clamshell Station. In this station, three operators work on manually assembling the CPUs, the FHS components, and instruction manuals into the folded cartons. First an FHS component, which is placed in a cardboard box with slots for a CPU unit and an instruction manual, is picked up. Afterwards, the CPU unit and instruction manual are placed at their designated slots in the cardboard box containing the FHS component. The FHS cardboard box containing a CPU unit and an instruction manual is then placed into a folded carton. After the components are combined into one folded carton, the finished package is placed back on the belt, open on one side, to progress to the next station.

- **Stage 5 - Folded Carton Closer & Label Printer:** The finished packages exit the Building Station and proceed into the Folded Carton Closer and Label Printer. In this station, the first step is closing the opened side of the finished package. Once the package is closed, the barcode on the CPU inside it is scanned with a camera through a transparent square opening. The barcode is then printed onto a label on the front side of the package. On the opposite side, a factory seal is also applied onto the package.

- **Stage 6 - Inpakker Station:** The finished package exits the Folded Carton Closer and enters what the company calls the "Inpakker Station". As the package enters this station, a second camera, called the "Matching Camera", again scans the barcode on the CPU and the barcode printed onto the finished packaged from Stage 5. This is an automated quality check to ensure that all packages entering the Inpakker Station have the correct labelling. If the box is rejected, it is pushed out of the conveyor belt towards the Inpakker Station operator for re-adjustment. If, however, the box is not rejected, it moves through the conveyor belt and towards the operator on the Inpakker Station. The operator makes a final quality check on each finished package, and any defective packages are sent back to the Building Station for re-adjustment. At this point, the operator takes the finished packages and places them into a larger box, where each of the larger boxes fits up to 5 smaller packages. The larger box is called a "DistiBox", and it contains the finished packages which are ready to be shipped. When a DistiBox is filled, the operator applies a label to it that contains its ID number and places it back onto the conveyor belt. The DistiBox is still open as it proceeds to the next stage.

- **Stage 7 - DistiBox Closer:** Upon entering the DistiBox Closer, a third camera scans the barcodes on each of the 5 finished packages inside the DistiBox. This is done so that the labels of the finished packages inside the DistiBox are printed onto it in the final stage. Once the scan is complete, the DistiBox enters the closer and is sealed on both sides. It then exits the closer and enters the final stage, the DistiBox Label Printer.

- **Stage 8 – DistiBox Label Printer:** In this final station, the DistiBox Label Printer prints the labels of the 5 finished packages inside it, which were scanned in the Stage 7. This assures that the contents of each sealed DistiBox are known. The printer also prints other details on the DistiBox, such as the order number, destination, the country of origin, country of assembly, etc. When a DistiBox is labelled, it is given a final quality check to ensure that no defects have occurred. Afterwards, it is placed onto a palette and is delivered to the distribution center once all of the order is complete.

The headcount required for one line is as follows:

- 1 operator at FHS Placement Station,
- 2 operators at Clamshell Station,
- 3 operators at Building Station,
- 1 operator at Inpakker Station,
- 1 operator for Quality Control.

This means that typically 8 individuals are required to operate one semi-automated line, or around 40 in total to operate the whole production process should all 5 lines be working simultaneously.

2.2.2 – Production Planning and Product Types

Production planning at Arvato is currently set up such that Arvato's production team processes orders from the customer on a day-to-day basis. In other words, the planning of orders for a single production day is done at the start of that same day. A typical order size consists of 1100 units, but orders of less than 1100 units are often processed as well. Orders of less than 1100 units are called partial orders, and they occur as a result of two things. First, it can part of the planning in which the customer requires a small amount of a single product type. Secondly, it can be the remainder of the last order processed from the previous production day, where the team has to complete the remainder of that order and then change over to produce an order of a different product type.

There are 2 categories of products that the company produces, namely Desktop CPU products and Mobile CPU products. Under the Desktop category are three product types, type D1, type D2, and type D3. Under the Mobile category are two product types, type M1 and type M2. Each of the 5 product types requires a (slightly) different configuration of the line than the others. Thus, when a line completes an order of product type A and is required to process an order of product type B afterwards, a changeover is required between both orders. The frequency of changeovers on one line depends on the number of product types that line is required to produce during a single day. It also depends on the number of partial orders received per day, as a higher frequency of smaller order sizes will lead to higher frequency of stoppages, specifically of each partial order is of a different product type. A typical changeover takes 10 to 20 minutes depending on the configuration being changed to. In the case of Arvato, the production process stops almost completely when a changeover occurs. The only stations that can operate when a changeover is in process are the manual stations, namely the Clamshell Station and Building Station. Furthermore, with the recent demand and production volumes, the team normally operates two or three lines to process all orders. Intuitively, this also increases the frequency of changeovers as 5 product types are produced using only 2 or 3 production lines. Changeovers have a significant effect on the frequency of production stoppages and the availability of the production process. Chapter 4 analyzes changeovers and their effect on the performance of the production process in further detail.

2.2.3 – Production Volumes

Table 1 contains the forecasted production volumes for each product type for Quarters 2, 3, and 4 of 2023. The purpose of this table is to provide an overview on the forecasted demand for each individual product type and highlight how much the production process is expected to produce across 3 quarters.

Product Type	Expected for Q2	Expected for Q3	Expected for Q4	Total
Desktop 1	304,600	490,900	540,300	1,335,800
Desktop 2	97,700	125,900	117,00	340,300
Desktop 3	11,000	16,600	24,900	52,500
Mobile 1	126,100	128,100	50,400	304,600
Mobile 2	2,200	500	0	2,700
Total	541,600	762,000	732,600	**2,035,900**

Table 1 - Forecasted Production Volumes

Table 1 shows that product type D1 is expected to be produced with the highest volume across the 3 quarters, amounting to about 1,335,800 units or 65.6% of total forecasted units. The product with the least forecasted volume is product type M2, amounting to a total of only 2,700 units. Furthermore, it shows that Q3 is expected to be the busiest quarter, amounting to around 762,000 units or around 37.4% of the total forecasted units for Quarters 2, 3, and 4.

Table 2 contains the actual weekly production volumes on the 5 semi-automated lines for the months of May, June, and July. The purpose of this table is to provide an overview on the total number of units the 5 semi-automated production lines were actually required to produce per week, for a period of 14 weeks. It is useful to compare the forecasted production volumes of each quarter with the actual production volumes the company has produced over the 14-week measurement period. While the 14- week measurement period in Table 2 does not align to the exact timeline of a single quarter in Table 1, the comparison shows the difference between the company's forecasts and its actual units produced, respectively, over a similar time horizon. Table 2 covers the weekly production volumes for the months of May, June, and July.

Week	Units Produced per Week
01/05/2023 – 05/05/2023	7,000
08/05/2023 – 12/05/2023	21,000
15/05/2023 – 19/05/2023	18,000
22/05/2023 – 26/05/2023	31,000
29/05/2023 – 02/06/2023	13,500
05/06/2023 – 09/06/2023	36,500
12/06/2023 – 16/06/2023	42,000
19/06/2023 – 23/06/2023	56,000
26/06/2023 – 30/06/2023	20,000
03/07/2023 – 07/07/2023	15,000
10/07/2023 – 14/07/2023	15,000
17/07/2023 – 21/07/2023	16,000
24/07/2023 – 28/07/2023	26,000
31/07/2023 – 04/08/2023	22,000

Table 2 - Recent Production Volumes

For the months of May, June, and July, the average weekly production volume is *24,214 units* , with a maximum of *56,000 units* and a minimum of *7,000 units*. The process produced around *339,00 total units* across these three months. The direct comparison between Table 1 and Table 2 shows that the total units produced in the 14-week measurement period is significantly less than any of the individual quarters in the forecast. This implies that the company's forecasts tends to overestimate actual production volumes, and it was confirmed by the logistics team that forecasts are usually an overestimation of actual volumes. In practice, however, it could also mean that the 14-week measurement period did not capture the bulk of production volumes for neither Quarter 2 nor Quarter 3. In either case, given the recent production volumes, the company is able to fulfill orders with the current capacity of the semi-automated production process. It is confirmed through several discussions with the team that the problem at hand is not a capacity problem, but an efficiency problem. However, the data that will be used to verify the effects of the proposed interventions will be the data from Table 1. The reasoning here is that since forecasted volumes could potentially be an overestimation of actual production volumes, designing a process that fulfills forecasted demand further assures its ability to fulfill actual demand. Chapter 4 proposes a redesigned production process that considers the data from Table 1.

2.3 – Conclusion on Current Situation

The current production process at Arvato underperforms in several aspects, specifically in terms of efficiency and utilization of resources. While the process does not have a capacity problem and does meet the customer's required quality standards, it fails to do so in an efficient manner, Thus, the main problem with the packaging process at Arvato is in the way it is designed, namely in terms of its layout, the utilization of the semi-automated lines, and the way certain stages within the process operate. Additionally, some machinery has degraded significantly and is therefore crucial to reinvest in. Chapter 3 includes a literature review on the theory required to identify and analyze the problems with the current production process and formulate solutions that address them.

Chapter 3: Literature Review

This chapter focuses on the concepts required to understand from existing literature that would aid in solving the problem at hand. Section 3.4 of this chapter provides the definitive answers to the following knowledge questions:

a) What KPIs can be monitored to effectively measure and evaluate the performance of a production process?
b) What are effective strategies and methods to optimize the bottlenecks in a production process?
c) Which methods of process automation can be implemented within a production process?

Section 3.1 defines Key Performance Indicators (KPIs), highlighting the importance of proper KPI selection for measuring and comparing performance. This section also studies the use of Performance Measurement Systems to stimulate KPI-driven improvement, while identifying relevant manufacturing KPIs, such as Overall Equipment Effectiveness, in the process. Section 3.2 identifies effective strategies used in the manufacturing industry, such as Lean Manufacturing and Bottleneck Analysis, to optimize processes and increase their efficiency. Section 3.3 discusses Industry 4.0 concepts, highlighting methods of process automation and uses of robotics that are implemented in production processes. It also discusses some of the challenges that come with implementing process automation.

3.1 - KPIs and Performance Measurement

This section provides the definition of key performance indicators (KPIs) and explains the importance of selecting relevant indicators when measuring and evaluating operational performance. The motive behind understanding KPIs and performance measurement is to compare the current performance of the production process at Arvato with the desired performance. It is also an effective way in evaluating the degree of improvement that the interventions of this research provide.

3.1.1 – KPIs and Their Importance in Manufacturing

Key Performance Indicators or KPIs are critical tools for measuring performance in manufacturing environments, both in shop floor and management levels, respectively (Samir et al., 2018). They are measurements of critical success factors and aid in both defining goals and achieving them. Furthermore, KPIs are effective in tracking progress and stimulating continuous improvement, which has proven crucial in maintaining an organization's competitiveness within its industry. Manufacturing companies track KPIs to identify problems and facilitate both production and maintenance strategies. KPI tracking is the foundation of Performance Measurement Systems (PMSs), which are a set of performance variables used to quantify the effectiveness and efficiency of a process (Schreiber et al., 2020). Section 3.1.2 highlights the use of KPIs to formulate Performance Measurement Systems, while identifying the most relevant KPIs used by manufacturing companies.

3.1.2 – Performance Measurement Systems

Companies use Performance Measurement Systems to gain real-time information about resources and processes and thus detect potential issues at an early stage (Schreiber et al., 2020). Through the use of a set of KPIs, PMSs allow companies to compare current with desired performance. There are two main methodologies for designing a PMS, which are the Balanced Score Card (BSC) approach and the concept of selective KPIs approach (Schreiber et al., 2020). The BSC includes both financial and operational variables and provides a summary of business operations. It considers four aspects, namely customer, internal company, innovation & learning, and financials, and a set of KPIs & targets are developed for each. The concept of selective KPIs is a method that supports decision-making processes for selecting KPIs by identifying relevant Strategic Performance Attributes (SPAs) and Operational Performance Attributes (OPAs). SPAs are identified based on company strategy and "are competitive advantages of a manufacturing company to create a long-term differentiation from the competition to enable economic success" (Schreiber et al., 2020). They are considered by manufacturing companies to be critical success factors and a means to gain a significant strategic advantage over competitors. Schreiber et al. (2020) highlight Cost, Time, Quality, and Flexibility, as SPAs from which companies derive their goals and targets. OPAs are more short-term focused and are "used to identify potential bottlenecks, problems in strategy realization, and to control potential risks". To ensure the success of the operational implementation of SPA-based strategic goals, a manufacturing company must constantly monitor progress and forecast potential bottlenecks by identifying OPA-driven KPIs (Schreiber et al., 2020). Schreiber et al. (2020) also highlights the most widely used KPIs for production and maintenance:

KPIs for Production	KPIs for Maintenance
Quality Rate	Error Rate
Availability	Mean Time Between Failures
Capacity Utilization	Mean Time Between Repair
Number of Rejected Products	Response Time
Production Capacity	Mean Time to Repair
Alteration in Downtime	Alteration in Downtime
Downtime Costs	Period-Specific Maintenance Costs
Alteration in Cycle Time	Maintenance-Related Underperformance Rate

Table 3 - KPIs for Production and Maintenance (Schreiber et al., 2020)

Utilizing some form of PMS is crucial for a company's continuous improvement, and subsequently is the proper selection of KPIs. Therefore, recognizing relevant KPIs such as the ones in Table 3 is essential for accurately measuring performance. Another study provides the results of a survey analysis on the real-life applicability of KPIs listed in the ISO 22400 (Zhu et al., 2018). The ISO 22400 standard defines the most critical and widely utilized KPIs in the manufacturing industry, with the goal of monitoring and managing manufacturing operations (Zhu et al., 2018). The results of the survey group the KPIs considered into three categories, namely Not Useful (NU), Useful & Unchanged (UU), or Useful but Changed (UC). One statistic that stood out was that availability was deemed NU, while overall equipment effectiveness (OEE) was deemed UU, although availability is one of the key components in calculating the OEE index (Zhu et al., 2018). Section 3.1.3 further discusses the use of OEE to drive continuous improvement and measure operational performance, highlighting its several benefits & limitations.

3.1.3 – Overall Equipment Effectiveness (OEE)

Overall Equipment Effectiveness (OEE) measures the effectiveness and utilization of equipment by considering all losses due to stoppages, performance issues, and quality defects (Janahi et al., 2020). It is computed by multiplying availability, performance, and quality ratio. Availability refers to the stoppage of equipment due to failures, changeovers, or set-up times. Performance rate considers inefficiencies and reductions in speed due to idle time or minor halts. Quality rate is the ratio of units that meet quality standards to the total number of units produced (Thiede, 2023). The OEE formula (Janahi et al., 2020) is calculated as follows:

$$OEE = A * PE * Q$$

where A, PE, and Q are:

$$Availability\ (A) = \frac{Run\ Time}{Planned\ Production\ Time}$$

$$Performance\ (PE) = \frac{Standard\ Cycle\ Time * Total\ Count}{Run\ Time}$$

$$Quality\ (Q) = \frac{Good\ Parts}{Total\ Count}$$

And Run Time is calculated as:

$$Run\ Time = Available\ Time - (Downtime\ from\ Planned\ Stoppages + Downtime\ from\ Unplanned\ Stoppages)$$

OEE accounts for losses in each of availability, performance, and quality (Esmaeel et al., 2018). The next paragraph explains each of the losses covered by OEE. A brief illustration (Figure 4) provides a more intuitive understanding of OEE losses.

OEE Losses

Availability loss covers any instances of stoppage in production for a significant period, whether planned, as in a changeover, or unplanned, as in a machine failure. Run time is given when availability loss is subtracted from total planned production time. Performance Loss refers to instances where the process runs at less than the ideal rate, which could be the effect of equipment degradation or congestion. Subtracting performance loss from run time provides the net run time of the process. Finally, quality loss accounts for manufactured units that are defective or below quality requirements. The time that remains when quality loss is subtracted from net run time is the time where the process is fully productive.

Figure 4 - OEE Losses

Benefits vs. Limitations of OEE

While OEE is a vital metric for measuring operational performance, it does have limitations (Janahi et al., 2020). First, OEE does not cover customer demand variations and other customer-oriented aspects. Second, OEE fails to cover flexibility, which is a critical competitive advantage in today's constantly changing environment (Esmaeel et al., 2018). However, research also shows that manufacturing companies gained several benefits from prioritizing OEE, including reduction in changeover times, productivity improvement, and cost reduction (Esmaeel et al, 2018). It is therefore reasonable to use OEE as a KPI for driving improvement, but also considering its limitations.

Section 3.2 explored the different methods and strategies used to optimize the bottlenecks of a production process. It also covers methods of Bottleneck Analysis (BA) and concepts of Lean Manufacturing, respectively, while also highlighting how proper KPI selection & OEE are linked to process optimization.

3.2 – Optimizing Production Processes

This section covers the different methods and strategies used to optimize a manufacturing process. It first reviews Bottleneck Analysis (BA), as it is one of the crucial initial steps in process optimization. The rest of the section discusses Lean Manufacturing principles as a means to optimize the production process by eliminating waste and increasing efficiency.

3.2.1 – Bottleneck Analysis

Bottleneck detection & analysis is the earliest and most critical action to improve overall manufacturing capacity (Roser et al., 2014). This research uses two definitions for bottleneck, according to the literature. The first defines a bottleneck of a production line as a function that limits the performance or output of the overall system (Hofmann et al., 2019). The second defines a bottleneck on the shop floor as the machine or station with the lowest production rate compared to other machines or stations in the system (Roser et al., 2014). Bottleneck Analysis (BA) consist of 4 phases, namely detection, diagnosis, prediction, and prescription (Mahmoodi et al., 2022).

1. *Bottleneck Detection* methods pinpoint the location of one or more bottlenecks in the system.
2. *Bottleneck Diagnosis* finds the root causes of the bottleneck.
3. *Bottleneck Prediction* methods and tools aid in decision-making processes by forecasting potential bottlenecks based on historical data analysis.
4. *Bottleneck Prescription* refers to formulating possible solutions, based on findings from descriptive and prescriptive analysis.

Before discussing the steps of Bottleneck Analysis (BA) and specific methods of bottleneck detection, it is important to understand the behavior of a bottleneck. By observing the states of other processes in the system, the bottleneck of the system can be located, or at least its direction in relation to the process being observed can be identified (Roser et al, 2014). According to Roser et al. (2014), processes are observed in one of three states, either "blocked", "starved", or neither. "Blocked" processes come to a halt due to the subsequent buffer or process being full. "Starved" processes come to a halt due to the preceding buffer or process being desolate. If the upstream process to the one being observed is blocked at a higher rate than the downstream process is being starved, then the process being observed is itself the bottleneck (Roser et al., 2014). Finally, if a process is running normally and is neither "blocked" nor "starved", then another process should be observed to help identify the direction of the bottleneck.

Bottleneck Detection Methods

Literature has shown that several methods of effective bottleneck detection are widely used in the manufacturing industry. One method of bottleneck detection is the process time approach, where the process times of each individual machine or station are measured in isolation (Roser et al., 2014). The machine or stage with a significantly higher process time is considered the bottleneck, or more accurately, the capacity limit of the system. Another method is the OEE-based approach, where performance losses are accounted for when monitoring OEE. The gap between net production time and total time is the focus of improvement and bottleneck detection in this approach (Roser et al., 2014). Two more simple yet effective approaches of bottleneck detection are the Go & See approach and the Bottleneck Walk method. Both methods are similar in principle, but the main difference between them is that Go & See is a principle derived from Lean Philosophy while the Bottleneck Walk is defined strictly as a bottleneck identification method. The Go & See approach is fundamentally derived from Lean and Shopfloor Management principles. It entices managers to not only systematically monitor KPIs, but also to go and inspect the activity on the shop floor themselves (Hofmann et al., 2019). The Bottleneck Walk is simply a "walk" along the flow of the production line and focuses on observing process states and inventory states (Roser et al., 2014). The observation of process states provides one of three conclusions. First, if the process being observed is the process waiting on another process, it is certainly NOT the bottleneck. Second, if the process being observed is "starved", or waiting for parts, then the bottleneck is located upstream, or in a stage before the process being observed. Third, if the process being observed is "blocked", meaning the subsequent buffer or process is full, then the bottleneck is located downstream, or in a stage after the process being observed (Roser et al., 2014). The observation of inventory states provides one of two conclusions. If the buffer between two processes is full or congested, the bottleneck is likely downstream, or the direction the parts are headed. Similarly, an empty buffer implies that the bottleneck is upstream (Roser et al., 2014). The Go & See method and the Bottleneck Walk method are both more suitable for older manufacturing systems, as they do not require advanced real-time data acquisition technologies to detect bottlenecks.

More advanced detection methods include simulation models and virtualization technologies, which allow decision-makers to see the effects of decisions before their implementation (Mahmoodi et al., 2022). Such methods require advanced real-time data acquisition technologies to be effective.

3.2.2 – Bottleneck Optimization Strategies

There are three classifications of bottleneck optimization strategies: "machine", "process", or "production layout" (Silva et al., 2021). Strategies in the "machine" classification include updating machine control policies and substituting for more advanced machines that provide better results (Silva et al., 2021). Strategies in the "process" category refer to changing process parameters, for example line speed. "Production layout" strategies consist of adding or removing new production lines or machinery (Silva et al., 2021). The applicability of each strategy depends on the process and the equipment used within it, but combining two or more strategies to better fit the situation is possible. As all three strategies have limitations and cannot induce improvement on all parameters, the selection and combination of bottleneck optimization strategies requires detailed consideration (Silva et al., 2021).

3.2.3 – Lean Manufacturing

Fundamentally, Lean Manufacturing is a set of methods that enhance operational performance through waste reduction (Slack et al., 2016). More specifically, Lean defines wastes as any Non-Value Added (NVA) within a system (Sundar et al., 2014). There are 3 causes of waste according to Lean philosophy, referred to by the terms "muda", "mura", and "muri" (Slack, 2016). "Muda" activities are wasteful because they are generally NVA activities. "Mura" refers to a lack of consistency that consequently causes an overloading of staff or machinery. “Muri” refers to the belief that requiring an unreasonable load from a process will ultimately deliver poor results (Slack, 2016). Furthermore, Lean identifies 7 main types of waste (Oliveira et al., 2019):

The 7 Types of Waste
Overproduction / Underproduction
Overprocessing
Transport
Motion
Waiting
Defects
Inventory

Table 4 – Lean’s 7 Types of Waste (Oliviera et al., 2019)

The focus on waste reduction or elimination to enhance productivity, increase quality, and minimize costs summarizes Lean’s philosophy of producing with less human effort, less machinery, less space, and less time (Oliviera et al., 2019).

The Gemba Walk

The “Gemba” Walk is a term used in Lean Manufacturing that encourages decision-makers to consistently visit the manufacturing process in order to identify waste and NVA activities (Slack, 2016). The Gemba Walk is directly related to the respective Bottleneck Walk and Go & See methods for bottleneck detection, as discussed in Subsection 3.2.1. This realization further strengthens the link between Lean philosophy and Bottleneck Analysis.

Single-Minute Exchange of Dies (SMED)

Single-Minute Exchange of Dies (SMED) is a method to reduce changeover times, where changeover time is the time between producing the last good unit of one order to producing the first good unit of the next (Karam et al., 2018). According to SMED, a changeover should take no more than a single digit-expressed time, meaning under 10 minutes (Karam et al., 2018). The major steps of SMED are as follows (Karam et al., 2018):

1- Measuring and analyzing changeover activities.
2- Splitting activities into “external” and “internal”.
3- Convert “internal” activities to “external”.
4- Standardize and practice the changeover routine.

“External” activities are ones that can be performed while the process is operating. “Internal” activities are ones that require the process to stop completely (Slack, 2016).

3.3 – Process Automation & Industry 4.0

3.3.1 – Introduction to Industry 4.0

Automation and the use of AI and Robotics in modern-day manufacturing can be summarized by the main concepts of Industry 4.0 (I4.0), also known as the Fourth Industrial Revolution. Industry 4.0 was introduced in the early 2010s with the goal of combining manual and automated operations for increased efficiency and performance (Ribeiro et al., 2021). It focuses on maintaining competitive industries through autonomy and process optimization (Walker et al., 2019). I4.0's focus on real-time data collection, automation, and human-robot interaction proved to have several benefits in terms of efficiency, productivity, safety, and sustainability. However, the implementation of I4.0 principles also poses difficult challenges to manufacturing companies. Subsection 2.3.2 will highlight both the main benefits and challenges of process automation and I4.0 implementation.

3.3.2 – Benefits & Challenges of Automation

Automation methods and strategies, such as Robotic Process Automation (RPA) offer advantages in automating operational, organizational, and business processes. The list in Table 5 provides a better understanding of the main benefits of automation and the use of AI and robotics in manufacturing:

	Benefits of Automation
1	Improved production performance, efficiency, & productivity. (Liu et al., 2022).
2	Improved accuracy & execution of tasks. (Realyvasquez-Vargas et al., 2019).
3	Improved flexibility & customization capabilities. (Walker et al., 2019).
4	Reduced repetitive tasks for operators.
5	Reduced occupational risks and hazards for operators. (Realyvasquez-Vargas et al., 2019).
6	Reduced human errors.
7	Enhanced data extraction and analysis.
8	Immediate response to production needs. (Javaid et al., 2022)
9	Implementable in smaller companies & more challenging environments. (Kopacek, 2019).

Table 5 - Benefits of Process Automation

The list above highlights a number of benefits provided by automation and robotics, as found in the literature. Going into more detail could highlight even more potential benefits, and the outlook for automation and robotics looks solid. Implementing automation and utilizing robotics also comes with a number of challenges, however, as they are both relatively recent concepts. Like the introduction of any new concept, there comes a number of challenges. In the case of automation and AI & robotics, the challenges manufacturing companies face are as follows:

	Challenges of Automation
1	Insufficient knowledge. (Walker et al., 2019).
2	Lack of previous experience.
3	Potential job displacement for uneducated workers. (Kopacek, 2019).
4	Need for highly skilled engineers. (Kopacek, 2019).
5	Operators need to program various types of robots for maximum benefit. (Emeric et al., 2020).
6	Can be expensive.

Table 6 - Challenges of Automation

The challenges identified in the list above serve as the main obstacles in implementing automation and progressing with Industry 4.0. These challenges can mostly be solved by time, however, as more and more people are educated and given knowledge about automation strategies and implementing robotics and AI in several different sectors.

3.3.3 – Implementing AI & Robotics

After understanding the main concepts, benefits, and challenges behind Industry 4.0 and automation in manufacturing, it is now crucial to understand how it is actually implemented within production processes. It is evident from the analysis of several pieces of literature that there are three common pillars for effective implementation of AI & robotics in manufacturing. The first pillar is the interaction between humans and collaborative robots (or co-bots). Co-bots are designed for direct human-robot collaboration in the workplace, improving worker safety and performing repetitive tasks (Javaid et al., 2022). They are easily programmable and can be integrated into existing workflows. They can, for example, optimize pick-and-place operations and are capable of assisting with delicate assembly tasks. Overall, they improve the performance of the whole production process. The second pillar is using machine learning to "teach" robots to perform more specific tasks. Machine learning is the process of fitting functions to data, and it enhances a robot's intelligence and adaptability (Liu et al., 2022). It can learn to imitate movement patterns of real humans, thus allowing it to perform tasks that are very specific to a certain process. Other ways of learning include value-function, actor-critic, and model-based robotic learning methods. The third and equally important pillar is the proper training of operators. Operators should receive sufficient knowledge to effectively collaborate with co-bots and program robots of various brands for maximal agility and autonomy within the process (Emeric et al., 2020). Insufficient skills from the operators can put them in great danger or at the very least, damage the robot or any of its parts. In summary, if workers can effectively collaborate with co-bots and align them to their goals, while learning how to program them to maximize their potential, the performance of the whole production process gains a significant boost.

3.4 – Key Findings from Literature Review

This section provides the definitive answers to three knowledge questions stated at the start of this chapter. The answers and theories provided in this section are fully derived from the literature reviewed throughout this chapter.

a) *What KPIs can be monitored to effectively measure and evaluate the performance of a production process?*

Literature has shown that KPIs are critical for measuring operational performance in manufacturing companies, specifically for comparing a manufacturing process's current state with its theoretical desired state (Samir et al., 2018). In order to achieve broader strategic goals, companies must select and monitor relevant operational KPIs (Schreiber et al., 2020). KPIs are the foundation of Performance Management Systems, which are used by companies to gather real-time data about processes and machines, and thus detect potential problems and bottlenecks (Schreiber et al, 2020). As such, KPI monitoring is a crucial part of Bottleneck Analysis and thus supports bottleneck optimization. There are several KPIs that are relevant in manufacturing environments (Schreiber et al., 2020), most notably:

- Quality Rate
- Availability
- Capacity Utilization
- Downtime
- Overall Equipment Effectiveness (Zhu et al., 2018)

Overall Equipment Effectiveness (OEE) is a widely used metric that measures the effectiveness and utilization of equipment (Janahi et al., 2020). OEE is computed by multiplying availability, performance, and quality ratio, and it accounts for losses in each of these variables (Esmaeel et al. 2018). Research has shown that OEE-driven process improvement successfully reduced changeover times, improved productivity, and reduced costs (Esmaeel et al. 2018). OEE is also effective in bottleneck detection, as it highlights the gap between net production time and total time (Roser et al., 2014)

b) *What are effective strategies and methods to optimize bottlenecks in a production process?*

Bottleneck optimization and process improvement first start by Bottleneck Analysis, more specifically bottleneck detection (Roser et al., 2014). By accurately defining a bottleneck and understanding a bottleneck's behavior, bottleneck detection methods are derived. The Bottleneck Walk method identifies bottlenecks by observing process states and inventory states (Roser et al., 2014). Process state observation leads to the following conclusions:

i. If the process being observed is the process waiting on another process, it is certainly NOT the bottleneck.
ii. If the process being observed is "starved" then the bottleneck is located upstream.
iii. If the process being observed is "blocked" then the bottleneck is located downstream.

Inventory state observation leads to the following conclusions:

i. If the buffer between two processes is full or congested, the bottleneck is likely downstream.
ii. If the buffer between two processes is empty, the bottleneck is likely upstream.

The Go & See approach is derived from Lean philosophy and Shopfloor Management, and it encourages bottleneck detection through accurate KPI monitoring and consistent, repeated observation of the process as it operates (Hofmann et al., 2019). OEE-based bottleneck detection is performed by analyzing the gap between net production time and total time (Roser et al., 2014).

Bottleneck optimization strategies are classified into three categories (Silva et al., 2021):

i. The "machine" category includes updating machine control policies and substituting for more advanced machines that provide better results.
ii. The "process" category refers to changing process parameters.
iii. The "production layout" category consists of adding or removing new production lines or machinery.

Lean Manufacturing is a set of methods and principles that enhance operational performance through the identification and reduction of waste (Slack et al., 2016). Lean defines waste as any Non-Value Added (NVA) activity within a system (Sundra et al. 2016) and identifies "muda", "mura", and "muri" as 3 causes of waste. There are 7 main types of waste according to Lean philosophy:

i. Overproduction / Underproduction
ii. Overprocessing
iii. Transport
iv. Motion
v. Waiting
vi. Defects
vii. Inventory

The focus on waste elimination to enhance performance and cut costs summarizes Lean's philosophy of producing at a high level with less input (Oliviera et al., 2019). Like the Bottleneck Walk and Go & See methods, the "Gemba" Walk encourages decision-makers to consistently visit the manufacturing process to identify waste (Slack, 2016). Single-Minute Exchange of Dies (SMED) is a method to reduce changeover times (Karam et al., 2018). It consists of splitting internal and external changeover activities, converting internal activities to external, and standardizing the changeover routine (Karam et al. 2018)

c) Which methods of process automation can be implemented within a production process?

Industry 4.0 focuses on real-time data collection, automation, and human-robot interaction to enhance efficiency, productivity, safety, and sustainability in manufacturing systems (Walker et al., 2019). I4.0 has a main goal of combining manual and automated operations for increased operational performance (Ribeiro et al., 2021). The use of process automation and robotics has proven to have several benefits including improved performance (Liu et al., 2022), increased flexibility (Walker et al., 2019), enhanced data extraction & analysis (Kopacek, 2019), and safer working environments (Realyvasquez-Vargas et al., 2019). However, when implementing process automation, one needs to consider its challenges, which include insufficient knowledge & experience (Walker et al, 2019), the need for highly skilled operators (Kopacek, 2019), and initial costs.

The first pillar for effective implementation of process automation is the interaction between humans and co-bots, which are designed for direct human-robot collaboration in the workplace (Javaid et al., 2022). Co-bots are easily programmable machines that can be integrated into existing workflows and handle delicate tasks. The second pillar is using machine learning, which is the process of fitting functions to data, enhancing a robot's intelligence and adaptability (Liu et al., 2022). Machine learning teaches robots to imitate humanlike movement patterns, allowing it to adapt to process-specific tasks. The third is the proper training of operators. Operators should have sufficient knowledge on collaboration with co-bots to maximize agility and autonomy within the process (Emeric et al., 2020).

Chapter 4: Analysis and Possible Interventions

Chapter 4 analyzes the problems and bottlenecks in the system and provides possible solutions for them, using the concepts learned from the literature. Section 4.1 provides the initial observations gained from early team discussions and observations. Section 4.2 highlights how the problems and bottlenecks in the production process are identified. Section 4.3 highlights the problems and bottlenecks in the system that we chose to address. It further discusses the problems and bottlenecks identified in Section 4.1, highlighting their negative effect on performance and efficiency. Finally, Section 4.4 provides interventions to the company on how to solve the system's problems and increase the overall performance of the lines.

4.1 – Key Observations from Current Situation Analysis

This section provides the initial observations gained from the current situation analysis. These findings are a result of early observations of the production process and discussions with the production team before any real data was gathered or analyzed. Sections 4.2 and 4.3 analyze some of these problems in further detail as they are a core part of this research. Appendix B contains an overview of the problems and bottlenecks that are selected to address and the ones that are not.

4.1.1 – Production Stoppages

The current production process contains several bottlenecks that negatively affect operational performance and lead to production stoppages. Initial observations of the process and team discussions identified stages in the process where congestion, blockages, and idle periods often occur. While the team is aware of some of the stages where the process underperforms, they have not conducted a full analysis of the process that identifies all bottlenecks and analyzes their effect on the process. Section 4.2 describes each bottleneck in detail and explains how it affects the production process.

4.1.2 - Equipment Degradation

The degree of degradation of the machinery on the line is the second problem observed within the current system. The production process has not been upgraded since 2008, and the production team confirms that the machines are either failing consistently or performing at a low output due to degradation. The degree of degradation or decrease in output can be calculated by measuring the discrepancy between a machine's specifications and the actual output it is providing. However, the team could not gain information on the exact specifications of the machinery and calculating the degree of degradation was not possible. Eliminating the effects of equipment degradation requires reinvesting in the machinery used on the lines, which Chapter 6 briefly discusses as part of the future recommendations provided to the company.

4.1.3 - Spare Part Availability

Spare part availability is another problem caused by the age of the machinery on the production lines. As some machinery is so outdated, their spare parts are not available on the market any longer. Currently, there are no notable instances where a machine with low spare part availability failed completely and led to an extended period of downtime. However, discussions with the team reveal that should these machines fail such that they require a replacement of spare parts, it would be highly expensive and time-consuming to repair. Chapter 6 identifies the machines that are low in spare part availability on the market.

4.1.4 – Opportunities for Automation

Further observations of the production process identify stages where process automation methods can be implemented. As the production process is outdated, it fails to utilize modern techniques of process automation, specifically through robotics and Artificial Intelligence. The two stages where process automation can be effectively applied are the Clamshell Station and Building Station. This is because the activities in these two manual stations are repetitive and could easily be automated. Furthermore, these two manual stations combine for 5 total operators required to operate them. Therefore, automating them through robotics significantly decreases the total number of operators required to operate a line. Section 4.4 includes a proposal for automating the respective Clamshell Station and Building Station.

4.2 – Identifying Problems, Bottlenecks, & Improvement Opportunities

This section includes the bottleneck identification process and highlights the methods used to identify the problems. It describes each bottleneck identified in the system.

4.2.1 – Overall Equipment Effectiveness

This section discusses the problems and bottlenecks with the current process identified by monitoring Overall Equipment Effectiveness (OEE) for a specified measurement period. OEE is calculated as a product of availability, performance, and quality (refer to Section 3.1.3). The production team measured OEE over 15 production days. The OEE measurement over the specified measurement period shows that availability has the most significant effect on the overall OEE scores. The formula for availability, as previously stated in Section 3.1.3, is as follows:

$$Availability\ (A) = \frac{Run\ Time}{Planned\ Production\ Time}$$

Where Run Time is calculated as:

$$Run\ Time = Available\ Time - (Downtime\ from\ Planned\ Stoppages + Downtime\ from\ Unplanned\ Stoppages)$$

Table 7 shows the scores on availability that the production process achieved over the 15-production day measurement period. A day corresponding to “N/A” means that no data was collected during that day, either because there was no production or because the team did not perform the measurements.

Date	Availability
Day 1	47.5%
Day 2	67.5%
Day 3	54%
Day 4	59%
Day 5	N/A
Day 6	50.5%
Day 7	83%
Day 8	83%
Day 9	82.5%
Day 10	N/A
Day 11	76%
Day 12	36%
Day 13	38.5%
Day 14	65%
Day 15	N/A
Average Availability (%)	**62%**

Table 7 – Availability of Current Process

For the entirety of the measurement period, the percentage of availability has not surpassed 83%. The average percentage of availability over said measurement period is approximately 62%. The low score in the availability component highlights how the system has a significant amount of downtime, from both planned and unplanned stoppages, relative to the total available time the system has to produce. The exact contributions of planned and unplanned stoppages, respectively, was difficult to measure. That is due to the randomness in the both the frequency and length of unplanned stoppages. Therefore, the team decided that the most applicable solution for eliminating unplanned stoppages is simply to reinvest in all outdated machinery. A full reinvestment in all the equipment used in the production process is currently not feasible, according to discussion with the team. Unplanned stoppages are thus not accurately measured by the team during this research. The next part of this subsection identifies and discusses the root causes for both planned and unplanned stoppages, respectively.

Planned & Unplanned Stoppages

This paragraph identifies and discusses the root causes of downtime due to planned stoppages. Planned stoppages occur in the system mainly due to changing over from one line configuration to another. A changeover occurs when a line requires reconfiguration from producing an order of one product type to an order of a different product type. Given the production volumes the process is normally required to output, the team runs only 2 or 3 of the 5 semi-automated lines to fulfill orders for 5 different product types. This results in a higher frequency of changeovers across the operating lines. Furthermore, the company does not plan production orders in a way that minimizes the frequency of changeovers. The system consequently faces a high frequency of stoppages due to changeovers. Note, however, that the problem does not lie in the length of a changeover, but rather in the frequency of the changeovers. While minimizing changeover length certainly can certainly have a positive effect, the team confirms that the changeover process is difficult to minimize further and are satisfied with 10- to 15-minute changeover procedure that they currently use.

This paragraph identifies and discusses the root causes of downtime due to unplanned stoppages. There are two main causes for unplanned stoppages within the system, and they are equipment failure and human errors. Equipment failure occurs as a result of the degree of equipment degradation that the equipment has faced over time. Since the equipment has not been upgraded since 2008, the significant degree of degradation results in a high frequency of stoppages due to equipment failure. Human errors occur frequently when a new team of operators is introduced. As new arrivals do not initially have enough experience operating the lines, human errors increase in the early adjustment period. Equipment failure and human errors are thus the two main causes for downtime due to unplanned stoppages. The team confirms that there are no other significant reasons for unplanned stoppages in the current production process.

Conclusions from the OEE Measurement

The OEE measurement provides insight on some problems and bottlenecks the system currently faces. The first finding is that the high frequency of changeovers is the root cause for the high frequency of planned production stoppages. Thus, it is also one of the causes for the production process's lower performance in the availability aspect of OEE. The second finding is that the failure of certain equipment is the most significant root cause for the high frequency of unplanned stoppages. Human errors are also an occasional cause for unplanned stoppages, but their effect is not significant enough to be considered in this research. Furthermore, human errors are almost eliminated when newly arrived operators pass their initial adjustment period. Therefore, the proposed interventions in Section 4.3 include a strategy to minimize changeover frequency and highlight equipment critical to re-invest in.

4.2.2 - The Bottleneck Walk

This section highlights the bottlenecks in the current process identified by the "Bottleneck Walk" detection method. The Bottleneck Walk requires managers to observe the production process systematically, specifically by observing process states and inventory states, respectively (see Section 3.2.1). In addition to the standard Bottleneck Walk, this specific observation of the production process also includes observing waste and for automation opportunities.

The Bottleneck Walk identifies the first bottleneck, located at the FHS Placement Station. At this stage, the operator's only task is to place FHS components from the palette onto the conveyor belt leading to the Building Station. The issue here is that the length of the conveyor belt between the position of the operator placing the FHS components and the Building Station is too small. As a result, the operator at the FHS Placement Station is tied to this station and must redundantly pick-and-place FHS components from palette to belt to ensure continuous flow. If the operator is away from the conveyor belt for long enough, the flow of FHS components to the Building Station is interrupted and the Building Station "starves" for FHS components. According to the Bottleneck Walk approach, when the observed process is "starved", or waiting for parts, then the bottleneck is located upstream (refer to Subsection 3.2.1). The "starved" state of the Building Station satisfies the condition that the bottleneck precedes the observed process. If the operator at the FHS Placement Station remains in place, the Building Station does not "starve", but the operator consequently cannot perform other, more value-added activities such as helping in the Building Station or assisting in quality checks. Having the operator stand in place for a full production period to perform one task is a non-value added (NVA) activity, especially considering that this stage could easily be automated. Eliminating NVA activities is a crucial principle in Lean philosophy (refer to Section 3.2.3).

The Bottleneck Walk identifies the second bottleneck at the DistiBox Label Printer. An observation of the state of the buffer preceding the DistiBox Label Printer identifies this bottleneck. According to the Bottleneck Walk method, if the buffer between two processes, in this case the DistiBox closer and DistiBox Label Printer, is congested or full, then the bottleneck is located downstream (refer to Section 3.2.2). This means that the bottleneck is located in the direction of the DistiBox Label Printer, and as the last station on the production line, it is inevitable that it is itself the bottleneck. The congestion at this stage happens because the rate at which the printer performs cannot keep up with the speed of the earlier stages in the process. This has recently become a problem when Hi Tech Co. increased the required label printing resolution to 600 DPI, while the current printers are designed to print effectively at 300 DPI. DPI stands for dots per inch, and it is a measure of print quality that refers to the number of dots a printer can produce per inch of printed output. To print with 600 DPI resolution, the printer takes significantly longer to process one DistiBox. The output per minute for the DistiBox Label Printer is included in Table 8. As more boxes keep entering this station, the conveyor belt leading to the DistiBox Label Printer becomes so congested that boxes start falling off the belt. To combat this, the operator at this station picks up the DistiBoxes that fall off and places them on a palette. Once the order is completed, all the remaining boxes are removed from the palette and placed back on the conveyor belt to be labelled. The 3 activities concerning the removal of boxes from the congested conveyor, placing them on a palette, and replacing them for (re)processing are all NVA activities that should be eliminated according to Lean Philosophy (refer to Section 3.2.3). They are examples of overprocessing waste that needs to be eliminated.

4.2.3 – Measuring Output per Part/Stage

Section 3.2.1 identifies two definitions this research uses for a bottleneck. The first defines a bottleneck of a production line as a function that limits the output of the overall system. The second defines a bottleneck on the shop floor as the machine or station with the lowest production rate compared to other machines or stations in the system. Thus, this section highlights the bottlenecks identified by measuring the output of individual stages and equipment on the production line. Real-time measurements, discussions with experts, and, in the case of the Folded Carton Erector and Folded Carton Closer, the statistics displayed on the machine's interface identify the output of each part on a line. Table 8 shows the output per minute for each station on a line:

Part / Stage	Output
Folded Carton Erector	21 units / minute
Building Station	36 units / minute
Folded Carton Closer	28 units / minute
Matching Camera	28 units / minute
Inpakker Station	37.5 units / minute
DistiBox Closer	6 DistiBoxes / minute 30 units / minute
DistiBox Label Printer	4.2 DistiBoxes / minute 21 units / minute

Table 8 - Output per Stage/Part

Table 8 shows that the machines with the two lowest outputs are the Folded Carton Erector and the DistiBox Label Printer, both equally standing at 21 units per minute. Thus, by definition, they are bottlenecks within the system, as they both limit the output of the overall system and have the lowest production rate in comparison to other machines in the system.

4.2.4 – Identification through Direct Observations and Team Discussions

This section highlights one additional issue with the current production process that was identified through consistent observations of the production process and discussions with the production team. The production team identifies an opportunity to automate two of the three manual stations in the current production process, namely the Clamshell Station and Building Station. The current processes at the Clamshell Station and the Building Station, respectively, are repetitive and can easily be automated to increase accuracy and decrease headcount.

This section identified the main problems and bottlenecks within the system and highlighted the different methods that were used to acquire them. Section 4.3 discusses which of these problems and bottlenecks this research addresses and states the motivation behind each selection.

4.3 – Choice of Problems & Bottlenecks to Address

This section highlights which of the problems and bottlenecks identified in Section 4.2 that this research chooses to address. Furthermore, it briefly explains why this research includes these specific problems & bottlenecks and excludes the remaining issues. Appendix B contains an overview on which problems were selected and which were not. The overview includes how the problem was identified and the reasoning behind why it was or was not selected.

4.3.1 – Changeover Frequency

Changeover frequency is the first problem this research chooses to address. The reasoning here is that one of the main ways to minimize the frequency of production stoppages, specifically planned stoppages, is by minimizing the frequency of changeovers. This holds true for the case of Arvato, as changeovers cannot be performed while the process is still running, and thus the frequency of changeovers and the frequency of planned production stoppages are positively correlated. Though the Clamshell Station and Building Station can operate while a changeover is in progress, the number of units they can output during the changeover period is minimal and does not significantly affect the performance or overall output of the system. Therefore, this research addresses the high frequency of changeovers by proposing a new strategy for production that minimizes changeover frequency in Section 4.3.

This research does not select changeover length as a problem to address. The reasoning here is that an average of 10 to 15 minutes to complete a changeover is reasonable considering the age of the equipment and the degree to which they degraded over time. This was reassured through the discussions had with the team that included several experts on the production process and its problems. Furthermore, to address the length of a changeover, one would have to consider the mechanical processes involved in the reconfiguration of the machinery, which is beyond the scope of this research. For the reasons mentioned in this paragraph, the research does not consider a strategy for minimizing changeover length and subsequently does not use tools, such as SMED (refer to Subsection 3.2.3), to shorten changeover length.

Furthermore, this research does not address the frequency of unplanned stoppages, as their occurrence and length is too arbitrary to conduct a proper analysis. Furthermore, the main solution for unplanned stoppages is simply to upgrade the machinery with modern equipment, which is not a broad enough topic to conduct this thesis on. The way unplanned stoppages can be significantly minimized is by reinvesting in all outdated machinery, which is a topic briefly discussed later in Chapter 6.

4.3.2 – DistiBox Label Printer

The research also chooses to address the bottleneck at the DistiBox Label Printer. The motivation for selecting this bottleneck is that it limits the capacity of a production line due to its significantly low output. From the numbers stated in Table 8 (Section 4.1.3), the output of the printer is 21 units per minute. Given 8 hours of available production time in a single production day and excluding planned and unplanned downtime, the maximum capacity is thus *10,080 units per day for a single semi-automated line* or *50,400 units per day for the 5 semi-automated lines*. This result also means that under the same conditions, the current production process can output up to *252,000 total units per week*, given 5 production days per week. Remember that this capacity is sufficient to meet current production requirements, and the production team does not face a problem with capacity. The main problem is that the production process is inefficient and that stoppages occur at a high frequency. The congestion caused by the low output of the DistiBox Label Printer is one of the reasons for the high frequency in production stoppages. This is because the production team either has to stop the process completely until the congestion is dealt with or remove some of the boxes on the conveyor belt to decrease the long buffer preceding the label printer. The boxes removed in the latter case are placed back on the conveyor belt when the order is complete. For the reasons aforementioned in this paragraph, the DistiBox Label Printer is deemed the most critical piece of equipment to reinvest in.

The Folded Carton Erector has a similar output to the DistiBox Label Printer, at 21 units per minute, and therefore it is also considered one of the bottlenecks in the system. However, it is not selected as one of the main bottlenecks that this research addresses. The reason is because the team has already formulated a strategy to compensate for the low output. The first part of the strategy entails running the Folded Carton Erector at times where no units are being produced, specifically during team breaks. Given that there are two 30-minute breaks in a single production day, the Folded Carton Erector can run for up to 60 additional minutes. At 21 units per minute, this means that the Folded Carton Erector outputs up to 1,260 additional folded cartons per line in two 30-minute breaks. The second part of the strategy involves manually folding cartons using the 3 manual lines. However, the number of manually folded carton that the 3 manual lines can produce depends on how busy the manual lines are during that day. For the aforementioned reasons, the Folded Carton Erector was not selected as one the bottlenecks this research addresses. This decision is further solidified through discussions with expert members of the production team, who ensure that the Folded Carton Erector is not presently one of the major bottlenecks in the process. The Folded Carton Erector does not cause a significant negative impact on the performance or capacity of the production process given the current production requirements and the company's strategy for dealing with its low output.

4.3.3 – FHS Placement Station

In addition to the higher frequency of changeovers and the bottleneck at the DistiBox Label Printer, this research also chooses to address the bottleneck identified at the FHS Placement Station. While the bottleneck can theoretically be solved by simply fixing the operator's position at the FHS Placement Station, it negatively affects the operator's physical wellbeing as a tradeoff. This is because the operator stands for a long time picking and placing FHS components from the palette to the belt. Also, the operator must constantly get lower to pick up FHS components from the palette as it is progressively emptied. Over several hours in a single production day and several working days during the week, some of which are consecutive, the task at this stage becomes significantly demanding on the operator's physical health. Furthermore, fixing the operator in position to repeatedly perform such a redundant task with minimal contribution to the final product is considered a non-value added (NVA) activity. Therefore, the bottleneck at the FHS Placement Station is selected not only for its effect on the production line's performance, but also to ensure the physical well-being of all individuals operating the production process and to further eliminate wastes and NVA activities.

4.3.4 – Clamshell Station & Building Station

Finally, this research addresses the opportunity for automating the Clamshell Station and Building Station. This is done by proposing a strategy to convert the manual Clamshell Station and Building Station into one integrated, fully automated station. The motivation behind this is that the tasks of the Clamshell Station and Building Station are repetitive and automating these stations reduces the headcount required to operate a single semi-automated production line. Another reason is to gain the benefits that come with implementing process automation in (part of) a production process, which are discussed in Section 3.3.2. These include eliminating human errors, improving the accuracy of the production process, and real-time data collection.

4.4 – Possible Interventions

This section proposes interventions to aid in solving the system's problems and optimizing its bottlenecks, using the knowledge gained from the literature. Section 4.4.1 proposes an alternative layout to the production facility and a new production planning strategy that addresses changeover frequency. Section 4.4.2 addresses the bottleneck at the DistiBox Label Printer and how upgrading the printers increases the overall capacity of the production process. Section 4.4.3 highlights process automation methods that can be implemented in the production process to further increase its degree of automation and enhance operational performance.

4.4.1 – Minimizing Changeover Frequency

A changeover occurs when a production line requires reconfiguration from producing one product type to another. As mentioned in Section 4.1.3, changeovers are the main cause for planned stoppages, and thus have a significant negative effect on availability. The problem here is not with the time a changeover takes, but rather with the frequency of changeovers during a production day. A high frequency of changeovers results in a high frequency of production stoppages, which is the main problem addressed by this research. Therefore, the rest of Section 4.4.1 proposes a strategy for minimizing changeover frequency, using a more efficient layout and improved production planning. The first part of the strategy entails decreasing the number of semi-automated lines from 3 to 5, as 5 lines is more than the company needs to meet current production requirements. The second part of the strategy entails planning orders in a way that minimizes the frequency of changeovers on a line.

Changing the Layout

The first part of the strategy proposes using 3 lines to fulfill production requirements instead of the current 5 lines. The reason behind this is that the company already meets recent production requirements using only 2 or 3 lines per week. As highlighted in Subsection 4.3.2, the output of one line is *10,080 units per day*, and thus using 3 lines outputs around *30,240 units per day*, *151,200 units per week* or approximately *1,814,400 units per quarter.* This is sufficient to meet current production requirements, which Table 1 highlights earlier in Chapter 2. Therefore, the first step in this proposal is to remove lines 2 and 4, and operate the process through lines 1, 3, and 5. This method falls under the "production layout" category of bottleneck reduction, which consists of adding or removing new production lines (Refer to Section 3.2.2). The second step is assigning each production line to two product types at most. Given that there are 3 desktop product types and 2 mobile product types, the proposal is to assign Line 1 to one desktop product, Line 3 to the two remaining desktop products, and Line 5 to both mobile products. Understanding the reasoning behind this set-up starts by observing Table 1 from Section 2.2.5, which includes the forecasted production volumes for second, third, and fourth quarters of 2023.

Product Type	Expected for Q2	Expected for Q3	Expected for Q4	Total
Desktop 1	304,600	490,900	540,300	1,335,800
Desktop 2	97,700	125,900	117,00	340,300
Desktop 3	11,000	16,600	24,900	52,500
Mobile 1	126,100	128,100	50,400	304,600
Mobile 2	2,200	500	0	2,700
Total	541,600	762,000	732,600	**2,035,900**

Table 1 (from Section 2.2.5) - Forecasted Production Volumes

Table 1 highlights the following key points about the production volumes for each product type:

i. Desktop products account for 84.9% of total forecasted volumes, with product type D1 alone accounting for around 65.6% of total forecasted volumes.
ii. From the total forecasted volumes for all Desktop products, type D1 accounts for 77.3% of the total, type D2 accounts for 19.7%, and type D3 accounts for 3%.
iii. From the total forecasted volumes for all Mobile products, type M1 accounts for 99.1% of the total while type M2 accounts for only 0.9% of the total.
iv. To meet the forecasted production volumes for each of Quarters 2, 3, and 4, the process has to produce per week the number of units highlighted in Table 11:

Product Type	Units/Week for Q2	Units/Week for Q3	Units/Week for Q4
Desktop 1	25,500	41,000	45,500
Desktop 2	8,200	10,500	9,750
Desktop 3	920	1,400	2,100
Mobile 1	10,500	10,675	4,200
Mobile 2	185	45	0

Table 9 - Units/Week/Quarter for each Product Type

It is important to note the aforementioned key points in deciding which product types to assign to which lines. The proposal is to set-up the 3 semi-automated lines as follows:

i. Line 1 is assigned to Desktop product type D1.
ii. Line 3 is assigned to the remaining Desktop product types D2 and D3.
iii. Line 5 is assigned to both Mobile product types M1 & M2.

With product type D1 accounting for 65.6% of total forecasted volumes, it is reasonable to assign one whole line to it. As there are no other product types on this line, Line 1 can produce D1 product types at its maximum capacity of 50,400 units per week. Note, however, that this is an upper limit of Line 1's capacity, as in practice, unplanned stoppages further reduce the line's capacity. While Line 1's set-up eliminates its need for changeovers, it is still prone to unplanned stoppages. Chapter 5 discusses the effect of unplanned stoppages on the performance of the production process under this new set-up.

Lines 3 and 5 are both assigned to two product types each. Line 3 produces the two remaining Desktop product types D2 and D3. If Line 3's output is divided equally between both product types, it can produce at a rate of 25,200 units per week for each product type. In practice, however, the team is freely able to alter how much of the line's output to dedicate to each of the product types. From the forecasted production volumes highlighted in Table 1, observe that the total volumes across quarters 2, 3, and 4 for products D2 and D3 combine for around 392,800 units, where around 86.6% is from D2 products only. Therefore, a more reasonable split is to commit 85% of Line 3's capacity to type D2 and 15% to Type D3. The theoretical outputs now change to around *42,850 units per week* for product D2 and *7,550 units per week* for product D3. With this strategy, Line 3 is able to output at least 3x the forecasted volumes for each of product types D2 and D3. These numbers are also upper limits of Line 3's capacity, as planned and unplanned stoppages will both affect these numbers. Planned stoppages in this case are due to changeovers. A later part of this section discusses a strategy for production planning that minimizes changeover frequency on Line 3.

Line 5 is assigned to producing product types M1 and M2. The case of products M1 and M2 is different from products D2 and D3 on Line 3, however. This is because the forecasted volumes for M2 products are low and account for less than 1% of mobile products. Furthermore, the team forecasts that no M2 products will be produced at all. As such, Line 5 is configured to produce M1 products, and a changeover only occurs when an order of M2 products is received. The rest of Line 5's capacity is assigned to supporting any potential capacity deficiencies that Lines 1 and 3 could face. This proposal entails committing around 65% of Line 5's capacity to product M1, 30% to support potential capacity deficiencies, and the remaining 5% to product M2. With this strategy Line 5 can output around 32,750 units per week and 2,520 units per week for product M2. The remaining capacity is dedicated to supporting any potential capacity deficiencies from Lines 1 or 3, capable of outputting up to *15,000 extra units per week* to support Lines 1 and 3. In practice, Line 1 is the most likely to require additional support, especially considering unplanned stoppages and any increase to product D1 demand.

With this strategy, the changeover problem is partially addressed by eliminating changeovers on Line 1. To make this proposal effective, the team must coordinate production planning to minimize changeover frequency for Lines 3 and 5.

Production Planning

Production planning at Arvato is set up so orders are processed daily. Therefore, the production planning strategy discussed here will also be per day, as it aligns with the current way of working between Arvato and the customer. To minimize changeover frequency, the proposal entails setting up production planning in a way that limits changeovers to 1 or 2 per day. This can be done by combining partial orders into one large order or eliminating partial orders entirely. The result of this is that a line continues to work one product type for a longer consecutive period. There are three scenarios that can occur during a single production day, all with different effects on changeover frequency. The first scenario starts with producing product type A at the start of a production day. The operating line does not changeover to product type B, if at all required, until all product type A units for the day are produced. If the line does changeover to product type B, it starts the next day by producing product type B. It only changes back over to product type A when all product type B units are produced, and so forth. This scenario assures that the line goes through only one changeover per day. This can be true for both Lines 3 and 5.

The second scenario also starts with producing product type A on a production day. Similarly, the line does not changeover to product type B until all product A units for that day are completed. However, the line is constrained to start the next day producing product type A. Thus, should a changeover from A to B occur, the line is required to change back over again from product type to B to type A at the end of the production day. In this scenario, there are two changeovers required in a single production day. This can also be true for lines 3 and 5.

The third and final scenario can only be true for Line 5, which is assigned to produce Mobile product types M1 and M2 and handle overflowing units from other lines. Overflowing units most likely come from Line 1 as it is the line that operates nearest to its full capacity. The occurrence of such a scenario is quite rare considering the extremely low forecasted volumes for product type M2. In this rare case, Line 5 is required during the same production day to produce both M1 and M2 products and support a capacity deficiency from Line 1. Line 3's capacity is self-sufficient, and it is highly unlikely that it will need further support from Line 5. Line 1, on the other hand, is more likely to require additional capacity support on production days where D1 production volumes reach extreme heights. In this scenario, Line 5 starts the day producing one of the two Mobile products, for example M1. Like the first two scenarios, the proposal is to change over from M1 to M2 only when all M1 products for that day are completed. Similarly, the line only changes from M2 products to D1 products only when all M2 products for that day are complete. So far, the team has performed 3 changeovers on this line in total. A fourth changeover can also occur if the line is required to start the next day producing a different product. In this scenario, Line 5 performs 3 to 4 changeovers during the production day. Note, however, that the occurrence of such a scenario is highly unlikely and can happen on only a few days per quarter. It will require smart planning to get through such a scenario efficiently, but it is highly unlikely that the team will face capacity issues in such an occurrence.

These three scenarios describe situations that the production process can be in when planning production daily. Note, however, that if production planning is done weekly instead of daily, changeover frequency can be reduced further. This is because under a weekly production planning, the company can produce all required units of a product type during a week and change over once to produce the units of the other product type. In this case, the three changeover scenarios mentioned in the three previous paragraphs occur per week rather than per day. Still, we only consider daily production planning in this research as it fits the current way of working between Arvato and its customer.

Best Case vs Worst Case

The information in the previous paragraph allows us to formulate best and worst-case scenarios, respectively, for a production day. Both cases assume that all product types are produced daily. Case #1, the best case, would be as follows:

- Line 1 self-sufficiently produces type D1 products in a continuous manner, with 0 changeovers.
- Line 3 produces one of D2 or D3 first, changeover occurs 1 time, then completes the orders for the other product type. The line starts the next day producing the same product type it finished the first day with.
- Line 5 produces one of M1 or M2 first, changeover occurs 1 time like Line 3, then completes the orders for the other product type. This line also starts the following day producing the same product type it finished the first day with.

In Case #1, Line 1 faces no planned stoppage downtime, Line 3 faces 10 minutes on planned stoppage downtime, and Line 5 also faces 10 minutes of planned stoppage downtime in a single production day.

Case #2, the least optimal case would look like the following:

- Line 1 produces type D1 but is incapable of doing so self-sufficiently as production volumes for D1 are extremely high.
- Line 3 starts by producing one of D2 or D3 first, a changeover occurs the first time, then completes the order for the other type. At the end of the day, the line changes back over to the initial product type configuration. Line 3 in this case performs 2 total changeovers.
- Line 3 starts by producing one of M1 or M2 first, a changeover occurs the first time, then completes the order for the other type. When both M1 and M2 product type orders are complete, the line changes over to producing product type D1 to support Line 1's capacity deficiency. At the end of the day, the line changes back over to the initial product type configuration. Line 5 in this case performs 4 total changeovers.

In Case #2, Line 1 faces no planned stoppage downtime, Line 3 faces 20 minutes of planned stoppage downtime, and Line 5 faces 40 minutes of planned stoppage downtime in a single production day. The two cases mentioned above describe, in theory, the best and worst possible circumstances for a single production day, assuming that all product types are produced daily. In practice, it can be true that NOT all product types are produced daily, which results in less daily changeovers. Chapter 5 discusses the impact that this intervention, consisting of the layout change and the improved production planning strategy, has on the theoretical performance of the production process.

Proposed Layout

Figure 5 visually represents how the production process would look like if lines 2 and 4 were removed. It is a similar illustration to the one in Section 2.1 (Figure 3) but focused solely on the production area (right side).

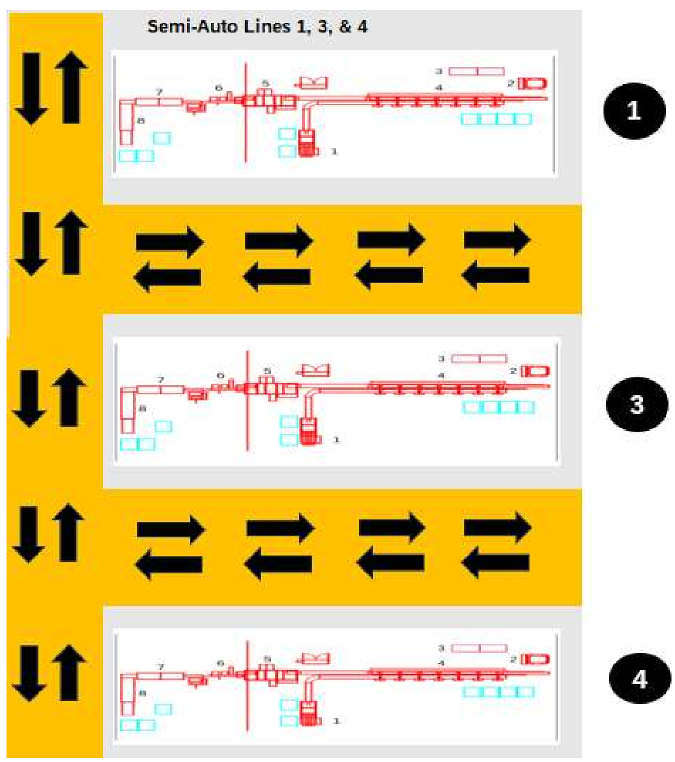

Figure 5 - Proposed Layout of Facility

The next section addresses the DistiBox Label Printer and how upgrading it significantly impacts the capacity of the production process.

4.2.2 – Increasing Capacity

This section discusses how upgrading the DistiBox Label Printer significantly affects the capacity of the production process. Re-investing in the printer is an essential step in optimizing the production process, as the output of the whole process inevitably depends on it. It is the most crucial piece of equipment on the line to reinvest in.

DistiBox Label Printer

By referring to Table 8 in Subsection 4.1.2, we see that the DistiBox Label Printer and the Folded Carton Erector both have the lowest output, equal to *21 units per minute*. Recall, however, the team already has a strategy set up to compensate for the low output of the Folded Carton Erector. The strategy is to run the Folded Carton Erector for a period of time before an order starts and during breaks, such that boxes are pre-folded ahead of the start of production. As previously established in subsection 4.2.2, a single Folded Carton Erector can produce up to 1,260 additional folded cartons per day given that it keeps running in the two 30-minute breaks. With 5 lines, this amounts to up to 6,300 additional folded cartons per day. If Intervention #1 is implemented, then with 3 lines, it amounts to up to 3,780 additional folded cartons per day. Furthermore, manual lines are assigned to pre-fold cartons in days when they are less busy or completely free. The team thus keeps a stock of pre-folded cartos that mitigates the low output of the Folded Carton Erector. The team thus confirms that the Folded Carton Erector's output of 21 units per minute is a significant underestimation of the actual number of folded cartons being processed per minute.

Replacing the current printer with a new one falls under the "machine" category of bottleneck optimization methods, which includes altering machine control policies or upgrading existing machinery (refer to Subsection 3.2.2). If the printer is upgraded such that it at least matches the machine or station with the second lowest output, it should be able to output 28 units per minute. Increasing the printer's capacity from 21 units per minute to 28 units per minute is a potential 33% increase in a single line's capacity, barring unplanned stoppages. Chapter 5 further analyzes the impact of upgrading the DistiBox Label Printer.

4.2.3 – Applying Process Automation

There are several stages of the current production process in which process automation methods can be applied to enhance operational performance and efficiency. This subsection will identify the stages of the process where process automation can be applied, highlighting how process automation can optimize the bottleneck at the FHS Placement Station.

FHS Placement Station

The first stage at which process automation can be applied is at the FHS Placement Station. At this stage, the operator's only task is to pick FHS components from a palette and place it onto the conveyor belt. As a result of the low capacity of the belt, the operator must remain in place to avoid "starving" the following stage, which is the Building Station. This means the operator cannot perform other value-added tasks on the production line and must remain fixed at the FHS Placement Station. Not only is this task considered an NVA activity, but it is also redundant and physically demanding for the operator.

The proposed solution for this bottleneck is applying robotic process automation, specifically through a pick-and-place robot. The only task required of the robot is to pick the FHS components and place them onto the conveyor belt. The use of a pick-and-place robot at this stage will eliminate the need for an operator to remain fixed in that position. The robot will also be able to respond instantly to production needs (refer to Section 3.3.2), so if the Building Station requires more components, the robot can instantly supply it with more. On the other hand, if too much work is being processed at the Building Station or if it gets congested or “blocked”, the robot will abstain from placing more FHS components on the belt until the process runs smoothly again.

Clam-shelling Station & Building Station

The second and third stages in which robotic process automation can be applied are the Clam- shelling Station and the Building Station. The Clam-shelling station is where the CPU units are placed in a plastic clamshell to protect them from damage. The Building Station is where the CPU units, FHS components, and instruction manuals are assembled into packages. The functions of both the Clam- shelling Station and the Building station can easily be programmed into a robot through machine learning, which teaches the robot to imitate humanlike movement patterns (refer to Subsection 3.3.3).

The recommendation here is to combine the separate tasks of the Clam-shelling Station and the Building Station into one, integrated Assembly Station. In the current production process, the Building Station is dependent on the Clam-shelling Station supplying CPU units in plastic clamshells, but the respective functions of the two stations are separate. The proposed strategy entails removing the Clam-shelling Station completely and placing three tables in place of the Building Station, perpendicular to the conveyor belt. Each table contains two machine learning processes performed by two robots. The first machine learning process is the Clam-shelling process, entailing the placement of CPU units into plastic clamshells. The second machine learning process is the Building process, assembling CPU units, FHS components, and instruction manuals into folded cartons. The proposed Assembly Station then operates as follows: two boxes are placed at the start of the table (opposite side to the conveyor belt), one containing the unprotected CPU units and one containing empty plastic clamshells. A third empty box is placed in the middle of the table, between the two machine learning processes, where the protected CPU units will be placed after the Clam-shelling process. A fourth box containing the instruction manuals will also be placed in the middle between both robots. The first machine learning process starts, in which the first robot picks a CPU unit, installs it into a plastic clamshell, and then places the protected clamshell into the empty box in the middle. As the first process continues, the second robot initiates the second machine learning process by first picking up an FHS component from the bottom conveyor belt. After that, the second robot picks a protected CPU unit and an instruction manual from the two boxes in the middle and installs them into their designated slots in the carboard box containing the FHS component. When the CPU unit and instruction manual are installed in place, the robot picks up a folded carton from the top conveyor belt, places the assembled CPU unit, FHS component, & instruction manual into the folded carton, and sets the finished package back onto the conveyor belt. The two machine learning processes repeat until the box containing unprotected CPUs is empty. When the boxes containing the unprotected CPU units and instruction manuals are emptied, it either means that the order is complete or that the empty boxes need to be replaced with full boxes.

Chapter 5: Impact Analysis and Feasibility

Chapter 5 analyzes the potential impact the proposed interventions have on the production process' performance. Section 5.1 discusses first the effects of each intervention individually, then proposes a combination of the proposed interventions that leads to the best results. Section 5.2 discusses the feasibility of each intervention according to Arvato.

5.1 – Impact of Proposed Interventions

This section analyzes the proposed interventions' impact on the process's performance. It highlights each intervention's effect on the system's KPIs. Furthermore, it highlights how the proposed interventions align the production process to the core concepts of bottleneck reduction and Lean Philosophy. The end of this section describes the effects of these interventions should the company choose to combine them.

5.1.1 – Intervention #1 Impact

Intervention #1 consists of changing the layout of the production process such that it operates through 3 lines and implementing a strategy for production planning that aims to minimize changeover frequency (refer to Section 4.3.1). The rest of this section discusses each of the benefits that this intervention provides.

Increased Availability

Improving the availability of the production process is the first benefit that intervention #1 provides. This is due to implementing an improved production planning strategy and decreasing the variety of product types that each of the 3 lines is required to produce. Section 4.3.1 highlighted two cases, one consisting of the most optimal conditions the process could potentially operate under and the other highlighting the least optimal conditions. The effect on availability in both cases, respectively, is the first topic of analysis in this section. Furthermore, the end of this section discusses how unplanned stoppages affect the results of this intervention.

In Case #1, Line 1 faces no planned stoppage downtime, Line 3 faces 10 minutes on planned stoppage downtime, and Line 5 also faces 10 minutes of planned stoppage downtime in a single production day. Recall the formula for production highlighted in Section 4.2.1. Assume that *x, y,* and *z* equal the downtime in minutes due to unplanned stoppage for each of Line 1, Line 3, and Line 5, respectively. The availability formula for each of Lines 1, 3, and 5 looks as follows:

$$Line\ 1 = \frac{480 - (0 + x)}{480} * 100\%$$

$$Line\ 3 = \frac{480 - (10 + y)}{480} * 100\%$$

$$Line\ 3 = \frac{480 - (10 + z)}{480} * 100\%$$

If we assume that $x = y = z = 0$, then the availability for Line 1 is 100%, for Line 3 is 98%, and for Line 5 is also 98%. Since the 3 lines work independently, and the (temporary) failure of one line does not result in the failure of the other two, the availability of the whole production process is the average of the three lines' respective availability scores. In Case #1, the theoretical availability of the production process is (100% + 98% + 98%) / 3 = 98.7%. In practice, the availability of the production process will be lower due to unplanned stoppages.

In Case #2, Line 1 faces no planned stoppage downtime, Line 3 faces 20 minutes of planned stoppage downtime, and Line 5 faces 40 minutes of planned stoppage downtime in a single production day. We again refer to the availability formula, where x refers to downtime in minutes from unplanned stoppages. The availability formula for each of Lines 1, 3, and 5 in this case looks as follows:

$$Line\ 1 = \frac{480 - (0 + x)}{480} * 100\%$$

$$Line\ 3 = \frac{480 - (20 + y)}{480} * 100\%$$

$$Line\ 5 = \frac{480 - (40 + z)}{480} * 100\%$$

Assuming that $x = y = z = 0$ yields the following results for availability on each line: Line 1 availability is at 100%, Line 2 at 96%, and Line 3 at 91.5%. The availability for the overall production process is thus (100% + 96% + 91.5%) / 3 = 95.8%. Like Case #1, the availability of the production process will be lower in practice due to unplanned stoppages.

Effect of Unplanned Stoppages on Availability

Assuming no unplanned stoppages, the availability of the process is, on average, between 95.8% and 98.7%. In practice, however, the actual availability of the process is heavily influenced by unplanned stoppages. Therefore, we first calculate the maximum amount of downtime due to unplanned stoppages that the proposed process can handle such that it maintains a higher percentage of availability than the current production process does. For the average availability of the production process under Intervention #1 to decrease to that of the current process, the average of the individual availability scores of each line should equal 62% (refer to Section 4.1.1). To simplify the calculation, assume that each of the individual lines is available only 62% of the time thus yielding an average of 62% for the whole production process. We also assume that all 3 lines are operating during that day. Consider first Case #1, where Line 1 faces no planned stoppage downtime and Lines 3 and 5 both face 10 minutes of planned stoppage downtime, respectively, in a single production day. Let x be Line 1's unplanned downtime in minutes, y be Line 3's unplanned downtime, and z be Line 5's unplanned downtime. The formulas for availability will thus look as follows:

$$Line\ 1 = \frac{480-(0+x)}{480} * 100\% = 62\% \rightarrow x = 182.4$$

$$Line\ 3 = \frac{480-(10+y)}{480} * 100\% = 62\% \rightarrow y = 172.4$$

$$Line\ 5 = \frac{480-(10+z)}{480} * 100\% = 62\% \rightarrow z = 172.4$$

The results of *x = 182.4* and *y = z = 172.4* minutes of downtime due to unplanned stoppages implies the following: under Case #1, Line 1's availability is greater than 62% if it does no changeovers and has less than 182.4 minutes of unplanned downtime. Line 3's availability is greater than 62% if it does 1 changeover and has less than 172.4 minutes of unplanned downtime. Line 5's availability is greater than 62% if it does 1 changeover and has less than 172.4 minutes of unplanned downtime. If unplanned downtime for each line is kept below the values of *x, y,* and *z* during a production day*,* the production process's availability will be greater than 62% in Case #1. Thus, the average availability of the newly proposed process will be greater than the current process. Note that it could still be greater than 62% if the availability of a certain line is high enough to compensate for the low availability of another. However, if one line underperforms such that its availability is less than 62%, that is in itself a problem. Thus, the goal is for unplanned downtime to be less than *x, y,* and *z* for each line. Now consider Case #2, where Line 1 faces no planned stoppage downtime, Line 3 faces 20 minutes of planned stoppage downtime, and Line 5 faces 40 minutes of planned stoppage downtime in a single production day:

$$Line\ 1 = \frac{480-(0+x)}{480} * 100\% = 62\% \rightarrow x = 182.4$$

$$Line\ 3 = \frac{480-(20+y)}{480} * 100\% = 62\% \rightarrow y = 162.4$$

$$Line\ 5 = \frac{480-(40+z)}{480} * 100\% = 62\% \rightarrow z = 142.4$$

The results of *x = 182.4*, *y = 162.4*, and *z = 142.4* minutes of downtime due to unplanned stoppages implies the following: under Case #2 Line 1's availability is always greater than 62% if it does no changeovers and has less than 182.4 minutes of unplanned downtime. Line 3's availability is always greater than 62% if it does 2 changeovers and has less than 162.4 minutes of unplanned downtime. Line 5's availability is always greater than 62% if it does 4 changeovers and has less than 142.4 minutes of unplanned downtime. Similar to Case #1, the goal is to keep unplanned downtime below these values of *x, y,* and *z* for each line such that the newly proposed process performs better in availability than the current process.

Increased Spacing

This strategy also increases the spacing between each line in the production process. This allows operators and forklifts to move freely between each line. Under the current process, forklift can only reach the starting point of a production line through 2 paths: either around all 5 production lines from the northern side of the production area or around all the lines from the southern side (see Figure 2 for clarification). Under the new setup the forklifts now have 4 paths to reach the starting point by adding two lanes, one between Lines 1 & 3 and one between Lines 3 & 5, a 100% increase. As a result, forklifts now have shorter paths to deliver materials to the production lines. This increase in spacing eliminates two types of waste identified by Lean Philosophy, which are transportation and motion, respectively. The shorter routes eliminate the wasted distance a forklift is required to drive to reach a certain point on a production line, thus minimizing transportation waste. As such, the operators driving the forklifts exert less overall effort and physical motion to navigate their vehicles through shorter routes, eliminating motion waste.

Reduced Costs

Cost reduction is another benefit of implementing this proposal. This is because maintenance and operation costs, respectively, to operate the production process with 5 lines are higher than to operate it with 3 lines. If we assume that each of the 5 lines costs Arvato the same amount to maintain and operate, then the maintenance and operation costs for the whole production process decrease by up to 40%. Furthermore, the spare parts from the scrapped lines can be kept in stock should the remaining the 3 lines ever require them.

5.1.2 – Intervention #2 Impact

Intervention #2 addresses the bottleneck at the DistiBox Label Printer. It consists of upgrading the DistiBox Label Printer such that it outputs at least as much as the station with the second lowest output, which is the Folded Carton Closer at 28 units per minute. This provides several benefits to the performance of the process.

Increased Capacity

Section 4.3.2 establishes how the output of the line is dependent on the capacity of the DistiBox Label Printer, given that it has the lowest output out of all the stations. This is especially true when excluding the output of the Folded Carton Erector, given that the team already applies a strategy that feeds the process enough pre-folded cartons. As such, upgrading the DistiBox Label Printer such that it outputs at least 28 units per minute results in a 33% increase in a single line's capacity. With the current layout using 5 lines, this increases the production process's capacity from *252,000 units per week* to *335,160 units per week*. If the company decides to implement Intervention #1 and use only 3 lines to operate the process, the capacity is then around *201,000 units per week.* In practice, the output of the lines will be lower than these numbers due to changeovers or failure of other pieces of equipment.

Decreased Stoppage Frequency

Intervention #2 also decreases the frequency of unplanned stoppages that occur within the process. This is because replacing the current printers with printers yielding a faster printing rate eliminates the congestion that occurs at the DistiBox Label Printer. As such, the preceding station, the DistiBox Closer is not "blocked" and, therefore, there will be no need to stop the process to deal with congestion related to DistiBox Label Printer. The exact reduction in production stoppage frequency is difficult to assess but given that the DistiBox Label Printer is confirmed by the team to be a significant cause for unplanned stoppages, upgrading it will in turn lead to lower frequency of stoppages.

Eliminated Waste

Waste elimination is the final benefit from this intervention. With the current printers, the team assigns an operator to remove the DistiBoxes that fall off the conveyor belt due to congestion and place them on a palette. The operator proceeds to placing these remaining DistiBoxes back on the belt when the order is complete. These activities are examples of NVA activities and result in overprocessing waste, according to Lean Philosophy. These activities are also considered motion waste, as the operator performs extra movements and exerts physical activity to perform them. Upgrading the printer such that it performs at a sufficiently higher rate will eliminate the congestion that causes DistiBoxes to fall off the conveyor belt. This in turn removes the need for an operator to perform these NVA activities and eliminates the overprocessing and motion wastes that result from dealing with the overflow of DistiBoxes.

5.1.3 – Intervention #3 Impact

Intervention #3 proposes a way to automate the FHS Placement Station, Clamshell Station, and Building Station, respectively, using robotics. The intervention suggests the use of a pick-and-place robot at the FHS Placement Station with the sole task of picking FHS components from a palette and placing them one-by-one on the conveyor belt. For the Clamshell Station and Building Station, the intervention proposes a way to integrate and automate each station's tasks into one Assembly Station, also through robotics and a simple machine learning procedure.

Bottleneck Optimization

Applying Intervention #3 solves the bottleneck at the FHS Placement Station. The use of a robot at this station eliminates the need for an operator to remain in this position redundantly picking and placing FHS components from a palette onto the belt. This means that either the operator is free to perform other VA activities in the production process, or headcount decreases by one. Furthermore, applying this change eliminates motion waste, as defined by Lean philosophy (refer to Subsection 3.2.3). This is because using a robot eliminates the entire motion that the operator performs when picking and placing FHS components from the palette onto the conveyor belt.

Reduced Human Errors and Headcount

The use of robots to automate the Clamshell Station and Building Station eliminates the chances of human errors occurring at these stations. This in turn minimizes the frequency of unplanned stoppages related to human errors. If combined with Intervention #2, where production stoppages related to the DistiBox Label Printer are addressed, unplanned stoppages are minimized further. Additionally, applying process automation decreases the headcount required to operate a single line. Currently, it requires 8 operators to operate one semi-automated production line. If the FHS Placement Station, Clamshell Station, and Building Station are all automated, the number of operators required to run one production line is reduced to 2, which is a 75% reduction from the current situation. The two remaining operators are at the Inpakker Station and the quality check at the end of the line. If all operators running the production lines cost the company the same amount, the 75% reduction in headcount results in a 75% reduction in labor costs for running the production lines. This specifically refers to the operators directly required to run the lines. Labor costs related to other teams essential to the full process, such as the operations management department or logistics team, are not included in this reduction.

Upgraded Process Flowchart

Intervention #3 alters the process flowchart by removing the activities of the Clamshell Station and Building Station and replacing them with a single "Assembly Station" stage. Appendix C.2 contains the upgraded process flowchart after applying process automation to the FHS Placement Station, Clamshell Station, and Building Station. The changes made from the current process flowchart in Appendix C.1 and the upgraded process flowchart in Appendix C.2 are highlighted in yellow on the upgraded flowchart.

5.2 - Feasibility of Proposed Interventions

This section analyzes how feasible it is for Arvato to implement each of the proposed interventions. The idea was to discuss with the team how feasible and how expensive implementing each intervention would be. Cost refers to the expenses associated with implementing the intervention, such as removal costs or costs of upgrading to new machinery and equipment. Feasibility refers to the applicability of each intervention from a strategic point of view. More specifically, it is a measure of how much each intervention aligns with the customer's requirements. A more feasible intervention requires minimal to no training from employees to work and is implemented without significantly altering Arvato's current way of working with its customer. Furthermore, a less expensive intervention also adds to the feasibility of it. A less feasible intervention, on the other hand, requires specific training or hiring technical specialists to implement it and the team must renegotiate certain agreements with its customer. Furthermore, it provides its benefits at a higher cost compared to the other interventions.

Both cost and feasibility will be scored from 1 to 5. A score of 1 in cost refers to the lower end of costs, while a score of 5 refers to the highest end. Similarly, a score of 1 in feasibility refers to the highest degree of difficulty to implement the intervention while a score of 5 refers to the lowest degree of difficulty. It is decided through discussions with the team that feasibility is slightly more important than costs when considering an intervention. The reasoning here is that a more expensive intervention can be invested in if it is expected to provide significant benefits according to the company. A more expensive intervention can also be invested in if it provides its benefits with minimal negotiation with the customer. Therefore, it is decided to weigh cost with a factor of 0.75 and feasibility with a factor of 0.25. The total score is then calculated as [(Cost * 0.25) + (Feasibility * 0.75)], where the final score for each intervention is out of 5 maximum points. The decision was to score each of the interventions on cost and feasibility as follows:

	Cost	Feasibility	Total
Intervention #1	*1*	*4*	*3.25*
Intervention #2	*2*	*5*	*4.25*
Intervention #3	*4*	*2*	*2.5*

Table 10 - Cost and Feasibility

As per Table 12, Intervention #1 turns out to be the cheapest intervention, as it only entails the removal costs for scrapping the two lines. Furthermore, the spare parts from the scrapped lines can optionally be sold to compensate for the costs of removal. The second cheapest is Intervention #2, which entails only upgrading the DistiBox Label Printer on each line. This intervention would be even cheaper if combined with Intervention #1, as in that case only 3 printers will require purchasing and not 5. Finally, the most expensive intervention is #3, as it includes purchasing robotic equipment and programming machine learning techniques into them. This intervention incurs the highest costs as robotic equipment is expensive, and so are the specialists that will be hired to program them. However, it is also cheaper to implement it in combination with Intervention #1. Table 12 also scores each intervention in terms of overall feasibility. The most feasible intervention turned out to be Intervention #2, upgrading the DistiBox Label Printer. Despite it being slightly more expensive than Intervention #1, it requires much less planning and negotiating with the customer. Still, Intervention #1 is highly feasible with a score of 4. It does require negotiating with the customer on a production planning strategy that minimizes costs as well as the process of removing two production lines, and it is thus slightly less feasible than Intervention #2. The least feasible intervention is Intervention #3, due to the excessive costs that come with implementing and testing it. Furthermore, it will require training from operators to learn how to maintain them or reprogram them if needed.

The total scores for the respective interventions are, from greatest to least, 4.25 for Intervention #2, 3.25 for Intervention #1, and 2.5 for Intervention #3. The next part of this section discusses the most optimal solution for Arvato, considering the proposed interventions.

Optimal Solution

With the information from Table 12, it is safe to assume that the optimal solution for Arvato would be to implement a combination of Intervention #1 and Intervention #2. Combining these two interventions is inexpensive compared to the benefits that they provide. The benefits of combining these two solutions are as follows:

1) Increase to the availability KPI of the production process:

The average availability of the production process increases as the frequency of changeovers and stoppages decreases. Section 5.1.1 establishes that the newly proposed production process from Intervention #1 scores around 95.8% and 98.7% for availability, on average, assuming no unplanned stoppages. Section 5.1.1 also establishes that if the sum of downtime due to unplanned stoppages from all 3 lines does not exceed 487.2 minutes in a single production day, the newly proposed production process will always score higher on availability than the current production process. This is true assuming all 3 lines are working on that day. Furthermore, upgrading the DistiBox Label Printer, as Intervention #2 states, eliminates unplanned downtime related to the DistiBox Label Printer. This also increases availability as it decreases total unplanned stoppage downtime.

2) Increase in the spacing between each production line:

Combining Interventions #1 and #2 increases the spacing between each semi-automated production line, thus providing more paths for forklifts to navigate around the production area. With the layout of the current production process using 5 lines, there are only two paths in the production area for a forklift to reach the easternmost side of the area, which is where the starting points of each line are located. These 2 paths are either around all 5 production lines from the northern side or around all 5 lines from the southern side (see Figure 2 for a visual representation). Changing the layout of the facility as Intervention #1 states adds two more paths for forklifts to navigate around the production area, specifically a lane between Lines 1 & 3 and Lines 3 & 5, which is a 100% increase from the current process.

3) Increase in the capacity of each individual production line:

Upgrading the DistiBox Label Printer as Intervention #2 states increases the capacity of a single production line by up to 33%. As it is combined with Intervention #1, it increases the production process's capacity using 3 lines from *151,200 units per week* to *201,000 units per week*. This further ensures that the capacity of the production process using 3 lines still fulfills demand requirements.

4) Reduction in setup and maintenance costs:

This solution also reduces maintenance and set-up costs for the production lines. If we assume that each of the 5 lines costs Arvato the same amount to maintain and operate, then the maintenance and operation costs for the whole production process decrease by up to 40%. Furthermore, a new DistiBox Label Printer is less likely to fail or breakdown than the current one being used. Thus, there is also a reduction in maintenance costs from upgrading the DistiBox Label Printer.

5) Reduction in wastes identified by Lean Philosophy:

Combining Interventions #1 and #2 reduces several wastes defined by Lean Philosophy, including overprocessing, transportation, and motion. Overprocessing waste is minimized as Intervention #2 eliminates the NVA activities related to fixing the DistiBox Label Printer problem. Transportation waste is minimized as Intervention #1 shortens the distances a forklift needs to travel to navigate around the production process and increases the number of paths a forklift can take to reach certain points around the production area. Motion waste is eliminated in two ways. First, is by eliminating the motion required by an operator to drive a forklift for longer distances to reach its destinations. Second, is by eliminating the motion involved with fixing the congestion at the DistiBox Label Printer.

Finally, this solution aligns well with the company's goals and resources. As Intervention #3 is expensive and not as feasible as the other two interventions, it is up to the company whether implementing it would still be necessary after analyzing the benefits of applying Interventions #1 and #2 only. Intervention #3, nevertheless yields benefits of its own, such as a reduction in human errors, a reduction in labor costs, and the optimization of the bottleneck at the FHS Placement Station.

Chapter 6: Conclusions, Recommendations, & Limitations

This chapter is the concluding chapter of this report. Section 6.1 provides answers to the knowledge questions solved throughout this research. Section 6.2 provides the company with further recommendations to improve the production process.

6.1 – Conclusions

This section includes the answers to each of the knowledge questions solved throughout this research. For each knowledge question, there are smaller sub-questions that help simplify it. The answers to these knowledge questions formulate the final answer to the main research question this research aims to solve.

"How is the packaging process designed and what is the current situation at the company?"

The "design" of the production process in this case refers to the current layout of the process and its stages. The answers to the following questions describe the current situation at Arvato by discussing its layout, its stages, the production volumes it normally produces, and the product types that are produced.

a) What is the current layout of the facility?

The facility is divided into a production area and a logistics area (called the warehouse), located on opposite sides of the facility. The production area includes a space for 5 semi-automated lines and a space for 3 manual lines. Figure 2 in Section 2.1 is a visual representation of the current layout of the facility. The focus throughout this research is on the production area, specifically on the 5 semi-automated production lines.

b) What are the stages of the current semi-automated production process?

There are 8 total stages in the production process. These stations are the Folded Carton Erector, the FHS Placement Station, the Clamshell Station, the Building Station, the Folded Carton Closer and Label Printer, the Inpakker Station, the DistiBox Closer, and the DistiBox Label Printer. The goal of the production process is to assemble different components of the customer's products into a single package. The headcount required to operate one semi-automated line is 8 operators. Section 2.2.1 includes a visual representation of one semi-automated production line (Figure 3) and a detailed description of the tasks performed in each of the 8 stages. Section 2.2.2 includes process flowcharts for each of the Clamshell Station, Building Station, and Inpakker Station. Section 2.2.3 includes the process flowchart for the full production process.

c) What product types are the lines required to produce?

The 2 categories of products that the company produces are Desktop CPU products and Mobile CPU products. There are 3 Desktop product types, type D1, type D2, and type D3. There are 2 Mobile product types, type M1 and type M2. Each product type requires a different configuration of the line to be produced, and thus the line performs a changeover to switch from producing one product type to the other. A typical changeover takes around 10 minutes if all its steps are performed correctly.

d) What are the recent production volumes for the semi-automated lines?

With the way production planning is currently set up in Arvato, the planning of orders for a single production day is done at the start of that same day. A typical order size consists of 1100 units, but the team also processes orders of less than 1100 units called partial orders. Table 1 in Section 2.2.5 includes the forecasted production volumes for each product type for Quarters 2, 3, and 4 of 2023. Table 2 in Section 2.2.5 includes the actual production volumes measured over 14 weeks covering May, June, and

July. It is confirmed through several discussions with the team that, given the recent production volumes, the company is able to fulfill orders with the current capacity of the semi-automated production process.

"What literature is required to formulate possible interventions for the problems with the current process?"

A literature review is required to formulate possible interventions for the current production process's problems. The topics covered by the literature review are KPI selection and measurement, bottleneck optimization methods, and process automation.

a) According to the literature, what KPIs can be monitored to effectively measure and evaluate the performance of a production process?

KPIs are critical for measuring operational performance in manufacturing companies. There are several KPIS relevant in manufacturing environments, including but not limited to quality rate, availability, capacity utilization, downtime, and OEE. OEE is computed by multiplying availability, performance, and quality ratio, and it accounts for losses in each of these variables. OEE-driven process improvement reduces changeover times, improves productivity, reduces costs, and is effective in bottleneck detection.

b) What are effective strategies and methods to optimize the bottlenecks in a production process?

Bottleneck optimization and process improvement start by bottleneck detection. The Bottleneck Walk method identifies bottlenecks by observing process states and inventory states. It identifies the direction of a bottleneck by observing whether a certain process is "starved" or "blocked". The Go & See approach encourages bottleneck detection through accurate KPI monitoring and consistent, repeated observation of the process as it operates. Bottleneck optimization strategies are classified into three categories. The "machine" category includes updating machine control policies and substituting for more advanced machines that provide better results. The "process" category refers to changing process parameters. The "production layout" category consists of adding or removing new production lines or machinery. Lean Manufacturing is a set of methods and principles that enhance operational performance through the identification and reduction of waste. The focus on waste elimination to enhance performance and cut costs summarizes Lean's philosophy of producing at a high level with less input. Like the Bottleneck Walk and Go & See methods, the "Gemba" Walk encourages decision-makers to consistently visit the manufacturing process to identify waste. Single-Minute Exchange of Dies (SMED) is a method to reduce changeover times. It consists of splitting internal and external changeover activities, converting internal activities to external, and standardizing the changeover routine.

c) Which methods of process automation can be implemented within a production process?

The use of process automation and robotics has proven to have several benefits including improved performance, increased flexibility, enhanced data extraction & analysis, and safer working environments. Co-bots are easily programmable machines that can be integrated into existing workflows and handle delicate tasks. Machine learning teaches robots to imitate humanlike movement patterns, allowing it to adapt to process-specific tasks.

"What are possible interventions for the problems within the current process?"

The current situation analysis and literature review allow us to formulate possible intervention for the problems within the process. The first step is to analyze the problems and bottlenecks within the system and understand how they affect performance. The next step is to generate interventions that address the problems and bottlenecks selected.

a) What are the system's main problems & bottlenecks and how are they identified?

This research highlights several problems and bottlenecks that exist within the current production process at Arvato. The high frequency of changeovers, the FHS Placement Station, and the DistiBox Label Printer are the problems and bottlenecks selected to solve through this research. An OEE measurement over a 15-production day measurement period highlights the changeover problem within the production process. The OEE measurement shows that the production process's low scores in availability has the most negative effect on OEE. Changeovers are the main cause for planned stoppages in the production process, and thus it was selected as a problem to address with this research. Section 4.2.1 states the effects that changeovers have on the performance of the process and includes a table (Table 7) with the daily availability scores over the 15-day measurement period. The Bottleneck Walk identifies the bottleneck at the FHS Placement Station. The operator at the FHS Placement Station is tied to this station and must redundantly pick-and-place FHS components from palette to belt to ensure continuous flow. Having the operator stand in place for a full production period to perform one task is a non-value added (NVA) activity. The Bottleneck Walk and a measurement of the output per minute for each machine highlights the bottleneck at the DistiBox Label Printer. Using both of these bottleneck identification methods shows that the low output of the DistiBox Label Printer blocks units from entering it from the preceding station. The output per minute for the DistiBox Label Printer is also the lowest of all other machines and thus limits the capacity of a production line. This research also highlights an opportunity to automate the Clamshell Station and Building Station and proposes a method to do so. Automating the tasks performed in the Clamshell Station and Building Station relieves operators from performing repetitive tasks and provides an opportunity to gain the benefits of process automation. It also decreases the headcount required to operate a single line and thus reduces labor costs. Appendix B contains a table that highlights the problems and bottlenecks selected to solve with this research and states the reasoning behind selecting them (Table 13). Appendix B also contains a table that highlights the rest of the problems and bottlenecks in the production process and states why they were not selected (Table 14).

b) How can the production process be redesigned to increase its efficiency and performance?

Intervention #1 consists of changing the layout of the production process such that it operates through 3 lines and implementing a strategy for production planning that aims to minimize changeover frequency. The first part of the intervention proposes removing lines 2 and 4 and operating the process through lines 1, 3, and 5. The second step is assigning each production line to two product types at most, specifically to assign Line 1 to one desktop product, Line 3 to the two remaining desktop products, and Line 5 to both mobile products. Line 1 is assigned to product type D1 as it accounts for 65.6% of total forecasted volumes across Quarters 2, 3, and 4. Line 3 is assigned to types D2 and D3, where 85% of its capacity is for D2 products and 15% is for D3 products. Line 5 is assigned to types M1 and M2, where 65% of its capacity is for M1 products, 5% is for M2 products, and 30% to compensate for any capacity deficiencies from the remaining two lines. This eliminates the changeover problem for Line 1.

To solve the changeover problem for Line 3 and 5, the team incorporates a newly proposed production planning strategy that minimizes changeover frequency. There are three scenarios that can occur during a production day with the new production planning strategy. The first scenario starts with producing product type A at the start of a production day where the line does not changeover to product type B until all product type A units for the day are produced. If the line does changeover to product type B, it starts the next day by producing product type B. This scenario is applicable for Line 3 and 5, and they both perform one changeover each in this case. The second scenario also starts with producing product type A on a production day. The line does not changeover to product type B until all product A units for that day are completed. However, the line is constrained to start the next day producing product type and is required to change back over again from product type to B to type A at the end of the production day. This scenario is also applicable for both Lines 3 and 5, where each line performs 2 changeovers each. The final scenario is only applicable for Line 5. In this scenario, Line 5 is required during the same production day to produce both M1 and M2 products and support a capacity deficiency from Line 1. It starts the day producing one of the two Mobile products. Like the first two scenarios, the proposal is to change over from Mobile product A to Mobile product B only when all product A units for that day are completed. Similarly, the line only changes from Mobile product B to producing D1 products only when all product B products for that day are complete. A fourth changeover can also occur if the line is required to start the next day producing a different product. In this scenario, Line 5 performs 3 to 4 changeovers during the production day. Section 4.4.1 highlights the best- and worst-case scenarios the process can face during a single production day. In the best-case scenario, Line 1 faces no planned stoppage downtime, Line 3 faces 10 minutes on planned stoppage downtime, and Line 5 also faces 10 minutes of planned stoppage downtime in a single production day. In the worst-case scenario, Line 1 still faces no planned stoppage downtime, but Line 3 faces 20 minutes of planned stoppage downtime, and Line 5 faces 40 minutes of planned stoppage downtime in a single production day.

c) *Which pieces of equipment are crucial to re-invest in?*

Intervention #2 proposes upgrading the DistiBox Label Printer such that it outputs at least as much as the station with the second lowest output, which is the Folded Carton Closer at 28 units per minute. The DistiBox Label Printer is deemed the most critical piece of equipment to invest in on the semi-automated production line. This is because the capacity of one line depends on the output of the DistiBox Label Printer as it has the lowest output of all machines on a production line. Increasing the printer's capacity from 21 units per minute to 28 units per minute is a potential 33% increase in a single line's capacity, barring unplanned stoppages. The Folded Carton Erector is another machine that was considered to upgrade. However, it is confirmed that the team already has a strategy to compensate for the lower output of the Folded Carton Erector, and thus it was not considered when formulating interventions.

d) *How can process automation be implemented within the production process to improve its performance?*

Intervention #3 proposes the use of a pick-and-place robot in place of the operator at the FHS Placement station. The only task required of the robot is to pick the FHS components and place them onto the conveyor belt. The use of a pick-and-place robot at this stage will eliminate the need for an operator to remain fixed in that position. The robot will also be able to respond instantly to production needs, so if the Building Station requires more components, the robot can instantly supply it with more. On the other hand, if too much work is being processed at the Building Station or if it gets congested or "blocked", the

Intervention #3 also proposes a strategy to integrate the tasks of the Clamshell Station and Building station into one Assembly Station. The proposed strategy entails removing the Clam-shelling Station completely and placing three tables in place of the Building Station, perpendicular to the conveyor belt. Each table contains two machine learning processes performing two machine learning processes. The first machine learning process is the clam-shelling process, entailing the placement of CPU units into plastic clamshells. The second machine learning process is the Building process, assembling CPU units, FHS components, and instruction manuals into packages. Section 4.2.3 describes the exact steps of both machine learning processes and how the robots collaborate together to assemble different components of a product into on package. The two machine learning processes repeat until the box containing unprotected CPUs is empty. When the boxes containing the unprotected CPU units and instruction manuals are emptied, it either means that the order is complete or that the empty boxes need to be replaced with full boxes.

"Which of the proposed interventions are best to implement for Arvato?"

The step after formulating possible interventions to address the problems with the current production process is deciding which if these interventions is best to implement. First is an analysis on the effects of each intervention on the performance of the production process. Afterwards, the team discusses which interventions are best to implement by assessing the cost and feasibility of each.

a) What are the effects of each proposed intervention on the performance of the production process?

Intervention #1 consists of changing the layout of the production process such that it operates through 3 lines and implementing a strategy for production planning that minimizes changeover frequency. The first benefit this intervention provides is an increase in the availability KPI. Barring unplanned stoppages, the production process proposed in this intervention can average between 95.8% and 98.7% depending on the number of changeovers each line performs per day. If unplanned downtime on Line 1 is less than 182.4 minutes, on Line 3 is less than 162.4 minutes, and on Line 5 is less than 142.4 minutes in one production day, than the availability of the full process is greater than 62%, which is the average availability percentage of the current process. This is assuming that the proposed production planning strategy is applied such that it minimizes the frequency of changeovers on each line. This is also assuming that changeovers take around 10 minutes to complete. Intervention #1 also increases the spacing between each line, allowing forklifts and operators to move freely around the process. It increases the number of paths a forklift coming from the logistics area can take from just 2 to 4, a 100% increase. This is because Lines 2 and 4 are removed, thus forming one lane between Lines 1 and 3 and another between Lines 3 and 5. Finally, Intervention #1 decreases maintenance and operation costs. If we assume that each of the 5 lines costs Arvato the same to maintain and operate, then the maintenance and operation costs for the whole production process decrease by up to 40%.

Intervention #2 consists of upgrading the DistiBox Label Printer. The first benefit this provides is an increase in capacity. As the capacity of each line increases by up to 33%, the production process is able to output 335,160 units instead of 252,000 units per week with 5 lines, or 201,000 units instead of 151,200 units per week with 3 lines. Intervention #2 also decreases the frequency of unplanned stoppages that occur within the process, as replacing the current printers with printers yielding a faster printing rate eliminates the congestion that occurs at the DistiBox Label Printer. The exact reduction in production stoppage frequency is difficult to assess but given that the DistiBox Label Printer is confirmed by the team to be a significant cause for unplanned stoppages, upgrading it will in turn lead to lower frequency of stoppages. Finally, Intervention #2 minimizes motion and overprocessing wastes as it eliminates the NVA activities that an operator performs to place overflowing DistiBoxes back onto the conveyor belt.

Intervention #3 proposes a way to automate the FHS placement station, Clamshell Station, and Building Station, respectively, using robotics. The intervention suggests the use of a pick-and-place robot at the FHS Placement Station and a method to automate the Clamshell Station and Building Station. The first benefit is that the use of a robot at this FHS Placement Station eliminates the need for an operator to remain in this position redundantly picking and placing FHS components from a palette onto the belt. This means that the operator is free to perform other VA activities in the production process. This also eliminates motion waste as the movements performed by the operator at this stage are eliminated. As such, this intervention addresses the bottleneck at the FHS Placement Station. Intervention #3 also decreases human errors as the chances of human errors occurring are eliminated in 2 stations. Additionally, it decrease the headcount required to operate a single line from 8 to 2, a 75% reduction.

b) How expensive is it to implement the proposed interventions?
c) How feasible are the proposed interventions?

To understand both how expensive and how feasible each intervention is, the team scored each intervention from 1 to 5 on both cost and feasibility, respectively. As feasibility is more important to the team than cost a total score is calculated for each intervention as [(Cost * 0.25) + (Feasibility * 0.75)], where the final score for each intervention is out of 5 points. Intervention #1 scored 5 on cost and 4 on feasibility for a total score of 4.25. Intervention #2 scored 4 on cost and 5 on feasibility for a total score of 4.75. Intervention #3 scored 2 on cost and 2 on feasibility for a total score of 2. With these scores, it is safe to suggest that the most optimal solution for Arvato would be to implement a combination of Intervention #1 and Intervention #2. Section 5.2 discusses in detail the effects of combining both solutions.

6.2 – Recommendations

This section includes recommendations for the company to consider to further improve the production process. The first recommendation for Arvato is to consider re-investing in the remaining machinery on the lines that are not addressed by this research. This research addresses the problems within the production process based on the resources and amount of investment that Arvato is willing to put in. However, it is still highly recommended to upgrade the machinery on the lines as soon as the company has the means to do so. This ensures the sustainability of the line over a longer run and is sure to have a positive effect on the performance of the production process.

The second recommendation for Arvato is to implement a more advanced Performance Measurement System to collect real-time data and predict problems before their occurrence. The KPIs currently being tracked by the production team are too basic to fully reflect the performance of the production process. Furthermore, data on the current performance of the process had to be gathered manually to gain information on the state of the production process. Tracking more operational KPIs provides the production team a more complete understanding on the strengths and weaknesses of the process.

6.3 – Limitations

This section includes some limitations that were met throughout this research. First is the limited availability of data that is important for this research. Data on several of the machines and stations within the production process had to be gathered manually by the researcher. Furthermore, access to several pieces of potentially important data was difficult to gain.

The second limitation is the quality of the data that had been collected manually. The accuracy of said data would have been higher if it was displayed in an interface on the machine or in a sensor that tracks its output. Tracking output manually, especially for manual stations which heavily depended on the performance of the operator themselves, might have slightly affected the accuracy of the data collected.

References:

1. Schreiber, M., Schutte, C. S. L., Braunreuther, S., & Reinhart, G. (2020). *A performance measurement system for integrated production and Maintenance Planning.* Procedia CIRP. Retrieved from: https://www.sciencedirect.com/science/article/perfroamncemeasuermentsystem

2. Thiede, S. (2023). *Advanced energy data analytics to predict machine overall equipment effectiveness (OEE): a synergetic approach to foster sustainable manufacturing.* Procedia CIRP. Retrieved from: https://www.sciencedirect.com/science/article/predictmachineoee

3. Janahi, R.A., Wan, H., Lee, Y., & Zarreh, A. (2020). *Effectiveness and fitness of production line to meet customer demand*. Procedia Manufacturing. Retrieved from: https://www.sciencedirect.com/science/article/effectivenessofproductionline

4. Samir, K., Khabbazi, M.R., Maffei, A., & Onori, M.A. (2018). *Key Performance Indicators in Cyber-Physical Production Systems.* Procedia CIRP. Retrieved from: https://www.sciencedirect.com/science/article/kpisincyberphysicalsystems

5. Zhu, L., Johnsson, C., Varisco, M., & Schiraldi, M.M. (2018). *Key performance indicators for manufacturing operations management – gap analysis between process industrial needs and ISO 22400 standard.* Procedia Manufacturing. Retrieved at: https://www.sciencedirect.com/science/article/kpisformanufacturingopmanagement

6. Esmaeel, R.I., Zakuan, N., Jamal, N.M., & Taherdoost, H. (2018). *Understanding of business performance from the perspective of manufacturing strategies: fit manufacturing and overall equipment effectiveness.* Procedia Manufacturing. Retrieved at: https://www.sciencedirect.com/science/article/fitmanufacturingoee

7. Roser, C., Lorentzen, K., & Desue, J. (2014). *Reliable Shop Floor Bottleneck Detection for Flow Lines through Process and Inventory Observations.* Procedia CIRP. Retrieved at: https://www.sciencedirect.com/science/article/shopfloorbottleneckdetection

8. Hofmann, C., Staehr, T., Cohen, S., Stricker, N., Haefner, B., & Lanza, G. (2019). *Augmented Go & See: An approach for improved bottleneck identification in production lines.* Procedia Manufacturing. Retrieved at: https://www.sciencedirect.com/science/article/augmentedgo&see

9. Mahmoodi, E., Fathi, M., & Ghobakhloo, M. (2022). *The impact of Industry 4.0 on bottleneck analysis in production and manufacturing: Current trends and future perspectives.* Computers & Industrial Engineering. Retrieved at: https://www.sciencedirect.com/science/article/industry4onbottleneckanalysis

10. Silva, V.S., Thomitzek, M., Abraham, T., & Herrmann, C. (2021). *Bottleneck reduction strategies for energy efficiency in the battery manufacturing.* Procedia CIRP. Retrieved at: https://www.sciencedirect.com/science/article/bottleneckreduction

11. Slack, N. et al. (2016). *Ch. 15: Lean Operations.* Operations Management (8th ed.). Pearson Education Ltd. Edinburgh Gate, UK.

12. Sundar R., Balaji, A.N., & Kumar, R.M.S. (2014). *A Review on Lean Manufacturing Implementation Techniques.* Procedia Engineering. Retrieved at: https://www.sciencedirect.com/science/article/pii/leanmanufacturingimplementation

13. Oliveira, M.S., Moreira, H.D.A., & Ferreira, L.P. (2019). *Using Lean Thinking Principles To Reduce Wastes In Reconfiguration Of Car Radio Final Assembly Lines.* Procedia Manufacturing. Retrieved at: https://www.sciencedirect.com/science/article/wastereductionlean

14. Karam, A., Liviu, M., Cristina, V., & Radu, H. (2018). *The contribution of lean manufacturing tools to changeover time decrease in the pharmaceutical industry. A SMED project.* Procedia Manufacturing. Available at: https://www.sciencedirect.com/science/article/SMED

15. Ribeiro, J. *et al.* (2021) *Robotic Process Automation and artificial intelligence in industry 4.0 – A literature review*, *Procedia Computer Science*. Available at: https://www.sciencedirect.com/science/article/Industry4

16. Kopacek, P.(2019) *Trends in production automation*. IFAC-PapersOnLine. Available at: https://www.sciencedirect.com/trendsinautomation

17. Walker, J., Childe, S. and Wang, Y. (2019) *Analysing manufacturing enterprises to identify opportunities for automation and guide implementation - A review*. IFAC-PapersOnLine. Available at: https://www.sciencedirect.com/manufacturingenterprises

18. Liu, Z. et al. (2022). *Robot learning towards smart robotic manufacturing: A Review.* Robotics and Computer-Integrated Manufacturing. Available at: https://www.sciencedirect.com/science/robotlearning

19. Realyvasquez-Vargas, A. et al. (2018). *Introduction and configuration of a collaborative robot in an assembly task as a means to decrease occupational risks and increase efficiency in a manufacturing company*. Robotics and Computer-Integrated Manufacturing. Available at: https://www.sciencedirect.com/science/collaborativerobots

20. Emeric, C., Geoffroy, D. and Paul-Eric, D. (2020). *Development of a new robotic programming support system for operators*. Procedia Manufacturing. Available at: https://www.sciencedirect.com/roboticsupportsystem

21. Javaid, M. (2022). *Significant applications of Cobots in the field of manufacturing*. Cognitive Robotics. Available at: https://www.sciencedirect.com/applicationsofcobots

Appendix A

Appendix A.1 – Problems Selected

Problem	Method(s) of Identification	Reasoning
Changeovers	OEE Measurement	The high frequency of changeovers result in a high frequency of production stoppages. Changeovers are also one of the main causes for planned stoppages within the process.
FHS Placement Station	Bottleneck Walk	The way the FHS Placement Station is currently operated places stress on the operator and poses a potential danger to their health. Furthermore, it is a redundant task that adds minimal value to the process.
DistiBox Label Printer	Bottleneck Walk Measuring Output per Part	The DistiBox Label Printer outputs the lowest units per minute of all the machines on the line. Its output limits the capacity of the production process and is one of the main causes for the higher frequency of stoppages.
Opportunities for Automation	Direct Observations	Automating The Clamshell Station and Building Station relieves operators from performing repetitive tasks and provides several benefits in terms of operational performance and cost-efficiency.

Table 11 - Problems Selected

Appendix A.2 – Problems Not Selected

Problem	Method(s) of Identification	Reasoning
Unplanned Stoppages	OEE measurement	Unplanned stoppages occur mainly due to machine failures ad human errors. The issue of machine failure is too narrow a topic to discuss in this report, and its solution lies in investing in new machinery. This research does address human errors by suggesting a method to automate certain stations using robotics.
Folded Carton Erector	Measuring Output per Part	The Folded Carton Erector has the lowest output of all machines in the process other than the DistiBox Label Printer. However, the team already has a strategy to compensate for its low output by letting the Folded Carton Erector run in breaks and by using the manual stations, whenever possible, to produce pre-folded cartons for the semi-automated production process.
Spare Part Availability	Direct Observation Team Discussions	Spare part availability is another problem with the current production process, as certain machinery have no available spare parts on the market. However, similar to the problem with unplanned stoppages, addressing the issue of spare part availability lies simply in investing in new machinery.

Table 12 - Problems Not Selected

Appendix B

Appendix B.1– Current Process Flowchart

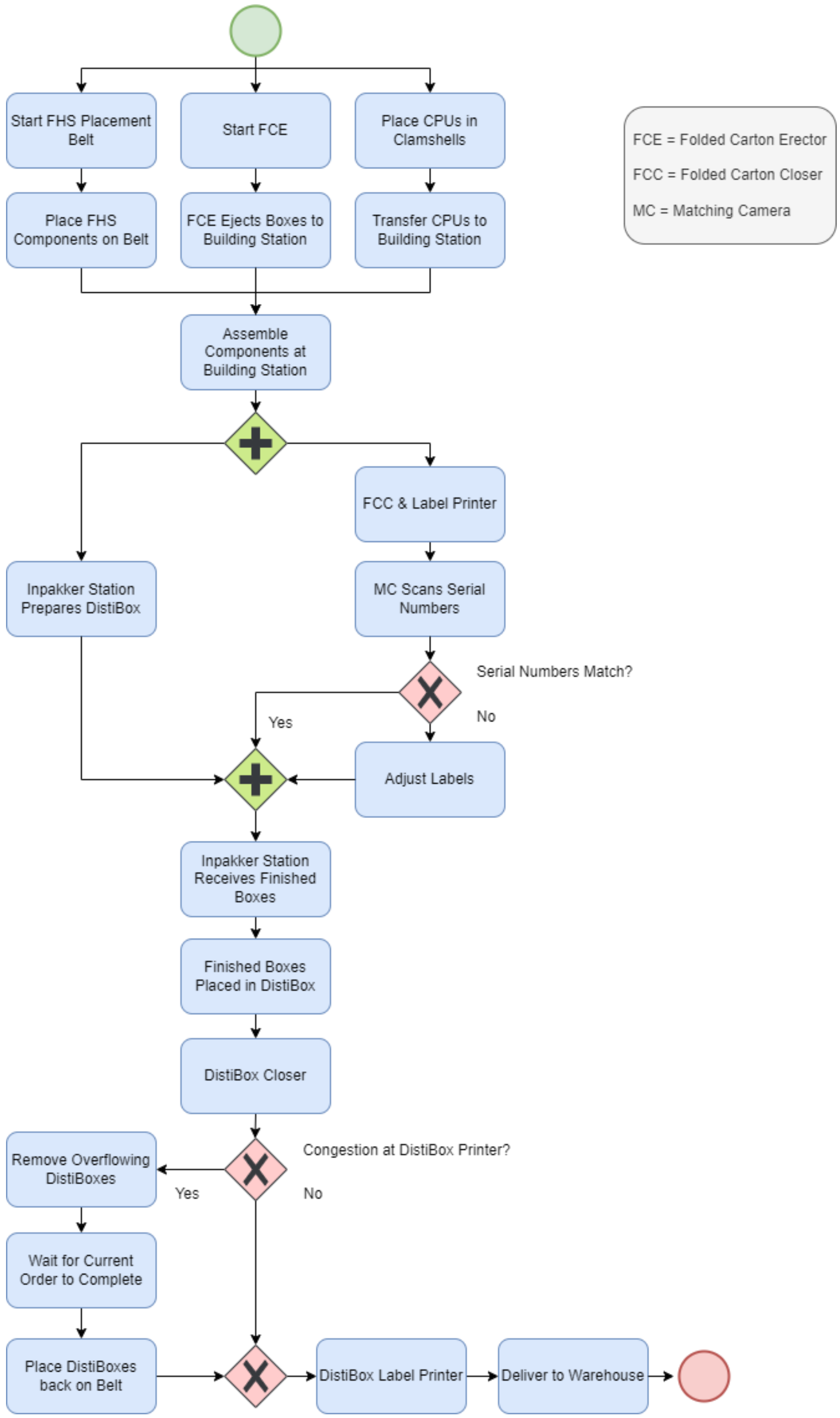

Figure 7 - Current Process Flowchart

Appendix B.2– Upgraded Process Flowchart

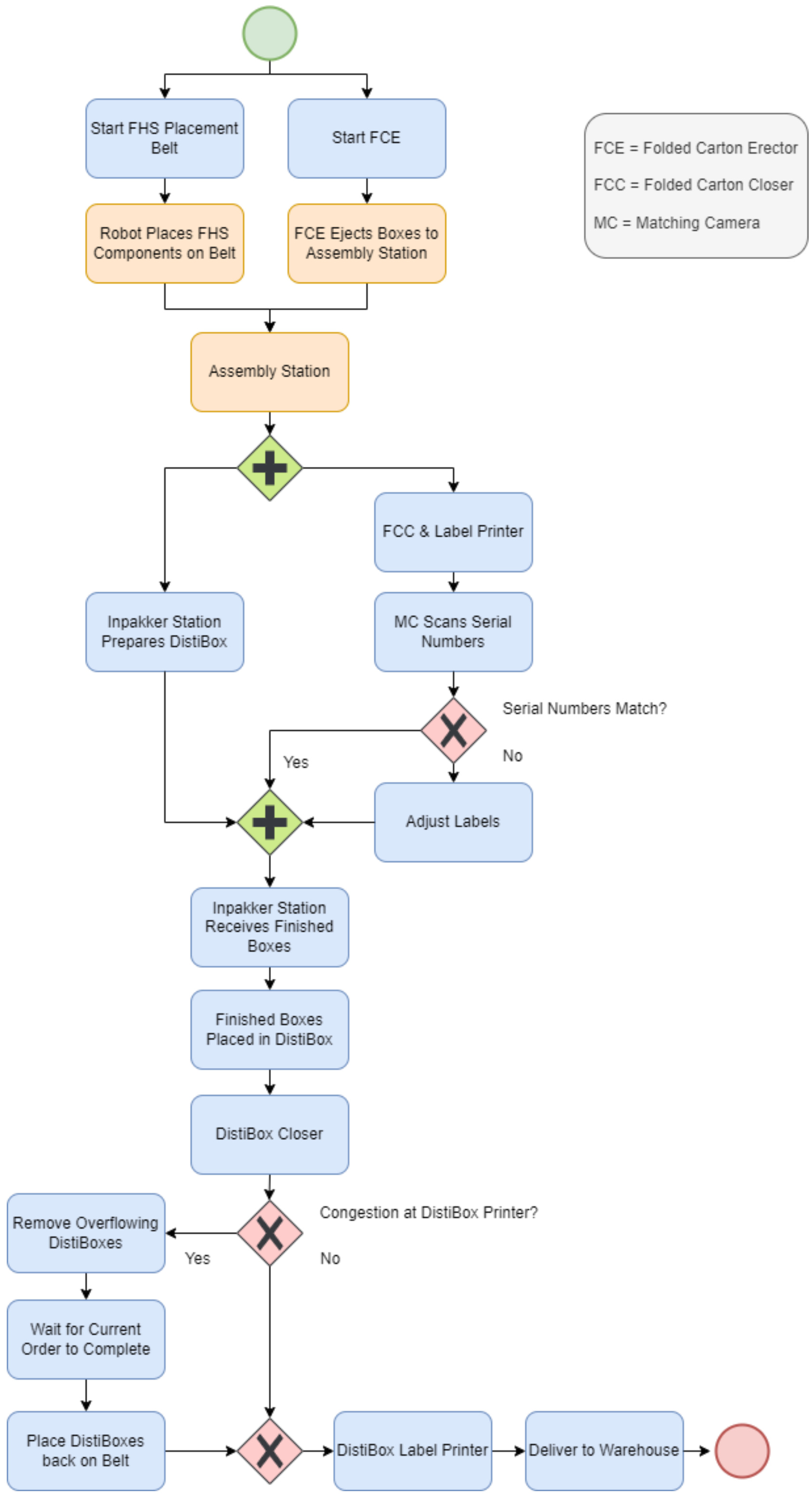

Figure 8 - Upgraded Process Flowchart