MANUAL ASSEMBLY LINE EFFICIENCY IMPROVEMENT

GRADUATION THESIS

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Manual assembly line efficiency improvement at Nijhuis Toelevering B.V.

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PREFACE

Dear reader,

You are about to read the bachelor thesis "Manual assembly line efficiency improvement". This research has been conducted at Nijhuis Toelevering B.V. in Rijssen, the Netherlands, as the final assignment for my bachelor Industrial Engineering and Management at the University of Twente. This thesis aims to increase the efficiency of the final assembly process, in order to increase the production output.

At Nijhuis Toelevering, I have gained many new insights and I am grateful for this opportunity they gave me. Especially since this research has been conducted in extraordinary circumstances, namely the Covid-19 pandemic. I would like to thank Nijhuis Toelevering for this opportunity and that I was allowed to work in the factory during these extraordinary circumstances.

Without any doubt, I would like to thank my supervisor Wilco Breukelman, who guided me during this research. I would like to thank him for his support, extensive feedback, and patience. During all the meetings we had, he was willing to help me with the challenges I faced. I also want to thank the employees of Nijhuis Toelevering who were open-minded towards my ideas and were always willing to help me and give answers to my many questions.

I would like to thank my UT supervisor Peter Schuur. I enjoyed our meetings, and he was always willing to help out and provide feedback. His feedback helped me to increase the quality of my research and I learned a lot about writing a thesis thanks to him. I would also like to thank Ipek Seyran Topan for her support during both the preparation and execution phases of this thesis. In these difficult and uncertain times, she was there if I needed her. Besides that, I want to thank her for being my second supervisor as well.

A last, I want to thank my family and friends for their support during this research. They always supported me. I especially want to thank Carmen Cijffers for being my buddy. She helped me to keep motivated and provided me with extensive feedback, help and opinions about the research. Because of her help, I was able to improve my thesis.

Rozan Hopman

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MANAGEMENT SUMMARY

This research has been conducted at Nijhuis Toelevering B.V. in Rijssen, the Netherlands. Nijhuis Toelevering is one of the biggest carpentry factories in the Netherlands and produces wooden window frames. The demand for wooden window frames has been increasing over the past five years and is expected to keep increasing during the upcoming years. To reach the growing demand, Nijhuis Toelevering needs to increase the production output of window frames as well. A higher output is not possible due to a low final assembly efficiency. By observing the final assembly process and conducting interviews with the employees, we identified the core problem of the low efficiency to be an uncertain availability of materials at the assembly lines. The uncertain availability of materials causes time waste in the final assembly process. This research aims to generate solutions to improve the materials flows within the production facility, in order to increase the efficiency of the assembly process. The main research question addressed in this thesis is formulated as follows:

"How to improve the efficiency of the current assembly process at Nijhuis Toelevering? In particular, how to increase the output so as to approach the intended (output increase) target of 50%?"

To create a better understanding of the situation at Nijhuis Toelevering, we analysed the current assembly process. By performing observations at the production facility as well as by conducting interviews, we were able to create better insights into the processes and materials flows at Nijhuis Toelevering. The final assembly process is executed by four separate assembly lines, with each has seven stations that carry out different tasks. We identified three material flows within the assembly process, which are internally produced materials, standard materials, and window frame-specific materials. The internally produced materials are produced and supplied by the production process at Nijhuis Toelevering. The standard and window frame-specific materials are supplied by external suppliers. The standard materials are supplied to the assembly lines in a 2-bin system. To provide an overview of the supply of the standard materials, we created a business process model. Next to that, a business process model for the supply of the window frame-specific materials is created.

After analysing the current final assembly process, a literature study on production improvement techniques was executed. We needed to know which production improvement techniques are suitable to improve the material flows at Nijhuis Toelevering. From this literature study, we identified three Lean manufacturing tools useful to improve the material flows at Nijhuis Toelevering. These three Lean tools are Value Stream Mapping (VSM), Kanban, and the 5S methodology. VMS helps to identify the wastes within a process regarding material and information flows. Kanban is a visual control tool used to control the production and inventory anomalies. 5S is used to provide a structured material use and materials flows within a process. The solutions to increase the efficiency are based on these three Lean concepts, but they are adapted to the practical situation at Nijhuis Toelevering.

To be able to generate solutions to increase the efficiency, we needed to establish a better understanding of the current performance of and the wastes within the assembly process. We first analysed the performance of the process by using the KPIs currently in place at Nijhuis Toelevering. The analysis of the KPIs shows that overall, the current performance of the assembly process reaches the stated norms of Nijhuis Toelevering. However, we do see a lot of fluctuations in the KPI values, which is due to the high variety in window frames that are produced at Nijhuis Toelevering. Next to the performance of the assembly process, it is important to identify the causes of waste with the process. By observing and conducting time measurements at assembly line 2, the causes of waste were identified. The outcomes of the observations and times measurements are analysed by creating a Value Stream Map and two Spaghetti diagrams. From this in-depth analysis of the observations and times

measurements, we concluded that most of the waste within the assembly process is caused by walking towards and searching for materials. We identified three problems and challenges, which are the employees walking paths, the lack of structure in material placement, and the production planning.

To eliminate the wastes occurring in the assembly process, we generated ten potential solutions to target each of the challenges identified with the analysis of the KPIs, observations, and time measurements. The ten potential solutions are:

Solution 1 – Strategic placement of materials in the production facility.
Solution 2 – Bringing the materials to the assembly lines.
Solution 3 – Arranging the materials in the buffer according to assembly lines.
Solution 4 – Arranging the materials in the buffer according to window frame series.
Solution 5 – Arranging the rotating parts based on size within a window frame series.
Solution 6 – Arranging the materials in the order in which the window frames are assembled.
Solution 7 – Dividing the series of window frames among the lines in the production planning.
Solution 8 – Include the difficulty of a window frame within the production planning.
Solution 9 – Connecting the nail and sealant gun at station 4 of the assembly lines both to their own air hose.
Solution 10 – Transport the window frames from the paint shop to the assembly lines hanging from the ceiling.

We weighted these potential solutions based on the requirements set by Nijhuis Toelevering. The four requirements are:

1. The solution has to be easy to implement.
2. Short-term implementation of the solution is possible.
3. The solution reduces the wasted time spent on searching materials.
4. The implementation costs need to be low.

With a weighted decision matrix, we chose solutions 2, 4, and 5 to further research and for which we write an implementation plan.

For each of the solutions, we examined the expected quantitative impact. Based on the time measurements performed at assembly line 2, the impact of solutions 4 and 2 is clearly definable. With solution 4, the assembly process can weekly assemble 3.80 extra window frames. This corresponds to an output increase of 0.69% per week. With solution 2, the assembly process can weekly assemble 18 extra window frames. This corresponds to an output increase of 3.27% per week. The impact of solution 5 is difficult to define based on the time measurements because the number of rotating parts varies each day. Therefore, we cannot estimate how much time waste is eliminated with solution 5. The employees indicated that implementing solution 5 would benefit them a lot. It is difficult to predict the impact of the implementation of all three solutions together since their interrelationships are unknown. We can estimate that the impact of all three solutions at least has the same impact as solution 4. Solution 4 is the solution that can support the other solutions in case they do not work. Therefore, we can state that the minimal impact of the three solutions together is the same as the impact of solution 4. Next to the quantitative impact, we also examined the social impact based on conducting interviews with the employees. The employees stated their concerns regarding the implementation of the solutions. Their main concern is that their work will become monotonous and that the social aspect of their work will be reduced when the solutions are implemented. The concerns of the employees need to be addressed in order to increase their willingness to participate in the implementation process of the solutions. By actively involving the employees in the decision-making process their concerns can be addressed and minimized.

For each solution, we wrote an implementation plan including the important steps that need to be taken in order the implement the corresponding solution. Each implementation plan also contains the person responsible to carry out the steps, the place where, and when the steps need to be carried out. One of the important parts of the implementation of the solutions is the involvement of the employees within the implementation process. It is important to acknowledge and resolve the concerns of the employees. This will increase their willingness to cooperate within the implementation process and therefore increase the chance of successful implementation of the solutions.

To evaluate the actual impact of the solutions on the assembly process, we implemented solutions 2 and 4 at assembly line 2 using a two-day pilot. Due to the time constraint of this research, the full implementation of the three solutions according to the implementation plans is not possible. Next to that, because of the limited resources available, not all three solutions could be implemented. While running the pilot, we performed similar time measurements as we did to assess the performance of the current assembly process. Based on the time measurements, observations, KPI values and interviews from the pilot, we are able to evaluate the actual impact of the implemented solutions.

The analysis of the KPIs shows that after the implementation of solutions 2 and 4 the performance of the assembly process and assembly line 2 is above the average before the solution implementation and according to the expected output increase. This higher performance can be the result of the implementation of the solutions, but other aspects also influence the KPI values. Therefore, we need to be careful when we use averages to compare our results. The analysis of the time measurement shows that the actual eliminated time waste is approximately the same as the expected time waste elimination. The actual eliminated time waste lies between the expected eliminated time waste by the implementation of solution 4 and the expected eliminated time waste of solution 2. This is because the actual eliminated time waste corresponds to the implementation of both solutions 2 and 4.

To evaluate the impact of the solutions on the employee walking paths, we created a new Spaghetti diagram that depicts these paths after the solution implementation. The first difference between the two Spaghetti diagrams is that the employees leave the line less frequent. This is the result of the implementation of solution 2. The second difference between the two Spaghetti diagrams is that the employees do not go to the sorting centre. By structurally arranging the materials, missing materials are easily detected. These missing materials were found before the assembly line needed them and therefore the assembly line employees do not have to go to the sorting centre. On a social level, the pilot showed the employees that the implementation of the solutions benefits them as well as the production process as a whole. By actually experiencing the solutions for a short period of time, the employees can develop an image of how the solutions work in practice.

Overall, Nijhuis Toelevering is able to improve the efficiency of the current assembly process by eliminating the wastes within the process. These wastes are mainly caused by walking towards and searching for materials. These wastes can be eliminated by implementing the proposed solutions.

Based on the conducted research, recommendations are made to Nijhuis Toelevering. The main recommendations are as follow:

* We advise Nijhuis Toelevering to implement the solutions to eliminate waste within the assembly process. This concerns both the chosen solutions and the other potential solutions. The other potential solutions need further research before they can be implemented.
* We advise Nijhuis Toelevering to create short feedback loops to evaluate the implementation of the solutions. In each evaluation session, occurring challenges are identified and solutions to these challenges found. Over time, if the solutions are hound to be working properly and no problems arise, the frequency of the evaluations can be reduced.
* The most important and last recommendation is that we advise Nijhuis Toelevering to often ask the assembly line employees about their opinions, ideas, and concerns. By frequently involving the employees in the decision-making process, their willingness to participate in the implementation of new solutions can increase. Organizing brainstorm sessions with the employees to find solutions to occurring challenges can be a good starting point.

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LIST OF ABBREVIATIONS

Abbreviation	Full name	First introduced
BPM	Business Process Model	Page 12
ERP system	Enterprise Resource Planning system	Page 7
JIT	Just-in-Time	Page 16
KPI	Key Performance Indicator	Page 8
MPSM	Managerial Problem-Solving Method	Page 5
NVA	Non-value-added	Page 19
TPS	Toyota Production System	Page 16
USA	United States of America	Page 16
VA	Value-added	Page 19
VSM	Value Stream Map/Mapping	Page 19
WIP	Work-in-Process	Page 20

LIST OF TECHNICAL TERMS

Technical term	Dutch translation	First introduced
Air hose	Lucht slang	Page 36
Door fittings	Deurbeslag	Page 7
Dry glazing	Droog beglazen	Page 40
Finger-jointing	Vingerlassen	Page 14
Glazing beads	Glaslatten	Page 15
Grating	Schaven	Page 14
Hinges	Scharnieren	Page 7
Inward-opening windows and doors	Naar binnen draaiende ramen en deuren	Page 7
Outward-opening windows and doors	Naar buiten draaiende ramen en deuren	Page 7
Overhead crane	Bovenloopkraan	Page 15
Profiles	Profielen	Page 14
Roller conveyor	Rollerband	Page 15
Sealant	Kit	Page 15
Sills	Dorpels	Page 7
Stillages	Bokken	Page 7
Suction cups	Zuignappen	Page 15
Tilt table	Kantel tafel	Page 9

1 INTRODUCTION

This bachelor thesis is conducted at Nijhuis Toelevering B.V. The goal of this research is to increase the efficiency of the final assembly process at Nijhuis Toelevering B.V. in order to increase the production output. The introduction of this research consists of three sections. Section 1.1 introduces the reader to Nijhuis Toelevering B.V. Section 1.2 describes the problem identification, and section 1.3 provides an overview of how this research is designed.

1.1 COMPANY DESCRIPTION

Nijhuis Toelevering B.V. is located in Rijssen, the Netherlands. The company is part of the Nijhuis Holding B.V. Next to Nijhuis Toelevering, Nijhuis Bouw B.V. and Toelevering Online B.V. are also part of the Nijhuis Holding. The Nijhuis Holding is an over 100 years old family company, which has rapidly grown throughout the last decades (Nijhuis Bouw B.V., 2019). Nijhuis Toelevering was founded in 1973 and is one of the biggest carpentry factories in the Netherlands. This company mainly produces wooden window frames, wooden facade elements, and prefabricated components for the construction of buildings. In 2019, Nijhuis Toelevering produced approximately 25,242 wooden window frames and 5,427 prefabricated components, of which 3,649 were facade elements (de Laat, 2019). In 2021, Nijhuis Toelevering plans to launch its own website on which customers can order wooden window frames.

The Nijhuis Bouw B.V. was founded in 1906. Currently, Nijhuis Bouw B.V. is located in the following five places in the Netherlands: Rijssen, Apeldoorn, Assen, Enschede, and Zwolle. Building on more than 100 years of experience, Nijhuis Bouw B.V. has developed great expertise in all real estate construction phases, from developing projects to service and maintenance. Toelevering Online B.V. was founded in 2017. This company sells window frames through an online platform. The wooden window frames produced by Nijhuis Toelevering B.V. are partly sold through the platform of Toelevering Online B.V.

1.2 PROBLEM IDENTIFICATION

This research is conducted at the wooden window frame department of Nijhuis Toelevering. The study mainly focuses on the final manual assembly of the window frames. The wood enters the production facility as wooden beams. This wood is cut and assembled to a window frame within the factory according to the customers' wishes, at the pre-assembly. After this, the window frames are painted and hung out to dry. Once they are all dried, the window frames are placed on stillages (Dutch: bokken) by the employees of the paint shop. These stillages are placed within a so-called buffer. This buffer contains all the window frames that need to be assembled during the day. Within the final assembly process, all the components are added to the window frame. This includes the windows, doors, and glass panels, among other things.

The final assembly consists of four assembly lines, which are occupied from Monday till Friday, from 7.00 AM till 4.00 PM. Lines 1 and 2 are identical and mainly assemble batches of standard-sized window frames. Line 3 assembles special-sized window frames, mostly window frames wider than three meters, and the batches are of a smaller size. This line mainly assembles window frames intended for the customers of Toelevering Online B.V. Line 4 assembles window frames for doors and is the shortest assembly line of the four lines.

Each assembly line consists of seven different stations at which different parts of the window frame are assembled. Figure 1 illustrates the assembly process steps, and the dotted box shows the stations at the assembly line. The stations are connected through a roller conveyor. At station 1, the window frame's outer side is assembled, which includes the sills (Dutch: dorpels) and the outward opening windows and doors (Dutch: naar buiten draaiende ramen en deuren). At station 2, the window frame's inner side is assembled, which includes the hinges (Dutch: scharnieren), door fittings (Dutch: deurbeslag), and the inward-opening windows and doors (Dutch: naar binnen draaiende ramen en deuren). Station 3 is a buffer within the assembly line to make sure that there is no stagnation in the line. At station 4, the glass panels are placed in the window frame. At station 5, the sealant (Dutch: kit) is added to the glass on the window frame's inner side, and at station 6, the sealant is added to the outer side. At the last station, station 7, the window frame is packaged for transport. Once the window frame is finished, it is moved to a place outside the factory until transportation to the customer. The rotating elements, like windows and doors, are assembled at a different place in the factory. These rotating elements do not yet contain the glass panels itself. All the activities at the different stations are carried out by the employees of the assembly lines.

The sorting centre within the factory sorts and collects the materials for the window frames. The materials are collected for each series of frames and put on carts by the sorting centre employees. Before the assembly lines start with the production, the assembly line team leader picks up the charts necessary for a specific series of window frames that are assembled during that particular day.

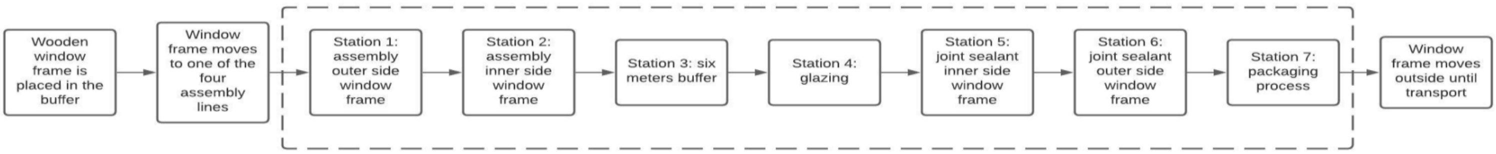

Figure 1.1: Assembly process at Nijhuis Toelevering

1.2.1 Problem cluster

To identify what causes the action problem, a problem cluster is made to map the related problems and their connections (Heerkens and Winden, 2017, p. 42). Figure 1.2 illustrates the occurring problems causing the action problem and the relationships between them. All the problem cluster problems have been identified by executing observations at the assembly lines and executing interviews with different stakeholders. The action problem is marked red in the problem cluster.

The demand for wooden window frames has been increasing over the past five years and is expected to keep increasing during the upcoming years. To be able to meet the growing demand, Nijhuis Toelevering must increase production as well. Currently, the assembly lines are not able to increase their production rate because the efficiency is too low. The final manual assembly of Nijhuis Toelevering, therefore, has one action problem. Namely, a low final assembly efficiency. This low efficiency is mainly because of time waste within the assembly lines. This time waste has three causes. Slow processes within the assembly lines are the first cause of time wasted. People-related problems are the second cause, and quality problems are the third cause of time wasted.

There are two slow processes within the final assembly. The first slow process is the packaging process. Due to an increase in demand, a large number of window frames need to be packaged at station 7. Next to this, each window frame has different instructions/rules on how it should be packaged. These rules and a large number of window frames result in a slow packaging process. The second slow process is the sealant process at stations 5 and 6. The sealant process contains a lot of different actions that need to be carried out. These different actions take time and cause this process to be a bottleneck within the assembly line.

The final assembly process is a manual process, and therefore there are people-related problems. The first people-related problem is that there is an uncertain availability of materials at the assembly line. we divide this uncertainty into two subproblems. The first subproblem is that wrong, or no materials are brought to the line by the sorting centre. The second subproblem is that the material storage within the factory is not optimal. Quite often, materials are stored at the wrong place or a suboptimal place.

One example of this is that today's window frames are often placed behind the window frames scheduled for tomorrow. The employee needs to put aside the window frames to reach the necessary ones and then put the other window frames back in their place. Due to the uncertain availability of materials, employees often search for the necessary materials and leave the assembly line. When searching for materials, the employees do not continue with their tasks within the assembly line. This causes an uncertain availability of people at the assembly line. Next to this, there are no rules on when to leave the line or on when to help each other within the line. When there are no rules, people can leave the line at a suitable time for them.

The last cause of time waste within the assembly lines is paint quality problems. Quite often, the window frames are not fully painted by the paint robots. This is most often detected at the assembly line, and it is not optimal to remove the window frame from the line and bring it to the paint shop. When it turns out that a window frame is not well painted, the assembly line employees will paint the window frame themselves. Next to that, the paint's quality on the glazing beads (Dutch: glaslatten) is also quite often not optimal. When employees at the assembly line are painting the frames instead of assembling them, valuable time is wasted.

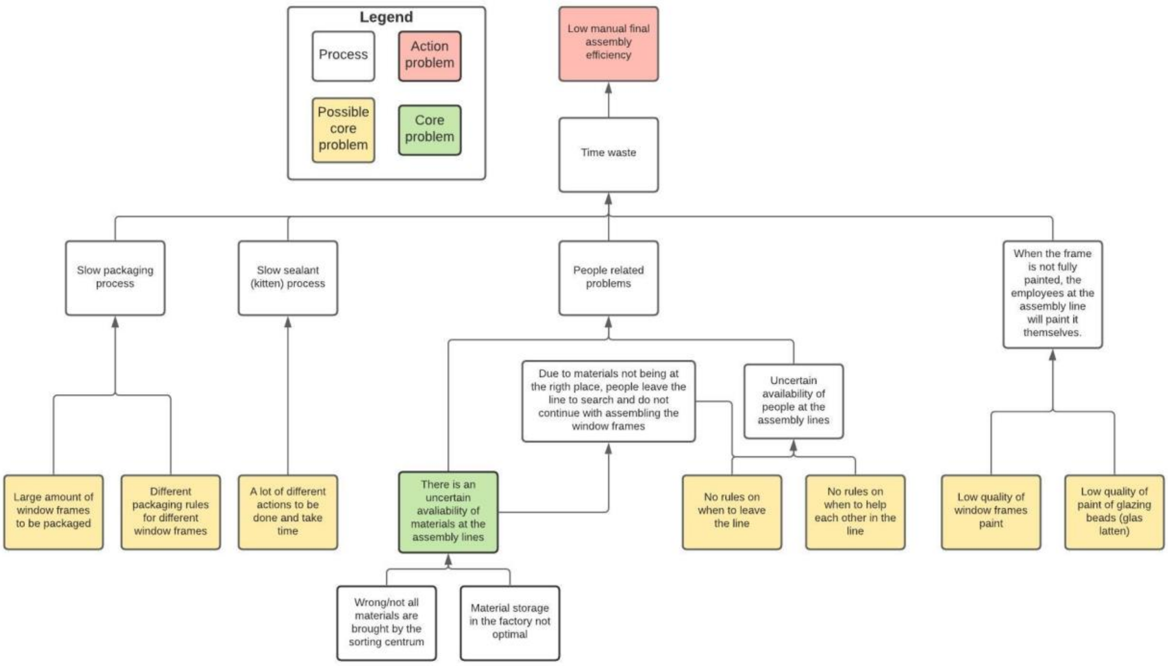

Figure 1.2: Problem cluster

1.2.2 Core problem

Based on the problem cluster in Figure 1.2, eight problems do not have a cause by themselves. These problems are marked yellow in the problem cluster and identified as potential core problems.

1. A large number of window frames to be packaged.
2. Different packaging rules for different window frames.
3. A lot of different actions to be done and take time.
4. There is an uncertain availability of materials at the assembly lines.
5. No rules on when to leave the line.
6. No rules on when to help each other in the line.
7. Low quality of window frame paint.
8. Low quality of paint of glazing beads.

According to Heerkens & van Winden (2017), core problems are the problems that can be influenced. From the seven potential core problems mentioned above, the first two problems cannot be influenced and therefore we cannot select the first two problems as core problem. At the moment of executing this research, Nijhuis Toelevering is already looking into options to optimize the sealant process to make it a less time-consuming process. Therefore, the problem 'a lot of different actions to be done and take time' is not selected as the core problem.

The potential core problems 'low quality of window frame paint' and 'low quality of paint of glazing beads' are problems caused by the paint shop of Nijhuis Toelevering. These problems occur due to the settings of the paint robots. Since the problems occur at the paint shop and the research focuses on the final assembly, they fall outside this research scope. Therefore, these problems cannot be chosen as the core problem of this research.

The last three potential core problems left are 'there is an uncertain availability of materials at the assembly lines,' 'there are no rules on when to leave the line,' and 'there are no rules on when to help each other.' If more problems can be selected as core problems, the most important one will be chosen as the core problem (Heerkens and Winden, 2017, p. 44). Therefore, in close consideration with Nijhuis Toelevering, 'there is an uncertain availability of materials at the assembly lines' is chosen as the core problem of this research. Solving this problem is expected to have the highest impact on the manual final assembly lines' efficiency. The core problem is marked green in the problem cluster in Figure 1.2.

1.2.3 Variables and indicators

The core problem needs to be made measurable with variables. With a measurable variable, the effect of the solution on the action problem can be properly examined. The variable is expressed in a reality value and a norm value. The reality value states the current situation, and the norm value states the variable's desired value (Heerkens and Winden, 2017, p. 45).

The core problem's reality value is "uncertain availability of materials," and the norm value is "certain availability of materials." These variables are broad and hard to measure. Therefore, indicators are identified to make the variables measurable (Heerkens and Winden, 2017). At Nijhuis Toelevering, several indicators are already measured. The first indicator is the 'average weekly output of the assembly lines.' Every day the number of window frames assembled is measured. At the moment, there is a weekly goal of 550 window frames. The demand and the planning differ each week, so the output per week also varies. On average, the goal of 550 window frames is reached. This research aims to increase the assembly process's efficiency to approach the target of a 50% increase in output. The norm value for this indicator, therefore, will be 825 window frames assembled per week.

The second indicator is the 'realized number of production hours per week.' Each order of a customer has a specific amount of production hours. These are the hours that can be declared by Nijhuis Toelevering to the customer and do not contain the hours of production that are 'wasted' on transporting materials through the factory, for example. These hours are not the same as the actual man-hours used to produce the output. The current level of production hours at Nijhuis Toelevering is 2,200 hours per week. When the efficiency of the assembly lines increases, more production hours can be realized. Therefore, the norm value for the realized production hours per week is 3,000 hours. This target is set by Nijhuis Toelevering.

The third indicator Nijhuis Toelevering uses is the 'efficiency of the hours used.' This efficiency is calculated by dividing the realized production hours by the used man-hours over a week. For example, in a week, the output is 2.536 realized production hours, and there are 2.392 man-hours used. This gives an efficiency of the hours used of 2.536/2.392*100% = 106%. The efficiency of the hours used shows the ratio of realized production hours and the used man-hours. When the ratio is greater than 100%, more production hours are realized than man-hours are used. In case the ratio is smaller than 100% more man-hours are used than production hours are realized. The man-hours indicate the actual hours that the employees are assembling window frames. The production hours are the predefined hours the customers pay for each order. A ratio greater than 100% shows that the production facility attains a specific number of production hours while using less resources (man-hours). This efficiency changes every week since the production also differs per week. Therefore, the average efficiency over 2020 and 2021 until week 20 is used as the reality value. This average is 110.5%. The norm value is set by Nijhuis Toelevering at 111%. Table 1.1 shows an overview of the reality and norm values of the indicators.

Table 1.1: Value of the reality and norm of indicators

Indicator	Reality	Norm
Weekly output of the assembly lines (units)	550	825
Realized production hours per week	2,200	3,000
Weekly efficiency of the hours used	110.5%	111%

1.2.4 Relevance of the solution

This research focuses on the material logistics of the final manual assembly of Nijhuis Toelevering. A solution to the core problem 'there is an uncertain availability of materials at the assembly lines' improves assembly lines' efficiency. Less time is wasted on the search for materials, and as a result, a higher output of the assembly lines is established. The knowledge acquired during this research can be used to implement the solution in other parts of the factory. The wooden facade elements and the prefabricated components departments can, for example, use the solution to increase their efficiency.

1.3 Methodology and research questions

This section provides an overview of the research design. Section 1.3.1 outlines the research phases and the research questions. Section 1.3.2 describes the scope of the research. In Section 1.3.3, we describe the limitations of the research. Section 1.3.4 defines the deliverables.

1.3.1 Problem-solving approach and research questions

This thesis aims to come up with a solution or solutions that increase the efficiency of the manual final assembly lines. The solution is in the form of an advisory report. To come up with a solution, the following main research question is answered during this research:

"How to improve the efficiency of the current assembly process at Nijhuis Toelevering? In particular, how to increase the output so as to approach the intended (output increase) target of 50%?"

To answer the main research question and solve the action and core problem, research is conducted. This is done by answering several research questions in different phases of the research. This research's problem-solving approach is the Managerial Problem-Solving Method (MPSM) of Heerkens and Winden (2017). The research questions are formulated according to the seven steps of the MPSM. To make the research question more accessible, sub-questions are formulated (Heerkens and Winden, 2017, p. 122).

Phase 1: Problem Identification

The first phase of the MPSM is the problem identification phase. In this phase, the research problem is defined. Next to this, the current situation is researched to obtain a better understanding of the processes. Interviews and observations are conducted to study the current final assembly process and the current material flows. The data collected during these interviews and observations is used to represent the current situation visually. These results are validated by the operational manager and the production manager. The following research questions are researched within this phase and these questions are answered in Chapter 2 Current assembly process:

1. *What is the current assembly process at Nijhuis Toelevering?*
    1.1. *What Key Performance Indicators (KPI) are currently in place?*
2. *How can the current logistic flows of materials for the assembly lines be determined?*

Phase 2: Solution planning

In this phase, the objectives of potential solutions are studied. This phase discusses the solution's intended achievement, the impact of the solution, and what is needed to come to the solution is studied. Next to this, literature is researched to obtain knowledge on potential methods to use in the solution generation phase (Phase 4). We use literature to answer the following research question in Chapter 3 Theoretical framework:

3. *What are the relevant production improvement techniques for improving the material flows at Nijhuis Toelevering?*
   3.1. *What are the pros and cons of the relevant production improvement techniques?*

Phase 3: Problem analysis

In this phase, data regarding the core problem is gathered and analysed. The core problem is analysed in terms of numerical data. The data used is already used by the management team of Nijhuis Toelevering. Next to this, we combine the data with independent measurements at the assembly lines. This data is combined and analysed in Excel. Within this phase the following research questions are researched and answered in Chapter 4 Problem analysis:

4. *What is the current efficiency performance of the assembly process at Nijhuis Toelevering?*
5. *What are the main causes of waste in the assembly process at Nijhuis Toelevering?*

Phase 4: Solution generation

In this phase, potential solutions are examined and formulated. The improvement solutions are based on the literature study in combination with the results of the data analysis. The literature study concerns production improvement techniques. As a result, potential solutions to improve the efficiency of the assembly lines are formulated. The following research question is researched within this phase and Chapter 5 Improvement options answers this question:

6. *Which possible improvement actions can be formulated based on the current material flows and the new insights?*

Phase 5: Solution choice

In this phase, a solution or a combination of solutions is chosen to be implemented. This choice of the solution is based on whether the solutions fit the requirements of Nijhuis Toelevering and is based on the potential impact the solutions have. The choice of solution is made in close consideration with Nijhuis Toelevering. Within this phase, the following research questions are researched, and Chapter 6 Solutions choice answers these questions:

7. *Which of the possible improvement actions is chosen to be implemented at Nijhuis Toelevering?*
   7.1. *What requirements does the chosen improvement action(s) need according to Nijhuis Toelevering?*
   7.2. *What is the expected quantitative impact of the chosen improvement action(s)?*
   7.3. *What is the expected impact of the chosen improvement action(s) on the stakeholders?*

Phase 6: Solution implementation

In this phase, an implementation plan is formulated for the solution or solutions chosen in phase five. Next to this, the expected impact of the improvements is researched. Not only the quantitative impact is studied, but also the impact on the employees and their tasks. For Nijhuis Toelevering, the human perspective is important. Therefore, the implementation plan also considers the employees' perspective on the solutions. Chapter 7 Implementation plan answers the following research question relevant for in this phase:

8. *How can the defined action(s) to improve the material flows be implemented?*
   8.1. *How can the different stakeholders be integrated within the implementation process of the improvement action(s)?*

Phase 7: Solution evaluation

In this phase, the chosen solutions and the research are evaluated on whether it has improved the efficiency of assembly lines. The indicator norms set at the beginning of the study are compared with the test results. Chapter 8 Solution implementation answers the following research question relevant for this research phase:

9. *What is the actual impact of the improvement action(s) on the assembly process at Nijhuis Toelevering?*

After answering the research question above, recommendations are made, and conclusions are drawn in Chapter 9 Conclusions and recommendations.

10. *What recommendations and conclusions can be made based on the results of the thesis at Nijhuis Toelevering?*

1.3.2 Research scope

As mentioned earlier, this research focuses on the wooden window frames department of Nijhuis Toelevering. Within this department, this research focuses on the final assembly process. This final assembly process consists of seven stations within each assembly line. The specific tasks at each of these stations are out of scope. This research focuses on the materials used in the final assembly process and the human resources at the assembly lines. At the moment of conducting this research, Nijhuis Toelevering researches the integration of an Enterprise Resource Planning (ERP) system. Therefore, this research does not take an ERP system as a solution into account. Next to this, this research only focuses on the material supply at the assembly lines. The optimal quantities of materials will not be studied.

1.3.3 Limitations

The previous section, Section 1.3.2, describes the scope of this research. To define the imperfections of the research design, the limitations of the research are identified (Cooper and Schindler, 2014). The first limitation of this research design is the time constraint. The time for the execution of this research is ten weeks, which means that certain parts of the assembly process are out of scope. The time constraint also means that the data gathering to analyse the core problem is done in a limited amount of time. This limited amount of time is considered to be taken as representative of normal operating circumstances. Section 4.7 further describes the limitations of the data used in this research.

The second limitation of this research design concerns the literature availability. Only open access literature and literature available through the databases accessible through the University of Twente are used because there is no budget for this research. The full text of certain articles might not be accessible. Production improvement techniques are luckily a widely discussed topic in literature. The last limitation of this research design concerns the data availability. There is a possibility that some necessary data is not available or not available in the right format. Nijhuis Toelevering also collects a lot of data regarding the assembly lines. This data is used to analyse the current performance of the assembly lines. We measure the missing data at the assembly lines if that is possible within the time limit. It might also be the case that it is not possible to measure some data.

1.3.4 Deliverables

This section provides an overview of the deliverables that resulted from the bachelor thesis conducted at Nijhuis Toelevering B.V.

1. A Business Process Model (BPM) of the current final assembly process.
2. A visual representation of the current material flows with the use of Spaghetti diagrams.
3. Advisory report on the steps Nijhuis Toelevering must take toward implementation.
4. An implementation and evaluation plan for the chosen solution or chosen set of solutions.
5. Recommendations, limitations, and conclusions from this research.

2 CURRENT ASSEMBLY PROCESS

This chapter contains a description of the current assembly process, and the material flows at Nijhuis Toelevering. This is done by answering the first two research questions and its sub-questions.

1. What is the current assembly process at Nijhuis Toelevering?

1.1 What Key Performance Indicators (KPI) are currently in place?

2. How can the current logistic flows of materials for the assembly lines be determined?

Answering these questions ensures a better understanding of the current processes that are important for this research. A logistic flow is defined as the material flow from the moment the materials enter the production facility until they are used in the assembly process. The questions are answered by giving a textual description and with the use of business process models (BPM) of the different logistic flows of the materials. Section 2.1 describes the overall production process at Nijhuis Toelevering. Section 2.2 outlines the current final assembly process and the KPIs currently used to evaluate the assembly process's performance. The three materials categories and the materials flows are described in Section 2.3. Lastly, a conclusion is made in Section 2.4. The input for this chapter is provided by conducting interviews and observing the current processes.

2.1 PRODUCTION PROCESS

The production process of the window frames at Nijhuis Toelevering uses batch production. This means that the window frames of one batch move through the process together. The batches have a maximum size of 50 window frames. Each series of frames has its serial number, and the batches are based on these serial numbers. That means that all the window frames from one order belong to the same batch.

The production process starts with the production of the wooden components for the window frames. The production of components process consists out of four steps that process the wood into components. The first step is finger-jointing (Dutch: vingerlassen) the timber into a long wooden beam. Figure 2.1 shows finger-jointed wood. The second step is shortening the wooden beam. The long wooden beam is cut to the correct sizes for the specific window frames. Each window frame consists out of four wooden pieces. The third step is grating (Dutch: schaven) the wooden pieces. This is done to ensure that the wood is perfectly smooth so that it does not lie skewed within the machine used in the fourth step. In the fourth step, the wood is profiled. This is done with the use of a machine called the Conturex. The profiles (Dutch: profielen) are added to the wood to create shapes in which, for example, the windows can be placed later in the process. The profiles give the window frame its shape and characteristics.

Figure 2.1: Finger-jointed wood

Once the components are finished, they go to the pre-assembly. The pre-assembly combines the components into the wooden construction of a window frame. After the pre-assembly, the window frames go to the paint shop, where they are hanged and painted by a robotized paint machine. Once the paint is dried, the window frames are placed into a buffer until they move to the final assembly. At last, the window frames are transported to the customers. Figure 2.2 shows a schematic representation of the production process of window frames at Nijhuis Toelevering.

Figure 2.2: Schematic representation of the window frame production process

2.2 FINAL ASSEMBLY PROCESS

Four separate assembly lines execute the assembly process. Section 1.2 gives a detailed description of the assembly lines. The assembly lines are occupied on Monday to Friday, from 7.00 AM till 4.00 PM. At assembly lines 1, 2, and 3, seven employees are divided among the different stations. At assembly line 4, on average, two employees are carrying out the tasks. The reason for this is because assembly line 4 is a shorter line than the other assembly lines.

The assembly process starts when the window frames are placed in the buffer between the paint shop and the assembly lines. The buffer is a place within the factory where all the window frames ready to be assembled are placed. For each workday, a planning is made on which series of window frames must be assembled during that specific day. At the beginning of the day, the four team leaders discuss which series of window frames are assembled at which assembly line. The employees take the right stillage with window frames from the buffer to the assembly line. Each stillage is provided with a paper on which the serial number is denoted. This serial number contains specific information about, for example, the necessary materials needed to assemble the window frames. Next to this, the employees pick up a cart with specific materials for the window frames at the sorting centre. These carts are also provided with a paper on which the serial number is denoted.

As explained in Section 1.2, the assembly lines consist of seven stations. At station 1, the window frame's outer side is assembled. The window frame is lifted from the stillage and placed on a tilt table (Dutch: kantel tafel) with the use of an overhead crane (Dutch: bovenloopkraan). The tilt table is used to tilt the platform horizontally on which the window frames are assembled and make goods more accessible in ergonomically sound workplaces. Once the tasks at station 1 are finished, the window frame is moved toward station 2 by an employee pushing it over the roller conveyor (Dutch: rollerband). At station 2, the window frame's inner side is assembled. The outer side of the window frame is the side that is on the outside of a building when the window frame is placed. The inner side is inside the building. Station 3 is a buffer within the assembly line to ensure no stagnation within the line. At station 4, the glass panels are placed in the window frame. The glass panels are lifted with suction cups (Dutch: zuignappen) or carried by the employees and placed in the frame. If the glass is in the right position, it is fastened with glazing beads (Dutch: glaslatten). The glazing beads are fastened on the window frame with nails. When the glazing beads are placed, the window frame is moved to station 5. At station 5, the sealant (Dutch: kit) is added to the glass on the window frame's inner side. The sealant is added to the intersection between the glazing beads and the glass. At station 6, the sealant is added to the outer side of the window frame. Figure 2.5 shows where the glazing beads are placed on the window frame and where the sealant is added. At the last station, station 7, the window frame is packaged for transport.

The window frame is lifted of the roller conveyor with the use of an overhead crane and placed on a stillage (Dutch: bokken).

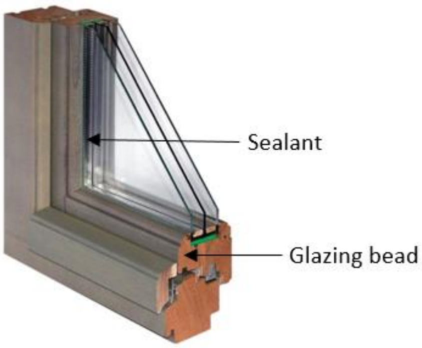

Figure 2.3: Window frame layout

The rotating parts, like the windows and doors, are assembled separately from the window frames and later in the process added to the window frames at stations 1 and 2. This is further explained in Section 2.3.1. 'Internally produced supply.' Figure 0.1 in Appendix A shows the layout of the assembly process within the factory hall at Nijhuis Toelevering.

Figure 2.4: Window frame before and after the assembly process

Key Performance Indicators
To evaluate the performance of the assembly process, several Key Performance Indicators are used by Nijhuis Toelevering. The first KPI that is measured is the daily window frame output per assembly line. Each day the total amount of assembled window frames by each assembly line is measured. Cumulating these daily totals gives the total weekly output of window frames. By comparing the daily and weekly output with the output goals, the performance of the assembly process and the individual lines can be examined.

The rotating parts are separately assembled from the window frames at the assembly rotating parts department and Nijhuis divides the parts into two groups: the windows and the doors. To evaluate the performance of this part of the assembly process, three KPIs are used. The first KPI is the daily output of the assembled doors, and the second KPI is the daily output of the assembled windows. Cumulating these daily totals gives the weekly output of the rotating parts.

The last three KPIs focus on the hours used to produce and assemble the window frames. These KPIs are also discussed in Section 1.2.3. The first KPI used is the 'realized number of production hours per week.' These are the hours the customer eventually pays for. Each customer order has a specific number of production hours. When the production planning is made, the number of production hours for that week is known because this number is a fixed number of hours. The realized production hours are the actual amount of production hours made that week. This depends on whether the assembly lines are ahead, behind, or precisely on schedule. The second KPI is the used man-hours per week. The assembly process is occupied eight hours per day, five days a week. The used man-hours are the number of employees times the hours they worked. The last KPI is the weekly efficiency of the hours used. This KPI is calculated by dividing the realized production hours by the used man-hours over a week.

So, the KPIs currently in place at the assembly process are:

1. Daily window frame output per assembly line
2. Weekly window frame output
3. Daily output rotating parts - doors
4. Daily output rotating parts - windows
5. Weekly output rotating parts
6. Realized number of production hours per week
7. Used man-hours per week
8. Weekly efficiency of the hours used

Section 4.1 describes what the KPIs look like and what the current performance of the assembly process at Nijhuis Toelevering looks like in terms of these eight KPIs.

2.3 MATERIAL SUPPLY TO THE ASSEMBLY PROCESS

At the assembly process, all the materials necessary to assemble the window frames come together. These materials are supplied to the assembly process through different material flows. Three different material categories are distinguished at Nijhuis Toelevering. These three groups are internally produced materials, standard materials, and window frame-specific materials. The internally produced materials are produced for specific series of window frames by the general production process. The standard materials are materials that are the same for every window frame that is assembled. The window frame-specific materials are different for each series of window frames. An external material supplier supplies the standard and specific materials. The three sorting centre employees supply the assembly lines with the materials delivered by the external supplier.

2.3.1 Internally produced supply

The internally produced materials consist of three groups: the window frames, the rotating parts (windows and doors), and the glazing beads. The window frames are stored in the buffer before they are assembled. The material flow of a window frame starts at the buffer, and then this frame moves through one of the assembly lines. At last, the window frame leaves the assembly line. Section 2.1 and Section 2.2 describe this process in detail.

The rotating parts include the windows and doors. These parts are assembled separately from the window frames. When the rotating parts are painted by the paint shop, they are placed in the buffer. The employees of the windows/doors assembly department pick up the necessary parts and assemble them. Once the rotating parts are assembled, they are again placed in the buffer. The employees of the assembly lines then pick up the necessary rotating parts and assemble them into the corresponding window frames. This is done at either station 1 or station 2 within the assembly lines.

The glazing beads are produced with the same processes as the window frames and the rotating parts, as described in Section 2.1. Once the glazing beads are painted, they are placed in bins. These bins are placed in the buffer. Each bin contains the glazing beads of one window frame series. The employees of the assembly lines pick up the necessary glazing beads from the buffer and assemble them to the window frame at station 4 within the assembly line.

2.3.2 Standard material supply

The standard materials are the same for every window frame that is assembled. Examples of such materials are door fittings and hinges. These standard materials are supplied to the assembly lines through a 2-bin system. The 2-bin system ensures the right inventory level present to meet the demand (Liberto, 2019). So, there is a right inventory of standard materials at the assembly lines at all times. Without the 2-bin system, the employees would need to walk to the stockroom and collect the materials once the materials are depleted. These walking times are a waste because then the employees are not assembling the window frames. The 2-bin system eliminates these walking times and thus eliminates some degree of waste.

A 2-bin system is an application of a Kanban system. A Kanban system is a tool that is related to the Lean manufacturing methodology. The inventory of materials is stored in two (or more) bins. The first bin is used to draw materials from, and the second bin is meant to serve as buffer inventory. The moment that the first bin is empty, one can replace the empty bin with the second bin, which is filled with materials. The empty bins are collected and refilled with new materials. After that, the bin is brought to the assembly line and becomes the buffer bin (Liberto, 2019). Figure 2.6 shows the 2-bin system at Nijhuis Toelevering.

Figure 2.5: 2-bin system at Nijhuis Toelevering

At the end of the day, an employee of the sorting checks all the bins on whether they are empty. In case a bin is empty, the employee brings the bin to the sorting centre. Each bin has a sticker with a barcode. This barcode contains information about which materials belong in the bin and the right quantity of materials. The sticker also states to which assembly line the bin belongs. Each day the material supplier supplies the sorting centre with the ordered materials. The empty bins are collected by the material supplier and taken to the suppliers' warehouse. The supplier fills the bins with the correct quantity of materials and transports them back to Nijhuis Toelevering. The employee at the sorting centre checks the bins and brings them to the assembly lines. Figure 2.7 shows the business process model (BPM) of the 2-bin system supply process.

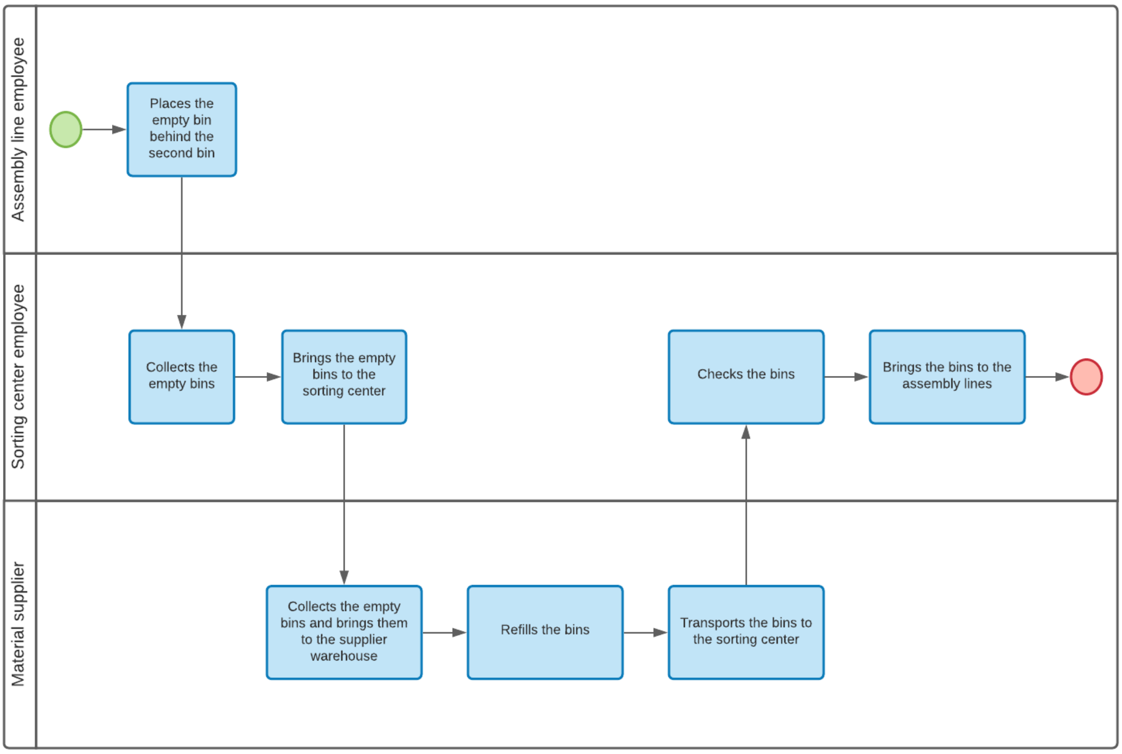

Figure 2.6: Business process model of the 2-bin system supply

2.3.3 Specific material supply

The specific materials differ for each window frame that is assembled. These are mostly tailored materials. This category consists of, for example, the ventilation grilles, the sills, and the glass panels. These specific materials are supplied to the sorting centre by external suppliers.

The process of material supply starts at the purchasing department. The window frames are ordered by the customers and based on these orders, the materials are purchased. The purchasing department orders the necessary materials at the suppliers. The supplier confirms the order, collects the materials, and eventually delivers the materials to the sorting centre at Nijhuis Toelevering. Meanwhile, a sorting centre employee checks whether the expected delivery date is the same as the production planning date. When these dates do not correspond, corrective actions need to be taken to either change the production planning or get the supplier to deliver earlier. When the dates do correspond, the production planning is finalized. The finalized production planning is distributed to the employees of the assembly lines, and a material planning is made. This material planning states when the carts with materials for a certain series of window frames needs to be packed with materials.

When the materials are delivered to the sorting centre, the employees check all the materials on whether the correct materials have been delivered. They also check quantities, colours, and quality. The carts are packed with materials for each series of window frames according to the material planning. On these carts, a paper with the serial number and the materials on it is added. Two carts are packed with each window frame series materials: one outer side cart and one inner side cart. The outside cart contains the materials used to assemble the outer side of the window frames, and this cart is used at station 1 of the assembly line. The inside cart contains the materials used to assemble the inner side of the window frame. This cart is used at station 2 of the assembly line. The two carts are used to ensure that every station has the materials close to the station. The two carts also ensure that employees do not have to walk to the cart every time they need materials. Once a cart is finished, it is placed in the carts buffer. The assembly line employees will take the necessary cart to the assembly line once they start with a series of window frames. Once the cart is empty, a sorting centre employee takes it back to the sorting centre. Figure 2.8 shows a business process model of the specific material supply process.

The glass panels are not placed on the carts but are separately delivered to the assembly lines by the glass sorting employees. An external supplier delivers the glass panels to the sorting centre on stillages. One employee is responsible for the glass panels. This employee checks the glass panels on whether the right panels are delivered and whether some panels broke during transport. The employee then sorts the glass panels and places them on other stillages. When an assembly line starts with a certain series of window frames, they call the employee that they need a certain set of glass panels. The employee will bring the stillages with the right glass panels to station 4 within the assembly line. When the stillages are empty, the employee will pick them up and place them outside the factory. Once the external supplier delivers new glass panels, the empty stillages are taken back to the suppliers' warehouse.

So, the overall material flow of specific materials through the factory at Nijhuis Toelevering is that the materials are delivered to the sorting centre. There the materials are checked and sorted based on the serial numbers. All the materials, excepts the glass panels, are placed on carts. The employees of the assembly lines pick up these carts. The materials are assembled in the window frames, and the empty carts return to the sorting centre.

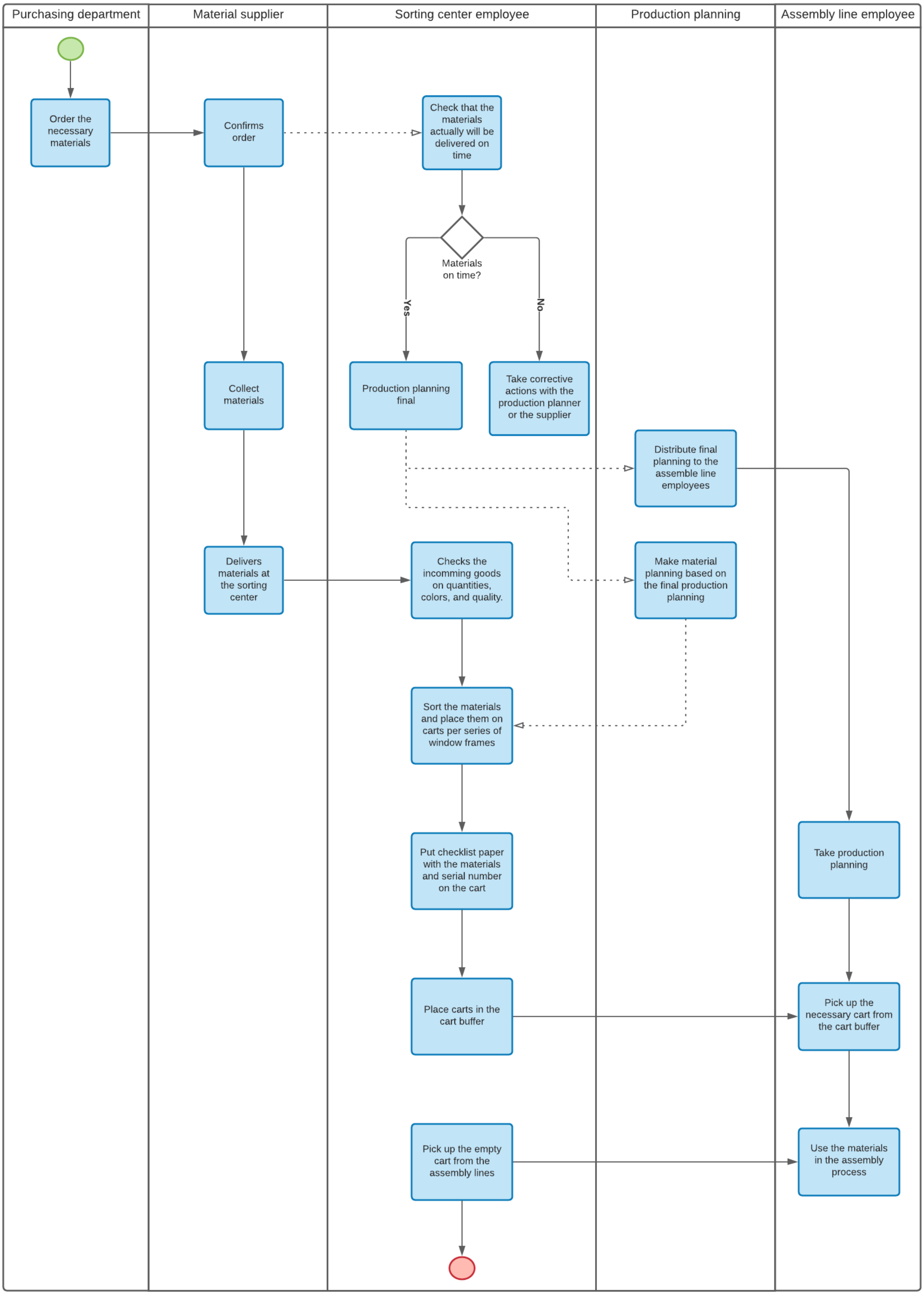

Figure 2.7: Business process model specific material supply

2.4 CONCLUSION

In this chapter, we analysed the current assembly process, and the material flows at Nijhuis Toelevering. This chapter answers the first two main research questions and its sub-questions.

1. What is the current assembly process at Nijhuis Toelevering?

The window frame production process at Nijhuis Toelevering consists of five steps. The steps are illustrated in Figure 2.2 and are component production, pre-assembly, paint shop, final assembly, and transportation to the customers. The production process used batches of window frames that together move through the factory. The size of these batches varies between 1 and 50 window frames. The assembly process consists of four assembly lines and a separate department to assemble the rotating parts. The assembly lines contain seven different stations where different components are added to the window frames.

1.1 What Key Performance Indicators (KPI) are currently in place?

Currently, eight KPIs are measured and examined by Nijhuis Toelevering. These KPIs are used to evaluate the performance of the assembly process and the separate assembly lines. The eight KPIs in place at the assembly process are:

1. Daily window frame output per assembly line
2. Weekly window frame output
3. Daily output rotating parts - doors
4. Daily output rotating parts - windows
5. Weekly output rotating parts
6. Realized number of production hours per week
7. Used man-hours per week
8. Weekly efficiency of the hours used

2. How can the current logistic flow of materials for the assembly lines be determined?

The material supply to the assembly process is divided into three categories: internally produced materials, standard materials, and window frame-specific materials. The internally produced materials are the window frames, rotating parts, and glazing beads. These materials follow the whole production process at Nijhuis Toelevering. The material flows of these materials start at the buffer and end at the assembly lines. The standard materials are the materials that are the same for every window frame that is assembled. These materials are supplied to the assembly lines using a 2-bin system. The material flow of the standard materials starts at the sorting centre and eventually ends at the assembly lines, where the materials are used in the assembly process. The window frame-specific materials are the materials that differ for each window frame. These materials start at the sorting centre and are first checked and sorted and then moved to the assembly lines, where these materials are used in the process.

3 THEORETICAL FRAMEWORK

This chapter describes the theoretical framework used within this research. A literature study is executed to gain more insights on what production improvement techniques can be used to improve the material flows in the production facility of Nijhuis Toelevering. In this chapter, the third research question and its sub-question are answered.

3. What are the relevant production improvement techniques for improving the material flows at Nijhuis Toelevering?

3.1 What are the pros and cons of the relevant production improvement techniques?

Section 3.1 describes the historic context of the evolution of Lean manufacturing and Section 3.2 describe the concept of Lean manufacturing. Section 3.3 introduces the concept of Value Stream Mapping. Sections 3.4 and 3.5, respectively, introduce the Lean methods Kanban and 5S. Finally, Section 3.6 gives the conclusion to this chapter.

3.1 HISTORIC CONTEXT

At the beginning of the twentieth century, the automobile was very expensive and attainable online for rich and privileged people (Tomac et al., 2019). Henry Ford's vision was to build a motor car for the great multitude, constructed of the best materials, by the best men to be hired, so low in price that no man making a good salary will be unable to own one (Tomac et al., 2019). Henry Ford adapted the moving assembly line process for the manufacture of artmobiles, which allowed him to manufacture, market and sell the Model T at a significantly lower price than his competition, enabling the creation of a new and rapidly growing market (Vlaskovits, 2011).

In 1929, Kiichiro Toyoda, founder of Toyota, arrived in the United States of America (USA) with the aim of scrutinizing the local companies in the automotive industry. He was particularly fascinated with the Ford production system (Dekier, 2012). Kiichiro decided to implement some of the resolutions he has witnessed. After a decrease in demand, Toyota was forced to change the methods of production in order to compete in the mass production automotive industry of European and American companies. Kiichiro understood that it was mandatory to create a fast and flexible process of production as a result of which the clients would obtain desired, high-quality and reasonably-priced automobiles (Dekier, 2012). Kiichiro commenced preparatory work to produce in the Just-in-Time (JIT) system, also known as the Toyota Production System (TPS) (Dekier, 2012).

After World War II, Japan was trying to rebuild its devastated industry. The Japanese tried copying Western production methodologies, which were considered the best of the world, but they soon encountered four problems (Plenert, 2007):

1. The Japanese lacked the cash flow to finance the large in-process inventory levels required by the USA batch-oriented production system.
2. The Japanese lacked the land space to build large USA-style factories.
3. The Japanese lacked the natural resources accessibility that the USA had.
4. Japan has a labour excess rather than a lobar shortage, which meant that labour efficiency systems were not very valuable.

The Japanese saw these problems as opportunities. Realizing that their competitive problem was a process problem, not a product problem, they proceeded to copy product technology and worked to innovate process technology oriented around materials efficiency (Plenert, 2007).

In the 1950s, Eiji Toyoda and Taiichi Ohno visited the Ford Company, and they were able to create a system linking the TPS with the Ford assembly line (Dekier, 2012). It is generally accepted that Toyota's industrial engineer Taiichi Ohno has developed the JIT system and build the Toyota's impressive growth into a world prominent manufacturing company. Ohno repeatedly pointed out that he learned it all from Henry Ford's book "Today and Tomorrow" (Tomac et at., 2019).

Lean manufacturing was coined in 1991 by James P. Womack, Daniel T. Jones, and Daniel Roos in their book "The machine that changed the world", in which they compared Japanese and American companies. The most efficient turned out to be Toyota Motor Company with its TPS. The TPS was the first system working in accordance with the guidelines of Lean (Dekier, 2021).

3.2 LEAN MANUFACTURING

Lean manufacturing has been one of the most popular paradigms in waste elimination in the manufacturing and service industry (Wahab et al., 2013). The Lean concept originated in Japan from the Toyota Production System (Uriarte, 2018). Lean manufacturing is a philosophy of consistently lowering waste in all types and all areas of manufacturing (Lamani, 2020). The Lean philosophy focuses on reducing waste and non-value-adding (NVA) activities (Domingo, 2007; Womack et al., 1990).

Lean manufacturing is the production of goods using less of everything compared to mass production, less waste, less human effort, less engineering hours, less space in the manufacturing facility, and so on (Lamani, 2020; Wang, 2019). Becoming "Lean" is a process of eliminating waste with the aim of creating value. Lean is realized via tools, techniques, and practices to acquire excessive-quality, the lowest cost, and shortest lead times (Lamani, 2020). Lean manufacturing was derived from the need to increase product flow velocity through the elimination of all non-value-added activities (Arnheiter & Maleyeff, 2005). This is the main reason that Lean manufacturing is used in this research instead of other optimization approaches like Six Sigma. Six Sigma is derived from the need to ensure final product quality (Arnheiter & Maleyeff, 2005) and thus focuses on defect reduction (Wang, 2019).

There are five key Lean thinking principles that are important to attain the Lean manufacturing goals. These principles will assist the way how to perform lean implementation (Lamani, 2020). The five Lean principles are:

1. Specific value. Lean focuses on the value perceived by the customer. The producer of a product must base its product or service on the needs of the customers.
2. Identify value streams. The second principle of Lean focuses on the performance of the processes from beginning to end. The goal is to identify the steps that do not create value and then find ways to eliminate those wasteful steps.
3. Make value flow continuously. After the waste has been removed from the value stream, the next step is to ensure that the remaining steps flow smoothly without interruptions, delays, or bottlenecks.
4. Let the customer pull value. With the improved flow, the customers can 'pull' the producer's product according to their own needs. This means that only the demand is produced.
5. Pursue perfection. The last principle of Lean is to pursue perfection through continuous improvement and incorporating Lean thinking into the corporate culture.

As said earlier, the Lean philosophy originated in Japan, and therefore Japanese terms are often used to describe the core ideas. The terms Muda, Mura, and Muri are Japanese words conveying three causes of waste (Slack et al., 2016, p. 506). Muda is a Japanese word for waste (Wahab et al., 2013). Muda are activities in a process that are wasteful because they do not add value to the operation of the customer. Mura means 'lack of consistency' or unevenness that results in periodic overloading of staff or equipment. Muri means absurd or unreasonable. It is based on the idea that unnecessary or unreasonable requirements put on a process will result in poor outcomes (Slack et al., 2016, p. 506). Within Lean manufacturing, there are eight types of waste (Wahab et al., 2013):

1. **Overproduction.** Overproduction is making too much, too early or "just in case". This type of waste is the most crucial of wastes as it is the root of so many problems and other wastes.
2. **Waiting.** Waste of waiting is directly relevant to flow, and it is probably the second most important type of waste. In a manufacturing facility, this type of waste occurs when processes do not fit together properly.
3. **Unnecessary motion.** Unnecessary motion refers to both human and layout. The human dimensions relate to the ergonomics of production where operators have to stretch, bend and pick up, move in order to see better and such waste is tiring for the employees and is likely to lead to poor productivity and quality problems. The layout dimensions refer to poor workplace arrangements, leading to micro waste movement. Motion waste is also a health and safety issue.
4. **Excessive transportation.** Movement of materials and double handling is waste. This will affect productivity and quality issues.
5. **Inadequate processing.** This waste refers to machines and processes that are not quality capable. A capable process requires correct methods, training, and required standard that does not result with making defects. Over-processing also occurs in situations where overly complex solutions are found for simple procedures.
6. **Unnecessary inventory.** There are three types of inventory, raw materials, work-in-process, and end items. Inventory tends to increase lead-time and prevents rapid identification of problems.
7. **Defects.** Defects in internal failure are scrap, rework, and delay, while external failure includes warranty, repairs, and field service. Defects are direct costs for both immediate and long term.
8. **Underutilized people.** This type of waste refers to more people being involved in a job than necessary, not involving the associates in process improvement, not leveraging the potential individual to the fullest, not using the creative brainpower of employees, uneven work distribution/load balancing, and losing time, ideas, skills, improvements, and learning opportunities by not engaging or listening to your employees.

Many Lean tools are available to assist companies in their Lean manufacturing journey. These tools constitute a toolbox that helps eliminate waste in every production area, including customer relations, product design, supplier networks, and factory management. This toolbox enables companies to incorporate less human effort, less inventory, less time to develop products, and less space to become highly responsive to customer demand while producing top-quality products in the most efficient and economical manner possible (Wang, 2019). Some of these tools are Value Stream Mapping (VSM), Kanban, and 5S.

3.3 VALUE STREAM MAPPING

In order to implement the Lean philosophy in a manufacturing organization, critical tools are needed (Jasti et al., 2019). Value Stream Mapping (VSM) is such a critical tool. VMS is a simple but effective approach to understanding the flow of materials and information as a product or service has value-added as it progresses through a process, operation, or supply chain (Slack et al., 2016, p. 509). VSM is a visual tool that facilitates the process of Lean production by helping to identify the value-added (VA) steps and eliminating the non-value-added (NVA) steps and the waste (W). The goal of the value stream map is to reduce wastes in the production line as much as possible. These wastes prevent the constant movement of material and information (Lamani, 2020). VA activities are operations for which the customer is willing to pay. They include all operations that change the state of a component/semi-finished part and are necessary to realize the product. These activities refer to only compliant products. NVA activities include operations that are necessary but do not transform the product toward completion. Waste activities include operations that do not transform the item toward completion and are unnecessary (Papetti et al., 2019).

VSM is a four-step technique that identifies waste and suggests ways in which activities can be streamlined (Slack et al., 2016, p. 509). The four steps are:

1. **Value stream scope.** In this first step, the value stream (the process, operation, or supply chain) that is to be mapped is identified.
2. **Current state.** This second step involves physically mapping the process, then, above it, mapping the information flow that enables the process to occur. This is the so-called ‘current state’ map. The current state map must be based on a set of data collected directly on the shop floor (Braglia et al., 2006).
3. **Future state.** In this third step, problems and wastes are identified, and changes are suggested making a future state map that represents the improved process. The future state map is designed to represent the ideal production process without the removed wastes (Braglia et al., 2006).
4. **Improvement plan.** In this fourth and last step, the changes are implemented.

VSM can be implemented in any organization, to any activity of concern expanded from downstream to upstream around the organization. However, while developing the current state map, there is a possibility of committing mistakes which leads to new problem creation instead of solutions and benefits to the organization (Jasti et al., 2019). It looks simple to develop a current state map, but when the process lacks standardization, it is difficult to capture the reality (Jasti et al., 2019).

With respect to other mapping techniques, VSM offers several advantages and disadvantages (Braglia et al., 2006; Braglia et al., 2009). The advantages of VSM are:

1. It forms the basis for Lean manufacturing implementation.
2. It shows the linkage between product flow and information flow.
3. It relates the manufacturing process internal to the facility to the whole supply chain.
4. It includes information related to production time as well as information related to inventory levels.
5. It helps to visualize the production process at the plant level, not just at the single process level.

6. It links ‘Products Planning’ and ‘Demand Forecast’ both to ‘Production Scheduling’ and to ‘Flow Shop Control’, using operating parameters such as Takt Time, which determines the production rate at which each processing stage in the manufacturing system should operate.
7. It gives managers and employees the same tool and a common language to communicate. VSM is a universal language that can be communicated in the form of symbols (Jasti et al., 2019).
8. It constitutes the basis of a well-structured implementation plan.

Unfortunately, VSM has also some main disadvantages:

1. It is a paper- and pencil-based technique, thus the accuracy level is limited, and the number of versions that can be handled is low.
2. It cannot address the complexity of high-variety low-volume type companies, whose value streams are composed of hundreds of industrial parts and products.
3. It lacks the spatial structure of the facility layout and how that impacts interoperation materials handling delays.
4. It fails to show the impact of inefficient material flows on work-in-process (WIP), order throughput and operating expenses.
5. It can be effectively applied only to linear product systems, as it fails to map value streams characterized by multiple flows merging together.
6. It lacks the capability for a rapid development and evaluation of multiple what-if analyses that are required to prioritize different alternatives.
7. It cannot be applied to engineering processes due to fundamental differences between manufacturing and engineering methods.
8. It is unable to give a real vision of the variability problems concerning the production process analysed.

VSM is a relatively simple tool that can be used as the basis to implement Lean manufacturing. However, there are several drawbacks to VSM that make VSM difficult to use in certain organizations.

3.4 KANBAN

The Kanban system plays an important role in material flows. In Lean manufacturing, material handling systems must contribute to synchronous material flows (Domingo, 2007). When a component is used to manufacture a product, it generates a purchase order. This is called a pull system because the production orders flow from a finished good to raw materials. On the other hand, in push systems, the production orders flow from raw materials to finished goods. The tool used to create a pull system is called Kanban.

Kanban is the Japanese word for card or signal (Slack et al., 2016, p. 514), and it is a Lean manufacturing tool (Santos, 2014). It was created to control inventory levels, the production and supply of components, and in some cases, raw materials (Lage Junior, 2010). Each step of the production process must deliver its output to the following step so as to neither delay the start of the production at this step nor to create excess in progress inventory (Price, 1994). When an item is running low at an operational station, there will be a visual cue specifying how much to order from the supplier. The person using the parts makes the order for the quantity indicated by the Kanban, and the supplier provides the exact amount requested (Halton, 2021). Kanban controls the flow of resources in a production process by replacing only what has been consumed (Wang, 2019). Implementing Kanban can help you eliminate waste in handling, sorting, and getting your product to the customer on time, every time (Wang, 2019). An example of an application of a Kanban system is the 2-bin system discussed in Section 2.3.2, which is used at Nijhuis Toelevering.

There are five elements to the successful implementation of the Kanban method (Anderson, 2010; Al-Baik and Miller, 2015):

1. Visualize the workflow,
2. Limit the work-in-process (WIP),
3. Manage flow,
4. Make policies explicit, and
5. Implement feedback loops.

The Kanban system can be used easily within a factory, but it can also be applied to purchasing inventory from external suppliers. The Kanban system creates visibility to both the suppliers and buyers. One of its main goals is to limit the build-up of excess inventory at any point on the production line. Limits on the number of items waiting at supply points are established and then reduced as inefficiencies are identified and removed (Halton, 2021). So, Kanban helps to reduce waste on inventory and WIP. The Kanban system also has some restrictions: it is not adequate in situations with unstable demand, processing time instability, non-standardized operations, long setup time, great variety of items, and raw material supply uncertainty. Due to these restrictions, it is difficult to use the Kanban system in its original concept. In such situations, variations (or adaptations) to the Kanban systems (different from the "original") were created to adapt properly to companies' specific reality (Lage Junior, 2010). Examples of such Kanban variations are Adaptive Kanban, Auto-Adaptive Kanban, and Virtual Kanban (Lage Junior, 2010).

3.5 5S Methodology

The 5S theory is a methodology for organizing, cleaning, developing, and sustaining a productive work environment. Improved safety, ownership of workspace, improved productivity, and improved maintenance are some of the benefits of the 5S program (Wang, 2019). The 5S methodology is identified with five Japanese words (Santos, 2014). These are five pillars that are important to create a structured use of materials and improve the material flows within a process.

1. **First pillar: sort (seiri).** When applying this pillar, necessary elements and those that are not should be differentiated.
2. **Second pillar: set in order (seiton).** This pillar's objective is to be able to organize the necessary elements so that anyone can find them, use them, and return them to the same place after their use. The second pillar's main goal is to cut the time required for (or completely eliminate) material searches and facilitate the movement of objects through the factory. Some of the most common wastes are an inability to find a tool, to have a drawer with mixed and unordered components, etc.
3. **Third pillar: shine (seiso).** This pillar focuses on the necessary tasks to clean the working area. A clean working environment encourages discipline, efficiency and reliability (Chandrayan, 2019).
4. **Fourth pillar: standardized of visual control (seiketsu).** This pillar keeps active the three previously lister pillars. After the effort these three pillars suppose, one cannot let the work go to waste. In addition, detecting anomalies in the process becomes easier.
5. **Fifth pillar: sustain (shitsuke).** These new working procedures need to be enforced until they become a habit.

5S focuses on visual order, organization, cleanliness, and standardization, and it helps to eliminate all types of waste relating to uncertainty, waiting, searching for relevant information, creating variation, and so on. By eliminating what is unnecessary and making everything clear and predictable, clutter is reduced, needed items are always in the same place, and work is made easier and faster (Slack et al., 2016, p. 518).

The advantages of implementing the 5S methodology are as follows (Gomes, 2013; Dulhai, 2008):

1. Increase of the work productivity.
2. Decrease of the production costs.
3. Improved quality of products and services.
4. Increase of the workplace safety.
5. Greater personal satisfaction with the employer's own performance.

The disadvantages of implementing the 5S methodology are that it takes a relatively long period to implement, and along with implementation, decreases in work productivity may occur (Dulhai, 2008). The implementation of the 5S methodology is not easy, and there are several problems that can arise, such as: lack of understanding of the methodology, lack of cooperation from employees or failure of the transmission of necessary information for its correct application (Gomes, 2013).

3.6 Conclusion

In this chapter, we executed a literature review to gain insight into the relevant production improvement techniques for improving the materials flows at Nijhuis Toelevering. This chapter answers the third research question and its sub-question.

3. What are the relevant production improvement techniques for improving the material flows at Nijhuis Toelevering?

3.1 What are the pros and cons of the relevant production improvement techniques?

From the literature review, we found that the relevant production improvement techniques are Lean manufacturing tools. In particular, VSM, Kanban, and 5S. VMS helps to identify the wastes within a process regarding material and information flows. Kanban is visual control tool used to control the production and inventory anomalies. 5S is used to provide structured material use and flows within a process. These three theoretical concepts will be used within this research to improve the assembly process at Nijhuis Toelevering. The solutions to increase the assembly process's efficiency will be based on these three concepts, but they will be adapted to the corporate culture. Next to that, the advantages and disadvantages of the concepts need to be taken into account when applying them within the solution design.

4 PROBLEM ANALYSIS

In Chapter 2, we discussed the current assembly process at Nijhuis Toelevering, and in Chapter 3, we gathered information on production improvement techniques useful for this research. In this chapter, we analyse the current performance of the assembly process based on KPIs and time measurements. This chapter answers the fourth and fifth research questions.

4. What is the current efficiency performance of the assembly process at Nijhuis Toelevering?

5. What are the main causes of waste in the assembly process at Nijhuis Toelevering?

In Section 4.1, we analyse the performance of the assembly process based on the KPIs we discussed in Section 2.2. In Section 4.2, we analyse the performance based on time measurements carried out at assembly line 2. Based on this analysis, we identify the causes of time waste with the use of a Value Stream Map in Section 4.3. Next to the VSM, we also analyse the causes of waste using Spaghetti diagrams in Section 4.4. In Section 4.5, we discuss the important observations made while carrying out the time measurements. Section 4.6 summarizes the causes of waste within the assembly process. In Section 4.7, we will discuss the limitations of the KPI values and the time measurements. At last, Section 4.8 gives the conclusion to this chapter.

4.1 ANALYSIS OF KPIS

In Section 2.2, we discussed the eight KPIs currently used by Nijhuis Toelevering to evaluate the performance of the assembly process. In this section, we will evaluate these KPIs using the available data at Nijhuis Toelevering starting 2020 until 2021 week 20. The eight KPIs currently in place are:

1. Daily window frame output per assembly line
2. Weekly window frame output
3. Daily output rotating parts - doors
4. Daily output rotating parts - windows
5. Weekly output rotating parts
6. Realized number of production hours per week
7. Used man-hours per week
8. Weekly efficiency of the hours used

The daily window frame output per assembly line differs each day because every day, different series of window frames are assembled. Each series of window frames and each individual window frame takes a different amount of time to be assembled, which results in a fluctuating daily output. Since each line assembles different series of window frames during the day, the total output of window frames on one day also differs for each assembly line. This means that one assembly line can assemble 30 window frames on a particular day while another line assembles 60 window frames during that same day. Figure 4.1 shows the average daily output in 2020, 2021, and the overall average for each assembly line.

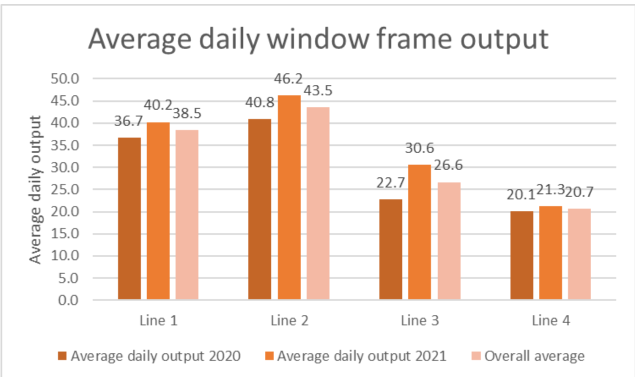

Figure 4.1: Average daily window frame output

Assembly lines 1 and 2 are identical and assemble the standard-sized window frames in larger batches, as explained in Section 1.2. Therefore, the average numbers of lines 1 and 2 are comparable. We can see that assembly line 2, on average, assembles more window frames than assemble line 1. Line 3 assembles special-sized window frames, which are mostly wider than three meters. These window frames that more time to assemble than the standard-sized window frame. Therefore, the average daily output of assembly line 3 is understandably lower than the output of lines 1 and 2. Line 4 is the shortest assembly line and assembles window frames for doors. This line is occupied by two employees instead of the seven employees at lines 1, 2, and 3. Therefore, the average daily output of line 4 is understandably lower than the output of lines 1, 2, and 3.

The average weekly output of window frames is, just like the daily output, dependent on the series of window frames that are scheduled to be assembled during a week. Some series contain larger and more complex window frames than other series, and some series contain more window frames to be assembled than others. That results in a fluctuating weekly output of window frames. The average weekly output of window frames assembled by all four lines is 549.4 window frames. Figure 4.2 shows the weekly output of window frames. Table 9.1 in Appendix B shows the corresponding values to Figure 4.2. The current norm of window frames that need to be assembled each week is 550 frames, which corresponds to 110 window frames a day. In Figure 4.2, we can see that the norm is not always 550 window frames due to holidays. From Figure 4.2, we conclude that overall, the norm of 550 window frames a week is reached. In order to reach the growing demand, Nijhuis Toelevering wants to increase the production rate by 50%. That means that the weekly output of window frames becomes 825 window frames. With the new norm of 825 window frames, Nijhuis Toelevering should be able to reach the growing demand.

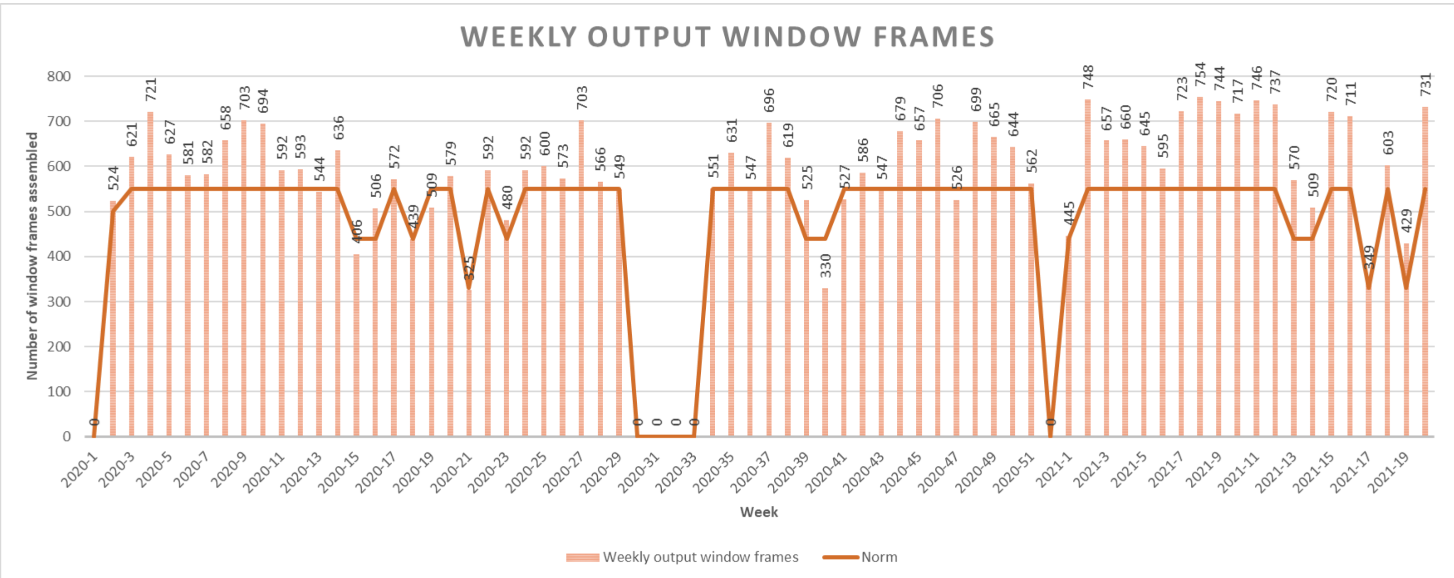

Figure 4.2: Weekly output window frames

The three KPIs, 'daily output rotating parts – doors', 'daily output rotating parts – windows', and 'weekly output rotating parts', are KPIs relating to the assembly rotating parts department and not with the assembly lines itself. The rotating parts are part of the internally produced supply and are delivered to the assembly lines. At the assembly lines, the rotating parts are assembled into the window frames. Therefore, these KPIs are not relevant for the evaluation of the performance of the assembly lines.

Like the previous KPIs that we discussed, the KPI 'realized number of production hours per week' also fluctuates each week. It fluctuates because each series of window frames has a different number of production hours attached to it. The average number of realized production hours per week is 2,495 hours per week. Table 9.2 in Appendix C shows the values of the realized production hours, the man-hours used, and the efficiency of the hours used. Figure 9.2 in Appendix C shows the realized production hours. Overall, no conclusion can be made on the realized production hours values because the relation of the production hours and the used man-hours is important since that shows how efficient the man-hours are used. The future goal of the 'realized production hours' is 3,000 hours per week.

The used man-hours are the number of employees times the hours they worked. Figure 9.3 in Appendix C shows the used man-hours. When comparing the Figure 9.2 and 9.3, we see that the graphs follow the same trend. When there is an increase in realized production hours, there is an increase in used man-hours as well. This indicates that the more man-hours used, the more production hours can be realized.

The weekly efficiency of the hours used shows how efficient the man-hour in relation with the production hours are used. Since the production hours fluctuate, the efficiency of the hours used fluctuates as well. The average efficiency of the hours is 112%. The weekly efficiency norm is 110%. Overall, this norm is reached except for a few weeks in the measurements. From these measurements, it can be concluded that the efficiency fluctuates a lot. In week 40 in 2020, we see a large decrease in efficiency of the hours used. In that week, the paint robots were installed at the paint shop. This caused a delay in production, and employees at the assembly line had to take two days off because the work could not continue. Therefore, this efficiency is lower than in other weeks.

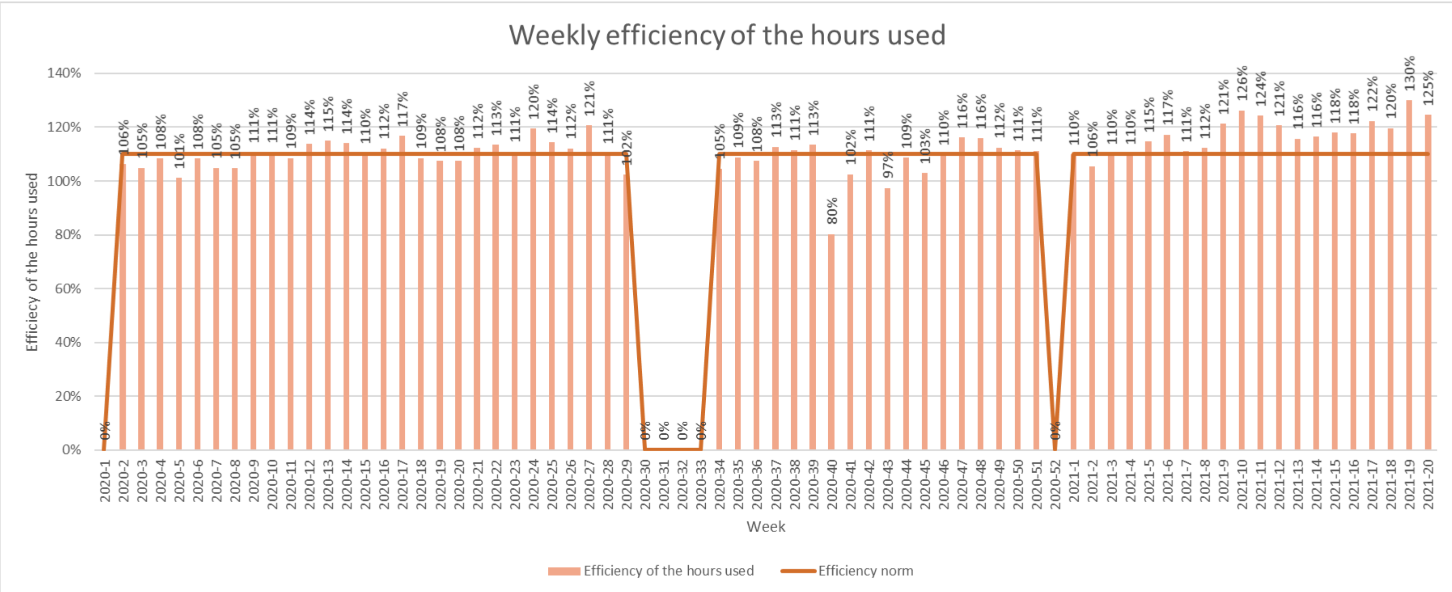

Figure 4.3: Weekly efficiency of the hours used

The analysis of the KPIs shows that overall, the assembly process reaches the norm values. The daily and weekly output are above the stated norm values. The efficiency on the hours used fluctuates a lot. This is caused by a high variety of different window frame series that are assembled. Each series has its own number of hours, and this causes fluctuations in efficiency. Overall, the current performance of the assembly process on the KPIs is sufficient based on the stated norms. This research aims to increase the efficiency of the assembly process, so that target norms for the KPIs can be reached.

4.2 TIME MEASUREMENTS

In order to identify the wastes in the assembly process at the assembly lines, we carry out time measurement at assembly line 2. The time measurements are conducted during a five-day period and are used to identify the percentage of the time spent on a window frame that is non-value-added (NVA) or waste. Next to that, the time measurements are used to identify other NVA or wasteful activities. The measurements required us to be physically present at the assembly line and measure the times using a stopwatch. Assembly line 2 is chosen as the research population for the time measurements because it is one of the two assembly lines that assemble standard-sized window frames. The choice for line 2 instead of line 1 is based on the position of line 2 in the production facility. Line 2 is centrally located in the assembly process. This central location ensures that we can use the time measurements from line 2 as a representative for the other assembly lines. Next to the central position, we also take the employees' experience at the assembly lines into account. Assembly line 2 has several employees with a lot of experience working at the assembly lines at Nijhuis Toelevering. No measurements are done on stations 3 and 7. Station 3 is a buffer within the assembly line, and no tasks are carried out at that station, so there are no measurements for this station. At station 7, the window frame is packaged for transport. The employee responsible for this also carries out many other tasks, such as placing the stillages with window frames outside the facility. Due to the uncertain nature of the tasks, it is difficult to measure the times. Next to that, station 7 does not add value to the window frame itself and therefore measuring times does not contribute to this research.

To identify the percentage of the time spent on a window frame that is NVA or waste, we need to know the cycle time per station in the assembly line. The cycle time can be defined as the average time between units of output emerging from a process (Slack et al., 2016, 186). So, it describes how much time a process takes. The cycle time includes both value-added (VA) times as well as non-value-added (NVA) times. At each station in the assembly line, the cycle time is the time it takes to carry out the tasks on one window frame. For example, station 1 starts with a window frame at 11:07:23 and moves the window frame to station 2 at 11:12:31; then the cycle time is 5 minutes and 8 seconds. Table 4.1 shows the minimum, maximum, and average cycle times for each station of assembly line 2. Table 4.1 also shows the standard deviation of the cycle times and the Coefficient of Variation values. The Coefficient of Variation for each station is about 50% or higher. This means that the standard deviation shows a large spread of measurements. This spread in cycle times is caused by the high variety in window frames that are assembled at the assembly lines.

Table 4.1: Window frame cycle times stations assembly line 2

	Min Time (mm:ss.ms)	Average Time (μ) (mm:ss.ms)	Max Time (mm:ss.ms)	Standard Deviation (σ) (mm:ss.ms)	Coefficient of Variation (σ/μ*100)
Station 1	03:40.0	07:48.9	18:48.0	04:01.7	51%
Station 2	01:23.0	06:01.8	09:57.0	03:01.9	50%
Station 4	04:02.0	10:35.2	25:20.0	06:34.9	62%
Station 5	03:33.0	06:18.1	11:54.0	02:55.8	46%
Station 6	03:07.0	05:20.6	10:23.0	02:22.1	44%

Next to the cycle times, we also need to know the NVA time within the cycle times. This NVA time consists of all the time when an employee does not add value to the window frame while assembling it. Let us take the example mentioned above, where the cycle time is 5 minutes and 8 seconds. These 5 minutes and 8 seconds contains both the VA and NVA time. The employee at station 1 spends, for example, 33.9 seconds on getting materials for the window frame, which means that these 33.9 seconds are part of the NVA time. While measuring the cycle times at the stations, we simultaneously measure the NVA time. Table 4.2 shows the minimum, maximum, and average non-value-added (NVA) times for each station of assembly line 2.

Table 4.2: Window frame non-value-added (NVA) times stations assembly line 2

	Min Time (mm:ss.ms)	Average Time (mm:ss.ms)	Max Time (mm:ss.ms)
Station 1	01:15.7	02:37.7	05:33.7
Station 2	00:33.9	01:30.6	03:05.9
Station 4	00:53.5	03:53.7	08:21.9
Station 5	00:19.6	00:37.7	01:30.3
Station 6	00:30.2	00:49.7	01:17.0

Based on the average cycle times and NVA times, the percentages of NVA time in the cycle times are determined. Table 4.3 shows the percentage for each station in assembly line 2. Comparing the percentages is difficult since each station performs different tasks, except for stations 5 and 6. Stations 5 and 6 are the stations where the sealant is added to the inner side and the outer side of the window frame. Since the tasks at stations 5 and 6 are the same, the NVA percentage for these two stations should be similar. From Table 4.3, we see that at station 5, the NVA time is 10.0%, and at station 6, it is 15.5%. This indicates that at station 6, a higher proportion of the time is NVA. Station 6 performs the same tasks as station 5, however, there are some small tasks that are performed at station 6 that are not performed at station 5. There are little stickers on the outer side of a glass panel to protect the panel against damage during transport. During transport, multiple panels are placed against each other on a stillage. The stickers make sure that the different panels can be placed against each other without them actually touching and thereby prevents the panels from damaging. These little stickers need to be removed at station 6, causing a higher NVA time.

Furthermore, from Table 4.3, we see that at stations 1, 2, and 4, over a fourth of the time spent is NVA. Although comparing stations with each other is difficult due to the different tasks being performed, the NVA times at stations 1, 2, and 4 are much higher than at stations 5 and 6. To draw conclusions on this, we look at the activities included in the NVA time and examine the amount of time each of these activities takes.

Table 4.3: Percentages non-value-added (NVA) times in cycle times stations assembly line 2

	Percentage non-value-added time in cycle time (%)
Station 1	33.6
Station 2	25.0
Station 4	36.8
Station 5	10.0
Station 6	15.5

While executing the time measurements, we measured the amount of time the NVA activities take. Each station has different activities included in the NVA times. Table 9.3 in Appendix D shows all possible activities that can be included in the NVA times. Depending on the series of window frames that is assembled, the NVA activities can differ. Some series, for example, include the assembly of ventilation grills, other series do not include ventilation grills. Next to the possible NVA activities per station, the average duration of these activities and the percentage of the NVA times they take up are included in Table 9.3. Figure 4.4 shows the division of the cycle times at each station of assembly line 2 into VA and NVA times and the subdivision of the NVA times. We base the allocation of the NVA activities on observations made while executing the time measurements.

At station 1, three main activities are included in the NVA times. These are 'getting materials from materials cart', 'new window frame on tilt table', and 'picking up rotating parts from the buffer'. 'Getting materials from materials cart' includes walking to the materials cart, which is located next to station 1, searching for the right materials, and walking back. 'New window frame on tilt table' describes the activity of using the overhead crane to tilt a window frame from the stillage onto the tilt table. In some cases, when the window frames are smaller, the two employees at station 2 carry the window frame onto the tilt table and do not use the overhead crane. 'Picking up rotating parts from the buffer' describes the activity of retrieving necessary rotating parts from the buffer. Next to these three main activities, the NVA time also included other more minor activities that are hard to measure. Therefore, these small activities are included in the 'other' activity. This 'other' activity includes activities such as getting nails, walking around the window frame and reviewing the technical drawings of the frame.

At station 2, two main activities and the 'other' activity are included in the NVA times. The main activities are 'getting rotating parts for window frame' and 'getting materials from material cart'. 'Getting rotating parts for window frame' describes the activity of walking to the rotating parts cart, located next to station 2, to retrieve the right rotating part. 'Getting materials from material cart' describes the activity of walking to the materials cart to retrieve the window frame specific materials. The 'other' activity includes walking to the 2-bin system to retrieve materials such as nails, hinges, and fittings.

At station 4, seven main activities and the 'other' activity are included in the NVA times. 'Searching for glazing beads' describes the activity of searching for the right glazing beads within the bin, located next to station 4. Each set of glazing beads includes four separate glazing beads connected with staples. 'Removing glazing beads staples' describes the activity of removing the staples in order to retrieve the separate beads. Each separate glazing bead must be provided with glass tape. 'Add glass tape to glazing beads' describes this activity. 'Getting glass panel' describes the activity of searching and retrieving the right glass panels for the frames from the stillages next to station 4. 'Searching and unpacking ventilation grille' and 'searching and unpacking rods' describe the activities of searching the right grille or rods on the materials cart and unpacking it. 'Replace sealant gun' describes the activity of an empty sealant tube with a new one. At station 4, sealant is used to fasten the glazing beads. Next to that, the glazing beads are also fastened with the use of a nail gun. The 'other' activity includes activities such as refilling the nail gun and retrieving the sealant gun. In comparison with the other stations, station 4 has substantially more NVA activities.

At stations 5 and 6, two main activities and the 'other' activity are included in the NVA times. The main activities are 'replace sealant gun' and 'searching an unpacking rods'. 'Replace sealant gun' describes the activity of an empty sealant tube with a new one. 'Searching and unpacking rods' describes the same activity as described at station 4. This activity is not included at station 5 since it is already carried out at station 4. At station 6, sealant is added to the outer side of the window frame. This outer side cannot be reached at station 4, and therefore the rods need to be added at station 6. Whether rods need to be added at stations 4 and 6 depends on the specifications of the window frame. The 'other' activity includes activities such as cleaning the sealant gun and removing stickers from the glass panel.

From the analysis of the NVA times included in the cycle times, we see that most of the NVA times are emerging at stations 1, 2, and 4 due to the large set of activities carried out at those stations. We also see that the NVA times primarily include activities concerning the retrieval of materials for the window frame assembly. Therefore, walking towards and searching for materials form the main cause of the NVA times. From the observations, a lack of structure in material placement is identified as the main cause for the employees having to search for materials.

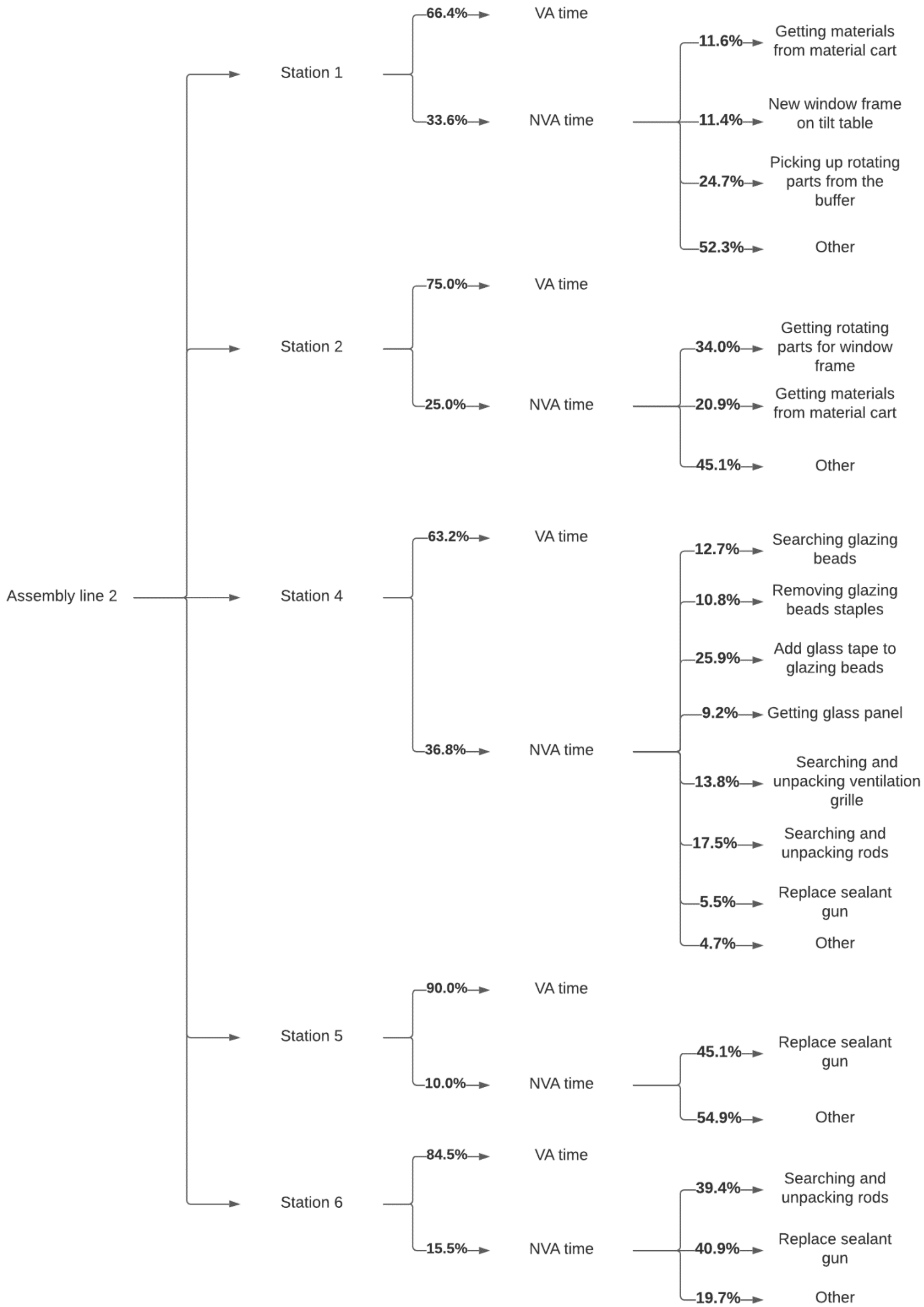

Figure 4.4: Division of the cycle times in value-added and non-value-added times

Next to the NVA times within the cycle times, there are also activities that are NVA that are not included within the cycle times of the window frames. Table 4.4 shows these activities and their average duration. At station 1, these activities are 'picking up new stillages window frames from the buffer' and 'returning empty stillages window frame to buffer paint shop'. At station 2, these activities are 'picking up carts rotating parts from the buffer' and 'returning empty carts rotating parts to buffer paint shop'. At station 4, these activities are 'picking up glazing beads bin from buffer paint shop' and 'returning empty glazing beads bin to buffer paint shop'. These activities include the retrieval and return of internally produced supply. From Table 4.4, we see that picking up the internally produced goods on average takes longer than returning the stillages, carts, and bins to the buffer paint shop. While executing the time measurements, we noticed that the search for these internally produced goods takes relatively a lot of time. From the time measurements and the observations at the assembly line, we estimate that about one-third of the time to retrieve the materials is used to locate them. A lack of structure in material placement in the production facility causes the search for materials. For example, there is no structure where the stillages with window frames for each assembly line are placed in the buffer.

To be able to compare the values of Table 4.4, we calculate the average total duration per day of these activities. The average total duration is calculated by the average duration times the average number of times the activity occurs each day. On average, three window frames are placed on one stillage. Assembly line 2 assembles on average 46 window frames per day. So, about 15 (46/3) times a day, a stillage with window frames is picked up from the buffer by an employee of station 1. That means that the average total time spent retrieving stillages takes 30 minutes and 28 seconds per day. The empty stillages are brought back to the buffer paint shop by the employees of station 1. This activity also occurs about 15 times a day. So, the average total time spent on returning the empty stillages takes 13 minutes and 42 seconds.

Picking up and returning the carts with rotating parts occurs on average six times a day. This results in an average total time spent picking up the carts of 8 minutes and 52 seconds a day. The average total time spent returning the carts takes 8 minutes and 49 seconds a day. Picking up the glazing beads bins occurs on average two times a day. So, the average total time spent picking up the glazing beads takes 5 minutes and 58 seconds a day. Returning the bins also occurs about two times a day, and this results in a total time spent of 3 minutes and 36 seconds.

Table 4.4: Non-value-added (NVA) activities outside cycle times

Station	Activity	Average duration (mm:ss.ms)	Average total duration per day (mm:ss.ms)
Station 1	Picking up new stillage window frames from the buffer	02:01.9	30:28.5
	Returning empty stillage window frames to buffer paint shop	00:54.8	13:42.0
Station 2	Picking up cart rotating parts from the buffer	01:28.8	08:52.8
	Returning empty cart rotating parts to buffer paint shop	01:28.2	08:49.2
Station 4	Picking up glazing beads bin from buffer paint shop	02:59.3	05:58.6
	Returning empty glazing beads bin to buffer paint shop	01:48.0	03:36.0

From the analysis of the time measurements, we conclude that the main cause of NVA time is walking towards and searching for the necessary materials. These NVA times both occur while assembling window frames, so included in the cycle times and outside the cycle times. At stations 1 and 4, the NVA times contribute over 30% to the cycle times. At station 2, the NVA times contribute about one-fourth (25%) to the cycle times. The NVA times at stations 5 and 6 contribute the least to the cycle times. Next to the NVA times included in the cycle times, NVA activities also occur outside the cycle times.

4.3 VALUE STREAM MAP

In Section 3.3, we discussed Value Stream Mapping as a tool to implement Lean manufacturing by helping to identify the value-added (VA) steps and eliminating the non-value-added (NVA) steps and the waste (W). In this section, we create a VSM following the steps in the assembly process. In Section 3.3, we also discussed the disadvantages of VSM. One of these disadvantages is that VSM cannot address the complexity of high-variety low-volume type companies. The production at Nijhuis Toelevering lies in the category high-variety low-volume. The value stream at Nijhuis Toelevering is composed of many parts and products coming together at the assembly process, and therefore it is hard to make a detailed VSM. The VSM applied to the assembly process at Nijhuis Toelevering can be seen in Figure 4.5. The VSM consists out of the seven stations of the assembly process.

The VSM is made to map the assembly process in combinations with the material and information flows. In order to make the VSM not too complex or extensive, we only mapped the steps within the assembly process. The cycle times stated within the VSM are the same as the cycle times from Section 4.2. Due to a great variety in produced window frame types, the cycle times vary quite a lot. In the VSM, we use the average cycle time as the starting point. In Section 4.7, we discuss the limitations of the time measurement. In this section, we also discuss that using averages can give a deceiving image of reality.

The value stream starts at the moment production control receives an order from a customer. Production control then makes a production order, and the necessary materials are either ordered at the material suppliers or are internally produced. The material suppliers deliver the ordered materials at the sorting centre, and the sorting centre delivers these materials at the assembly lines. The internally produced goods are directly delivered to the assembly lines. Section 2.3 describes the different material flows in detail. At the assembly lines, the materials are assembled within the window frame. Section 2.2 describes the assembly process and the different stations in detail. At the end of the assembly process, the window frames are packaged at station 7 and picked up for transport to the customer.

In the VSM, we see that the average cycle times of stations 1, 2, 5, and 6 are relatively similar. The cycle time at station 4 is substantially higher. In Section 4.2, we saw that the NVA times of station 4 contain more activities than the NVA times at the other stations. This causes a higher cycle time at station 4. The higher cycle time theoretically indicates that station 4 is the bottleneck within the assembly line. The VSM, however, is based on the averages and to indicate the bottleneck, we need to take the practical situation into account. While observing the assembly line, we saw that each station in the line can become the bottleneck at some point, depending on the types of window frames that are assembled. Some window frames are more difficult for, for example, station 1 to assemble than for station 5. In Section 4.5, we discuss this further.

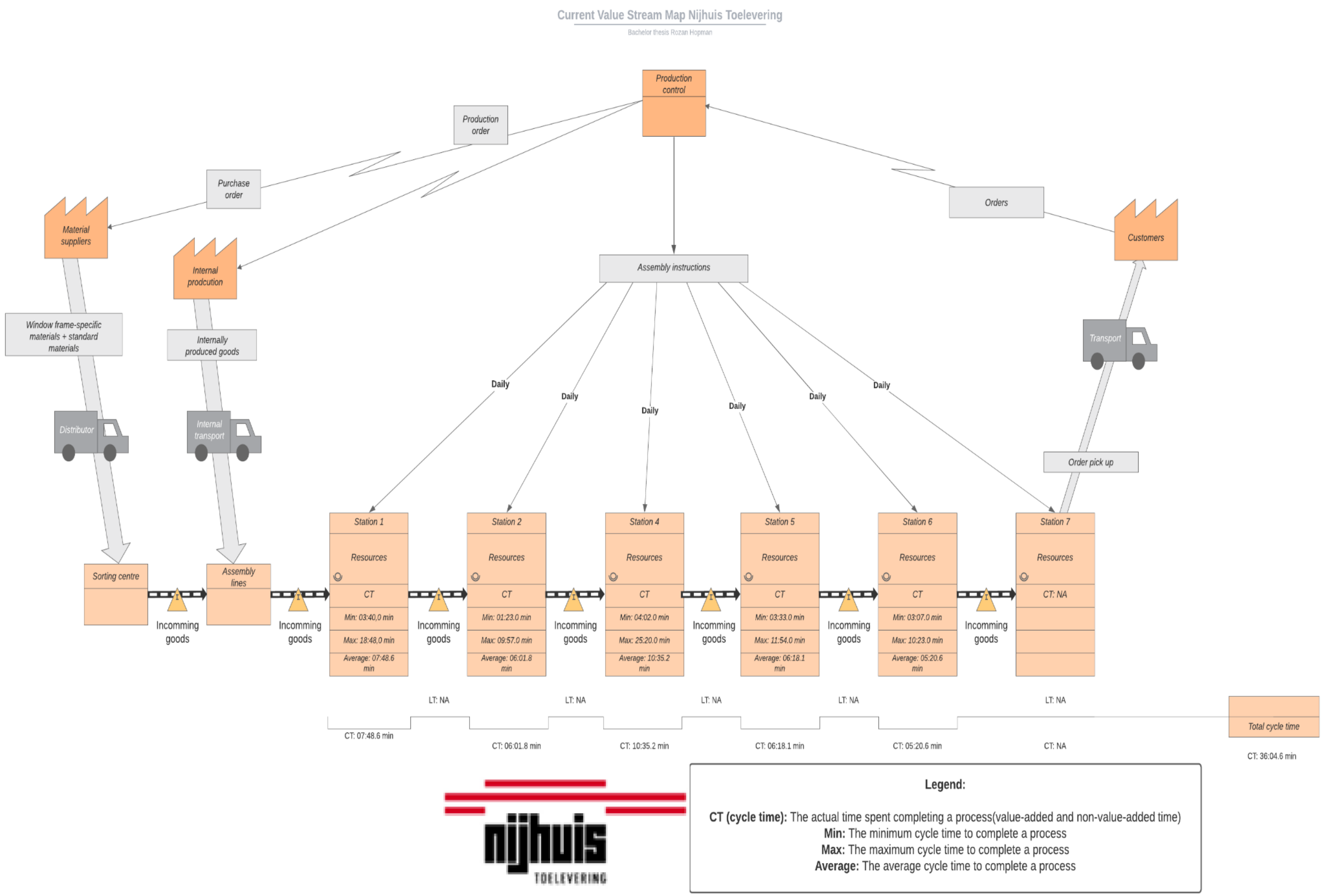

Figure 4.5: Value Stream Map assembly process at Nijhuis Toelevering

4.4 SPAGHETTI DIAGRAMS

In the previous sections, we saw that most of the NVA times are caused by walking towards and searching for the necessary materials. To analyse the material flows and the walking paths of the employees, we create two Spaghetti diagrams. One Spaghetti diagram illustrates the materials flows through the production facility and the other Spaghetti diagram illustrates the employee walking paths through the production facility. A Spaghetti diagram is a Lean tool used to identify wastes within a process (Senderska et al., 2017). With the use of a Spaghetti diagram, we can visualize and analyse the movement of resources through the production facility (Senderska et al., 2017). We gathered the information used to create the spaghetti diagrams during interviews and observing the assembly process.

4.4.1 Materials flows

In Section 2.3, we discussed the different material flows within the assembly process at Nijhuis Toelevering. Figure 4.6 shows the Spaghetti diagram of the material flows of the assembly process. In order to make this Spaghetti diagram not too complex, only the key material flows are mapped. In Figure 4.6, each different colour represents a different material stream. The dots in Figure 4.6 represent places where the materials are stored for different amounts of time.

The blue lines represent the material flow of window frame-specific materials. External suppliers deliver these materials to the sorting centre. The materials are placed on carts and moved to the 'material carts' area. The carts with materials move from there towards station 1 of the assembly lines. Once the carts are empty, they return to the 'material carts' area.

The yellow lines represent the flow of glass panels. The glass panels are delivered by an external supplier at the sorting centre and are placed in the 'sorting glass panels' area. When the glass panels are needed at the assembly lines, they are moved from the 'sorting glass panels' area to station 4 at the assembly lines. The empty stillages are moved outside the facility, where the external supplier picks them up.

The red lines represent the flow of window frames. The window frames that need to be assembled are placed in the buffer by the paint shop employees. Once they are needed, the stillages with window frames are picked up and moved to station 1 of the assembly lines. The window frames move over the assembly line, and when finished, they move outside the facility, where they are picked up and transported to the customer by an external distributor. The empty stillages move from station 1 back to the buffer and then to the buffer paint shop.

The purple lines represent the flow of rotating parts. The rotating parts are stored in the buffer and picked up by the employees of the assembly rotating parts department. Once they finish assembling the rotating parts, the employees return the parts to the buffer. When one of the assembly lines needs certain rotating parts, then station 1 or 2 employees pick up the carts with rotating parts from the buffer. At station 1 or 2, the rotating parts are assembled within the window frames. The empty carts are afterwards returned to the buffer paint shop by the assembly line employees.

The orange lines represent the material flow of standard materials. The standard materials are delivered to the sorting centre by an external supplier. A sorting centre employee checks the incoming materials and brings them to the 2-bin system at station 2 of the assembly lines.

The green lines represent the flow of glazing beads. The glazing beads are stored in the buffer paint shop, and when needed, the employee at station 4 picks up the glazing beads bins and brings them to the assembly line. The glazing beads are assembled within the window frame, and the empty bins are returned to the buffer paint shop by the assembly line employees.

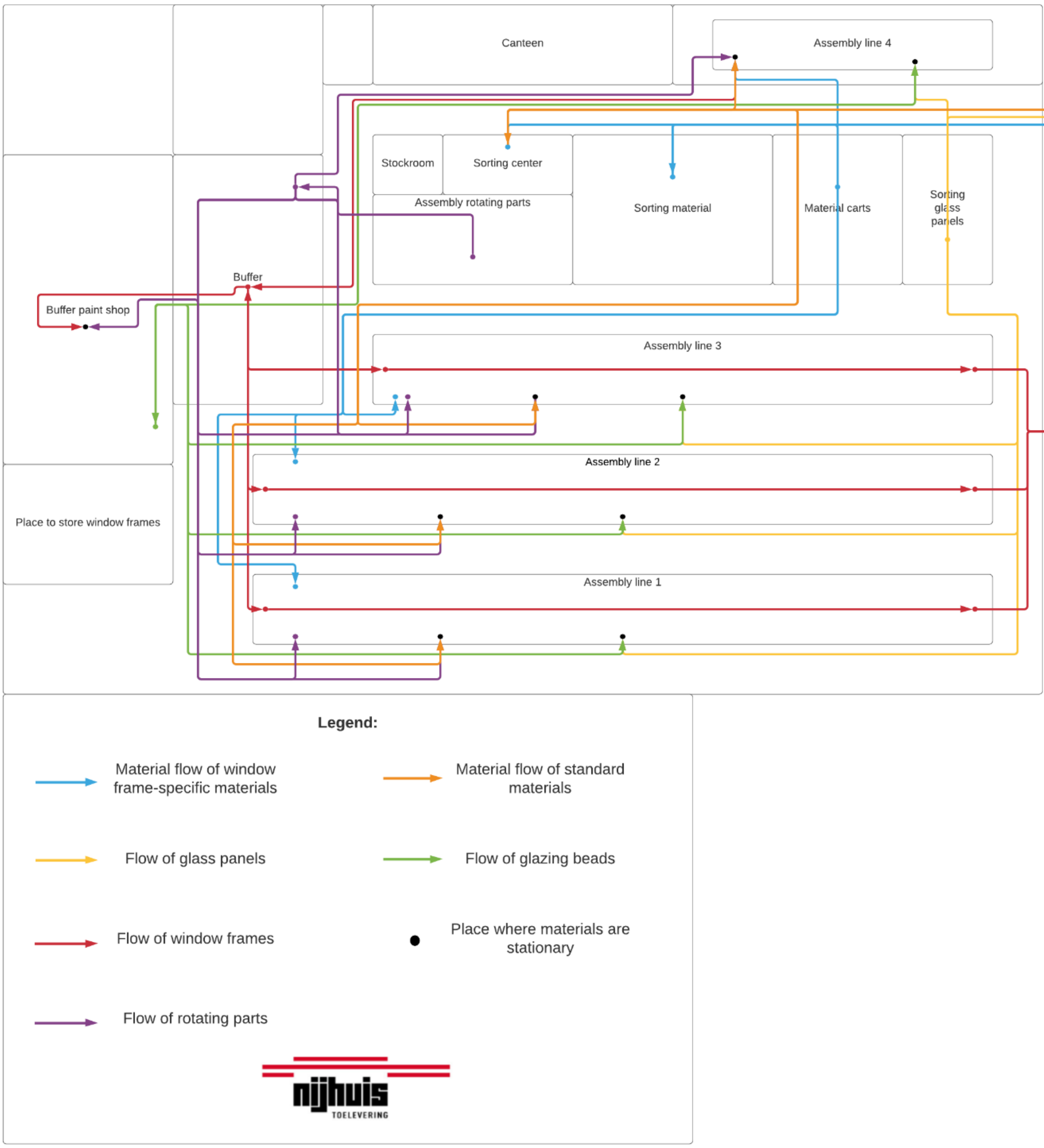

Figure 4.6: Spaghetti diagram material flows assembly process

The Spaghetti diagram in Figure 4.6 shows that the different materials move through the facility a lot. The materials are not automatically moved through the facility, so an employee has to take the materials to the right place every time. Except for the glass panels and the specific material carts, all the materials are picked up by the employees of the assembly lines. In Section 4.2, we saw that quite some time is spent on walking towards and searching for materials. The Spaghetti diagram in Figure 4.6 shows the movements causing the NVA times at the stations of the assembly lines.

4.4.2 Employee walking paths

In Section 4.4.1, we see that the employees walk a lot through the production facility to retrieve materials. To be able to completely analyse the movements of the employees at the assembly lines, we create a Spaghetti diagram of the walking paths of the employees at assembly line 2. Figure 4.7 shows this Spaghetti diagram. The information for this diagram is gathered while executing the observations and conducting the time measurements at assembly line 2, therefore the diagram only depicts assembly line 2.

In Figure 4.7, the red lines represent the walking paths of station 1 employee 1, and the dark green lines represent the walking paths of station 1 employee 2. The orange lines represent employee station 2, and the purple lines represent employee station 4. At last, the yellow and blue lines represent the walking paths of the employees of stations 5 and 6, respectively.

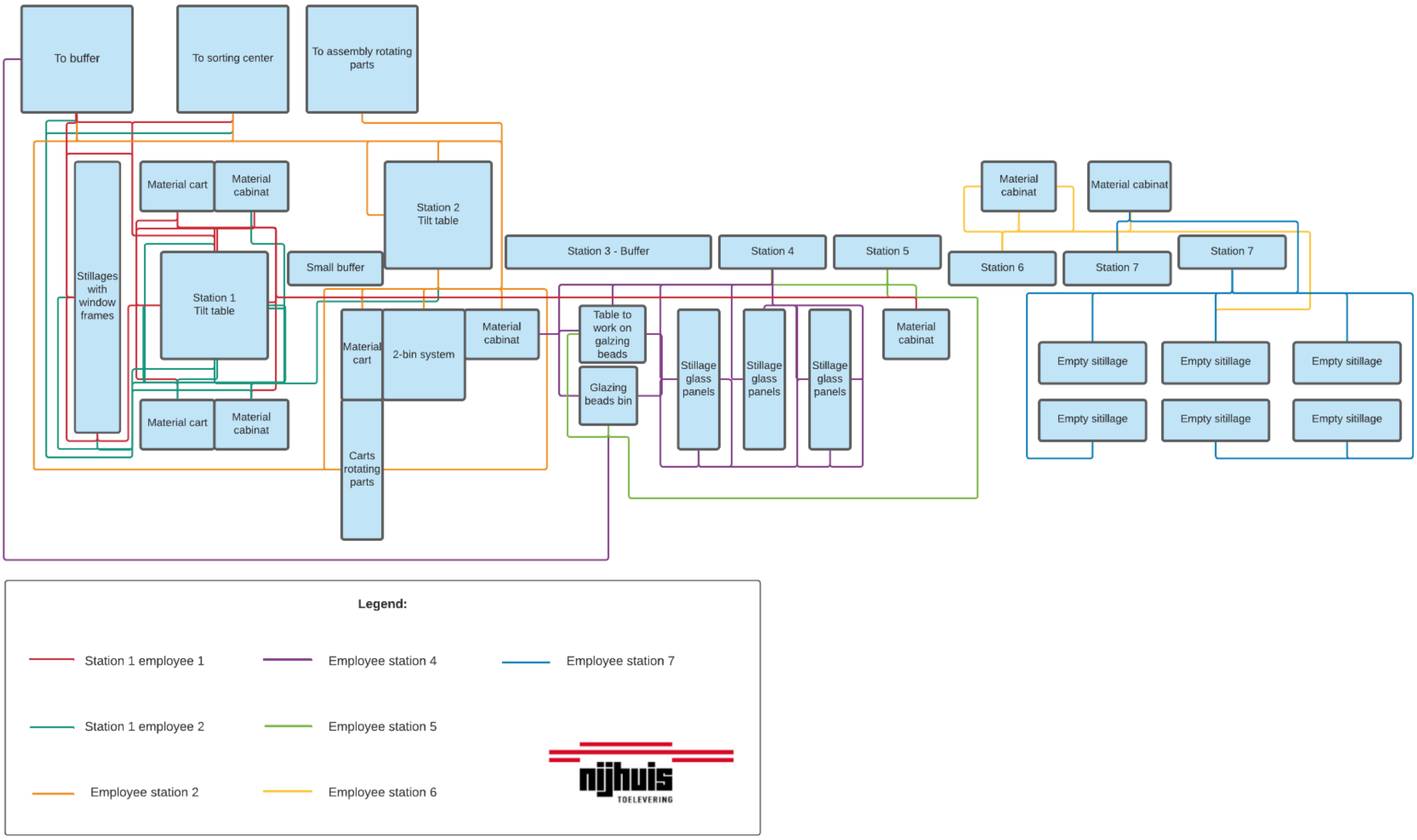

Figure 4.7: Spaghetti diagram employee walking paths assembly line 2

In the Spaghetti diagram in Figure 4.7, we see that at stations 1, 2, and 4, many walking paths emerge. At station 1, the employees mostly walk around the tilt table and towards the material carts and cabinets. Next to that, the employees often walk to the buffer to pick up stillages with window frames and to the sorting centre if necessary.

At station 2, the employee walks around the tilt table to reach all the sides of the window frame. The employee also walks to the material carts and cabinets. These walking paths emerge quite often since the employee needs to retrieve materials and bring them to the window frame. Next to the walking paths relatively close to the window frame, the employee walks to the buffer to pick up rotating parts, to the sorting centre to pick up materials if they are not delivered to the line, and to the assembly rotating parts department in case something is wrong with the rotating parts. Walking to the buffer occurs most frequently at station 2.

At station 4, we see a lot of movement relatively close the window frame to retrieve materials, such as the glazing beads and the glass panels. The employee also walks to the buffer to retrieve the glazing beads. The walking paths emerge often and are relatively short in nature, but when repeated, this adds up to a considerable distance.

At stations 5, 6, and 7, there is less movement than at the other stations. At these stations, no materials need to be retrieved from, for example, the buffer. The employees stay relatively close to the window frame. The employee at station 5 also helps at station 4 if needed, so then his walking paths collide with the walking paths of the employee of station 4.

Overall, from the Spaghetti diagrams, it can be concluded that there are many movements of both materials and employees through the production facility. These movements are considered to be waste by the Lean principles. At the assembly line itself, we see many employee movements at stations 1, 2, and 4. These movements all concern the retrieval of materials and bringing them to the window frame.

4.5 IMPORTANT OBSERVATIONS

This section discusses three observations that cannot be expressed using cycle times or NVA times. These observations were made while conducting the time measurements. These observations are essential because they describe inefficiencies within the assembly process that are not visible within the time measurements or KPIs. These events can only be noticed by being physically present at the assembly process and, in this case, at assembly line 2.

The first important observation concerns *the production planning at the assembly lines.* As mentioned before, each series of window frames consists of different types of window frames. Some window frames have two glass panels, and others have four glass panels. Some window frames include rods, and others do not. Window frames that include rods require more time at stations 5 and 6 because rods divide the glass panel into smaller squares that all need to be provided with sealant. It takes more time to add sealant to four squares instead of one square. On day x of conducting the time measurements, assembly line 2 had to assemble a series of window frames that included a lot of rods. The employees at stations 5 and 6 had difficulty keeping up with the pace of the rest of the assembly line due to the rods being more work and taking more time. Eventually, the assembly line stagnated, and stations 1, 2, and 4 could not start with a new window frame because they could not move the window frame to the right place. On day x + 1, assembly line 2 had to assemble a series of window frames without rods. This was relatively easy work for the employees at stations 5 and 6. However, station 1 could not keep up with the pace of the rest of the assembly line. Meaning that stations 2, 4, 5, and 6 worked faster than station 1, resulting in these stations not having any window frames to assemble. At this moment, the assembly line was nearly empty. So, one day the line completely stagnates because of the heavy work for stations 5 and 6 and the next day, the line is almost empty because station 1 cannot keep up with the overall pace of the line. This is a large inefficiency because, on both days, several stations cannot continue assembling window frames. The production planning does not take the difficulty of the window frame series into account. Next to that, the production planning also does not schedule on which line which series of window frames will be assembled. Therefore, the materials cannot be arranged according to the assembly lines. This relates to the lack of structure in material placements we discussed in Section 4.2.

The second observation concerns *the sealant and nail guns.* The sealant and nail guns work on air pressure. For this, the sealant and nail guns are connected to an air hose (Dutch: lucht slang). At station 4, the sealant and nail gun are both used, but there is only one air hose present. This means that the employee at station 4 needs to connect the sealant gun to the air hose when he wants to use it. If he after using the sealant gun needs to use the nail gun, he needs to disconnect the sealant gun from the air hose and connect the nail gun. This is a relatively easy task, but it does take time. Next to that, the air hoses are present at stations 1, 4, 5, and 6 and they sometimes obstruct the employee from easy reaching the place where they need the sealant or nail guns.

The third observation concerns *the occupation of station 1 at assembly line 2.* On two days within the five-day period, the employee at station 1 occupied station 1 alone. Normally, station 1 is occupied by two employees. This low occupation of station 1 causes more work for the single employee at station 1 and more walking around the window frame to reach all sides. Because of this, a lot more time is wasted on walking to get the materials to the right side of the window frame.

4.6 PROBLEMS AND CHALLENGES

In the process of analysing the KPIs, a better insight into the current performance of the assembly process at Nijhuis Toelevering is created. By conducting the time measurements and making the Value Stream Map and Spaghetti diagrams, the wastes within the assembly process related to the core problem, "*There is an uncertain availability of materials at the assembly lines*", were able to be identified. The main problems and challenges, resulting from the analysis in this chapter, are:

1. **Employee walking paths**
   When it comes to the retrieval of materials, a lot of walking takes place to reach the materials. The employees of the assembly lines retrieve all materials themselves, except for the standard and window frame-specific materials and the glass panels. The retrieval of materials takes time that is not spent on assembling window frames.
2. **Lack of structure in material placement**
   As mentioned above, the employees of the assembly lines retrieve almost all materials themselves. From the observations and interviews conducted at the assembly process, it can be concluded that the search for the right materials takes a significant amount of time. A lack of structure in the placement of materials within the production facility causes the employees to search for materials instead of just picking them up.
3. **Production planning**
   The production planning does not take the difficulty of window frames into account. This causes inefficiencies in the assembly lines because some stations may have too much work and other stations too little. Next to that, the production planning does not schedule on which line which series of window frames will be assembled. Therefore, the materials cannot be arranged according to the assembly lines. This relates to the lack of structure in material placement.

Figure 4.8 shows the three main problems and challenges in an impact/effort matrix. Challenges 1 and 2 do not require much effort in order to be solved and have a high impact on the efficiency of the assembly process. Solving challenge 3 requires more effort but also has a higher impact than solving challenges 1 and 2. For these three challenges, we discuss potential solutions in Chapter 5, and in close consideration, with Nijhuis Toelevering, one solution or a set of solutions is chosen to write an implementation plan for.

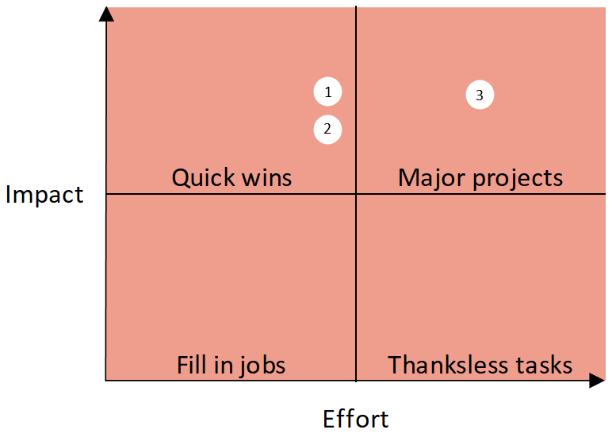

Figure 4.8: Impact/effort matrix

In Chapter 5, we discuss potential solutions to the three challenges mentioned above. We discuss all the potential solutions instead of only the chosen solution, because during this research a lot of knowledge is gained on the three challenges and it would be a waste not to use this knowledge. In Chapter 6, we choose one solution or a set of solutions for which we write an implementation plan in Chapter 7.

4.7 Limitations of the measurements

Due to the time constraint of this research, we took five days to perform the time measurements. These five days are taken as a representative of the overall process. Because of the time constraint, we decided to perform measurements at assembly line 2. Therefore, line 2 is taken as a representative for the other assembly lines. These limitations of the measurements need to be taken into account in the decision-making process.

For the time measurements, we used direct observation because we were physically present at assembly line 2. This physical presence means that the employees at the assembly line were aware of the measurements taking place. This could threaten the reliability of the measurements because when the employees notice the measurements taking place, they could start to work harder or differently. Although we have not noticed a behavioural difference while observing the assembly line and measuring the times, this reliability threat needs to be considered in the decision-making process. To minimize this threat, the employees were only notified that measurements were to be carried out and not on when the measurements were taken place, so they could not prepare anything.

A weakness of direct observation is that it can be challenging for the observer to observe everything when events move quickly, reducing the accuracy of the observations (Cooper and Schindler, 2014, p. 177). To minimize information overload, we choose to focus on one or two stations simultaneously instead of on the whole assembly line at once. The focus on one or two stations simultaneously can result in missing information from other stations. To reduce the effect of missing information, we conducted measurements on multiple days and return to stations multiple times.

In Section 4.2, we used averages durations to compare the time measurements. In practical situations, there is a lot of variety in the time it takes to execute certain activities. The variety is visible in the measurements with the minimum and maximum observation times. Using averages can give a deceiving image of reality. Due to the time restrictions of this research, a statistical analysis of the data is out of the scope of this research. The flaw of averages and the high variety in time it takes to execute activities must be taken into account in the decision-making process by the management of Nijhuis Toelevering.

4.8 CHAPTER CONCLUSION

In this chapter, we analysed the efficiency of the assembly process at Nijhuis Toelevering by answering the fourth and fifth research questions.

4. What is the current efficiency performance of the assembly process at Nijhuis Toelevering?

The current efficiency performance is evaluated with the use of the KPIs already in place at Nijhuis Toelevering. The analysis shows that overall, the current performance of the assembly process based on the KPIs reaches the stated norms. The daily and weekly output are above the stated norm values. The efficiency on the hours used fluctuates a lot. This is caused by a high variety of different window frame series that are assembled. Each series has its own number of hours, and this causes fluctuations in efficiency. In the future, the norm values will be reviewed and changed according to the changes made to the assembly process.

5. What are the main causes of waste in the assembly process at Nijhuis Toelevering?

The causes of waste in the assembly process are identified by observing and conducting time measurements at assembly line 2. The outcomes from these observations and time measurements are analysed, and a VSM and two Spaghetti diagrams are made. From the problem analysis in this chapter, it is concluded that most of the waste within the assembly process at Nijhuis Toelevering is caused by walking towards and searching for materials. We identified three problems and challenges that can be resolved during this research: the employee walking paths, the lack of structure in material placement, and the production planning.

For these three challenges, we discuss potential solutions in Chapter 5, and in close consideration with Nijhuis Toelevering, one solution or a set of solutions is chosen, for which to write an implementation plan. Chapter 6 discussed the chosen solution or the chosen set of solutions.

5 IMPROVEMENT OPTIONS

This chapter describes the potential solutions to the three challenges stated in Section 4.6 by answering the sixth research question.

6. Which possible improvement actions can be formulated based on the current material flows and the new insights?

The potential solutions are based on the insights gained during this research and the Lean manufacturing principles and tools we discussed in Chapter 3. There are no solutions that target stations 5 and 6 of the assembly lines. At the moment of conducting this research, Nijhuis Toelevering is researching a technique called 'dry glazing' (Dutch: droog beglazen). With this technique, the glass panels are fastened using a rubber profile instead of sealant. These developments are out of the scope of this research, and therefore Nijhuis Toelevering wants the solutions to focus on stations 1, 2, and 4.

Section 5.1 discusses the potential solutions to the employee walking paths challenge. Section 5.2 discusses the potential solutions to the lack of structure in material placement, and Section 5.3 discusses the potential solutions to the production planning challenge. Section 5.4 describes other potential solutions that do not target one of the three challenges. At last, Section 5.5 gives the conclusion to this chapter. In Chapter 6, the potential solutions are evaluated based on the requirements of Nijhuis Toelevering.

5.1 EMPLOYEE WALKING PATHS

As discussed in Chapter 3, excessive transportation and unnecessary motion are wastes according to the Lean philosophy. In Chapter 4, we concluded that the walking paths of employees through the production facility are waste within the assembly process. The employees of the assembly lines retrieve all materials themselves, except for the standard materials, the window frame-specific materials, and the glass panels. Walking and searching for the materials takes time that the employees do not spend on assembling window frames. Therefore, walking and searching for materials has to be eliminated within the assembly process. Potential solutions to eliminate the waste caused by employees walking through the production facility are:

1. **Strategic placement of materials in the production facility.**
   Strategically placing materials within the buffer and around the assembly lines to ensure that employees walk the shortest distance to the materials as possible.
2. **Bringing the materials to the assembly lines.**
   An employee outside the assembly lines brings the materials instead of assembly line employees picking up the materials. This could also be done by an external supplier.

5.2 LACK OF STRUCTURE IN MATERIAL PLACEMENT

The employees of the assembly lines retrieve almost all the materials themselves. From the observations and interviews conducted at the assembly process, it can be concluded that the search for the right materials takes a significant amount of time. A lack of structure in the placement of materials within the production facility causes the employees to search for materials instead of just picking them up. Potential solutions to eliminate the waste caused by the lack of structure in material placement are:

3. **Arranging the materials in the buffer according to assembly lines.**
   Arranging the materials (window frames, rotating parts, and glazing beads) in the buffer according to assembly lines instead of placing all the materials together. Standardizing the place of the materials for each assembly line relates to the 5S methodology discussed in Chapter 3.
4. **Arranging the materials in the buffer according to window frame series.**
   Arranging the materials (window frames, rotating parts, and glazing beads) according to the window frame series they belong to, instead of placing all the materials together. The different series of window frames can be indicated in the buffer using, for example, coloured cards.
5. **Arranging the rotating parts based on size within a window frame series.**
   At the moment of conducting this research, the rotating parts are not arranged according to the window frame series on the carts. The rotating parts are placed on carts at the paint shop, and each rotating part is randomly put on a cart. The rotating parts for one window frame series are produced at the same time and are placed on carts at the same time, but they are scattered across a lot of different carts. Due to this, the employees at the assembly lines have to search for the right rotating part of different carts. This problem can be resolved by arranging the rotating parts according to the window frame series on the carts. Next to this, it is also an option to arrange the rotating parts of one series according to size. Most window frame series contain multiple window frames that are similar and require the same type of rotating parts. When the rotating parts are arranged by size, an employee does not have to search on the different carts for every single part.
6. **Arranging the materials in the sequence in which the window frames are assembled.**
   To resolve the lack of structure in the material placement to the fullest, all materials should be organized in the sequence in which the window frames are assembled. That means that when frame x is assembled first, all the materials for frame x are placed in front or on top of other materials. The materials for frame x + 1 should then be placed behind or underneath the materials for frame x.

5.3 PRODUCTION PLANNING

The production planning does not take the difficulty of window frames into account. This causes inefficiencies in the assembly lines because some stations may have too much work and other stations too little. Next to that, the production planning does not schedule on which line which series of window frames will be assembled. Therefore, the materials cannot be arranged according to the assembly lines. This relates to the lack of structure in material placement. Potential improvements to the production planning are:

7. **Dividing the series of window frames among the lines in the production planning.**
   Include which assembly line will assemble which series of window frames on a particular day within the production planning. This ensures that materials can be organized according to the lines on which the series of window frames are going to be assembled.
8. **Include the difficulty of a window frame within the production planning.**
   By including the difficulty of a window frame within the production planning, different series of window frames can be combined to balance the work for each line. This resolved the line stagnation issue discussed in Section 4.5.

5.4 OTHER IMPROVEMENT OPTIONS

Next to the potential solutions that target the three challenges, there are other potential solutions to optimize the assembly process that lie outside these three areas.

The first improvement option relates to the nail gun and sealant gun at station 4. In Section 4.5, we discussed the issue of the nail gun and sealant gun at station 4. At station 4, the sealant and nail gun are both used, and there is only one air hose for both tools. This means that the employee at station 4 needs to reconnect either the sealant or nail gun whenever he needs to use it. This can be solved by adding an extra air hose to station 4, so that the sealant and nail gun are both connected to their own air hose.

At station 1, the window frames are placed on the tilt table either by using the overhead crane or the employees carry the window frames from the stillages. In the interviews with the employees of the assembly lines, they clearly stated the wish to transport the window frames hanging from the ceiling from the paint shop to the assembly lines. This reduces the time it takes to get a window frame on the tilt table.

5.5 Chapter conclusion

In this chapter, we discussed the potential solutions to the three challenges stated in Section 4.6 by answering the sixth research question.

6. Which possible improvement actions can be formulated based on the current material flows and the new insights?

The potential solutions presented in this chapter are based on the insights we gained during this research and on the Lean manufacturing principles and tools discussed in Chapter 3.

The potential solutions to eliminate the waste caused by employees walking through the production facility are:

1. Strategic placement of materials in the production facility.
2. Bringing the materials to the assembly lines.

The potential solutions to eliminate the waste caused by the lack of structure in material placement are:

3. Arranging the materials in the buffer according to assembly lines.
4. Arranging the materials in the buffer according to window frame series.
5. Arranging the rotating parts based on size within a window frame series.
6. Arranging the materials in the order in which the window frames are assembled.

The potential improvements to the production planning are:

7. Dividing the series of window frames among the lines in the production planning.
8. Include the difficulty of a window frame within the production planning.

Next to the potential solution to target the challenges stated in Section 4.6, two other solutions based on the observations at the assembly process and the interviews with employees are formulated. These potential solutions are:

9. Connecting the nail gun and sealant gun at station 4 of the assembly lines both to their own air hose.
10. Transport the window frames from the paint shop to the assembly lines hanging from the ceiling.

Chapter 6 discusses the chosen solution or set of solutions. The solution choice depends on the requirements of Nijhuis Toelevering and the expected impact on both the assembly process and the stakeholders.

6 SOLUTION CHOICE

This chapter describes the decision-making process for the solution choice. The solution choice is based on set requirements by Nijhuis Toelevering. This chapter also discusses the expected impact of the chosen solution on the assembly process and the expected impact on the stakeholders. This chapter answers the seventh research question and its sub-questions.

7. Which of the possible improvement options is chosen to be implemented at Nijhuis Toelevering?

7.1 What requirements does the chosen improvement option(s) have to meet according to Nijhuis Toelevering?

7.2 What is the expected quantitative impact of the chosen improvement option(s)?

7.3 What is the expected impact of the chosen improvement option(s) on the stakeholders?

In Section 6.1, we discuss the requirements that the solution(s) must meet. These requirements are set by Nijhuis Toelevering. Next to the requirements, a weighted decision matrix is used to choose a solution or multiple solutions. In Section 6.2, we discuss the impact of the chosen solution(s) on the assembly process in terms of output. In Section 6.3, we discuss the social impact of the chosen solution(s). Finally, we conclude this chapter in Section 6.4.

6.1 CHOSEN SOLUTION

Each of the potential solutions we discussed in Chapter 5 will probably positively impact the efficiency of the assembly process and will probably be implemented sooner or later. Due to the time constraint of this research, it is not possible to research all the potential solutions. Therefore, Nijhuis Toelevering set several requirements the chosen solution(s) must meet. These requirements are:

1. The solution has to be easy to implement.
2. Short-term implementation of the solution is possible.
3. The solution reduces the wasted time spent on searching materials.
4. The implementation costs need to be low.

We use a weighted decision matrix to evaluate the potential solutions based on the requirements of Nijhuis Toelevering. Table 6.1 shows the weighted decision matrix. In the weighted decision matrix, each requirement is linked to a specific weight. This weight indicates how important the requirement is for Nijhuis Toelevering. We determined these weights together with the management of Nijhuis Toelevering. A weight of one means that the requirement has a low priority to Nijhuis Toelevering. A weight of five indicates a high priority. Each potential solution is reviewed on each requirement and is given a score. These scores were decided upon by the management of Nijhuis Toelevering. The scores range from one to five. A score of one indicates a low desirability according to the requirement, and five indicates high desirability. The total score for each solution is calculated by multiplying the score with the requirement weight. The sum of the total scores determines the ranking of the potential solutions.

Solutions 3, 6, 7, and 8 can be implemented once the ERP system is integrated at Nijhuis Toelevering. This is due to the administrative limitations Nijhuis Toelevering currently has. At the moment of conducting this research, a project regarding the implementation of ERP is taking place. The implementation of solutions 3, 6, 7, and 8 are because of the need for ERP long-term solutions, which are hard to implement. Therefore, these solutions received a low score on requirements 1 and 2.

Most of the solutions reduce the time wasted searching for materials, except for solutions 7, 8, and 9. Solutions 7 and 8 are related to the production planning and probably positively impact the efficiency of the assembly process, but these solutions do not reduce the time searching for materials. Solution 9 is an extra improvement to the assembly process and does not relate to the time spend on searching materials.

Table 6.1: Weighted decision matrix

Weighted decision matrix																					
		Solution options																			
Requirements	Weight (1-5)	1		2		3		4		5		6		7		8		9		10	
		Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Easy to implement	5	5	25	5	25	1	5	5	25	5	25	1	5	1	5	1	5	4	20	1	5
Short-term implementation	4	4	16	5	20	3	12	5	20	5	20	1	4	2	8	1	4	5	20	1	4
Reduce time wasted on searching materials	3	5	15	5	15	5	15	5	15	5	15	5	15	4	12	2	6	1	3	4	12
Low implementation costs	1	3	3	4	4	4	4	5	5	5	5	2	2	3	3	2	2	3	3	1	1
	Total		59		64		36		65		65		26		28		17		46		22
	Ranking		4		3		6		1		2		8		7		10		5		9

Solution 1	Strategic placement of materials in the production facility
Solution 2	Bringing the materials to the assembly lines
Solution 3	Arranging the materials in the buffer according to the asseembly lines
Solution 4	Arranging the materials in the buffer according to the window frame series
Solution 5	Arranging the rotating parts based on size within a window frame series
Solution 6	Arranging the materials in the sequence in which the window frames are assembled
Solution 7	Dividing the series of window frame among the lines in the production planning
Solution 8	Include the difficulty of a window frame within the production planning
Solution 9	Connecting the nail gun and sealnt gun at station 4 of the assembly lines both to their own air hose
Solution 10	Transport the window frames from the paint shop to the assembly lines hanging from the ceiling

The final ranking of the potential solutions is as follows:

1. Solution 4
2. Solution 5
3. Solution 2
4. Solution 1
5. Solution 9
6. Solution 3
7. Solution 7
8. Solution 6
9. Solution 10
10. Solution 8

In the decision matrix, we see that solutions 4, 5, and 2 score about the same on the requirements. In close consideration with Nijhuis Toelevering, it is decided that an implementation plan for these three solutions is written. Solutions 4 and 5 concern adding structure to the placement of materials in the buffer. Solution 2 ensures that the employees do not have to leave the line to retrieve materials. Nijhuis Toelevering can implement these three solutions simultaneously because they are complementary to each other.

In Section 6.2, we discuss the expected quantitative impact of these three solutions on the output of the assembly process. In Section 6.3, we discuss the social impact of these three solutions.

6.2 QUANTITATIVE IMPACT

In this section, we examine the quantitative impact of the solutions on the output of the assembly process of Nijhuis Toelevering. This examination is based on the analysis of the KPIs and time measurements of Chapter 4. In Section 4.7, we discussed the flaw of averages and the deceiving image of reality averages could cause. In this section, we examine the quantitative impact of the solutions based on the averages from Chapter 4. This section, therefore, shows Nijhuis Toelevering the quantitative benefits of the solution implementation. These benefits do not consider the high variety of window frame series and the relating cycle times. Nijhuis Toelevering must take this into account in the decision-making process.

Solution 4 concerns the structural arrangement of the materials in the buffer according to their respective window frame series. This means that the glazing beads bins, the window frame stillages, and the rotating parts carts from each series are all placed together in the buffer. So, solution 4 ensures that employees do not have to search on different places in the production facility for the materials, which results in less time spent on getting the materials to the assembly lines. Table 4.4 in Section 4.2 shows the duration of the NVA activities outside the cycle times. The NVA activities in this table all concern the retrieval and return of the window frames, rotating parts, and glazing beads. These NVA times are caused by employees walking towards and searching for the right materials. In Section 4.2, we estimated that about one-third of the time to retrieve the materials is used to locate them. This estimation is based on the time measurements and observations. Solution 4 eliminates searching for materials since all the materials from one series of window frames are placed together. Table 6.2 shows the eliminated time waste by implementing solution 4 and the number of extra window frames that, in theory, could be assembled per day. At station 1, solution 4 saves 10 minutes and 9 seconds. In order to calculate the number of extra window frames that can be assembled, we divide the eliminated times waste by the average cycle time at station 1. This results in 1.30 extra window frames per day at station 1. At station 2, each day, 0.49 extra window frames can be assembled and a station 4, 0.19 extra window frames. These values are based only on the averages from Chapter 4. In Chapter 4, we discussed the flaw of averages and showed a high variety in window frames and thus the times it takes to assemble different frames. The values in Table 6.2 provide insight into the impact of the solution, but reality can deviate from the averages.

The number of extra window frames at each station may seem low, but these are only the daily extra frames. These tiny extras seem to make little difference on any given day, and yet the impact they deliver over months and years can be enormous (Clear, 2018, p. 16). The 1.3 extra window frames at station 1, for example, cumulate to 6.5 extra frames a week and 288.6 extra frames over a year of 222 production days. These values are for one assembly line and the assembly process contains four assembly lines. “The difference a tiny improvement can make over time is astounding” (Clear, 2018, p. 15).

Table 6.3: Expected eliminated time waste after the implementation of solution 4

Station	Activity	Average total duration per day (mm:ss.ms)	Expected eliminated time waste by implementing solution 4 (mm:ss.ms)	Average cycle time (mm:ss.ms)	Number of extra window frames per day (units)
Station 1	Picking up new stillage window frames from the buffer	30:28.5	10:09.5	07:48.9	1.30
Station 2	Picking up cart rotating parts from the buffer	08:52.8	02:57.6	06:01.8	0.49
Station 4	Picking up glazing beads bin from buffer paint shop	05:58.6	01:59.5	10:35.2	0.19

Solution 5 concerns sorting the rotating parts on the carts based on size within a window frame series. By arranging the rotating parts according to size, an employee does not have to search on different carts for every single part. Solution 5 thus targets the activity 'getting rotating parts for window frame', and this activity is included in the cycle time at station 2. The cycle time at station 2 consists of 25.0% out of NVA time, and 34.0% of this NVA time consists of getting the rotating parts. Getting the rotating parts, on average, takes 30 seconds and 8 milliseconds. Solution 5 diminishes the time this activity takes. It is difficult to determine how much time will be saved when solution 5 is implemented because the number of rotating parts varies each day. Therefore, we also cannot determine how many extra window frames can be assembled. The employees indicated that implementing solution 5 would help them a lot. Next to that, solutions 4 and 5 are complementary, so they can be implemented simultaneously.

Solution 2 states that all the materials are brought to the assembly lines by an employee outside the assembly lines. That ensures that the employees rarely have to leave the line to retrieve materials. At the moment, all the materials, except for the window frames, rotating parts, and glazing beads, are brought to the assembly lines. Solution 2 changes this by also bringing these materials to the assembly lines. Table 4.4 in Section 4.2 shows the duration of the NVA activities outside the cycle times. The NVA activities in this table all concern the retrieval and return of the materials mentioned above. Implementing solution 2 means that the times spent on the NVA activities outside cycle times would be eliminated. Table 6.3 shows the eliminated time waste by implementing solution 2 and the number of extra window frames that, in theory, could be assembled per day. At station 1, 44 minutes and 10 seconds can be saved when the window frames, rotating parts, and the glazing beads are brought to and picked up at the assembly line. In order to calculate the number of extra window frames that can be assembled, we divide the eliminated times waste by the average cycle time at station 1. This result in 5.65 extra window frames per day on station 1. At station 2, each day, 2.94 extra window frames can be assembled and a station 4, 0.90 extra window frames. These values are also based only on the averages from Chapter 4 and provide insight into the solution's impact, but reality can deviate from the averages.

The number of extra window frames at station 1 is higher than at station 4. Due to this, the whole line cannot assemble five more window frames. Yet, there are window frames that contain doors, and only station 1 carries out tasks for these window frames. Such window frames can be assembled in between other frames by station 1.

Table 6.4: Expected eliminated time waste after the implementation of solution 2

Station	Expected eliminated time waste by implementing solution 2 (mm:ss.ms)	Average cycle time (mm:ss.ms)	Number of extra window frames per day (units)
Station 1	44:10.5	07:48.9	5.65
Station 2	17:42.0	06:01.8	2.94
Station 4	09:34.6	10:35.2	0.90

Up till now, we only evaluated the eliminated time waste of each of the solutions but not the expected impact of the solutions on the daily and weekly window frame output. With this research, Nijhuis Toelevering wants to find solutions to improve the efficiency of the assembly process so as to approach the intended output increase of 50%. The expected impact of the solutions on the other KPIs is hard to predict since the variety in window frames produced at Nijhuis Toelevering is high. In Chapter 8, we analyse the impact of the solutions on among others the KPIs with the use of the actual implementation of the solutions during a two-day pilot. Next to that, as explained earlier, the expected impact of solution 5 in terms of output increase is hard to predict.

To evaluate the expected impact of the solutions on the daily and weekly window frame output, we look at the number of extra window frames that can be assembled per day from Tables 6.3 and 6.4. In these tables, the number of extra window frames that can be assembled per day is given for each station in one assembly line. In our case, the data is based on assembly line 2. The lowest number of extra frames in the tables is the maximum number of extra frames an assembly line can assemble extra during a day since otherwise, line stagnation will occur. For example, station 4 can assemble five extra frames and station 1 ten extra frames. In this case, the maximum number of extra frames the assembly line as a whole can assemble is five. When six extra frames are assembled the line will stagnate at station 4. Therefore, daily 0.19 extra window frames can be assembled with the implementation of solution 4 and 0.90 extra window frames with the implementation of solution 2. Weekly, this corresponds with 0.95 and 4.50 extra window frames respectively. These numbers are based on one assembly line. The assembly process at Nijhuis Toelevering consists of four assembly lines. By all four assembly lines, daily 0.76 extra window frames can be assembled with the implementation of solution 4 and 3.60 extra window frames with the implementation of solution 2. Weekly, this results in 3.80 extra window frames with solution 4 and 18 extra window frames with solution 2. Table 6.5 shows the impact of the solutions on the daily and weekly outputs.

As explained earlier, the three chosen solutions are complementary to each other. Therefore, we also need to evaluate the impact of the implementation of all three solutions together on the daily and weekly outputs. However, it is hard to predict the impact of all three solutions together since their interrelationships are unknown. These relationships need to be researched further and that is not possible within the time constraint of this research. We can estimate that the impact of all three solutions at least has the same impact as solution 4. Solution 4 is the solution that can support the other solutions in case they do not work. For example, when the employee responsible for bringing the materials as part of solution 2 cannot bring the materials for some reason, then solution 4 ensures that the searching time for materials is minimized. Therefore, we can state that the minimal impact of the three solutions together is the same as the impact of solution 4.

Table 6.5: Impact of solutions on the daily and weekly outputs

KPI	Solution 4	Solution 5	Solution 2
Assembly line			
Daily output (units)	+ 0.19	X	+ 0.90
Weekly output (units)	+ 0.95	X	+ 4.50
Assembly process			
Daily output (units)	+ 0.76	X	+ 3.60
Weekly output (units)	+ 3.80	X	+ 18.0

With this research, Nijhuis Toelevering wants to find solutions to improve the efficiency of the assembly process so as to approach the intended output increase of 50%. The current weekly output norm is 550 window frames. With solution 4, the assembly process at Nijhuis Toelevering can weekly assemble 3.80 extra window frames, which results in 553.8 window frames per week. This means that the output increases by 0.69%. With solution 2, the assembly process at Nijhuis Toelevering can weekly assemble 18 extra window frames, which results in 568 window frames per week. This means that the output increases by 3.27%.

Table 6.6: Percentual increase in weekly window frame output per solution

Solution	Percentual increase in weekly window frame output (%)
Solution 4	0.69
Solution 5	X
Solution 2	3.27

6.3 Social impact

The proposed solutions not only impact the output of the assembly process but also impact the employees of the assembly lines. The employees at the assembly lines work together, and the social aspect of their work is important. There are three social concerns of the solutions that we need to take into account in the decision-making process.

During the interviews, the employees expressed concerns about being bound to the assembly lines. The solutions from Section 6.1 ensure that the employees rarely leave the assembly lines and can assemble more window frames. The employees explained that walking to retrieve materials is a nice interruption between the window frames, and they fear the work will become more monotonous when that changes. This could be resolved by for example alternating tasks between employees.

Next to the work becoming monotonous, the employees fear that they will need to work harder than they are doing at the moment of conducting this research. The employees believe that they are on their maximum performance. Implementing the solutions can result in employees feeling more stressed because they think they need to work harder and faster. This research aims to ensure that the employees can work more efficiently instead of working harder. During this research, we communicated this aim to the employees. Nonetheless, the employees are reluctant towards the 50% output increase Nijhuis Toelevering wants to establish.

Almost all the employees stated that they like the current ambience on the work floor. They enjoy working with each other, and the social aspect contributes to the employees' work ethics. The employees do not want the social aspect of their work to change when a higher window frame output is expected. They think that the time to socialize with their colleagues will be much more limited and that the ambience on the work floor will change.

“We as individuals and organizations are creatures of habit, so change is not always easy” (Galli, 2018). The employees clearly state their concerns with the changes caused by the implementation of the solutions. Without the willingness from the employees, the process to implement changes will almost always fail (Galli, 2018). Therefore, these concerns need to be addressed and minimized by Nijhuis Toelevering when implementing the solutions. The concerns can be addressed and minimized by actively including the employees in the decision-making process. We further address the inclusion of the employees in the decision-making process in the implementation plan in Chapter 7.

6.4 Chapter conclusion

In this chapter, we discussed the decision-making process for the solution choice. The solution choice is based on set requirements by Nijhuis Toelevering. For the chosen solutions, we examined the expected quantitative and social impact. In this chapter, we answered the following research questions:

7. Which of the possible improvement actions is chosen to be implemented at Nijhuis Toelevering?

7.1 What requirements does the chosen improvement action(s) need according to Nijhuis Toelevering?

Nijhuis Toelevering set four important requirements the solution(s) must meet, and these are:

1. The solution has to be easy to implement.
2. Short-term implementation of the solution is possible.
3. The solution reduces the wasted time spent on searching materials.
4. The implementation costs need to be low.

The solution options from Chapter 5 are weighed against the requirements in a weighted decision matrix. This weighted decision matrix resulted in three chosen solutions. These solutions, as labelled in Chapter 5, are:

Solution 2 – Bringing the materials to the assembly lines.
Solution 4 – Arranging the materials in the buffer according to window frame series.
Solution 5 – Arranging the rotating parts based on size within a window frame series.

Chapter 7 discusses the implementation plan for each of these three chosen solutions. The implementation plan discusses the important steps towards implementation for each solution.

7.2 What is the expected quantitative impact of the chosen improvement action(s)?

The three chosen solutions are complementary to each other and can therefore be implemented simultaneously. For each of the three solutions, the expected quantitative and social impact is examined. Based on the time measurements from Chapter 4, the impact of solutions 4 and 2 is clearly definable. With solution 4, the assembly process at Nijhuis Toelevering can weekly assemble 3.80 extra window frames. This corresponds to an output increase of 0.69%. With solution 2, the assembly process at Nijhuis Toelevering can weekly assemble 18 extra window frames. This corresponds to an output increase of 3.27%. The impact of solution 5 is difficult to define based on the time measurements because the number of rotating parts varies each day. Therefore, we cannot estimate how much time waste is eliminated with solution 5. The employees indicated that implementing solution 5 would benefit them a lot.

It is difficult to predict the impact of the implementation of all three solutions together since their interrelationships are unknown. These relationships need to be researched further, which is not possible within the time constraint of this research. We can estimate that the impact of all three solutions at least has the same impact as solution 4. Solution 4 is the solution that can support the other solutions in case they do not work. Therefore, we can state that the minimal impact of the three solutions together is the same as the impact of solution 4.

7.3 What is the expected impact of the chosen improvement action(s) on the stakeholders?

There are three social implications the employees have indicated during the interviews. First, the employees fear the work becoming monotonous when Nijhuis Toelevering implements the solutions. Second, the employees think that they need to work harder than is possible. At the moment of conducting this research, the employees believe that they are working on their maximum performance. Third, the employees fear that the social aspect of their job will be reduced. In Chapter 7, we address the inclusion of the employees in the decision-making process to minimize the employees' concerns.

7 IMPLEMENTATION PLAN

In Chapter 6, we discussed the solution choice and the three solutions that are most compatible with the requirements of Nijhuis Toelevering. In this chapter, we develop an implementation plan for each solution. The implementation plans contain the steps that need to be carried out by Nijhuis Toelevering in order to implement the solution. Next to that, the person or department responsible for carrying out the steps, and the place and when the steps need to be carried out are included in the implementation plan. Chapter 7 answers the eighth research question and its sub-question.

8. How can the defined actions to improve the material flows be implemented?

8.1 How can the different stakeholders be integrated within the implementation process of the improvement action(s)?

Section 7.1 describes the implementation plan for solution 4, 'arranging the materials in the buffer according to window frame series.' Section 7.2 describes the implementation plan for solution 5, 'arranging the rotating parts based on size within a window frame series.' Section 7.3 describes the implementation plan for solution 2, 'bringing the materials to the assembly lines.' At last, Section 7.4 concludes this chapter.

7.1 IMPLEMENTATION PLAN SOLUTION 4

In order to successfully implement the structural arrangement of the materials according to the window frame series in the buffer (solution 4), five steps need to be carried out. First, a general division of the buffer must be established. This division must include where which materials will be placed and form the guideline for the employees. Once this step is finished, the information must be communicated to the employees of the different departments. The production leader of the paint shop needs to be informed about the general division of the materials so that he can inform the employees of the paint shop on where they need to place the materials in the buffer. The employees of the assembly lines and the assembly rotating parts need to be informed by the production leader final assembly so that they know how the materials are arranged in the buffer. The production manager or the logistics coordinator must inform other involved employees, like the sorting centre employees. Table 7.1 shows the step-by-step approach for the implementation of solution 4 and when and by who these steps need to be carried out. The implementation process of solution 4 is estimated to take about 12 to 14 hours.

Table 7.1: Step-by-step approach implementation solution 4

	Step	Place	Who	When
1	A general division of the buffer must be established so that the materials are always placed in the buffer the same way	Production facility	Production manager and production leader final assembly	This step must be carried out before the other steps can follow
2	The production leader paint shop must be informed so that he can inform the paint shop employees	Production facility	Production manager	After step 1 is finished
3	The employees of the paint shop need to be informed on where they need to place materials	Production facility	Production leader paint shop	After step 2 is finished
4	The employees of the assembly lines and assembly rotating parts must be informed	Production facility	Production manager and production leader final assembly	After step 1 is finished
5	All other employees involved must be informed	Production facility	Production manager and logistics coordinator	After step 1 is finished

7.2 Implementation plan solution 5

Solutions 4 and 5 can be implemented simultaneously. Five steps need to be carried out when implementing solution 5. First, the production manager and the production leaders of the pre-assembly, paint shop, and final assembly must discuss whether it is possible to paint the rotating parts according to size at the paint robots. That means that the rotating parts of one size within a window frame series are painted as a batch. Whether this is possible is depended on the limitations of the paint robots. After this is examined, the production manager and the production leader paint shop must inform the paint shop employees on their new tasks. The rotating parts need to be sorted according to size and placed on the carts by the paint shop employees. Next to the paint shop employees, the employees of the assembly rotating parts also need to be informed about their new tasks. They have to check whether the rotating parts are correctly sorted at the paint shop. If the parts are not correctly sorted, the assembly rotating parts employees need to rectify this. At last, the assembly line employees and other involved employees need to be informed about the new way of sorting the rotating parts.

Table 7.2 shows the step-by-step approach for the implementation of solution 5. Table 7.2 also shows when and by who the steps need to be carried out. The implementation process of solution 5 is estimated to take about 10 hours.

Table 7.2: Step-by-step approach implementation solution 5

	Step	Place	Who	When
1	Discuss whether it is possible to paint the rotating parts according to size at the paint robots. By doing this, the employees at the paint shop can sort the parts more easily.	Production facility	Production manager, production leader pre-assembly, production leader paint shop, and production leader final assembly	This step must be carried out before the other steps can follow
2	The employees at the paint must be informed about their new task to sort the rotating parts and place them on the carts according to size.	Production facility	Production manager and production leader paint shop	After step 1 is finished
3	The assembly rotating parts employees need to be informed that they need to check whether the rotating parts are correctly sorted.	Production facility	Production leader final assembly	After step 1 is finished
4	The employees of the assembly lines must be informed about the new way the rotating parts are sorted.	Production facility	Production leader final assembly	After steps 2 and 3 are finished
5	All other employees involved must be informed	Production facility	Production manager and logistics coordinator	After all the previous steps are finished

7.3 Implementation plan solution 2

In order to implement solution 2 and arrange that all the materials are brought to the assembly line, four steps need to be carried out. First, the management of Nijhuis Toelevering must consult the employees of the sorting centre to discuss whether they can bring the materials to the assembly lines. If this is not an option, the management must discuss whether to hire a new employee for these tasks. After this, a protocol must be drawn up on how the communication between the employees at the assembly lines and the employee bringing the materials is established. For this protocol, the help and expertise of the assembly line team leaders can be used.

In Section 6.3, we discussed the concerns of the assembly line employees regarding being bound to the assembly line. To resolve these concerns, an explanation session with the employees must be held. In this session, the solution can be explained, and the employees can express their opinions and concerns. Together, solutions to resolve these concerns can be found. Such an explanation session ensures that employees feel heard and included, and this increases the willingness to participate in the implementation process. Next to such an explanation session, an independent employee of Nijhuis Toelevering should become the contact person for the employees on this topic. In a group, employees may be hesitant to express their concerns, and therefore an independent employee can resolve that barrier. At last, all the other employees involved must be informed by the production manager and the logistics coordinator.

Table 7.3 shows the step-by-step approach for the implementation of solution 2 and when and by who the steps need to be carried out. The implementation process of solution 2 is estimated to take about 20 hours. This depends on whether a sorting centre employee can bring the materials, or a new employee must be hired. Hiring a new employee is a time-costly activity.

Table 7.3: Step-by-step approach implementation solution 2

	Step	Place	Who	When
1	Management of Nijhuis Toelevering must consult with the employees of the sorting centre to discuss whether they can bring the materials to the assembly lines. Otherwise, management must discuss whether to hire a new employee.	Production facility and the office	Operational manager and production manager	This step must be carried out before the other steps can follow
2	A protocol must be drawn up on how the communication between the employees at the assembly lines and the employee bringing the materials is established.	Production facility	Production manager, production leader final assembly, and assembly line team leaders	After step 1 is finished
3	An explanation session needs to be scheduled with the employees of the assembly lines. This session is used to explain the solution, and in this session, the employees can express their opinions and concerns. Solutions to resolve the concerns can be found together.	Production facility	Operational manager, production manager and production leader final assembly	After step 2 is finished
4	An independent employee of Nijhuis Toelevering must be available to be the contact person for the employees regarding their concerns on the implementation of solution 2	The office	Operational manager and production manager	Simultaneously to step 3
5	All other employees involved must be informed.	Production facility	Production manager and logistics coordinator	After step 2 is finished

7.4 Chapter conclusion

In this chapter, we discussed the steps of the implementation process for each solution chosen in Chapter 6. Chapter 7 answers the following research questions:

8. How can the defined actions to improve the material flows be implemented?

For each solution chosen in Chapter 6, we developed an implementation plan. These implementation plans contain the steps that need to be carried out in order to implement the specific solution. Next to the steps, the stakeholders involved in the implementation process are included in the implementation process. At last, the place where and when the steps need to be carried out are included.

8.1 How can the different stakeholders be integrated within the implementation process of the improvement action(s)?

In Section 6.3, we discussed the concerns of the assembly line employees regarding being bound to the assembly line. This concern directly relates to the implementation of solution 2 because solution 2 ensures that the employees rarely have to leave the assembly line. To acknowledge the concerns of the employees, an explanation session must be held in which the solution is explained. In this session, the employees can express their opinions and concerns. Together with the employees, solutions to resolve the concerns can be found. Next to the explanation session, an independent employee should become available as the contact person for the employees. In a group and during an explanation session, employees may be hesitant to express their concerns. By instating an independent employee, this barrier can be minimized.

It is important to include the employees in the implementation process to ensure the willingness of the employees to participate in the process. And therefore, we recommend that Nijhuis Toelevering actively involves its employees within the decision-making and implementation process.

8 SOLUTION IMPLEMENTATION

In Chapter 6, we evaluated the expected quantitative impact of the solutions on the assembly process and the expected impact of the solutions on the stakeholders. To evaluate the actual impact of the solutions on the assembly process, we implement solutions 2 and 4 at assembly line 2 using a two-day pilot. Due to the time constraint of this research, the full implementation of the three chosen solutions according to the implementation plans from Chapter 7 is not possible. Next to that, there are limited resources available to execute the pilot, because the employees at the assembly process had to execute their daily tasks while the pilot was executed. Because of the time constraint and the limited resources available, only solutions 2 and 4 were implemented in the pilot. The implementation of solution 5 required more resources and therefore this solution is not included in the pilot.

While running the pilot, we performed the same time measurements as we did to evaluate the current performance of the assembly process in Chapter 4. Based on the new time measurements and the analysis from Chapter 4, we are able to evaluate the actual impact of the solutions on the assembly process at Nijhuis Toelevering. The time measurements during the pilot are, as well as the time measurements from Chapter 4, carried out at assembly line 2. This chapter answers the ninth research question.

9. What is the actual impact of the improvement action(s) on the assembly process at Nijhuis Toelevering?

Section 8.1 outlines a detailed description of how solutions 2 and 4 were implemented using the two-day pilot. In Section 8.2, we evaluate the impact of the solution implementation based on the KPIs from Chapter 4. Section 8.3 analyses the impact of the solutions based on the time measurements conducted during the pilot and we compare these time measurements with the time measurements of Chapter 4. In Section 8.4, we create a Spaghetti diagram that shows the employee walking paths after the solution implementation. In Section 8.5, we address the social impact of the solutions. At last, Section 8.6 give the conclusion to this chapter.

8.1 PILOT DESCRIPTION

This section discusses the setup of the two-day pilot and how we implemented the solutions within the production facility of Nijhuis Toelevering. During the two-day pilot, we implemented two of the three chosen solutions from Chapter 6. Namely, solution 2 'bringing the materials to the assembly lines' and solution 4 'arranging the materials in the buffer according to window frame series'. To implement solution 2, an employee of the sorting centre brought the materials (window frames, rotating parts, and glazing beads) to assembly line 2. Because the sorting centre employee brings the materials to line 2, the employees at the assembly line do not need to walk towards the buffer to pick up the materials. During the pilot, the employees had to execute their daily tasks and therefore the sorting centre employee was not able to always bring the materials to line 2. To minimize the time the employees search the materials when they cannot be brought to the line, the materials in the buffer are arranged according to window frame series (solution 4). Solutions 2 and 4 complement each other nicely. To implement solution 4, we placed all the materials of the right window frame series together in the buffer the evening before each pilot day. Next to that, we also checked whether none of the materials were missing.

While running the pilot, we performed the same time measurements as we did to evaluate the current performance of the assembly process in Chapter 4. The time measurements of the pilot have the same limitations as explained in Section 4.7. By performing the time measurements in the same way as the time measurements from Chapter 4, we ensure that the two data sets are comparable.

8.2 KPI RESULTS

In Section 4.2, we evaluated the performance of the assembly process based on the KPIs used by Nijhuis Toelevering. In this section, we evaluate the performance of the assembly process after the implementation of the solutions and compare the new values of the KPIs with the KPI values from Chapter 4.

The first KPI Nijhuis Toelevering uses is the daily window frame output. Figure 8.1 shows the average daily output for each assembly line from Chapter 4 and the daily output on the two pilot days. Solutions 2 and 4 are implemented at assembly line 2, so to evaluate the impact of these solutions we need to look at the output of this assembly line. The average daily output at assembly line 2 before the implementation of the solutions is 43.5 window frames. On the first pilot day, assembly line 2 assembled 49 window frames. This is 5.5 window frames more than the average. On the second pilot day, assembly line 2 assembled 45 window frames which is 1.5 window frames more than averages. These numbers show that on the two pilot days the output of assembly line 2 was higher than on average.

There are three things we need to take into account when evaluating these output values. First, the output values of the two pilot days are compared with the average output value. In Section 4.7, we discussed the flaw of averages. Averages can give a deceiving image of reality, so we must be careful when comparing the daily output of the pilot days with the average output of assembly line 2. Second, the difficulty of window frames varies each day. On a particular day, the window frames that are supposed to be assembled can be more work than on another day. The daily output does not take the difficulty of the window frames into account. Third, the pilot only ran for two days, which means that the data set we collected is quite small in comparison with the data set from Chapter 4 which is based on approximately one and a half years. To get a more precise image of the impact of the solutions, the data set should be larger. Due to the time constraint, a longer pilot run is not possible. Therefore, we need to take into account that the evaluation is based on a small data set, which can give a deceiving image.

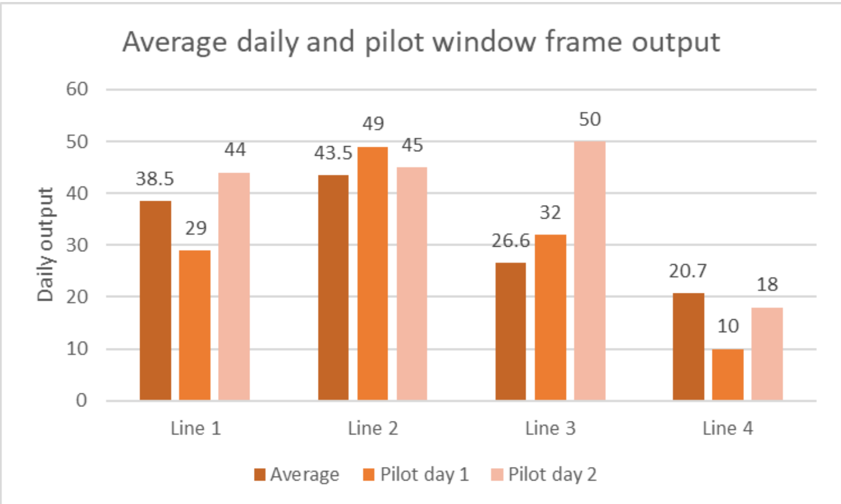

Figure 8.1: Average daily and pilot window frame output

The second KPI is the weekly output of window frames and the norm for this KPI is 550 window frames a week. The weekly output of window frames of the week in which the pilot was held is 694 window frames were assembled. This is 144 window frames more than the norm, which is an increase of 26.2%. this value is based on the whole assembly process, which consists of four assembly lines. Table 8.1 shows the weekly window frame output for each assembly line. From this table, we can conclude that assembly line 2 is the best performing assembly line during that week. This can be a result of the implementation of solutions 2 and 4 at assembly line 2, but other aspects, like the difficulty of the window frames, can also have an impact on the performance of assembly line 2. The output increase at assembly line 2 and of the assembly process as a whole is approximately the same as the expectations from Chapter 6.

Table 8.1: Weekly window frame output per assembly line

	Line 1	Line 2	Line 3	Line 4	Total
Total weekly output (units)	194	229	190	81	694

The third KPI is the 'realized number of production hours per week'. In Chapter 4, we described the average realized production hours to be 2,495 hours per week. The realized production hours of the week in which the pilot was held is 3,120 hours. This is 625 hours more than the average number of realized production hours. In Section 1.2.3, we described the future norm of realized production hours to be 3,000 hours a week. During the week the pilot was held, this future norm of 3,000 hours was reached. This shows that the number of realized production hours during this week was much higher than normal. This can be a result of the implementation of solutions 2 and 4.

The number of man-hours used in the week in which the pilot was held is 2,457 hours. Overall, no conclusion can be made on the number of man-used used because the relation between the realized production hours and the man-hours used is important. That relation shows how efficient the man-hours are used.

The weekly efficiency of the hours used of the week in which the pilot was held is 127%. The average weekly efficiency of hours is 112% and the weekly norm is 110%. In the week of the pilot the efficiency van 15% higher than the average. This efficiency shows that the assembly process realized a lot of production hours with the relative normal use of man-hours. That means that the assembly process performed well on the efficiency of the hours used.

The analysis of the KPIs shows that after the implementation of solutions 2 and 4 the performance of the assembly process in terms of KPIs is higher than on average. On all KPIs, the norm values are reached. This can be the result of the implementation of the solutions, but other aspects also influence the KPI values. We need to be careful when we use averages to compare our results. Therefore, we will also evaluate the impact of the solutions based on the time measurements performed during the pilot, on the Spaghetti diagram of the employee walking paths, and on the social impact of the solution implementation. At last, we cannot give a solid answer to what the impact of the solutions is in terms of a percentage increase in output. We see that the overall performance of the assembly process and assembly line 2 is above average after the solution implementation.

8.3 PILOT TIME MEASUREMENTS

In Section 4.2, we discussed the NVA times outside the cycle times. Implementing solution 4 eliminates searching for materials since all the materials from one series of window frames are placed together and therefore eliminates time waste concerning the retrieval of the materials from the buffer. Implementing solution 2 eliminates the time spent on the NVA activities outside the cycle times and concerns both the retrieval and return of materials. In this section, we analyse the average duration of the NVA activities outside the cycle times before (Chapter 4) and after the implementation of the solutions. Next to that, we also compare the expected eliminated time waste of each solution from Chapter 6 with the actual eliminated times waste after the implementation of solutions 2 and 4.

Table 8.1 shows the average duration and the average total duration per day of each NVA activity outside the cycle times from Chapter 4. Next to that, this table shows the average duration of each NVA activity based on the time measurements performed during the pilot. While executing the pilot, we counted the number of times the employees had to retrieve and return the materials themselves. The pick-up and return of window frames, on average, occurred five and nine times a day, respectively. The pick-up of rotating parts occurred on average four times a day and the return of rotating part carts occurred on average six times a day. The pick-up and the return of glazing beads, on average, occurred one and two times a day, respectively. With the number of times the employees had to retrieve and return the materials, we calculate the average total duration per day. The average duration to pick-up stillages with window frames from the buffer is 53 seconds and 6 milliseconds. This activity, on average, takes place five times a day. That results in an average total duration per day of 4 minutes and 28 seconds.

Using the average durations of each of the NVA activities, we see that the average duration of each activity is less after the implementation of the solutions than before the solutions were implemented. This decrease in average duration indicates that solution 4 minimizes the time spent on searching the materials in the buffer. Solution 2 ensures that the number of times the employees have to retrieve and return the materials themselves is less than before the pilot. As we explained in Section 8.1, the sorting centre employee responsible for bringing the materials to the assembly line was not always available to bring the materials to the line. In that case, the assembly line employees had to retrieve and return the materials themselves. When that occurs, the NVA time is minimized by solution 4.

Solution 4 concerns the arrangement of the materials in the buffer according to the window frame series. This mainly minimizes the NVA times concerning the retrieval of the materials from the buffer. However, we see that the activities concerning the return of the materials to the buffer also decreased after the implementation of the solutions. During the pilot, we saw that the buffer was more organized and that the employees could more easily move the stillages, carts, and bins through the buffer. This causes the NVA times of the activities concerning the return of the materials to decrease as well as the activities concerning the retrieval of the materials.

Table 8.2: Pilot non-value-added (NVA) activities outside cycle times

Station	Activity	Chapter 4 Average duration (mm:ss.ms)	Chapter 4 Average total duration per day (mm:ss.ms)	Pilot Average duration (mm:ss.ms)	Pilot Average total duration per day (mm:ss.ms)
Station 1	Picking up new stillage window frames from the buffer	02:01.9	30:28.5	00:53.6	04:28.0
	Returning empty stillage window frames to buffer paint shop	00:54.8	13:42.0	00:43.1	06:27.9
Station 2	Picking up cart rotating parts from the buffer	01:28.8	08:52.8	01:12.1	04:48.4
	Returning empty cart rotating parts to buffer paint shop	01:28.2	08:49.2	00:47.5	04:45.0
Station 4	Picking up glazing beads bin from buffer paint shop	02:59.3	05:58.6	00:48.5	00:48.5
	Returning empty glazing beads bin to buffer paint shop	01:48.0	03:36.0	00:47.0	01:34.0

In Chapter 6, we analysed the expected eliminated time waste by implementing each solution. Based on the average total durations before and after the implementation of the solutions, we calculate the actual eliminated time waste by implementing solutions 2 and 4. Table 8.2 shows the expected and actual eliminated time waste by the implementation of solutions 2 and 4. From Table 8.2, we conclude that the actual eliminated time waste lies between the expected eliminated time waste by the implementation of solution 4 and the expected eliminated time waste of solution 2. This is because the actual eliminated time waste corresponds to the implementation of both solutions 2 and 4. We do not know how each solution contributes to the time waste elimination, because the interrelations between the solutions are unknown and need to be further researched.

The biggest time waste elimination occurs at station 1 with the retrieval of stillages with window frames from the buffer. The retrieval of stillages with window frames is the most frequent occurring NVA activity outside the cycle times at the assembly lines. The smallest time waste elimination occurs at station 4 with the return of the empty glazing bead bins to the buffer. This activity occurs the least frequent of all NVA activities outside the cycle times at the assembly lines.

Overall, we conclude that the actual eliminated time waste is approximately according to the expectations from Chapter 6. The actual eliminated time waste lies between the expected eliminated time waste by the implementation of solution 4 and the expected eliminated time waste of solution 2.

Table 8.3: Expected and actual eliminated time waste by the implementation of solutions 2 and 4

Station	Activity	Expected eliminated time waste by the implementation of solution 4 (mm:ss.ms)	Expected eliminated time waste by the implementation of solution 2 (mm:ss.ms)	Actual eliminated time waste by the implementation of solutions 2 and 4 (mm:ss.ms)
Station 1	Picking up new stillage window frames from the buffer	10:09:5	30:28.5	26:00.5
	Returning empty stillage window frames to buffer paint shop	X	13:42.0	07:14.1
Station 2	Picking up cart rotating parts from the buffer	02:57.6	08:52.8	04:04.4
	Returning empty cart rotating parts to buffer paint shop	X	08:49.2	04:04.2
Station 4	Picking up glazing beads bin from buffer paint shop	01:59.5	05:58.6	05:10.1
	Returning empty glazing beads bin to buffer paint shop	X	03:36.0	02:02.0

8.4 SPAGHETTI DIAGRAMS

In Chapter 4, we created two Spaghetti diagrams. One Spaghetti diagram illustrates the materials flows through the production facility and the other Spaghetti diagram illustrates the employee walking paths through the production facility. In this section, we create a new Spaghetti diagram illustrating the employee walking paths after the implementation of solutions 2 and 4. With this new Spaghetti diagram and the Spaghetti diagram from Chapter 4, we evaluate the impact of the implementation of solutions 2 and 4 by comparing both diagrams. We do not create a new Spaghetti diagram for the materials flows through the production facility, because the solutions do not affect the material flows.

Figure 8.1 shows the Spaghetti diagram of the employee walking paths at assembly line 2 after the implementation of solutions 2 and 4. In Appendix E, both Spaghetti diagrams of the employee walking paths before and after the solution implementation are depicted in one figure.

The first difference between the two Spaghetti diagrams is that the employees leave the line less frequent. The line from stations 1, 2, and 4 to the buffer are thinner indicating that the walking paths emerge less frequent after the solution implementation. This is the result of the implementation of solution 2. The materials that are placed in the buffer are now brought to the assembly line and therefore the employees at the line have to go to the buffer to retrieve the materials themselves less frequent. As we explained earlier, the sorting centre employee responsible for bringing the materials to the line had to execute his daily tasks and therefore could not always bring the materials to the assembly line. In the case the materials could not be brought to the line, the employees had to retrieve the materials themselves. Therefore, the Spaghetti diagram does show lines from the different stations to the buffer.

The second difference between the two Spaghetti diagrams is that the employees do not go to the sorting centre. The materials in the buffer are arranged according to their respective window frame series. By structurally arranging the materials, missing materials are easily detected. These missing materials were found before the assembly line needed them and therefore the assembly line employees do not have to go to the sorting centre to receive information on the missing materials.

At last, the walking path towards the assembly rotating parts department did not change. The station 2 employee sometimes goes to the assembly rotating parts department because of missing rotating parts. Solution 5 concerns the arrangement of the rotating parts on size within a window frame series. Solution 5 was not part of the pilot and therefore was not implemented. Therefore, the walking path towards the assembly rotating parts department did not change.

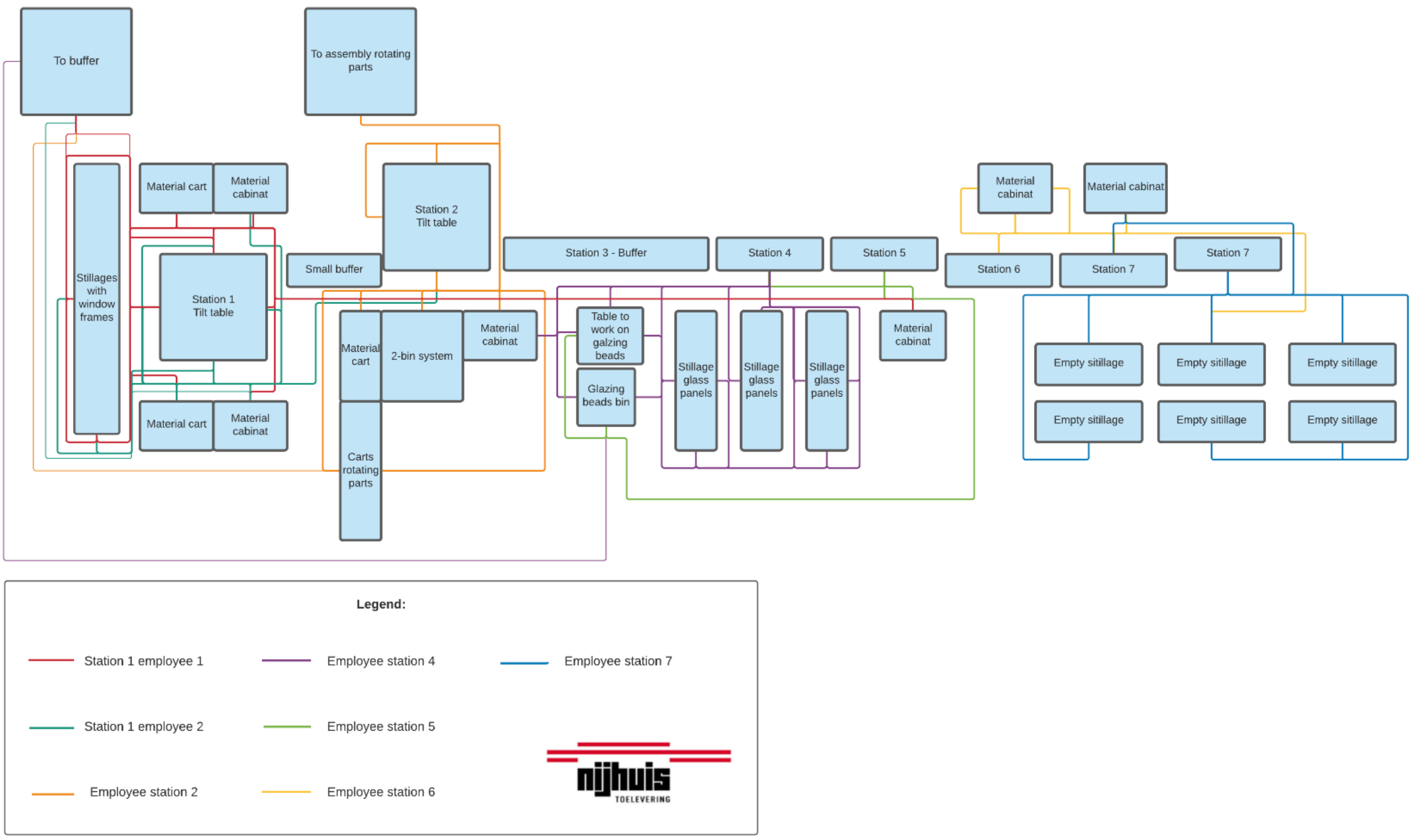

Figure 8.2: Spaghetti diagram employee walking paths after implementation solutions 2 and 4

8.5 SOCIAL IMPACT

In Section 6.3, we discussed three social concerns the employee had about the implementation of the solutions. In this section, we evaluate the social impact of the implementation of the solutions based on interviews held with the employees at the assembly lines.

The first social concern of the employees was regarding being bound to the assembly line. The employees feared that the work would become monotonous when they would not have to leave the line to retrieve materials from the buffer. After the pilot, we conducted interviews with the employees to get insight into their opinion with regard to the solutions. The employees, especially at stations 1 and 2 were glad that the searching for materials was less than on normal days. Next to that, they thought it was nice that sometimes the materials were brought to the assembly line and sometimes they had to retrieve the materials themselves. The employees still had a small interruption between the work now and then, which was less frequent than before the implementation of the solutions but still enough to keep the work from becoming monotonous.

The second concern was that the employees feared that they would have to work harder than they were already doing to work towards a 50% output increase. With the use of the pilot, the view of the employees on this topic changed. They saw that the solution implementation helped them to work more efficient instead of harder. They also saw that with the same effort their daily output was quite high in comparison with before the solution implementation.

The third social concern was that the employees feared that the social interaction between the employees would change when the solutions were implemented. During the pilot days, the employees did not experience a change in ambience on the work floor. With the pilot, the concerns the employees had regarding the ambience on the work floor are eliminated.

At last, the employees expressed their appreciation towards to way they were involved in the decision-making process regarding the pilot. They value that they are asked about their opinions and concerns. On a social level, the pilot showed the employees that the implementation of the solutions benefits them as well as the production process as a whole. By actually experiencing the solutions for a short period of time, the employees can develop an image of how the solutions work in practice. Overall, the employees view on the implementation of the solutions is quite positive. This increases their willingness to participate in the implementation process of the solutions.

8.6 CHAPTER CONCLUSION

In this chapter, we evaluated the actual impact of the solutions on the assembly process at Nijhuis Toelevering. This chapter gives an answer to the following research question:

9. What is the actual impact of the improvement action(s) on the assembly process at Nijhuis Toelevering?

We evaluated the impact of the solutions with the use of the KPI values before and after the implementation of solutions 2 and 4. The analysis of the KPIs shows that after the implementation of solutions 2 and 4 the performance of the assembly process and assembly line 2 is higher than the average before the solution implementation and approximately according to the expectations. This higher performance can be the result of the implementation of the solutions, but other aspects also influence the KPI values. Therefore, we need to be careful when we use averages to compare our results.

Based on the time measurements conducted during the pilot, we conclude that the actual eliminated time waste is approximately according to the expectations from Chapter 6. The actual eliminated time waste lies between the expected eliminated time waste by the implementation of solution 4 and the expected eliminated time waste of solution 2. This is because the actual eliminated time waste corresponds to the implementation of both solutions 2 and 4. We do not know how each solution contributes to the time waste elimination, because the interrelations between the solutions are unknown and need to be further researched. The biggest time waste elimination occurs at station 1 with the retrieval of stillages with window frames from the buffer. The retrieval of stillages with window frames is the most frequent occurring NVA activity outside the cycle times at the assembly lines.

To evaluate the impact of the solutions on the employee walking paths, we created a new Spaghetti diagram that depicts the employee walking paths after solutions 2 and 4 are implemented. By comparing the Spaghetti diagram from Chapter 4 with the new Spaghetti diagram, we are able to evaluate the impact of the solutions. The first difference between the two Spaghetti diagrams is that the employees leave the line less frequent. This is the result of the implementation of solution 2. The second difference between the two Spaghetti diagrams is that the employees do not go to the sorting centre. The materials in the buffer are arranged according to their respective window frame series. By structurally arranging the materials, missing materials are easily detected. These missing materials were found before the assembly line needed them and therefore the assembly line employees do not have to go to the sorting centre to receive information on the missing materials.

On a social level, the pilot showed the employees that the implementation of the solutions benefits them as well as the production process as a whole. By actually experiencing the solutions for a short period of time, the employees can develop an image of how the solutions work in practice. The first of three social concerns the employee expressed is their fear of their work becoming monotonous after the solution implementation. The employees, especially at stations 1 and 2 were glad that the searching for materials was less than on normal days. Next to that, they thought it was nice that sometimes the materials were brought to the assembly line and sometimes they had to retrieve the materials themselves. The employees still had a small interruption between the work now and then, which was less frequent than before the implementation of the solutions but still enough to keep the work from becoming monotonous. The second concern was that the employees feared that they would have to work harder than they were already doing to work towards a 50% output increase. The employees saw that the solution implementation helped them to work more efficient instead of harder. They also saw that with the same effort their daily output was quite high in comparison with before the solution implementation. The third social concern was that the employees feared that the social interaction between the employees would change when the solutions were implemented. During the pilot days, the employees did not experience a change in ambience on the work floor. The pilot also increased the willingness of the employees to participate in the implementation process of the solutions.

Overall, we conclude that the impact of the implementation of the solutions is quite large. The KPI performance is above average, and the expected amount of time waste is eliminated due to the solution implementation. The walking paths of the employees toward the buffer to retrieve materials are less frequent and the social concerns of the employees are minimized by the use of the pilot.

9 CONCLUSIONS AND RECOMMENDATIONS

Within this thesis, solutions are proposed to increase the efficiency of the final assembly process at Nijhuis Toelevering. Each chapter in this thesis relates to one or more research questions that were answered in the chapter conclusions. All these conclusions contribute to the goal of answering the main research question of this thesis. In this chapter, the main conclusions, recommendations and potential future research topics are described.

10. What recommendations and conclusions can be made based on the results of the thesis at Nijhuis Toelevering?

Section 9.1 describes the conclusions of this research. In this section, we answer the main research question with the use of the answers from the sub-research questions. In Section 9.2, we give our recommendations. Section 9.3 outlines the potential future research topics. In Section 9.4, we describe the theoretical and practical contribution of this research.

9.1 CONCLUSIONS

The goal of this thesis is to increase the efficiency of the final assembly process in order to increase the production output. The demand for wooden window frames has been increasing over the past five years and is expected to keep increasing during the upcoming years. A higher production output is not possible due to a low final assembly efficiency. In order to generate solutions that will increase the efficiency of the assembly lines, we are looking for the answer to the main research question:

"How to improve the efficiency of the current assembly process at Nijhuis Toelevering? In particular, how to increase the output so as to approach the intended (output increase) target of 50%?"

To answer this main research question, research is conducted. This is done by answering several research questions in the different phases of the research. We will first look at the answers to these research questions:

1. What is the current assembly process at Nijhuis Toelevering?

The current assembly process consists of four assembly lines and a separate department for the assembly of the rotating parts. Each assembly line contains seven different stations where different components are added to the window frames.

2. How can the current logistic flows of materials for the assembly lines be determined?

The material supply to the assembly process is divided into three categories: internally produced materials, standard materials, and window frame-specific materials. The internally produced materials are the window frames, rotating parts, and glazing beads. The standard materials are the same for every window frame that is assembled. The materials are supplied using a 2-bin system. The window frame-specific materials are different for each window frame and are tailored materials.

3. What are the relevant production improvement techniques for improving the material flows at Nijhuis Toelevering?

The relevant production improvement techniques for this research are Lean manufacturing tools. In particular, VSM, Kanban, and the 5S methodology. VSM helps to identify the wastes within the process regarding materials and information flows. Kanban is a visual control tool used to control the production and inventory anomalies. 5S is used to provide a structured material use and material flows within a process.

4. What is the current efficiency performance of the assembly process at Nijhuis Toelevering?

The efficiency performance is evaluated with the use of the KPIs measured by Nijhuis Toelevering. There are a lot of fluctuations in the values of the KPIs due to the high variety in window frames that are assembled. However, the analysis shows that the current performance of the assembly process overall reaches the stated norms.

5. What are the main causes of waste in the assembly process at Nijhuis Toelevering?

The causes of waste in the assembly process are identified by observing and conducting time measurements at assembly line 2. From the created VSM and Spaghetti diagrams, it is concluded that most of the waste within the assembly process is caused by walking towards and searching for materials. We identified three challenges that cause waste in the process, which are the employees walking paths, the lack of structure in material placement, and the production planning.

6. Which possible improvement actions can be formulated based on the current material flows and the new insights?

For each of the three challenges identified by answering research question 5, we formulated potential solutions. Next to that, we formulated two solutions that do not target one of the three challenge areas. In total, we formulated ten potential solutions.

7. Which of the possible improvement actions is chosen to be implemented at Nijhuis Toelevering?

From the ten formulated solutions, we selected three solutions to implement based on the requirements set by Nijhuis Toelevering. For the selection of the solutions, we used a weighted decision matrix. The three chosen solutions, as labelled in Chapter 5, are:

2. Bringing the materials to the assembly lines.
4. Arranging the materials in the buffer according to window frame series.
5. arranging the rotating parts based on size within a window frame series.

For each of the three solutions, the expected quantitative and social impact is examined. Based on the time measurements from Chapter 4, the impact of solutions 4 and 2 is clearly definable. With solution 4, the assembly process at Nijhuis Toelevering can weekly assemble 3.80 extra window frames. This corresponds to an output increase of 0.69%. With solution 2, the assembly process at Nijhuis Toelevering can weekly assemble 18 extra window frames. This corresponds to an output increase of 3.27%. The impact of solution 5 is difficult to define based on the time measurements because the number of rotating parts varies each day. Therefore, we cannot estimate how much time waste is eliminated with solution 5. The employees indicated that implementing solution 5 would benefit them a lot. It is difficult to predict the impact of the implementation of all three solutions together since their interrelationships are unknown. We can estimate that the impact of all three solutions at least has the same impact as solution 4. Solution 4 is the solution that can support the other solutions in case they do not work. Therefore, we can state that the minimal impact of the three solutions together is the same as the impact of solution 4.

There are three social concerns the employees have indicated during the interviews. First, the employees fear the work becoming monotonous when Nijhuis Toelevering implements the solutions. Second, the employees think that they need to work harder than is possible. At the moment of conducting this research, the employees believe that they are working on their maximum performance. Third, the employees fear that the social aspect of their job will be reduced.

8. How can the defined action(s) to improve the materials flows be implemented?

For each of the three chosen solutions, we developed an implementation plan. These plans contain the steps that need to be carried out in order to implement the specific solution. Each plan also includes the stakeholders involved in the implementation process. With the implementation of the solutions, it is important to include the assembly line employees within the process to ensure the willingness to participate in the process.

9. What is the actual impact of the improvement action(s) on the assembly process at Nijhuis Toelevering?

We evaluated the impact of the solutions with the use of the KPI values before and after the implementation of solutions 2 and 4. The analysis of the KPIs shows that after the implementation of solutions 2 and 4 the performance of the assembly process and assembly line 2 is higher than the average before the solution implementation and approximately according to the expectations. This higher performance can be the result of the implementation of the solutions, but other aspects also influence the KPI values. Therefore, we need to be careful when we use averages to compare our results.

Based on the time measurements conducted during the pilot, we conclude that the actual eliminated time waste is approximately according to the expected time waste elimination. The actual eliminated time waste lies between the expected eliminated time waste by the implementation of solution 4 and the expected eliminated time waste of solution 2. This is because the actual eliminated time waste corresponds to the implementation of both solutions 2 and 4.

To evaluate the impact of the solutions on the employee walking paths, we created a new Spaghetti diagram that depicts the employee walking paths after solutions 2 and 4 are implemented. The first difference between the two Spaghetti diagrams is that the employees leave the line less frequent. This is the result of the implementation of solution 2. The second difference between the two Spaghetti diagrams is that the employees do not go to the sorting centre. The materials in the buffer are arranged according to their respective window frame series. By structurally arranging the materials, missing materials are easily detected. These missing materials were found before the assembly line needed them and therefore the assembly line employees do not have to go to the sorting centre.

On a social level, the pilot showed the employees that the implementation of the solutions benefits them as well as the production process as a whole. By actually experiencing the solutions for a short period of time, the employees can develop an image of how the solutions work in practice. The three social concerns of the employees are eliminated because of the pilot. With that, the willingness of the employees to participate in the implementation process of the solutions also increased.

Based on the pilot, we conclude that the impact of the implementation of the solutions is quite large. The KPI performance is above average, and the expected amount of time waste is eliminated due to the solution implementation. The walking paths of the employees toward the buffer to retrieve materials are less frequent and the social concerns of the employees are minimized by the use of the pilot.

Overall, Nijhuis Toelevering can improve the efficiency of the current assembly process by eliminating the wastes within the process. These wastes are mainly caused by walking towards and searching for materials. These wastes can be eliminated by implementing the proposed solutions.

9.2 Recommendations

With the results of this research, Nijhuis Toelevering has a starting point for increasing the efficiency of their final assembly process. In this section, we describe the recommendations for Nijhuis Toelevering.

First, we advise Nijhuis Toelevering to implement the solutions to eliminate waste within the current final assembly process. This concerns both the chosen solutions and the other solutions from Chapter 5. The other solutions need further research before they can be implemented. We transfer this report to the operational manager, the production manager, and the logistics coordinator so that they can further research the potential solutions.

We advise Nijhuis Toelevering to evaluate the solutions when they are implemented. It is important to evaluate the practical impact of the solutions. This concerns both the impact on the KPIs, but also the impact on the employees. It is recommended to evaluate the solutions and find solutions to occurring challenges. These challenges should be resolved and then the solutions need to the evaluated again. Over time, if the solutions are hound to be working properly and no problems arise, the frequency of the evaluations can be reduced. We recommend the short feedback loops so that continuous improvement is established.

The most important and last recommendation is that we advise Nijhuis Toelevering to often ask the assembly line employees about their opinions, ideas, and concerns. By frequently involving the employees in the decision-making process, their willingness to participate in the implementation of new solutions can increase. Organizing brainstorm sessions with the employees to find solutions to occurring challenges can be a good starting point.

9.3 Future research

This bachelor thesis has been conducted in a time period of ten weeks. Extensive research was therefore not possible. The limitations in the scope of this research provide opportunities for future research topics.

First, this research has been focused on the final assembly department of Nijhuis Toelevering. During this research, we identified some problems occurring at the paint shop that directly influence the efficiency of the final assembly process, like the paint quality. Research can be executed in order to find solutions to the problems.

Second, the specific tasks at each of the stations are out of the scope of this research. Research can be conducted on whether it is possible to carry out certain tasks more efficiently. The way certain actions, like placing the glazing beads, are performed can maybe be carried more efficient.

At the moment of conducting this research, the integration of an Enterprise Research Planning (ERP) is researched. Therefore, this research did not take an ERP system as a solution into account. The integration of ERP offers a lot of opportunities to increase the efficiency of the final assembly process. It could be possible to, for example, track a window frame through the production facility and collecting data on the cycle times, output values, and other KPIs. Research can be conducted on how ERP can help to increase the efficiency of the final assembly process.

At last, during this research, we saw that the difficulty of a window frame series is not taken into account within the production planning. The sales department also does not look at how difficult a window frame series is when agreeing with the customer on the delivery date. As we saw, the difficulty of a window frame series can have a huge impact on the assembly lines. Research can be executed on how the difficulty of a window frame could be taken into account in the production planning.

9.4 Contribution

This section describes the theoretical and practical contribution of this research.

Theoretical contribution

In this research, a literature study is performed on the topic of production improvement techniques, such as Lean manufacturing. There are a lot of different theories and models that can be used to improve production processes. This research mainly uses the Lean principles and techniques to develop solutions to improve the assembly process of window frames. The Lean manufacturing tools used in this research are Value Stream Mapping, Kanban, and the 5S methodology. The theoretical contribution of this research consists of how the principles of the different Lean tools can be used in practice. When the process lacks standardization, it is difficult to capture the reality (Jasti et al., 2019). We showed how the principles of the different Lean tools can be used in a high-variety, low-volume company.

Practical contribution

This research is performed at Nijhuis Toelevering B.V. The practical contribution of this research is threefold. First, the research yielded three solutions Nijhuis Toelevering can use to improve the efficiency of the assembly process and work towards the intended output increase of 50%. Second, this research gives Nijhuis Toelevering serval implementation plans on how to implement the different solutions. These implementation plans also contain the active involvement of the employees in the decision-making process. Third, this research shows Nijhuis Toelevering how waste in a production process can be identified and eliminated. Nijhuis Toelevering can use this research at other departments within the production process to identify and eliminate wasteful activities.

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APPENDIX

APPENDIX A: LAYOUT ASSEMBLY PROCESS

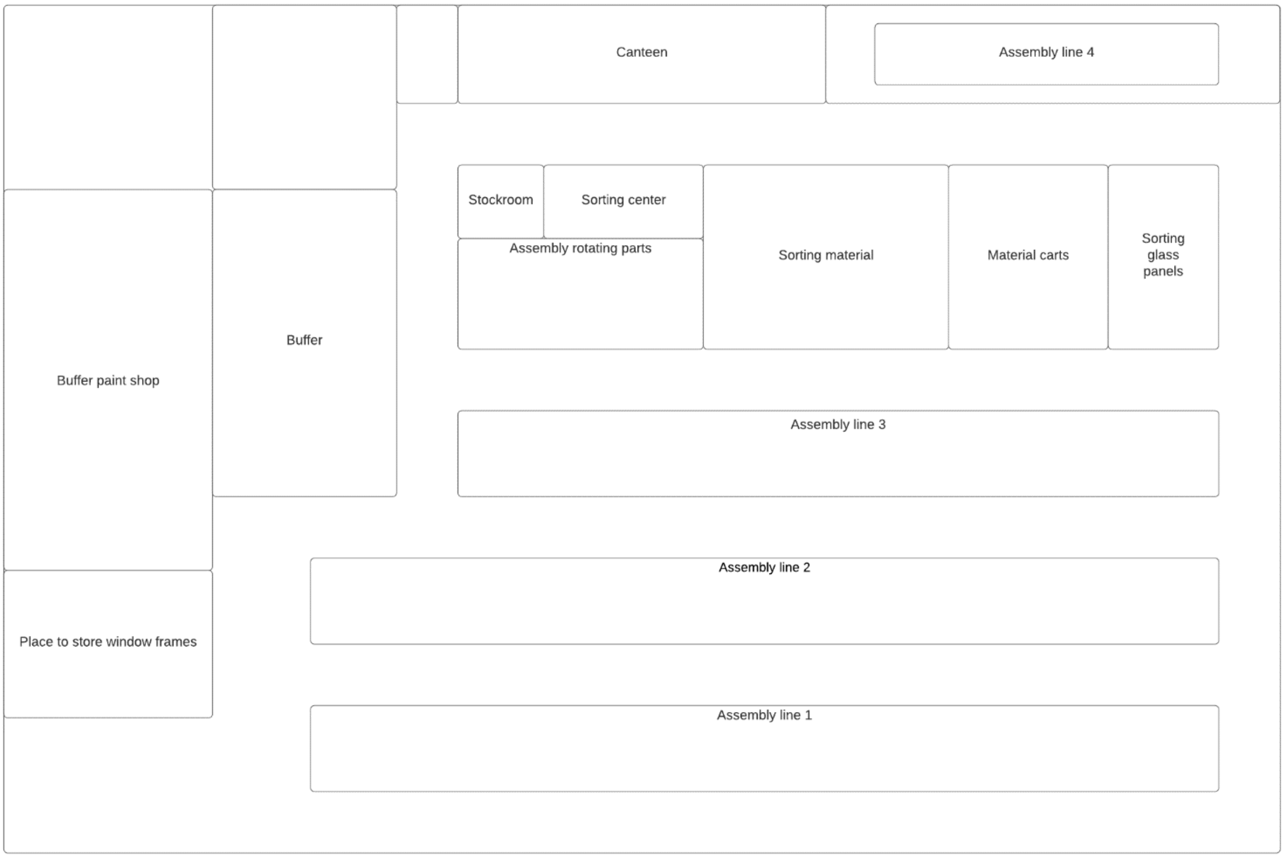

Figure 0.1: Layout assembly department at Nijhuis Toelevering

APPENDIX B: WEEKLY WINDOW FRAME OUTPUT

Table 0.1: Weekly window frame output

Week	Weekly output window frames	Norm
2020-1	0	0
2020-2	524	500
2020-3	621	550
2020-4	721	550
2020-5	627	550
2020-6	581	550
2020-7	582	550
2020-8	658	550
2020-9	703	550
2020-10	694	550
2020-11	592	550
2020-12	593	550
2020-13	544	550
2020-14	636	550
2020-15	406	440
2020-16	506	440
2020-17	572	550
2020-18	439	440
2020-19	509	550
2020-20	579	550
2020-21	325	330
2020-22	592	550
2020-23	480	440
2020-24	592	550
2020-25	600	550
2020-26	573	550
2020-27	703	550
2020-28	566	550
2020-29	549	550
2020-30	0	0
2020-31	0	0
2020-32	0	0
2020-33	0	0
2020-34	551	550
2020-35	631	550
2020-36	547	550
2020-37	696	550
2020-38	619	550
2020-39	525	440
2020-40	330	440
2020-41	527	550
2020-42	586	550
2020-43	547	550
2020-44	679	550
2020-45	657	550
2020-46	706	550
2020-47	526	550
2020-48	699	550
2020-49	665	550
2020-50	644	550
2020-51	562	550
2020-52	0	0
2021-1	445	440
2021-2	748	550
2021-3	657	550
2021-4	660	550
2021-5	645	550
2021-6	595	550
2021-7	723	550
2021-8	754	550
2021-9	744	550
2021-10	717	550
2021-11	746	550
2021-12	737	550
2021-13	570	440
2021-14	509	440
2021-15	720	550
2021-16	711	550
2021-17	349	330
2021-18	603	550
2021-19	429	330
2021-20	731	550

APPENDIX C: REALIZED PRODUCTION HOURS AND EFFICIENCY OF HOURS

Table 0.2: Realized production hours and efficiency of hours

Week	Realized production hours	Man-hours used	Efficiency of the hours used	Efficiency norm
2020-1	0	0	0%	0%
2020-2	2476	2331	106%	110%
2020-3	2474	2358	105%	110%
2020-4	2556	2358	108%	110%
2020-5	2379	2351	101%	110%
2020-6	2518	2324	108%	110%
2020-7	2433	2319	105%	110%
2020-8	2412	2302	105%	110%
2020-9	2500	2260	111%	110%
2020-10	2466	2225	111%	110%
2020-11	2468	2274	109%	110%
2020-12	2438	2144	114%	110%
2020-13	2477	2155	115%	110%
2020-14	2536	2224	114%	110%
2020-15	2069	1875	110%	110%
2020-16	2138	1907	112%	110%
2020-17	2701	2313	117%	110%
2020-18	2073	1910	109%	110%
2020-19	2469	2297	108%	110%
2020-20	2463	2289	108%	110%
2020-21	1530	1362	112%	110%
2020-22	2621	2309	113%	110%
2020-23	2053	1850	111%	110%
2020-24	2698	2257	120%	110%
2020-25	2647	2316	114%	110%
2020-26	2553	2278	112%	110%
2020-27	2844	2355	121%	110%
2020-28	2615	2366	111%	110%
2020-29	2413	2357	102%	110%
2020-30	0	0	0%	0%
2020-31	0	0	0%	0%
2020-32	0	0	0%	0%
2020-33	0	0	0%	0%
2020-34	2378	2275	105%	110%
2020-35	2639	2425	109%	110%
2020-36	2646	2460	108%	110%
2020-37	2627	2331	113%	110%
2020-38	2548	2286	111%	110%
2020-39	1997	1760	113%	110%
2020-40	1665	2076	80%	110%
2020-41	2378	2321	102%	110%
2020-42	2636	2367	111%	110%
2020-43	2420	2485	97%	110%
2020-44	2903	2672	109%	110%
2020-45	2707	2631	103%	110%
2020-46	2729	2484	110%	110%
2020-47	2690	2317	116%	110%
2020-48	2646	2283	116%	110%
2020-49	2591	2304	112%	110%
2020-50	2584	2321	111%	110%
2020-51	2387	2063	111%	110%
2020-52	0	0	0%	0%
2021-1	2157	1962	110%	110%
2021-2	2536	2403	106%	110%
2021-3	2617	2378	110%	110%
2021-4	2618	2375	110%	110%
2021-5	2720	2372	115%	110%
2021-6	2691	2296	117%	110%
2021-7	2666	2400	111%	110%
2021-8	2756	2457	112%	110%
2021-9	2771	2284	121%	110%
2021-10	2821	2235	126%	110%
2021-11	2848	2293	124%	110%
2021-12	2781	2305	121%	110%
2021-13	2217	1916	116%	110%
2021-14	2315	1989	116%	110%
2021-15	2846	2413	118%	110%
2021-16	2869	2438	118%	110%
2021-17	1749	1430	122%	110%
2021-18	2855	2386	120%	110%
2021-19	1788	1375	130%	110%
2021-20	2875	2310	125%	110%

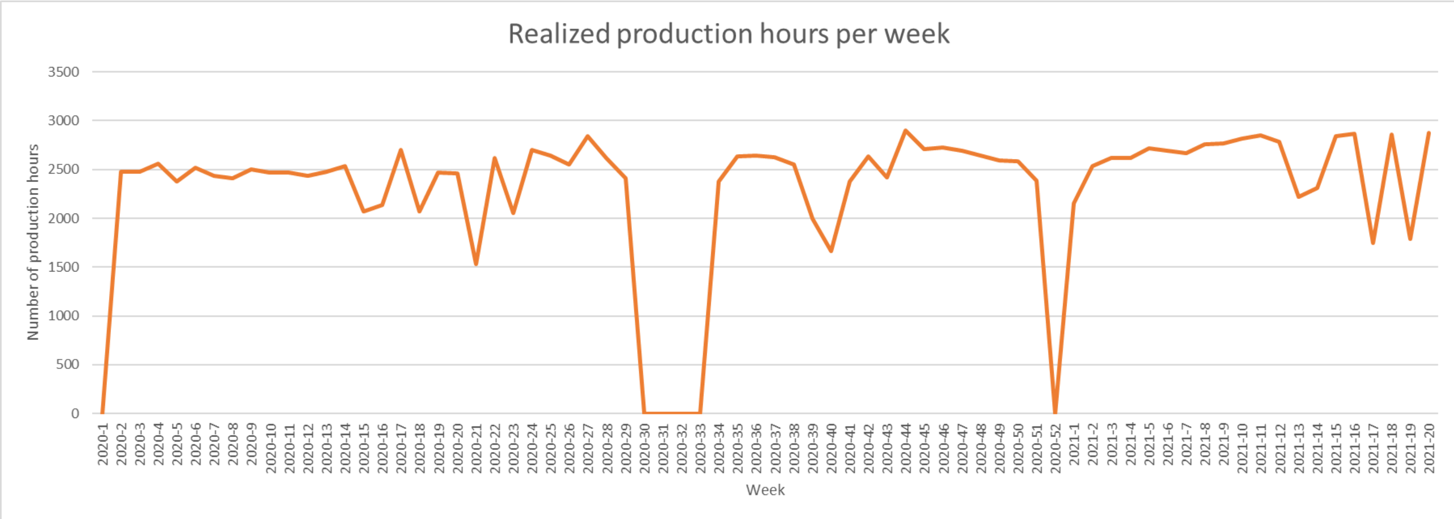

Figure 0.3: Realized production hours per week

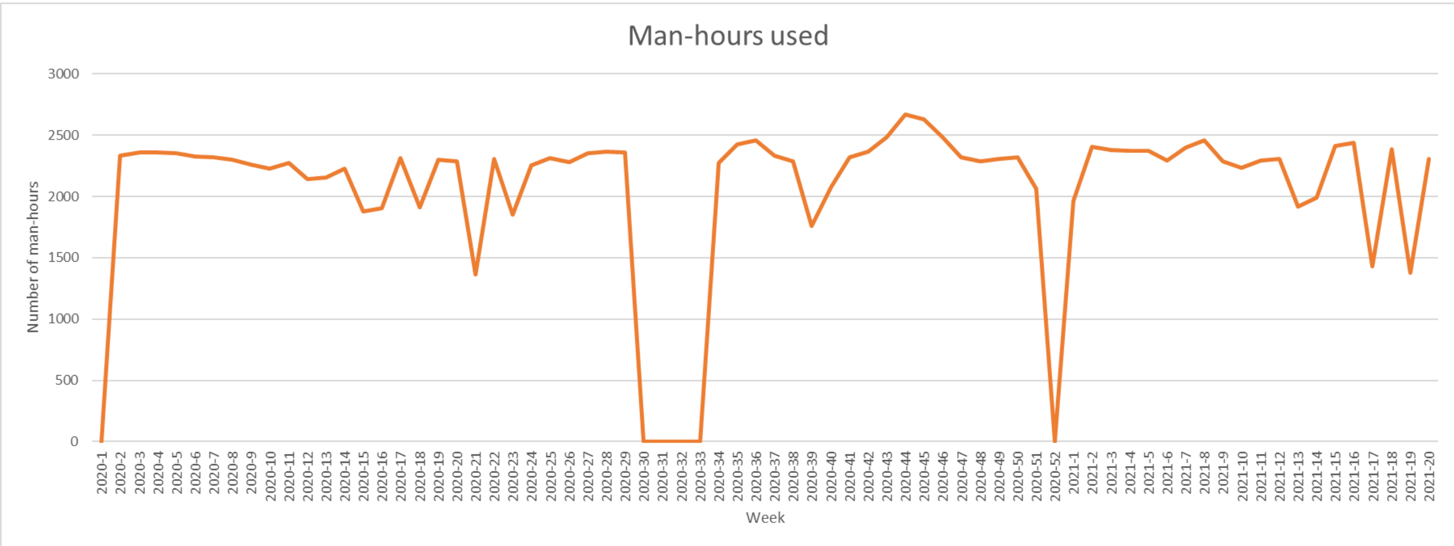

Figure 0.2: Man-hours used per week

Appendix D: Non-value-added (NVA) division in cycle times

Table 0.3: Non-value-added (NVA) activities included in cycle time

Station	Activity	Average duration (mm:ss.ms)	Percentage of NVA time (%)
Station 1	Getting materials from material cart	00:18.3	11.6
	New window frame on tilt table	00:18.0	11.4
	Picking up rotating parts from the buffer	00:39.0	24.7
	Other		52.3
Station 2	Getting rotating parts for window frame	00:30.8	34.0
	Getting materials from material cart	00:18.9	20.9
	Other		45.1
Station 4	Searching glazing beads	00:29.6	12.7
	Removing glazing beads staples	00:25.3	10.8
	Add glass tape to glazing beads	01:00.4	25.9
	Getting glass panel	00:21.4	9.2
	Searching and unpacking ventilation grille	00:32.2	13.8
	Searching and unpacking rods	00:40.9	17.5
	Replace sealant gun	00:12.9	5.5
	Other		4.7
Station 5	Replace sealant gun	00:17.0	45.1
	Other		54.9
Station 6	Searching and unpacking rods	00:19.6	39.4
	Replace sealant gun	00:20.3	40.9
	Other		19.7

APPENDIX E: EMPLOYEE WALKING PATHS SPAGHETTI DIAGRAMS

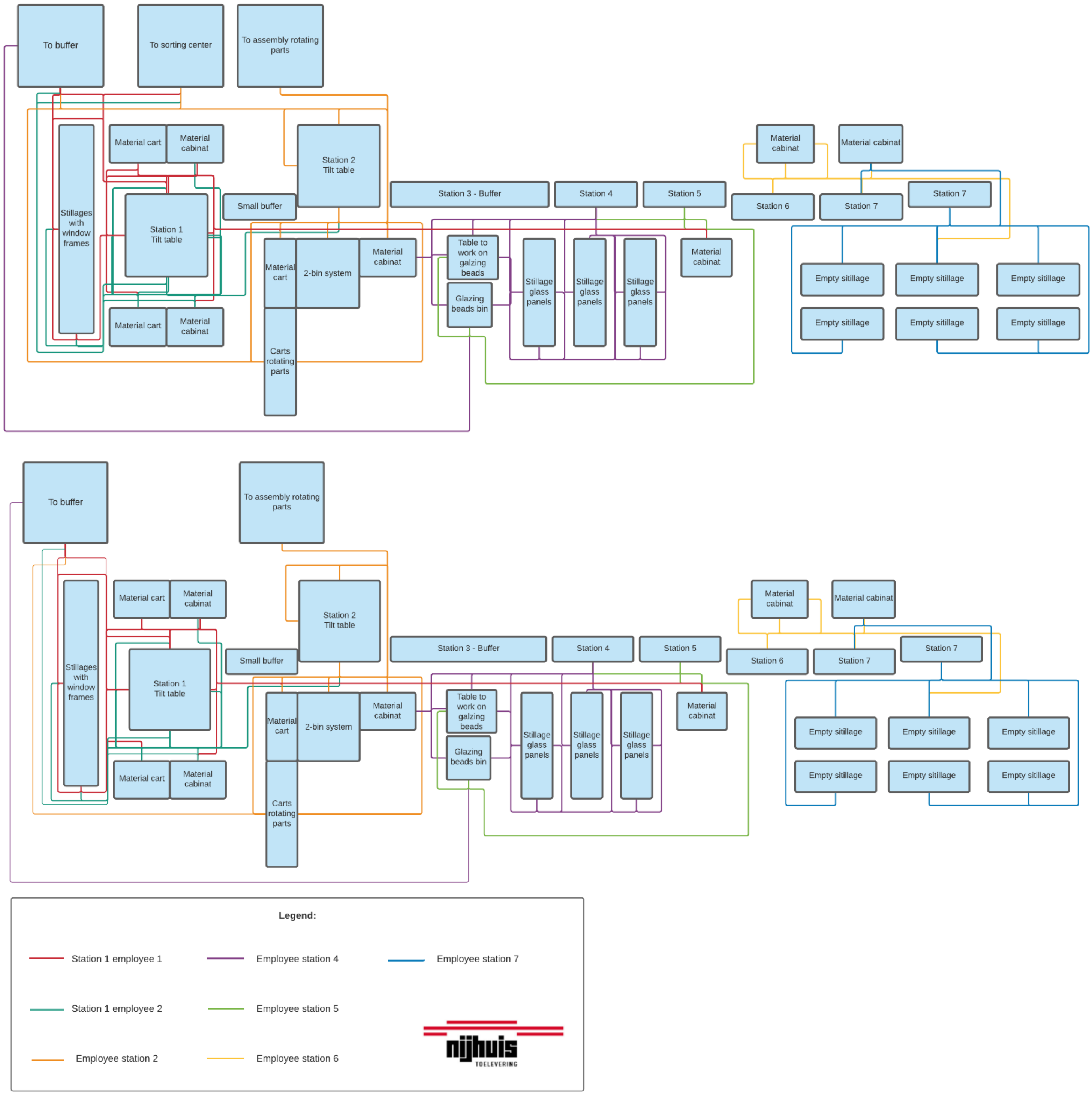

Figure 0.4: Spaghetti diagrams employee walking paths before and after solutions implementation