Master’s Design Project

Optimizing Production Capacity of Royal Bel Leerdammer Cheese Manufacturing B.V.

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Abstract

This paper describes a plan to improve the efficiency of the mould handling circuit of the Royal Bel Leerdammer Cheese manufacturing plant in Dalfsen, in order to increase the maximum production capacity. To keep a competitive advantage in the manufacturing of one of the oldest known products: cheese. Throughout the ages the process of cheese manufacturing developed substantially. Manufacturing plants therefore need to continuously optimize their, sometimes outdated, facilities. One way to optimize a system is assembly line balancing. Many papers can be found in this field, however surveys addressing real practical problems are still scarce. This research could help close the gap between theories and real practical problems. The used DMAIC method (comparable with the regulative cycle) proves to be an useful method in this research.

To analyze the system and to validate possible improvements, the mould handling circuit is recreated in Tecnomatix plant simulation 13.1. This simulation provides insights in some of the problems observed in the real system. Especially problems related to variations in the availability of 'supplement equipment' (moulds and lids). Other results show variations in processing speed of different machines in the mould handling circuit. Some machines operate more than 30% of the time below the desired lower boundary. All the variations in the system influence each other, mostly in a negative way. Partly as a result of these variations, 9,777 minutes of short stops occurred in this system, in 2018. This amount of short stops is equal to an amount of cheese above 900 tons.

In 2018 the system produced an average of 8.13 cheeses per minute, while the system was able to produce on average 8.19 cheeses per minute. Recommended improvements (as for instance a standardized amount of moulds and lids in the system, enabling more moulds in front of the moulding machine by adding one stopper and replacing a sensor, adding a lid-buffering machine, and adding stoppers and an ensured chain in front of the presses) have the potential to increase the average production output and decrease the downtime of the system. All in all compared with 2018, a production output of 40,801 tons of cheese could be achieved, with an investment of €118,000. With these improvements, Royal Bel Leerdammer could save €280,175.

Keywords: Cheese manufacturing, Assembly line balancing, Lean, Tecnomatix plant simulation, Mould handling circuit, Optimizing production output
## Abbreviations

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<th>Meaning</th>
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<tr>
<td>BKD</td>
<td>Breakdown (identified stops, longer than three minutes)</td>
</tr>
<tr>
<td>DMAIC</td>
<td>Define, Measure, Analyse, Improve and Control</td>
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<td>HT</td>
<td>Holding table</td>
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<tr>
<td>JIT</td>
<td>Just in time</td>
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<tr>
<td>Leli</td>
<td>Leerdammer Light 30+</td>
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<tr>
<td>LOR</td>
<td>Lack of resource</td>
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<tr>
<td>NPC</td>
<td>Name Plate Capacity</td>
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<tr>
<td>OEE</td>
<td>Overall equipment effectiveness</td>
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<tr>
<td>PLC</td>
<td>Programmable Logic Controller</td>
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<tr>
<td>SST</td>
<td>Short stops (unidentified stops, shorter than three minutes)</td>
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## Nomenclature

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<td>Mould</td>
<td>Vat</td>
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<td>Lid</td>
<td>Volger</td>
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<td>Moulding machine</td>
<td>Casomatic</td>
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<tr>
<td>Transport direction converter</td>
<td>Overzetter</td>
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<tr>
<td>Lid placer</td>
<td>Volgerlegger</td>
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<td>Presses</td>
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<td>Remoulder</td>
<td>Ompakker</td>
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<tr>
<td>Holding tables</td>
<td>Omloop tafels</td>
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<tr>
<td>Demoulder</td>
<td>Uitpakker</td>
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<tr>
<td>Mould cleaning machine</td>
<td>Spoeltunnel</td>
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<td>Mould-buffer</td>
<td>Vatenbuffer</td>
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1 Introduction

Cheese is one of the oldest known products developed and consumed by humans. Possibly, it started between 9000 and 7500 BC when the population growth in the Middle East leaded to the domestication of animals, first for their meat and later on also for their milk [1]. It is likely that the milk production was targeted on feeding children, because most adults at that time suffered from lactose intolerance. In these warm climates the shelf life of milk was short. It could have happened that sour milk separated in whey and curd particles. These particles appeared to be edible and nourishing, also for the adults. Nomadic tribes would transport milk in animal-skin bags, where bacteria started to ferment the milk sugars causing the milk to curdle. Motions of the trip would break the curd, resulting in solid curd particles and drinkable whey [2].

The discovery of pottery manufacturing between 7000 and 6500 BC increased the capabilities to collect and store surplus milk. In here, due to the warm climate, milk would also coagulate. After draining the whey, only curd (or cheese) was left. The shelf life of cheese is longer than milk and it was easier to transport [1]. With the development of humankind, cheese manufacturing also evolved over the centuries.

Nowadays, the increasing world population demands the food industry to increase and to develop. Cheese is consumed all over the world. A major player in the world wide production production of cheese is 'the Bel Group'. Products are sold in 120 countries and in 2017 the company generated a turnover of 3.3 billion euros. The Bel group consists of five major brands (La Vache qui rit®, Kiri®, Boursin®; Babybel® and Leerdammer®) together with 25 local brands. Three out of the 30 production locations are established in the Netherlands, namely in Schoonrewoerd, Wageningen and Dalfsen. Together they form the brand 'Royal Bel Leerdammer’. Royal Bel Leerdammer produces yearly 73,000 tons of cheese. On average 730 million kg milk is needed to produce this amount of cheese. Most of the cheese (±55%) is produced in Dalfsen. Here, eleven different types of cheese are produced and this plant can be considered as a producer of semi-finished products.

The overall production process of the Bel Leerdammer cheese manufacturing plant in Dalfsen is depicted in figure 1. In essence, this system is the same for every cheese manufacturing plant. The production process can be divided in three parts: Pre-factory (green, blue and red boxes), cheese factory (yellow boxes) and cheese warehouse (turquoise box). The pre-factory consists of the processes before ‘curd preparation’ in figure 1. Here, raw milk from the dairy farmers enters the plant. The milk is treated in a thermal and a bactofugation process to reduce the number of micro-organisms before flowing to the cheese factory.
In the 'curd preparation' step the milk is coagulated. This means that a thick gel is formed. Hereafter, the gel is cut in the tank, forming solid flakes of curd flowing in liquid whey. A broader explanation of the cheese making process can be found in Appendix A. After preparation, curd and whey are pumped into nine columns of the 'moulding machine'. In these tall columns, curd flakes settle down at the bottom. The difference in mass makes it possible to drain the whey at the top of the moulding machine. Curd particles at the bottom are compressed together due to the gravity effect of all the settled curd. Thick rectangular blocks of packed curd are cut off at the bottom of the moulding machine. The 'cheeses' need to be pressed to reduce the moisture content and they are stored for a while to achieve the right pH value.

Hereafter, the cheeses enter the brining (or salting) process in figure 1. Brining of the cheese also helps to drop the moisture content even more. Moisture in the cheese will flow from the low osmotic value in the cheese surface to the high osmotic value of the brining-bath. The minerals in the brining-bath will flow the other way around until the values are balanced. Salts give an extra flavor to the cheese and ensure that salt-sensitive micro-organisms occur at the center of the cheese and salt-tolerant micro-organisms occur at the surface of the cheese. Beside moisture content, taste and inhibition of microorganism-growth, this process is needed to achieve the desired texture, rind formation and aroma [3]. Cheeses stay in the salting bath from 45 hours to 100 hours, depending on type. Next, cheeses are sealed with a plastic foil and placed in the cheese warehouse. Here, cheeses need to mature. After seven to twenty weeks, depending on the type of cheese, cheeses are transported to other factories where the blocks are cut and packed for sale.

In essence, all the produced cheeses in Dalfsen have the same size, namely rectangular shaped blocks of ± 50 cm x 26 cm x 10 cm. Cutting and packaging of these cheeses are processes carried out in other plants. 60% of the total pro-
duction in Dalfsen is transported to the Bel Leerdammer plant in Wageningen, where the blocks of cheese are processed further. Also, the Bel Leerdammer plant in Schoonrewoerd has a cutting/packaging line. This line is for the production of extra thin slices of cheese. Furthermore, cutting and packaging of the cheeses is outsourced to FrieslandCampina. They have two cutting/packaging lines especially for Bel Leerdammer products. At last, some countries (like Belgium and the UK) process the blocks of cheese themselves.

Like all manufacturing companies, the factories of the Bel Group need to keep on developing to acquire competitive advantages. Increasing production capacity and efficiency, decreasing costs, elimination of waste and keeping sustainability in mind are all approaches towards these advantages. Lean principles are widely used for these approaches. Within cheese factories, the approaches described before meet the chemical, biochemical and microbiological industrial processes of cheese manufacturing. This combination is the basis of the study: Industrial Engineering & Management. Especially in the 'Product & Process Technology' direction chemical engineering and biotechnology are combined in a business setting.

The core of this thesis deals with a problem in the production capacity of the Royal Bel Leerdammer cheese manufacturing plant in Dalfsen. The current process does not give the desired production output. In the next section, before describing the scope of the research, the detailed problem will be defined. The plan to investigate the problem will be given thereafter, followed by the results and analysis. The analysis of the results will be used to develop a new design for the system. Final improvements will be discussed and the recommendation for the new design will be given in the conclusion. In the end, the outcome of this research will be generalized, in order to help other companies.
2 Definition of the Problem and Research Approach

The following section is meant to explain the problem at Royal Bel Leerdammer in Dalfsen. Thereby, a description of the production process with some general information will be given to clarify the industrial system of cheese manufacturing in this plant. The described and illustrated system will help to understand the core of this study.

2.1 Problem definition

In February 2018 the plant in Dalfsen almost could not fulfill the weekly demand of 767 tons cheese (67,000 cheeses of 11.45 kg). It was noticed that the so called ‘mould’ handling system became the new bottleneck of the cheese manufacturing in Dalfsen (24-hour per day, 7 days a week in operation). The flow of curd could be increased by increasing the supply of milk. However, the mould handling system headed to its maximum production capacity (NPC: Name Plate Capacity). Buffers became full, causing more and more a pushing effect in the mould handling system. Teams were created to solve problems and the production was successfully increased. Thereby, demand decreased a bit for the rest of the year. With the average production speed and losses of the mould handling system, the company could produce 40,000 tons cheese in the whole year 2018. For this year, this amount was sufficient, so for the moment no problem occurred. Nonetheless, the vision of the company, based on future demand expectations, is a desired annual production of 40,200 and 40,789 tons cheese in 2019 and 2023, respectively. To achieve the desired output in 2019 and 2023, annual production needs to increase by 200 and 789 tons cheese, respectively. The production speed of the mould handling system in 2018 was on average 8.13 cheeses per minute. The average time loss per day was 262 minutes. This number is calculated from the difference in operating time and total time (Appendix B). Potentially, the maximum production capacity of the mould handling system, so without breakdowns and short unidentified stops (SST), is 42,100 tons cheese per year. Thus, production output can be increased by accomplishing a higher efficiency (reduce time loss), or by increasing the total capacity of the system. Through increasing the production capacity of the mould handling system, a pull-effect can be ensured in the future. The problem is summarized in the next problem statement:

The current production speed and time losses realize a production capacity of the mould handling system of 40,000 tons cheese per year, while the potential maximum production capacity is 42,100 tons per year. Currently, Royal Bel Leerdammer cheese manufacturing B.V. in Dalfsen will not be able to achieve the desired production output of 40,200 and 40,789 tons cheese in 2019 and 2023, respectively.
Where this 'mould' handling system is placed and how it connects with the rest of the production process will be described next.

2.2 Scope of the research

The scope of the research is indicated in the production outline by a red dashed line in figure 1. Actually, this red dashed line includes the whole mould handling system. The focus of the project is only on this system. A more detailed depiction of the mould handling 'circuit' is given in figure 2.

As explained in the introduction, rectangular blocks of curd (cheeses) are sliced off at the bottom of the moulding machine. The cheeses fall into rectangular shaped moulds which transport the cheeses further. This is the first step of the system. A lid is placed on top of the cheese and several processes, for example pressing of the cheeses, are performed in this setup. The moisture content in the cheese needs to drop. By pressing, the curd particles merge even more and residual whey is removed. The pressing process consists of five pressing tables with a capacity of 152 moulds each (38 rows of 4 moulds). The time of pressing, usually around 75 minutes, depends on the type of cheese. Whenever one pressing table is completely filled, the process will start and the next pressing table will be loaded with moulds. Due to pressing a sharp edge, created by the lid,
arise at the top of the cheese. For this reason the cheese needs to be turned over in the mould. Another reason for turning is the redistribution of the residual moisture in the cheese. After turning, the sharp edge will be at the bottom of the mould and it will disappear due to the weight of the cheese pressing on the edge.

Before de-moulding, bacteria in the cheeses need some time to develop the cheese. Therefore, the moulds are placed on four holding tables. Two of these have capacities of 102 moulds and the other two have capacities of 99 moulds (rows of three moulds). When the cheeses reach the right pH they will be taken out of the moulds, tagged, weighted and the moisture content is determined before entering the brining-bath. The scope is completed with a cleaning machine. Empty moulds and lids are washed and returned to the moulding machine. All described processes are carried out by machines. Transportation of the moulds between the machines is required. Therefore, many transport and moving equipment with some buffers complete the mould handling system.

Figure 2 is a schematic representation of the mould handling circuit. This figure does not represent the real layout of the system clearly. To help reading this report and understanding the system, a more realistic system layout is recreated in Microsoft Visio [4] and given in figure 3.

![Figure 2: Schematic representation of the mould handling circuit.](image)

Figure 3: Schematic top view of the mould handling system. Indicated are the most important machines in the system. Furthermore, transport and moving equipment connect those machines. The attic at the bottom right represents a storage where moulds are placed during the planned daily cleaning. Note, after the demoulder and in front of the remoulder the transport lines are split in a transport line for moulds and one for lids.

Now, the production process and the scope of the research are explained in more detail. The previous stated problem in this research affects different stakehold-
2.3 Problem owner analysis

The plant manager of the Royal Bel Leerdammer cheese manufacturing plant in Dalfsen is M. van Zuilen. He is in charge and responsible for all the events in this factory. As the leader of the management, he desires to always meet the demanded production of the plant. Therefore, the management is not eager to stop production for adjustments. However, their vision for 2023 requires some improvements. Still, implementations should be worth both the investment and the production stop. Only then, the management will cooperate with the project.

2.4 Stakeholder analysis

In this section the stakeholders related to the mould handling system are described. A stakeholder can be identified as: 'Any group or individual who can affect or is affected by the achievement of the organization’s objective' (Freeman, 1984) [5]. Potential stakeholders are for example persons, groups, neighborhoods, organizations, institutions, societies and even the natural environment [6]. First stakeholders are described who have a direct stake or can directly influence the system.

Supply chain department

The first stakeholder is the supply chain department of Royal Bel Leerdammer B.V. Here, they know the market and forecast the demand. For example, when a commercial campaign is launched they expect an increase in demand. The orders are based on this sale expectation and the production capacity of the factory. Information on fat- and protein-content in the supplied milk is received and the current storage of cheeses is known. Based on this, the actual orders for the cheese manufacturing plant in Dalfsen are set up by the supply chain department. They also organize all the logistics and therefore know what is reasonable to produce. All in all, the supply chain department can be seen as a customer for the cheese manufacturing plant in Dalfsen. See Appendix C for an interview, on the expectation of future demand, with M. Vendrig from the supply chain department.

Sequel processing plants

The second stakeholder is the group of sequel processing plants. As said before, the plant in Dalfsen is a manufacturer of semi-finished products. The produced cheese need to be transported to for example the plant in Wageningen, where the cheese is cut and packed for customer sale. The capacity of these sequel processing plants need to satisfy an increase in the production output of the plant in Dalfsen. In case those capacities are not sufficient, inventory at the plant in Dalfsen will increase.
Operators and mechanics
Operators and mechanics are the last group with a direct stake in the project. Training, motivation, workload and maintenance are important social factors influencing the system. Performance of the operators and mechanics determine for a great part the performance of the system. The other way around is that the system could influence the amount of maintenance and workload, indirectly influencing the motivation and required training. Thereby, their cooperation to the project could benefit the end product of this project.

Indirect stakeholders
These stakeholder have no direct effect on the system. However, indirectly their behavior could still influence the system and the project. Their actions affect the actions of the other stakeholders.

Bel Group management
Investments are provided by the general management of the Bel Group to each factory. Whenever the general management decides to lower the investment, it could harm the project. A more efficient process benefits the production, which indirectly benefits the general management.

Dairy farmers and other resource suppliers
The dairy farmers provide the important resource: milk. The company will always be dependent on the amount and the quality of milk provided by their contracted dairy farmers. If the dairy farmers cannot provide the necessary amount or quality, then the company has to buy milk from third parties. Also, suppliers of supplement resources affect the system. The availability of resources influences the amount of curd provided by the pre-factory to the mould handling system. Too little amounts of curd will automatically reduce the throughput of the mould handling system. If the total throughput of the factory needs to increase, this party should also satisfy the desired throughput.

Stores and end customers
Stores and end customers are the buyers of the end products and they determine the actual demand. With this actual demand the sales department can estimate the future demand. The demand determines if the production capacity is sufficient. On the other hand, the buyers could benefit from a more efficient system, because this could lead to a reduction in price of the end product. The lower price gives the company a better competitive advantage.

All these stakeholders affect or are affected by the outcome of this project. The stakeholders should be taken into account to acquire support for a successful output.
2.5 Research goal

A clearly defined goal helps every project towards a successful output. Basic understanding of the site and processes contribute to the investigation of the problem causes. When the cause(s) of the problem are known, the system can be effectively improved. The following goal for this project is formulated:

*To increase the production capacity of the mould handling system of Royal Bel Leerdammer in Dalfsen, by re-designing the system and validating it in 18 weeks, that will give an improvement plan to increase efficiency and/or capacity, in order to be able to produce the company’s desired outputs of 40,200 tons and 40,789 tons of cheese in 2019 and 2023, respectively.*

The limited time asks for a tight planning of the project. In the next section the methodology of the project will be discussed. Also, a roadmap will be given which explains the steps during this project.

2.6 Methodology

The previous stated goal requires first research to the main causes of the problem. This comes forward in the structure of this research, which follows the DMAIC improvement cycle [7] (explained later in this section). After the define phase, the design phase starts. This is the basis of many design methods. Hevner in 2004 described the design science paradigm. He states that in ‘the design-science paradigm, knowledge and understanding of a problem domain and its solution are achieved in the building and application of the designed artifact’[8]. In the current research, actually building of the current system, in Tecnomatix plant simulation 13.1 [9], can be allocated to the define, analysis and improve phase. Where it is used for problem understanding, data analysis and validating possible solutions.

Another useful tool, comparable with the DMAIC cycle, is the regulative cycle (or problem solving cycle), described by van Strien in 1997 [10]. The regulative cycle starts with the identification of the problem, followed by the described diagnose phase. Herein van Strien also includes a possible remedy to the problem. This remedy is further analyzed in a plan of action. Changes in the desired direction could be made in the intervention (or implementation [11]) step and at last the new situation is evaluated.

In the current research the implementation and evaluation phases will only be applied to the designed system in Tecnomatix plant simulation 13.1. The project deals with a practical problem and is executed at a company. The implementation and evaluation of re-designed system at the production site will not be realistic in the time frame of 18 weeks.

The practical problem in this project can be subjected to the exploitation quad-
rant of the Knowledge Innovation Matrix [12], see figure 4. There is a lot of knowledge about the system. Problems can be very specific, however they could occur in many different production facilities. Usually the problems are typical production problems. In the first place, the solutions will be very specific applicable for the cheese manufacturing plant in Dalfsen. In that way the goal is not to only add knowledge to the knowledge base. Exploitation can include optimizing the system. For example with positive changes in efficiency, productivity, services, quality, competitiveness or market share. As also with improvement innovation research, it is important to clearly represent and communicate the new design. The differences with the old system and the outcome of the new system should be described explicitly. In the evaluation step, convincing evidence of the improvement over the old system must be provided [12].

Figure 4: Knowledge Innovation Matrix (KIM) with Opportunities for Research and External Impact Outcomes [12].

DMAIC is also a process optimizing methodology [7]. The methodology is widely used in quality improvement and waste reduction projects. With the help of these projects efficiency, productivity or quality can be improved. DMAIC stands for Define, Measure, Analyze, Improve and Control. In the first section the problem, the customer of the problem and critical-to-quality attributes are defined. Processes influencing these attributes are identified and their performance is measured. In the analyze section the causes of problems and bottlenecks in the process are determined. Problems and the bottleneck cause variation in the process. The process needs to be improved to an acceptable variation range. The control section ensures that the variation in the process stays within the acceptable range [7]. Actually, with the reduction of variation
the system becomes more balanced. More explanation on the reduction of variation and other Lean principles will be given next.

**Improvement of production processes**
Companies adapt their processes to achieve a competitive advantage. The processes or products become better, cheaper, faster or more agile. A company can be seen as a pipeline. On one hand side raw materials flow into the pipe and on the other hand side end-products flow out of the pipeline. This idea can also be applied to the mould handling circuit of Royal Bel Leerdammer Dalfsen. A shorter throughput time is better, because the customer is sooner supplied with the end product. Also, due to a decrease in throughput time a company becomes more agile.

An ideal flow in a production pipeline is uniform and without bottlenecks. The material is pulled down through the pipe. The throughput is determined by the rate limiting step. Obstacles causing the bottleneck and variations in the flow should be eliminated. This is one goal of Lean production. The obstacles and anything in the process or organization that does not add value is considered waste. In principle seven types of waste can occur in factories [7, 13]:

- Waste from defects
- Waste in transportation
- Waste from inventory
- Waste of waiting
- Waste from over-production
- Waste from over-processing
- Waste of motion

**Defects**
Defects are an obvious source of waste. In case customers detect defects it could result in expenses and loss of existing/potential customers. Preferably, defects are detected and fixed by the producer. However, detecting and fixing processes are time consuming and costly activities. When a product can not be fixed it must be thrown away or sold as a second grade product. For these products all the processing, raw materials and other expenses are (partly) waste. Thereby, defects in products delay production and increase the throughput time of the product. This also holds for breakdowns of equipment. Reparation is costly and time consuming.

**Transportation**
Products or people move from one location to another. Transportation is needed due to the layout of a factory or the routing sequence of operations [7]. This
movement costs time and transportation equipment is needed, requiring space, maintenance and energy. Thereby, during transportation no value is added. So, transportation is considered waste.

**Inventory**
Inventory are stored items or buffers in the process. The products wait to be processed further. In this time of waiting no value is added to the product. Storage in general requires space, administration, moving time, insurance and security, resulting in costs. This capital cannot be used anymore somewhere else in the business. Buffers in a system are actually covering up other waste in a system. For example product defects or equipment breakdowns. Therefore this inventory has been named 'just-in-case management' [7]. Due to buffers the work in process (WIP) increases. In circuits this is especially harmful, because it causes line imbalance.

**Waiting**
As described above a buffer can arise in case something goes wrong. In a system downstream machines will have to wait. This is a waste. In an ideal situation every product arrives at a machine just in time (JIT). This Lean principle means that every resource is available just before the process starts. Operators that have to wait could do other tasks. A pitfall here is the chance of over-production.

**Over-production**
Producing products without an order from a customer is a waste. Storage of these products is needed. When no demand will come in the future, the products need to be eliminated or sold at a reduced price. The costs made for these products increase. However, in food-processing this is more complex, because often the end-products have a longer shelf life than the raw products. On the other hand, raw materials could be sold to third parties.

**Over-processing**
The processes itself could include steps that are ineffective, inefficient or unnecessary. Manual processing usually takes more time than automated processing. Other steps can be optimized or eliminated.

**Motion**
Related to over-processing is motion. Being in motion, operator or machine, does not mean that value is added. Motion occur for example in searching, selecting, picking up, transporting, loading, re-positioning and unloading [7]. Time of motion can be reduced or eliminated. Searching time for example can be reduced with 'the Five S’s’ [14].

- 'Sort' everything and get rid off unnecessary material.
- 'Set in order': Give everything a specific place and indicate that place.
- 'Sine’ includes washing and cleaning of equipment and workplaces. It also
includes indicating dangerous places, to acquire more attention.

- The fourth S is 'standardize': Make procedures or principles to execute the first three S’s.

- The last S: Take responsibility to 'Sustain' the neat workplace.

Now, in which form could waste occur in the mould handling circuit? A conceptual causal model is developed with different types of waste and possible causes, in section 2.7.2. After data-gathering and data-analysis an empirical causal model has been developed. In that model possible causes are excluded, bringing forward the focus for a (re)design. This model can be found in section 3.5.

All in all, the described methodology’s and improvement cycles show many similarities. Mainly, the DMAIC improvement cycle, with the Lean principles, will be used in this research. This methodology fits the exploitation type of research described before. Moreover, in the cheese manufacturing plant in Dalfsen this methodology is already used for continues improvement. So, this methodology fits a project at this company, as the company is already familiar with it. In figure 5 a schematic overview of the work procedure in the current project is given. The overview is a type of planning to show each step in the execution of the research. A combination of the DMAIC cycle, the regulative cycle and common sense is used to develop the work procedure.

![Figure 5: Schematic overview of the work procedure. See Appendix D for an actual time planning for each step in this research.](image)

The project starts with basic understanding of the factory and the definition of the problem. Hereafter, a goal statement is formulated, leading to a design of the research. This conceptual research design will be defined in the next session.
2.7 Conceptual Research Design

2.7.1 Research question

The research part of this project mostly deals with the identification of the problems and the bottleneck of this system. Knowing the origin of the problems and identifying the bottleneck will give a solid basis to start the redesign. In the design phase a new question, the design question, will be formulated. The research question is stated below:

What are the factors influencing the production output of the mould handling system?

Sub-questions will be given later on in section 2.7.3. First, a conceptual causal model is developed by using: Information acquired from stakeholders, company reports, first observations in the factory, theory from the Lean principles and at last common sense. Sub-questions will be developed, each taken some possible causes of the problem into account. A scope will be determined and justified, on which parts of the conceptual causal model the research will not focus.

2.7.2 Conceptual causal model

The main problem is a production output that does not satisfy the desired output in the upcoming years. General causes of this problem could be that the current production speed is too low, the throughput time is too long or too much production time is lost, to realize desired production output in upcoming years. As said before in section 2.1, time losses per day in 2018 were on average 262 minutes. These losses are saved in company reports under different subjects, for instance: Organization losses (planned maintenance, around 4 days/year or planned daily cleaning, 140 minutes/day) or efficiency losses (OEE) (breakdowns, lack of resources and short unidentified stops). Every time loss is sorted and registered by a Programmable Logic Controller (PLC) in company reports. Possible origins of all causes are implemented in the next conceptual causal model. Hereafter, data will be gathered and analyzed to find the origin(s) of the main problem, which will be used as a basis for a redesign. After analysis, an empirical causal model will be given to show this basis for the redesign.
2.7.3 Sub-questions

In the conceptual causal model in figure 6 possible causes (parameters) of the main problem are given on the left hand side. By observation, measurements, using the existing knowledge base and communicating with operators and mechanics, it will be attempted to find the cause of the main problem. In this
section, sub-questions are composed as guidelines for the observation or measurements. The sub-questions include more parameters. Each question includes one color of the conceptual causal model. The parameters without a color will not be investigated in this research. For instance, root causes of breakdowns or no optimal performance, because these parameters are purely technical. For most of these parameters it will be hard to determine if they really are the root cause, especially when taken into account the time span of 18 weeks of this project. Also, 'incidents' appears without a color. Company reports do not mention incidents in this system. Most of the system is already protected by fences around the machines and transporting lines. Due to the fences it is impossible to touch the system. When a fence is opened, the machine will stop. In this way the risk of incidents is reduced. Thus, it is no cause of the main problem in this project. Still, in developing the redesign of the system, safety should be taken into account. The last group which is out of scope of this research are the organization losses. Planned daily cleaning and planned maintenance are necessary in the system. Projects within the company already tried to minimize time needed for those processes.

- Green: What are the processing times of the machines incorporated in the system?
- Red: What are the main causes of breakdowns of the machines and to what extend do all processes and machines contribute effectively to the system?
- Yellow: What impact do all the processes and machines physically have on the moulds in general?
- Blue: To what extend is the availability of all resources satisfying for the system?

2.7.4 Research plan

For each discussed sub-question described above, the tools and techniques for data-gathering and data-processing will be given here. The observation part of the research is performed to investigate causal inferences between parameters of the causal model and the main problem. This type of research goal is typical for 'Single Case mechanism experiments'. This test involves real-world cases, where the researcher has access to the architecture of the object of study. Thereby, the behavior of this object of study is explained in terms of this architecture [15]. The object of study in the current research is the mould handling circuit. To acquire the best image of the current situation it is important to perform randomized controlled trials. Observations will be performed in the same way, in the form of triple (or more) measurements, on different days and with different types of cheese. In these trials, exceptional factors will be canceled out when the average is taken from many measurements or observations.
Data gathering and processing plan

What are the processing times of the machines incorporated in the system?

In the circuit are in total 26 machines connected by transport lines. Each machine has its own cycle time. This cycle can be for example from the input of a mould until the input of the next mould. To acquire reliable results it is important that the second mould is ready to enter, before the first mould exits the machine. The time necessary for each cycle will be measured (Appendix E). Due to the fact that the cycle times can differ, it is crucial to repeat the time measurements at least three times per measurement and also on at least two different days. In some cases, think of the remoulder for example, it is required to measure the cycle times also when different types of cheese are processed. Leerdammer Light 30+ cheese for instance is less heavy than other types of cheese, due to the lower fat content in the cheese. Hence, in the moulding machine bigger blocks of cheese will be sliced off to ensure the same weight for every type of cheese.

The data will be processed in Microsoft Excel [16] to obtain the maximal capacity per hour for each machine. Standard deviation between the measurements will be checked and the variance will be analyzed to check if the measurements are statistically different. On the basis of these time measurements, the bottleneck of the system in the current situation can be found. The data will also be used to simulate the current system in Tecnomatix plant simulation 13.1.

What are the main causes of breakdowns of the machines and to what extend do all processes and machines contribute effectively to the system?

In the above mentioned situation measurements will be performed when no breakdowns occur. Unfortunately, breakdowns of the machines and transport equipment do occur in the system. Every breakdown is reported and can be reviewed in online data reports of the company. These data reports will be analyzed to find the main causes of the breakdowns. The downtime is also recorded for each breakdown. This data will help to determine the significance of each breakdown. The different causes will also be checked on similarities. The same cause could lead to different breakdowns. Another point is to what extend processes effectively contribute to the system. Unnecessary handling and long transportation is time consuming and could increase the risk of breakdowns. Observations in the factory will be made whether over-processing occurs. Talking to operators and mechanics could lead to new insights.

What impact does the system have on the moulds in general?

This sub-question is composed to find out how the moulds are treated in the system. Are some actions unnecessary in the system? And, how do machines and operators treat the moulds? Deviations in the structure of the moulds could lead to reduced performance or breakdowns of the machines, leading to a reduced efficiency of the system. Data for this sub-question will be obtained by observations. The data, for instance the time an unnecessary action takes, will be analyzed and the contribution to the inefficiency will be determined.
In which extend is the availability of all resources satisfying for the system?
The online data reports also contain downtime due to a lack of resource. The
data together with own observations in the factory will give an overview of the
availability of resources. When a machine is ready to process, but does not
have all the necessary resources, the efficiency of that machine will decrease.
The number of 'lack of resource' or 'short stops' appearances and the average
downtime will be analyzed. The total downtime can be transformed in a potential
number of cheeses.
3 Measurements & Analysis

In this section the gathered data related to the sub-questions, in section 2.7.3, will be presented. Here, information on processing times, breakdowns, physical impact on moulds and availability of resources will be given. This information is gathered by observations, time measurements and analysis of company reports. The average speeds of different machines are shown in tables. Data is gathered when enough moulds are available to handle. Each machine with low average speeds or machines with high variations in production speed will be analyzed more. In the end, an empirical causal model will be made to determine the focus for a redesign of the system.

3.1 Processing times

In an ideal situation only value adding processes occur. Between these value adding processes transportation should be minimal. Everywhere in the system moulds will arrive just in time for their processes. However, such a situation is for now not realistic in this mould handling circuit. Jams and other disruptions occur in the system which lead to variations in the throughput time of the moulds. These variations lead to short stops (SST’s, actually stops shorter than three minutes) or breakdowns (BKD’s, actually stops longer than three minutes) in the system. Especially for the first machine in the system, the moulding machine, this is unfavorable. Whenever this machine is not able to produce, it could lead to standstills in the curd preparation. To remain the quality, the curd need to be cooled in that case. Still, this is a risk which could lead to variations in the end product. Therefore, the mould handling system is constructed that the moulding machine is the rate determining machine of the system. This machine must be able to produce at all times. The other processes can handle more moulds per hour. A mould buffering system and the transport lines in front of the moulding machine make it possible for the empty moulds to buffer. For the remaining part of this section, keep in mind that all processes should handle at least the same amount or more moulds per hour than the moulding machine, to ensure that enough moulds are available for the moulding machine. The measurements were performed when the machines were processing at their maximum capacity, so with maximum supply of moulds.

Moulding machine

Per type of cheese the moulding machine has fixed 'moulding' times. Actually, it is the first transformation from settled curd to a rectangular block of cheese. Although around ten types of cheese are produced in the system, the moulding machine only has three different 'moulding' times. Most types are produced with a moulding speed of 64s per nine cheeses (nine columns of the moulding machine, figure 7). This means 506.25 cheeses per hour. 73% of the total production is produced with this speed (Appendix C and F). Furthermore, Leerdammer Light 30+ and Caractère léger 35+ have a moulding speed of 72s per nine cheeses, meaning 450 cheeses per hour. Due to the low fat content,
a bigger block of cheese is needed to end up with the desired weight of the end product. Also, other processes within the moulding machine, like draining, take longer. From the total production 18% is produced with this speed. The third 'moulding' time is for the high fat content cheese: Delacrème 50+. Here, processes within the moulding machine also take longer. The moulding time is 69.5s per nine cheeses, which is equal to 466.18 cheeses per hour. On average 9% of the total production is produced with this speed. In table 1 the speeds are summarized. The missing types of cheese, for example the B2B brands (HolGa 47+, Bel 47+ and Bel 48+), all have the moulding speed of 64s. Only when the moulding time at this machine takes longer than the setting speed, due to for example a lack of curd, a lack of moulds or a jam of moulds, the time loss is added to company reports by the PLC.

Table 1: Speed of moulding machine per type of cheese.

<table>
<thead>
<tr>
<th>Cheese Type</th>
<th>Time (s) per mould</th>
<th>Machine setting speed (s) per 9 cheeses</th>
<th>Moulds per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leerdammer 45+</td>
<td>7.11</td>
<td>64</td>
<td>506.25</td>
</tr>
<tr>
<td>Leerdammer WTP 45+</td>
<td>7.11</td>
<td>64</td>
<td>506.25</td>
</tr>
<tr>
<td>LeLi 30+</td>
<td>8.00</td>
<td>72</td>
<td>450.00</td>
</tr>
<tr>
<td>Caractère 49+</td>
<td>7.11</td>
<td>64</td>
<td>506.25</td>
</tr>
<tr>
<td>Caractère Léger 35+</td>
<td>8.00</td>
<td>72</td>
<td>450.00</td>
</tr>
<tr>
<td>Delacrème 50+</td>
<td>7.72</td>
<td>69.5</td>
<td>466.18</td>
</tr>
</tbody>
</table>
After the moulding machine, some transport direction converters, two buffer transport lines and a lid placer are located. These are relatively simple machines and they are not dependant on the type of cheese. Therefore, their processing speeds are given together in tables 6 and 7. Later on, those tables will be explained. Firstly, 'bigger' machines or machines with a processing speed dependant on the type of cheese will be described. To start with the pressing machine.

**Presses**

The pressing machine consists of five presses. In order from the first press to the last one: D-C-B-A-Z, see figure 3. Moulds wait in front of press D, by a stopper, until a train of four moulds is assembled. Thereafter, the train is transported to the press which need to be filled. In the mean time, a new train is assembled. While inserting the train into the press, the whole transport line is stopped. That is why the other moulds are stopped while making a new train. Also, when a train is ready, the next mould is held for one or two seconds to obtain a distance between the train and arriving moulds. The input times are equal to the output times because when one train is inserted, another train will leave at the back of the press. The time between inserting trains is developed by the distance between the trains on the transport line before the presses. This dis-
tance meanwhile, is developed by the time to assemble a train. Thus, the time to assemble a train of four moulds is equal to the input and output time of a press. Figure 8 depicts two trains in front of the presses, which are transported to the last press (Z). Also, the assembly of a train is depicted. Again, see figure 3 for a schematic representation of the mould handling system, where the layout of the presses can be seen.

![Figure 8: Picture of the transport line before presses. On the left-hand side the assembly (waiting) of a train, in front of press D, is showed. The two moulds are stopped by a stopper. On the right-hand side two trains proceed on the transport line, now to the last press: Z. When a train reaches the right press, the whole transport line will be stopped, while inserting the train into the press.](image)

Another observation was made in case the outputs of presses were blocked, for example when the remoulder stopped or the transport line was jammed. The insert system at press D and C went back to the starting position, enabling a new train to go already to the right position on the transport line. However, the insert mechanism at presses Z, A and B stayed in a position of 'inserting' (See figure 9 for this situation). In this situation the transport line remains stopped. So, a new train cannot go to the right position, which stops the total system even sooner. This is because the inserting mechanism is slightly different. It is a software problem, because observed was that the inserting mechanism was at its 'end' position. At press Z, A and B the inserting system has to wait until the press starts moving up all the moulds in the press, before it can go back.
This is not the case for press D and C.

Figure 9: Picture of the inserting system at press Z in a position of 'inserting'. At this point the transport line is stopped.

In table 2 the average speeds of each press is given. Note, the big deviation for some presses. This variation will be explained now.

Table 2: Speed of input & output Pressing machines, measured when maximum supply and on different days.

<table>
<thead>
<tr>
<th>Press</th>
<th>Time (s) per mould</th>
<th>Standard deviation</th>
<th>Moulds per hour</th>
<th>Number of measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Press D</td>
<td>6.41 ± 0.11</td>
<td>562.19</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>2nd Press C</td>
<td>6.98 ± 0.17</td>
<td>516.25</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>3rd Press B</td>
<td>6.87 ± 0.27</td>
<td>525.12</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td>4th Press A</td>
<td>6.89 ± 0.11</td>
<td>522.64</td>
<td>104</td>
<td></td>
</tr>
<tr>
<td>5th Press Z</td>
<td>7.00 ± 0.29</td>
<td>515.10</td>
<td>93</td>
<td></td>
</tr>
</tbody>
</table>

The presses have maximum supply when the bufferlines between the moulding machine and the presses are occupied. The results of the measured speeds at different days are depicted in figure 10.
Figure 10: Input & Output speed of all presses at maximum supply. With the red dashed line as the desired lowest boundary. The line in the blue box indicates the median and the blue box itself includes 50% of the measurements. The straight lines or ‘whisker’s’ extend the boxes to the maximum and minimum data points within 1.5 box heights. They represent the ranges for the bottom 25% and the top 25% of the data, excluding the outliers. These outliers are indicated by stars. Number of measurements: D - 44, C - 47, B - 88, A - 104 and Z - 93.

Showed in the graph in figure 10 is the barrier line of 506 moulds per hour. This number corresponds to the lowest moulding time at the moulding machine (9 cheeses per 64s = 506 moulds or cheeses per hour). The inserting and leaving of moulds at the presses is not cheese-type dependent, so this handling should always be performed at or above 506 moulds per hour. This is unfortunately not the case. Although the average speeds of presses Z, A, B and C are above the boundary line, these presses still are able to operate below the desired speed. The reason for these fluctuations will be explained next.

After a lid is placed on top of the mould, they are transferred to the line 'before press'. As said before, the moulds wait in front of press D (the first press) until they form a train of four moulds. Hereafter, the train will be inserted in press D or the train will be transported to the assigned press. In order to acquire some space, a new mould has to wait for a bit (± 1 or 2 seconds). Next, the new train will be formed while the previous train(s) is still on the line. When a train arrives at the right press, the transportation line will be stopped to insert the train into the press. This means that the assembly of a new train of four moulds is also interrupted. Due to this interruption it can occur that a mould is ready to be transferred onto the line 'before presses', but it is blocked. While
the transport line starts again, the transferring has to wait until there is enough space. This blockage can also take up to 2 seconds. It depends on the interval between stopping the line, how the system performs. If the supply to the presses changes, due to the amount of moulds or lids, this interval can change again. In a worst case situation a press is completely filled at low inserting speed. In figures 11 and 12 the measured data is sorted.

![Variation input & output speed Press-D](image)

**Figure 11**: Normal distribution of input/output speed measurements on Press-D. Measurements when maximum supply to the press, with the red dashed line as the desired lowest boundary.

The first press is press D. The input/output speed of this press is fastest and all the measurements are above the desired speed. In figure 10 can be seen that this press performs at a different level than the other presses. An explanation is simply the fact that this press is the first press. A train of four moulds is assembled in front of press D. It means that the waiting time of a new mould, to acquire some space, does not apply when press D is filled because there is no train on the transport line anymore.
In the other presses the speed varies more and the speed sometimes drop below 506 moulds per hour. Actually, for press Z the number of measurements below 506 per hour even is 34%. With those speeds buffers will not vanish and the presses will determine the speed of the whole system. This means no optimal production, because the moulding machine will be waiting for moulds after some time. The reason why press Z gives even more variation is because it is the last press, see figure 3. After filling press D (first press), press Z is filled (So: D-Z-A-B-C-D-Z-A-B-C-D.. etc). Often, the remoulder is still handling the moulds from press D, causing a buffer in front of the remoulder. So, press Z cannot immediately be filled, because the output of the press is blocked. This causes a stop of the transport line before the presses, moulds cannot proceed and soon a buffer will arise on the two buffer lines in front of the presses. Automatically, this buffer means later on maximum supply to the presses, which increase the chance of variation.

Remoulder

The moulds from the presses go to a lid taker machine. Again, the speed of this machine will be described later on. Hereafter a remoulder is placed. The first step is a process of turning the mould with the cheese in it up side down. Afterwards, a blow section makes sure that the cheese is loose in the mould
The mould is lifted. In case the cheese is stuck, compressed air will be applied on top of the mould to loosen the cheese. Sometimes two or three times. This can take up to ten seconds. Different fat contents, the amount of moisture and the weight of the cheese determine the ease of this process. The mould is removed from the cheese and the empty mould is turned again. A vacuum plate places the cheese back in the mould and the mould can go on to a lid placer. The ease of the vacuum plate is also determined by the type of cheese. Data in the next table, table 3, is measured from the speed of 3 or 11 cycles in a row. So, included are the times when a cheese is stuck in a mould for a few seconds. This also explains the high standard deviations. More analysis will be given after table 3.

Note, only the most produced Leerdammer brands are given. Due to a 24-hour process, measurements only between 8:00 and 17:30 and different orders each week, it was not possible to measure all the types of cheese.

<table>
<thead>
<tr>
<th></th>
<th>Time (s) per mould</th>
<th>Standard deviation</th>
<th>Moulds per hour</th>
<th>Moulds measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leerdammer 45+</td>
<td>7.16</td>
<td>±0.90</td>
<td>509.34</td>
<td>301</td>
</tr>
<tr>
<td>LeLi 30+</td>
<td>7.33</td>
<td>±1.04</td>
<td>499.39</td>
<td>285</td>
</tr>
<tr>
<td>Caractère 49+</td>
<td>6.85</td>
<td>±0.33</td>
<td>526.89</td>
<td>39</td>
</tr>
<tr>
<td>Delacrème 50+</td>
<td>7.57</td>
<td>±0.23</td>
<td>476.26</td>
<td>210</td>
</tr>
</tbody>
</table>

Table 3: Speed of the Remoulder. Measured when maximum supply of moulds on at least two different days.
In figure 14 variations in the speed of the remoulder can be observed. Especially with Leerdammer Light 30+ (Leli) cheese the machine has troubles. When this type of cheese enters the machine, the pressure of the blow section is already increased by an operator (often from 3.5 bar to 4.0 bar). On average the machine still operates above the production speed of Leli cheese. However, it occurs that a new type of cheese is already produced at a higher speed and that this machine still needs to turn Leli cheeses. Fully occupied transport lines will occur until all the Leli cheeses passed the remoulder. Due to planning issues (brining times, demand and risk of recalls) it is not possible to produce all the cheeses of one type of cheese at once. So, it happens that cheeses with a short moulding time are produced after cheeses with a long moulding time.

Note, as said before it was possible to measure only four types of cheese due to the 24-hour production day, measurements between 8:00 and 17:30 and the differences in orders. So, measurements were dependant on which type of cheese is produced when. In figure 15 the normal distribution of the measurements per type of cheese are given. Most measurements are from three cycles in a row. Some measurements are even more specific with eleven cycles in a row. The vertical red dashed line in those graphs indicate the production speed of the specific types of cheese at the moulding machine. The graphs show that stuck cheeses occur with every type of cheese. Some however more than others.
Figure 14: Speed of the Remould with different types of cheese. Also, indicated by the red dashed lines the production speed of each type of cheese at the moulding machine. The line in the blue box indicates the median and the blue box itself includes 50% of the measurements. The straight lines or ‘whisker’s’ extend the boxes to the maximum and minimum data points within 1.5 box heights. They represent the ranges for the bottom 25% and the top 25% of the data, excluding the outliers. These outliers are indicated by stars. Number of moulds measured: Leerdammer45+ - 301, Caractere49+ - 39, Leli30+ - 285 and Delacreme 50+ - 210.
Figure 15: Normal distribution of measurements on the speed of the Remoulder for different types of cheese. The red dashed line indicates the production speed of the specific type at the moulding machine. The desired lower boundary of 506 moulds per hour is given in every graph.

**Holding tables**

A lid is placed again on the top of the mould and the moulds go on to the holding tables. Here, a comparable situation as at the presses occur. However, due to stoppers and a two-part transport line before and after the holding tables, distance between trains could become smaller. An ensured chain (synthetic bars along the chain) at the line before the holding tables, makes it possible to keep the line running while inserting a train into the holding tables (see figure 16). This enables a smoother and more balanced input and output, because the moulds keep going. Still, one part of the line after the holding tables is stopped when a train is pushed of the holding table. When the line is stopped, the previous train is still on that line and cannot continue. This happens when the first and the third holding table are filled/emptied, because the transition between the two parts of the line lays between holding table 2 and 3. Furthermore, trains at the holding tables consist of three moulds. Shown in table 4 are the average input/output speeds of each holding table.
Figure 16: Picture of the transport line before the holding tables. Indicated are the stopper and the ‘ensured’ chain. The chains are ensured by two synthetic bars to keep the chain at the same place.

Table 4: Speed of input & output Holding Tables. Measured on at least two different days with a maximum supply of moulds.

<table>
<thead>
<tr>
<th></th>
<th>Time (s) per mould</th>
<th>Standard deviation</th>
<th>Moulds per hour</th>
<th>Number of measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT1</td>
<td>6.28</td>
<td>±0.29</td>
<td>574.61</td>
<td>n = 15</td>
</tr>
<tr>
<td>HT2</td>
<td>6.53</td>
<td>±0.31</td>
<td>552.62</td>
<td>n = 22</td>
</tr>
<tr>
<td>HT3</td>
<td>6.43</td>
<td>±0.19</td>
<td>560.21</td>
<td>n = 13</td>
</tr>
<tr>
<td>HT4</td>
<td>6.63</td>
<td>±0.16</td>
<td>542.97</td>
<td>n = 8</td>
</tr>
</tbody>
</table>

The average speed and the low standard deviations show that moulds at the holding tables are processed easily. This is also shown in the next two figures. Figures 17 and 18 depict perfectly that the holding tables are not the bottleneck of the system. Actually, most of the time the holding tables are waiting for moulds.
Figure 17: Input & Output cheese of the Holding tables. The red dashed line indicates the desired lower boundary. The line in the blue box indicates the median and the blue box itself includes 50% of the measurements. The straight lines or 'whisker's' extend the boxes to the maximum and minimum data points within 1.5 box heights. They represent the ranges for the bottom 25% and the top 25% of the data, excluding the outliers. These outliers are indicated by stars. Number of measurements: HT1 - 15, HT2 - 22, HT3 - 13 and HT4 - 8.
Figure 18: Normal distribution of measurements of input/output speeds at the Holding tables. The red dashed line indicates the desired lower boundary.

Demoulder

The last machine that depends on the type of cheese, is the demoulder. This machine also makes use of a vacuum plate to lift the cheese out of the mould. A lid taker is placed before the vacuum plate and a mould turner completes the demoulder. The moulds go on to the cleaning machine. The data in table 5 is also from 3 or 11 cycles in a row.
Figure 19: Picture of the Demoulder. First the lid is removed from the mould. Then, the cheese is taken out of the mould. Cheeses go on from here to the brining-bath. Moulds, after being turned, and lids proceed to the cleaning machine.

Note, also for the demoulder, data gathering was dependant on which type of cheese was produced at which day and time, because data was gathered between 8:00 and 17:30. That is why only three types of cheese could be measured.

Table 5: Speed of cheese de-moulding per type of cheese

<table>
<thead>
<tr>
<th>Cheese Type</th>
<th>Time (s) per mould</th>
<th>Standard deviation</th>
<th>Moulds per hour</th>
<th>Moulds measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leerdammer 45+</td>
<td>6.81 ± 0.03</td>
<td></td>
<td>528.99</td>
<td>112</td>
</tr>
<tr>
<td>LeLi 30+</td>
<td>6.80 ± 0.15</td>
<td></td>
<td>529.60</td>
<td>142</td>
</tr>
<tr>
<td>Caractère 49+</td>
<td>6.77 ± 0.00</td>
<td></td>
<td>531.47</td>
<td>33</td>
</tr>
</tbody>
</table>

Looking at table 5 and figures 20 and 21 it can be concluded that the demoulder more or less has a constant speed for each type of cheese. This speed is also well above the barrier line of the desired speed. Note, for Caractère in figure 21 only three measurements are in the graph. However, those measurements are averages of 11 cycles, so 33 moulds were measured.
Figure 20: Processing time of the Demoulder per type of cheese. The red dashed line indicates the desired lower boundary. The line in the blue box indicates the median and the blue box itself includes 50% of the measurements. The straight lines or ‘whisker’s’ extend the boxes to the maximum and minimum data points within 1.5 box heights. They represent the ranges for the bottom 25% and the top 25% of the data, excluding the outliers. These outliers are indicated by stars. The number of measured moulds were 112 for L45+, 33 for Caractere49+ and 142 for Leli30+.
Normal distribution of speed measurements at the Demoulder for different types of cheese. The red dashed line indicates the desired lower boundary.

**Figure 21:**

**a)** Leerdammer 45+

**b)** Leli 30+

**c)** Caractère 49+

**Remaining machines**

Now, the average processing speeds of all the 'bigger' machines or machine dependant on type of cheese are given. In table 6, processing speeds of transport direction converters, lid take/placers and a mould turner are given. In essence, these processes are steady and they can process a lot of moulds. This is also shown in table 6. Their processing speeds are satisfying for the system. However, in some cases it is important to ask if an action is really necessary or could it be done in a different way. More on this in the end of this section.
Table 6: Speed of different ‘small’ machines. Measurements from at least two different days and in triplets.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Time (s) per mould</th>
<th>Standard deviation</th>
<th>Moulds per hour</th>
<th>Number of measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport Converter 1</td>
<td>4.93 ± 0.07</td>
<td>729.73</td>
<td>n = 6</td>
<td></td>
</tr>
<tr>
<td>TC 2</td>
<td>4.74 ± 0.10</td>
<td>759.63</td>
<td>n = 6</td>
<td></td>
</tr>
<tr>
<td>TC 3</td>
<td>5.78 ± 0.44</td>
<td>622.84</td>
<td>n = 7</td>
<td></td>
</tr>
<tr>
<td>Lid placer 1</td>
<td>6.31 ± 0.34</td>
<td>570.16</td>
<td>n = 15</td>
<td></td>
</tr>
<tr>
<td>TC 4</td>
<td>5.61 ± 0.13</td>
<td>642.09</td>
<td>n = 6</td>
<td></td>
</tr>
<tr>
<td>Lid taker 1</td>
<td>6.08 ± 0.24</td>
<td>592.18</td>
<td>n = 13</td>
<td></td>
</tr>
<tr>
<td>Lid placer 2</td>
<td>6.65 ± 0.30</td>
<td>541.53</td>
<td>n = 14</td>
<td></td>
</tr>
<tr>
<td>Mould turner</td>
<td>6.70 ± 0.20</td>
<td>537.58</td>
<td>n = 6</td>
<td></td>
</tr>
</tbody>
</table>

All machines machines described above are connected by transport lines. These conveyors have different speeds, shown in table 7. The last column in this table gives how much moulds could be transported along one point of the transport line in one hour, if there would be one continuous stream of moulds. Every data point is the average of three measurements.

Table 7: Speed of different transport lines. Note, moulds are actually transported on only a part of the lines ‘before’ and ‘after’ presses and holding tables.

<table>
<thead>
<tr>
<th>Transport line</th>
<th>Speed m/s</th>
<th>Standard deviation</th>
<th>Length m</th>
<th>Moulds hour⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line under moulding machine</td>
<td>0.45</td>
<td>±0.00</td>
<td>9.00</td>
<td>2869</td>
</tr>
<tr>
<td>Line after moulding machine</td>
<td>0.39</td>
<td>±0.00</td>
<td>5.00</td>
<td>3010</td>
</tr>
<tr>
<td>2 buffer lines behind moulding machine</td>
<td>0.28</td>
<td>±0.01</td>
<td>10.40</td>
<td>3651</td>
</tr>
<tr>
<td>Line before lid placer 1</td>
<td>0.26</td>
<td>±0.00</td>
<td>3.50</td>
<td>1671</td>
</tr>
<tr>
<td>Line after lid placer 1</td>
<td>0.26</td>
<td>±0.00</td>
<td>1.40</td>
<td>1671</td>
</tr>
<tr>
<td>Line before press</td>
<td>0.17</td>
<td>±0.02</td>
<td>16.62</td>
<td>1120</td>
</tr>
<tr>
<td>Line after press</td>
<td>0.18</td>
<td>±0.01</td>
<td>16.00</td>
<td>1146</td>
</tr>
<tr>
<td>Line before lid taker</td>
<td>0.28</td>
<td>±0.00</td>
<td>5.50</td>
<td>1793</td>
</tr>
<tr>
<td>Line before remoulder</td>
<td>0.29</td>
<td>±0.00</td>
<td>6.50</td>
<td>1845</td>
</tr>
<tr>
<td>Line before lid placer 2</td>
<td>0.29</td>
<td>±0.00</td>
<td>3.41</td>
<td>1845</td>
</tr>
<tr>
<td>Line after lid placer 2</td>
<td>0.29</td>
<td>±0.00</td>
<td>1.88</td>
<td>1845</td>
</tr>
<tr>
<td>Line before HTs</td>
<td>0.32</td>
<td>±0.00</td>
<td>12.00</td>
<td>2036</td>
</tr>
<tr>
<td>Line after HTs</td>
<td>0.35</td>
<td>±0.00</td>
<td>12.00</td>
<td>2232</td>
</tr>
<tr>
<td>1st line after HT</td>
<td>0.19</td>
<td>±0.00</td>
<td>13.20</td>
<td>1189</td>
</tr>
<tr>
<td>2nd line after HT</td>
<td>0.25</td>
<td>±0.01</td>
<td>15.76</td>
<td>1621</td>
</tr>
<tr>
<td>Line before lid taker 2</td>
<td>0.35</td>
<td>±0.00</td>
<td>4.93</td>
<td>2266</td>
</tr>
<tr>
<td>Line before mould cleaning machine</td>
<td>0.27</td>
<td>±0.01</td>
<td>2.00</td>
<td>1749</td>
</tr>
<tr>
<td>Mould cleaning machine</td>
<td>0.14</td>
<td>±0.00</td>
<td>18.00</td>
<td>900</td>
</tr>
<tr>
<td>Line after mould cleaning machine</td>
<td>0.27</td>
<td>±0.00</td>
<td>6.30</td>
<td>1736</td>
</tr>
<tr>
<td>Two lines before moulding machine</td>
<td>0.26</td>
<td>±0.00</td>
<td>18.4</td>
<td>1691</td>
</tr>
</tbody>
</table>
3.2 Breakdowns and unnecessary handling

All the machines described in the previous part work 24 hours a day. During the day, unfortunately, short and longer disruptions or breakdowns occur in the system. The system registers a stop whenever the moulding machine needs more time than the set moulding time, due to for example a lack of moulds. If this stop is shorter than three minutes, a short stop (sst) is registered. These stops are unidentified. Stops longer than three minutes are registered as breakdowns (bkd). Operators need to identify these stops. On the other hand, if one machine stops for a short period and the moulding machine is not affected, no breakdown or short stops will be added to the company reports. Breakdowns in the reports are labelled to the machines causing the problem. In table 8 the breakdowns in 2018 are summarized. In most cases, the cause of the breakdown is purely technical and those root causes are not in the scope of this project. However, unnecessary handling could be a problem. If processes could be eliminated, the risk of breakdowns will decrease and the throughput time will increase.

Observed in the system are many transport direction converters. These converters push moulds from one transport line to another (instead of turns). If the transport lines were placed in a straight line, those processes could be eliminated. In the period of 01-01-2018 until 01-1-2019, 338 minutes of breakdowns were subjected to the transport converters (part of transport lines, table 8). With an average speed of 8.13 cheeses per minute in 2018 and a weight of 11.45 kg per cheese, this means a missed production of almost 31 tons of cheese. Thereby, the short stops caused by these machines are not taken into account. In the registered period of 2017, Appendix B, the downtime due to transport converters was even more, namely 462 minutes.

Other unnecessary handling could occur at the lid takers and lid placers. One lid taker and one lid placer turn the lid after taking or before placing the lid on top the mould. The second lid taker and lid placer leave the lid in the same position. Less processes reduce the risks of breakdowns.

The length of production lines could also be subjected to unnecessary handling. In an ideal situation all the machines are implemented right behind each other, to minimize transportation. Unfortunately, this is not possible due to space issues. Still, buffer lines are used at all times. The length of transport lines is sometimes increased in order to retain more moulds. This means that in some situations machines are able to handle moulds, however they have to wait until the moulds arrive at the machine.
Table 8: Breakdowns of machines in mould handling circuit in 2018 (01-01-2018 - 01-01-2019)

<table>
<thead>
<tr>
<th>Machine</th>
<th>Total number</th>
<th>Total time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remoulding</td>
<td>391</td>
<td>2827</td>
</tr>
<tr>
<td>Moulding machine</td>
<td>240</td>
<td>2380</td>
</tr>
<tr>
<td>Demoulding</td>
<td>227</td>
<td>1874</td>
</tr>
<tr>
<td>Presses</td>
<td>202</td>
<td>1285</td>
</tr>
<tr>
<td>Transport lines</td>
<td>205</td>
<td>1167</td>
</tr>
<tr>
<td>Mould cleaning machine</td>
<td>176</td>
<td>1117</td>
</tr>
<tr>
<td>Holding tables</td>
<td>86</td>
<td>644</td>
</tr>
<tr>
<td>Lid placer after moulding machine</td>
<td>57</td>
<td>386</td>
</tr>
</tbody>
</table>

If the number of processes is reduced, the risks of breakdowns will be reduced. Less breakdowns means less downtime and therefore more time to produce. This will benefit to the production capacity. Note that the named breakdowns are all longer than three minutes. Jams causing gaps between moulds in the system and therefore causing short stops for the moulding machine are not indicated here. In total 20,365 short stops occurred in 2018, together 9,777 minutes. More on this later on in section 3.4.

3.3 Physical impacts on moulds

Some breakdowns are caused by broken moulds. These moulds could block machines or transport lines. In here, different observations on impacts on the moulds are described. Over a longer period of time all these impacts could lead to broken moulds. Broken moulds could lead to high repair costs or costs for new moulds. Also, when many moulds are broken it could occur that not enough moulds are available in the system to produce optimally.

1. One of the transport converters smashes the moulds against the side of the next conveyor line (TC in front of the presses). All the smashes will have an impact both on the mould and the side of the conveyor line.
2. When moulds enter the remoulder, they are pushed by an extendable mechanism. Sometimes, the mechanism extends to early. The part which drops down hits the mould on the edge.
3. Holding tables 1 and 2 are located a bit higher than the conveyor line after the holding tables. When the moulds are transferred out of the holding tables the smash towards the side of the transport line due to gravity.
4. Cleaning machine, temperatures of 60 degrees and chemicals will affect the moulds.
5. Before the daily planned cleaning, many moulds need to be stored on a kind of attic. Here around 350 moulds are stacked by operators. Often not in the most gentle way.
6. Moulds need to wait in the system due to various reasons. Transport chains
keep on running below the moulds. It has a scraping effect on the bottom of the mould.

7. Some gravity lines are used in the system. These lines have the advantage that they do not need energy. However, moulds exiting these lines smash into the previous mould.

8. Some stoppers in the system stop the moulds on the side. This part of the mould is not the strongest part. Especially, when more moulds are pushing behind the mould which is stopped. Large forces will be applied on this part of the mould.

3.4 Availability of resources

In some cases there is not enough curd available. The moulding machines cannot continue, leading to stops. However, this type of 'Lack of resources' are caused by processes before the moulding machine. These processes, like curd preparation, have the potential to produce 42,335 tons of cheese per year (75 tanks per day, 135 cheeses of 11.45 kg per tank). Therefore, these processes are out of scope for this research. All other registered short stops are caused by shortage of moulds at the moulding machine or a blocked output of the moulding machine (breakdown somewhere in the system).

Again, the total amount of short stops in the used period in 2018 was 9,777 minutes. This amount is equal to 910 tons of missed cheese. The numbers of longer stops, registered in company reports as breakdowns, together in 2018 were 11,679 minutes. In some cases one stop actually causes more stops. The causes of some stops, while observing, are given in the table in Appendix G. Also, the total time of some stops could be decreased. This will be explained next, with help of the simulation. The places of all important machines in the simulation are indicated in figure 22. Some big machines seem very compact in the figure (moulding machine, presses and holding tables), however this is just the appearance in the figure. In the simulation they can be extended. This simulation gives more insight in the described observations and improvements later on, in section 4. Improvements can also be tested for their effects on the system.
Figure 22: Top view of the mould handling system recreated in Tecnomatix Plant Simulation 13.1 [9]. Indicated by the red circles are the most important machines in the system. Furthermore, transport and moving equipment connect those machines. The transport lines at the bottom right represent an attic, where moulds are stored during the planned daily cleaning. The two symbols in the upper left corner and the M’s (methods) are required to run the simulation properly. Note, after the demoulder and in front of the remoulder the transport lines are split in a transport line for moulds and one for lids.

Lids
After the daily planned cleaning, moulds with lids need to be placed back in the system. The circuit of lids is smaller than the circuit of moulds, because moulds have to go underneath the moulding machine (one lid leaving will make a lid return in around 815 seconds and one mould leaving will make a mould return in around 920 seconds). Due to this shorter track, less lids are needed in the system than moulds. Lids are taken out of the system, otherwise the cleaning machine will not proceed due to a full line of lids before the lidplacer. Meaning, moulds will also not proceed out of the cleaning machine, figure 23. Larger distances between the moulds will cause short stops. See figure 24 for clarification.
Figure 23: Picture of the output of the cleaning machine. Both transport lines in this machine are stopped simultaneously, when one output is blocked by a mould or a lid. Transport line above: lids. Transport line below: Moulds.
On the other hand, lids are often not placed back in the system when needed. In case of a breakdown or disruption somewhere in the system, a mould-buffer (when full) in front of the moulding machine makes it possible to keep on producing. However, after a while lids are not available anymore at the lidplacer, causing jams of moulds at the bufferlines after the moulding machine. Later on, this jam could cause a shortage of moulds at the moulding machine. So, even while lids are stacked up next to the transport line, moulds cannot proceed due to a shortage of lids. Some lids should be placed back in the system and whenever the whole system works properly again, they should be taken out of the system again.

All in all, the balancing of the number of lids in the system is done by hand. Therefore, it appears to be done only a few times after the daily planned cleaning and not later during the day on when also necessary.

**Moulds**

In principle moulds are always available at the moulding machine, because all other machine process faster. The system pulls the moulds back to the moulding machine. However, when the cleaning machine is stopped due to too much lids, larger distances between the moulds entering the moulding machine will cause waiting time for the moulding machine. Also, the mould-buffering system (figure 25) does not work optimally. Sometimes, when the mould-buffer is unloading, the moulds are not available in time at the moulding machine.
Thereby, it takes too long before the mould-buffer starts with unloading, due to the settings. When unloading is needed and possible it takes up to nine seconds before the unloading actually is performed. These gaps could cause short stops.

![Figure 25: Picture of the mould buffering system with 20 moulds (capacity is 24 moulds). Other moulds proceed underneath this buffering machine. The machine automatically insert or exclude moulds in/from the system.](image)

In the current system, when cheese is produced, moulds ideally wait already in front of the moulding machine. Still, the buffering system start already to buffer when only half of the transport line is full. If the moulding machine does not produce, a number of 14 to 18 moulds (observed) wait in front of the moulding machine. Other moulds have the wait at the mould-buffer. Only when 18 moulds (two cycles) wait in front of the moulding machine, enough time is available for moulds, exiting the mould-buffer, to arrive on time at the moulding machine. All this waiting for moulds by the moulding machine results in short stops. Thus, half of the transport line is unused (figure 26), which reduces the pull-effect of the system.
Variations in the amount of moulds available are also caused by producing cheeses with short times at the moulding machine (Leerdammer 45+ or Caractère 49+, 64s) after cheeses with long times at the moulding machine (Delacrème 50+ or Leli 30+, 69.5s or 72s respectively). The cheeses with long moulding times often take more time at the remoulder. Consequently, it takes longer before moulds arrive back at the moulding machine where they now are needed even sooner.

When a machine is broken or a line is blocked, it takes also longer for the moulds to arrive at the moulding machine. Transport lines in front of a disrupted machine will stop when full, leading to stops of the other machines. This becomes clear at the transport lines before the demoulder. If this machine cannot continue, two out of three transport lines after the holding tables stop (except the last small one before the demoulder). Therefore, no accumulation can occur and the holding tables will not be able to continue. Soon, this will lead to stops of the remoulder and later the presses. In figure 27 this situation is depicted.
An shortage of lids or moulds means that at another place in the system an accumulation or buffering of lids or moulds occurs. These variations unbalance the system which lead to more and more variations. If cheese is produced at the moulding machine, moulds should move on if possible in order to keep a pull situation for new moulds with cheese. Meaning, reducing waiting of moulds on transport lines. Moulds and processes after a jam should not be affected by the jam. Also, too much moulds in the system will lead sooner to stops of the moulding machine, because more moulds will occupy the transport line between the place of disruption and the moulding machine. On the other hand, too little amount of moulds in the system will develop larger gaps between the moulds on the transport lines, causing eventually short stops at the moulding machine.

Now, observations, measurements and analyses regarded the four sub-questions are explained. Next, the focus for improvements will be determined with help of an empirical causal model.

### 3.5 Focus Improve section & Empirical causal model

The research question stated before in section 2.7.1 was:

*What are the factors influencing the production output of the mould handling system?*
This research question can be answered with the information in section 3, which was gathered on the basis of the following sub-questions:

- What are the processing times of the machines incorporated in the system?
- What are the main causes of breakdowns of the machines and to what extend do all processes and machines contribute effectively to the system?
- What impact do all the processes and machines physically have on the moulds in general?
- To what extend is the availability of all resources satisfying for the system?

Actually, the moulding machine determines the production output of the mould handling system. Whenever this machine produces not optimal, the maximum production output will decrease. Unfortunately, some machines in the system are able to process with a lower speed than the moulding machine. This could cause a lack of moulds at the moulding machine later on. Furthermore, the transport direction converters seemed to be unnecessary handling of the moulds. The transportation between transport lines could be done in a different way. However, company specialist already looked into this option before, so in the current research this will not be investigated in depth. This also applies for the physical impacts on moulds. At last, the availability of moulds and lids will be a major focus for the improvement section. Especially, due to the amount of short stops and the observed situations in the system. Concluding, a not optimal production of the moulding machine and therefore a lower production output is determined by:

- Lack of curd (out of scope)
- Breakdown moulding machine (out of scope)
- Planned maintenance (out of scope)
- Planned daily cleaning (out of scope)
- Moulds not available at the moulding machine (SST or BKD)
- Moulds not able to move from moulding machine (SST or BKD)

Based on the demand of different types of cheese, the moulding machine should be able to produce on average 8.19 cheeses per minute (table 1, Appendix C and F). However, in 2018 the average production speed was 8.13 cheeses per minute. If in 2018 cheese was produced at a speed of 8.19 cheeses per minute, with the same average time loss (4.38 hours a day), 300 tons of cheese could be produced more with the same system. Fixed costs per kg of cheese is around €0.35. However, labour costs also is a fixed cost due to the continues production. The fixed costs per kg of cheese then will be around €0.50 (Information from Controlling Manager, B. Middag). 300 tons of cheese will then yield between €105,000 and €150,000.
Hence, short stops and longer stops (or BKD’s) determine the operating time and therefore the average production speed. The total downtime need to be decreased. Disruptions in the system may not or only once cause a stop of the moulding machine. From the observations and measurements can be concluded that more stops originated from one disruption (figure 28) and that gaps could arise from variations in processing speed (variations in throughput time).

Concluding, this lead to two main items to focus on in the ‘Improve’ section. The first focus will be on the unnecessary’ stops of the moulding machine. Eliminating these stops will increase the operating time and also the average production speed. If the average production speed reaches 8.19 cheeses per minute, the average downtime (4.38 hour/day in 2018) should at least be decreased by 15 minutes (to 4.13 hour/day) to achieve the desired output of 40,800 tons of cheese in 2023. This focus covers the blue part of the conceptual causal model (figure 6) and the empirical causal model (figure 29).

The second focus is on reducing the throughput time and its variation. This will give a more balanced system. Especially, at the presses and the remoulder variations can be decreased. The differentiation in processing speed leads to an unbalanced system with short stops, which is not able to reach the maximum
production capacity. Looking back at the conceptual causal model (figure 6) and towards the empirical causal model (figure 29), this focus covers the green blocks of the models.

**Figure 29:** Empirical causal model of the main problem of mould handling system. Each color includes one sub-question in this research. ‘No color’ means that these subjects are not investigated in depth. From right to left, possible causes are dissembled. The crossed out boxes are not in the scope for the improvement section.
4 Selected Improvements & Effects

In this section possible solutions will be given to increase the production capacity of the mould handling system. First, different design questions will be developed. These questions will be answered with different solutions. Included for each solution are the explanation of the improvement, the costs, the gains and a solution classification. This classification will be determined on the basis of an impact quadrant and an ease of implementing quadrant. Solutions with a high impact, which are easy to implement are considered the best solutions: Quick wins. See figure 30.

![Action priority matrix](image)

**Figure 30:** Action priority matrix [17]. Quick wins are considered as the best solutions and hard slogs as the least favorable solutions.

4.1 Design questions

Design questions are developed to tackle the causes described in section 3.5. The main focus items for this improvement section are:

1. Eliminating unnecessary stops of the moulding machine.

2. Reducing variations in the throughput time of the mould handling system.

The corresponding design questions are given below. Both question could give more possible improvements.

- How to enable an at all time availability of moulds and lids in the beginning of the system (at the moulding machine and the lidplacer)?
• How to reduce the variability in the required time to handle moulds at the presses and the remoulder?

Low costs and high impact solutions are most favorable, due to a high return on investment (ROI). Therefore, meetings are held with the process technologist, the mechanics from the maintenance department, the shift leaders from the production department, the project leaders and the management to get input from all 'directions'. Also, the cheese manufacturing plant in Schoonrewoerd has been visited to acquire knowledge of another cheese manufacturing plant. All this, together with own observations and information from the knowledge base, help to find possible solutions. Expected costs of the improvements will be made with help of the company specialists and for some improvements manufacturing companies will be approached. Still, the costs will be an indication so it can only be used to get an idea of the order of magnitude of the costs. Furthermore, the possible gains of the improvements will be explained in savings and OEE increase. Thereby, the possible improvements will be validated in section 4.3 with the simulation in Tecnomatix plant simulation 13.1[9]. The problems are specific, practical oriented, for this cheese manufacturing plant. However later on, in section 6, is described how this research could be of use for the general knowledge base. Additionally, lean principles come forward in the improvements.

4.2 Improvements

A wide range of ideas is shorted out to the best solutions for the suggested problem. The solutions can be grouped together for the two focus items. Still, solutions together could influence the outcome. Each improvement will first be explained, where after the costs and the gains are estimated.

4.2.1 Focus item 1: Eliminating unnecessary stops of the moulding machine

1. Insert right number of moulds & lids in the system: class: Fill in
2. Automatic buffering system for lids: class: Major project
3. Make mould-buffer smarter (faster) & Enable more moulds in front of the moulding machine: class: Quick win

Focus 1.1 explanation: Insert right number of moulds & lids in the system

Basically, this improvement deals with the following principle. Inserting too little moulds in the system will result in larger spaces between moulds, leading to short stops at the moulding machine. Inserting too many moulds in the system will lead to a congested system. This will affect the part of the system where value is added (yellow boxes, figure 2). Too many moulds will be occupying the transport line, leading sooner to completely occupied transport lines and stops
of the moulding machine, in case of a disruption in the system. Thereby, more moulds will be pushing against each other, which increases the forces applied on stoppers and transport lines. The risk of breakdowns therefore increases.

The right number of moulds and lids can be calculated. Required for this calculation are the moulding speeds (table 1), the time it takes for one mould, leaving the moulding machine, to return another mould to the moulding machine (e.g. one mould inserted in the press, enables one mould leaving the press), the capacity of moulds in the presses and the holding tables, and the extra buffering capacity in front of the moulding machine. The time moulds need for one ‘round’ was measured, namely 15 minutes and 20 seconds. This number can be divided by the different moulding speeds of table 1, to get the ideal amount of moulds on the transport lines. Added to this amount should be the capacity of moulds in the presses (760) and the holding tables (402) and the extra buffering capacity in front of the moulding machine (The buffering machine and extra on transport line, together 37). Shown in table 9 are the ideal numbers of moulds for each moulding speed. The round of lids is shorter, namely 852 seconds. Therefore, the corresponding amount of lids is lower than the amount of moulds. Different numbers of moulds and lids are tested and observed in the system, see Appendix G.

Table 9: Ideal number of moulds and lids in the mould handling circuit for each moulding speed.

<table>
<thead>
<tr>
<th>Type of cheese</th>
<th>Moulding machine</th>
<th>Ideal number of moulds</th>
<th>Corresponding number of lids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leerdammer 45+</td>
<td>64 s</td>
<td>1329</td>
<td>1277</td>
</tr>
<tr>
<td>Caractère 49+</td>
<td>64 s</td>
<td>1329</td>
<td>1277</td>
</tr>
<tr>
<td>Leli 30+</td>
<td>72 s</td>
<td>1316</td>
<td>1264</td>
</tr>
<tr>
<td>Delacrème 50+</td>
<td>69.5 s</td>
<td>1319</td>
<td>1268</td>
</tr>
</tbody>
</table>

Costs Focus 1.1
This implementation could be fast and easy. Already 1354 moulds are available, when none are broken. The number of moulds in the system should be counted and made visible for operators. Possibly by an automatic impulse-counter after the inserting point of moulds (between holding tables and demoulder). After the daily planned cleaning, before the system starts up again, the counter should be set to zero. Every mould in the system will pass the counter and after a while also the new inserted moulds will pass the counter. The total number of moulds will be visible for the operator inserting the moulds from the attic. In Appendix H a broader explanation on the usage of this counter is given. The costs will be around €1,000 to get this counting system [18].

Focus 1.2 explanation: Automatic buffering system for lids
Taking and inserting of lids is already done in the mould handling system. How-
ever, not in all necessary cases. Moulds should move on as far as possible in order to get a pull-effect. Therefore, the cleaning machine should not be stopped due to a full line of lids (explained in figure 24). To solve this, sensors and a flashing light (below other flashing lights in the system) could be implemented to warn operators when too many (or too little) lids occupy the transport line before the lidplacer. Action is needed before downtime. Still, it depends whether the operator takes action or not. However, due to other job-activities (resolving disruptions for example) this solution will not be feasible.

More favorable is an automatic buffering system for lids. An automatic buffer for the lids will keep on balancing the system throughout the day. The system then pulls moulds and lids even more towards the beginning of the system, also in case of a disruption somewhere in the system. Due to this pull-effect, the moulding machine will have more moulds available which reduces the amount of short stops. Another advantage of this improvement is that it makes the system less dependent on operators.

Also, due to this buffer more lids are automatically available for the lid placer. This reduces the chance that moulds have to wait on the two buffer-lines after the moulding machine. Variation in throughput time from the moulding machine towards the presses will be reduced and which also benefits the similarity in quality of the cheeses.

Costs Focus 1.2
To estimate the costs of such a machine, the company which installed the mould buffering machine (figure 25) was contacted. In 2002 that machine was placed at a total cost of around €80,000. Still, a rough estimation was complicated. So, the order of magnitude of the costs will be around €100,000 [19] for a machine which can buffer around 28 lids.

Focus 1.3 explanation: Make mould-buffer smarter (faster) & Enable more moulds in front of the moulding machine

Currently, the mould-buffer machine works not efficient. The machine (before in figure 25) requires too much time before actual unloading starts. Also, the retaining of moulds sometimes starts to soon. The time needed for unloading is a software issue. When all sensors indicate 'no mould' it still takes a few seconds ($\pm 7s$) before the system starts to go down. This time should be decreased to for example 2 seconds. Every time no moulds exit the cleaning machine and no moulds are underneath the mould-buffer, must be an trigger to unload directly.

Another way is to replace the sensor, which triggers the 'retaining and loading' of moulds in the mould-buffer, more backwards (closer to the mould-buffer). This ensures later retaining of moulds, so more moulds in front of the moulding machine. Also, new moulds from the mould-buffer will sooner exit, because the sensor sooner indicates 'no mould'. More than 18 moulds could give problems
of pushing moulds. Therefore, a stopper could be inserted to hold the moulds. With a stopper it is possible to use the whole line in front of the moulding machine. The capacity to buffer will then be increased by 16 moulds (9.2 meters extra used).

This improvement then influences the first improvement. The extra buffer capacity of moulds may also be inserted in the system. Thus, an option is to name one ideal number of moulds in the system, like 1335 moulds, and use this number at all times. Then, no counter or extra manual actions are required. Thereby, if the whole line before the moulding machine is used with the stopper, it is less important to adjust the software of the mould-buffer. This, because the space between the moulds before the moulding machine and mould-buffer is decreased (eliminated).

A third option could be to replace a mould turner, which is now located directly after the mould-buffer, more towards the moulding machine. Moulds exiting the cleaning machine are upside down. If it is preferred to accumulate the moulds in this way, due to the risk of contamination, the mould buffer or the mould-turner could be replaced more towards the moulding machine. This improvement will have the same effect as the above described stopper. However, this will cost a lot more than the stopper. Thereby, at the bufferlines after the moulding machine, it also occurs that moulds have to accumulate without a lid, even with a cheese in it.

Costs Focus 1.3
The addition of one stopper is considered as the best option. This could be realized with around €2,000. This estimation is made by two company specialists, namely: Project leader R. de Bruijn and Project leader J. Weergang. Together with product information from a supplier [20].

Gain of all improvements in Focus 1
The gains of the improvements together in Focus 1, can be estimated in two ways. The first approach relate to the expected production rate and the second approach to the expected decrease in downtime of the system. Later on, in section 4.3, all improvement together are validated in a simulation of the system.

Due to these three improvements a lot of unnecessary short stops will be eliminated. So, the moulding machine can produce optimally. Explained in section 3.5 was that the current average production speed of 8.13 cheeses per minute (Appendix B, figure 34) than will increase to 8.19 cheeses per minute. Including the same downtime of 4.34 hours per day will give an increased production of 300 tons of cheese per year (actually downtime will decrease). A saving of the fixed costs between €0.35 and €0.50 per kg of cheese, realize a gain of €105,000-€150,000. Thereby, the system will be less dependant on operators.
Another way to reason is that at least half of the short stops will be eliminated with these three improvements. This number is based on own observations in the factory, Appendix G. Together, the total amount of short stops in 2018 was 9,777 minutes. This amount is equal to 80,000 cheeses and 900 tons of cheese. A reduction of half of the short stops could lead to an increase in the production capacity of 450 tons of cheese (used: 8.13 cheeses per minute). This amount is equal to a saving of €150,000. Moreover, the OEE would have been 94.24% instead of 93.14% in 2018.

4.2.2 Focus item 2: Reducing variations in the throughput time of the mould handling system

1. Equalize software of all presses: class: Fill in
2. Split up transport line before press, ensure transport chain and add stoppers: class: Quick win
3. Lift one side of mould at the transport chain in front of remoulder: class: Major Project
4. Accumulated transport lines after holding tables, extra split up and stoppers: class: Fill in
5. Split line after presses and extra split behind holding tables: class: Hard slog

Focus 2.1 explanation: Equalize software of all presses

The mechanism of inserting at presses Z, A and B should be the same as at presses C and D. So, the software should be checked and equalized for all presses. This improvement enables new trains in front of presses Z, A and B while the output of the press is blocked. More moulds could be occupying the line in front of the presses and time is saved when the machine is able to continue.

Focus 2.2 explanation: Split up transport line before press, ensure transport chain and add stoppers

In the analysis, section 3, can be seen that the presses Z, A, B and C give variations in processing speed. For those presses the processing speed could drop below the desired lower boundary. The previous improvement is only related to a situation when the output is blocked. However, this solution will eliminate the risk of variations in processing speed. When the chain of the transport line in front of the presses is assured, it won’t be necessary to stop the whole transport line while inserting a train. Stoppers should be placed in front of each press, like the situation at the holding tables (figure 16). Also, it is better to split the transport line in two and add another motor to ease the other motor when the transport line is full. This ensures that the maximum number of trains in front of the presses can be reached. Moreover, it ensures a constant inserting speed in case of maximum supply of moulds at all the presses, of around 520 moulds per hour. The whole system will become more balanced. Moulds will be taken
away more easily behind the moulding machine, contributing to the pull-effect of the system. At last, it will enable more time before the moulding machine stops producing (is blocked), in case of a breakdown somewhere in the system.

**Costs Focus 2.1 & 2.2**
The estimated costs of improvements 2.1 and 2.2 together are based on the addition of four stoppers, ensuring the transport chains and adjusting the software. Only four stoppers are needed, because in front of press D already a stopper exist. The costs (estimated by company specialists, project leaders: R. de Bruijn and J. Weergang) will be around €10,000 to €15,000.

**Gain Focus 2.1 & 2.2**
Due to a more balanced system short stops will be reduced. This, however, is complex to quantify. Another benefit was later downtime of the moulding machine, due to a higher capacity of moulds on the transport line in front of the presses. The capacity will increase by 4 or 5 moulds, which is equal to half the number of columns at the moulding machine. Meaning, on average half of the moulding time will be saved for every breakdown of the presses, remoulder, holding tables or transport lines in between. The amount of BKD’s here was 692 in 2018 (table 8). This number times half the moulding speed, table 1 (used: 32s), is equal to 369 minutes of time saved. Again, with the average production speed of 8.13 cheeses per minute in 2018, the average weight of 11.45 kg per cheese and the compared saving of fixed costs of €0.35 per kg, this results in a total saving of €12,000. Based on the extra production, the OEE would have been 93.24% instead of 93.14%.

**Focus 2.3 explanation: Lift one side of mould at the transport chain in front of remoulder**

This machine is in essence much faster than the moulding machine. However, shown in figure 14 was that a lot of variation occurs in the processing speed with all types of cheese. In all measurements it happens sometimes that a cheese get stuck in the mould. The blow section then has to apply pressure two or three times to get the cheese out. Also, when the cheese is not fully out, it cannot be detected and the machine will lift the mould again. This takes sometimes up to more than ten seconds. Proposed is an option to loosen the cheese in the mould, already on the transport line before the remoulder. Tilting of moulds is already common in the production of cheese wheels, see figure 31.
The challenge here is dealing with the rectangular moulds. Tests are performed on different days (around 11 per day) by lifting up one side of the mould for three to five seconds, before entering the remoulder. At all cases, cheeses in non-tested moulds were stuck sometimes. The results are given in table 10. The stuck non-tested cheeses were only counted at the last four measuring days out of 11 measuring days. Further in the table, one column indicates the pressure at the blow section (norm is 3.5 bar). This pressure is sometimes increased by the operators. The results in table 10 show that only five cheeses got stuck from the 127 tested moulds.

**Table 10:** Results mould tilting tests to reduce variation of processing speed at the remoulder. Results from eleven different days, last column from last four days.

<table>
<thead>
<tr>
<th>Type</th>
<th>Pressure (bar)</th>
<th>Measuring days</th>
<th>Tested moulds</th>
<th>Not stuck (blow 0,1)</th>
<th>Stuck (blow 2&gt;)</th>
<th>Non-tested moulds stuck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leerdammer 45+</td>
<td>3.5-4.0</td>
<td>6</td>
<td>82</td>
<td>3</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Leli 30+</td>
<td>4.0-4.4</td>
<td>2</td>
<td>20</td>
<td>1</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Caractère 49+</td>
<td>nk</td>
<td>1</td>
<td>6</td>
<td>0</td>
<td>nk</td>
<td></td>
</tr>
<tr>
<td>Caractère léger 35+</td>
<td>nk</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>nk</td>
<td></td>
</tr>
<tr>
<td>Beldammer 47+</td>
<td>4.0</td>
<td>1</td>
<td>10</td>
<td>0</td>
<td>nk</td>
<td></td>
</tr>
</tbody>
</table>

**Costs Focus 2.3**

It was not possible to estimate costs for such an option, simply because no specific option is available. A simple option, increasing the height of one of the two
chains, was tested. However, due to the lubricated chain, moulds were not able to proceed. Thus, a more advantage option is needed (for example: side driving chain). For now, this is not specific enough to estimate the costs.

**Gain Focus 2.3**
The gain of an improved remoulder particularly could eliminate short stops after a change of cheese type (from Leli30+ to Leerdammer45+ for example) and short stops around 2 to 2.5 hours after the daily planned cleaning. Again, during the daily planned cleaning, around 550 moulds with cheeses still occupy the presses. After around two hours the last of these moulds, e.g. driest cheeses, exit the presses. Often, this results in short stops, together of around two minutes. The type of cheese change, from Leli30+ cheese to another type of cheese, occurs on average 2 times a week. This results in short stops together of around two minutes. Consequently, an improvement will save 938 minutes per year compared to 2018. This amount is equal to a saving of €30,561. The OEE, related to the extra production of cheese, would have been 93.37% instead of 93.14%. Additionally, expensive compressed air, used in the blow section, will be saved.

**Focus 2.4 explanation: Accumulated transport lines after holding tables, extra split up and stoppers**
This improvement is important in case a breakdown occurs at the cleaning machine or the demoulder. In the current situation a breakdown will block/stop the whole system in around two minutes. Many moulds are still waiting on conveyors. This because the transport line between the holding tables and the demoulder does not accumulate. If this line could accumulate, it will take longer before the other machines, like the presses and the remoulder, stop producing. So, the pull-effect of the system will increase.

**Costs Focus 2.4**
The specific transport line is respectively long. In order to accumulate it is better to split the line in two and add a motor. Otherwise, the motor could have troubles with all the moulds on the line. Possibly, lubrication and the addition of stoppers is enough. Depending on the strength of the stoppers, two or four stoppers should be added. Two stoppers will cost around €4,000.

**Gain Focus 2.4**
The actual gain will depend on the amount of moulds buffering in front of the moulding machine. When a breakdown occurs at the cleaning machine or demoulder, no moulds will exit these machines. If enough moulds are available, it is estimated that the moulding machine can do two cycles more than in the current situation per breakdown. However, if enough moulds were available at the moulding machine is not known, in case of a breakdown at the cleaning machine and the demoulder. So, no specific assumption on gain could be made with the information from table 8.
Focus 2.5 explanation: Split line after presses and extra split line behind holding tables

When moulds are pushed out of the presses or the holding tables, the line after is stopped. Already described for the holding tables is that while exiting a train from the holding tables, a previous train has to stop also on the conveyor after the holding tables. In some cases this means that the demoulder is waiting for moulds, causing variations in the distance between empty moulds going to the moulding machine.

The transport line after the presses is even worse, because that transport line is one complete chain. Meaning, that when for example trains exit press D, four previous trains (16 moulds) also have to stop. In this way, no pull-effect occurs and gaps between moulds will not become smaller.

Costs & Gain Focus 2.5
The costs for a transport line of 3 meters will be around €5,000[21]. Behind the presses ideally 5 are needed. However, the remoulder first must be more reliable in order for this improvement to have an effect. So, the gain for now is only a smoother throughput of moulds in the system.

4.3 Validation of Improvements

Now, these proposed improvements will be validated with help of the system in Tecnomatix Plant simulation [9]. Already showed in section 3.4 were pictures of the simulation of the current mould handling circuit. The current situation in the simulation gives an output of the moulding machine of 10,188 cheeses per day. This is based on full production in 24 hours, so without daily planned cleaning and breakdowns. Also, in this situation no lids were taken out of the system. So, the cleaning machine was 24.4% of the simulated time blocked.

The simulation of the improved system has an automatic lid buffering machine after the cleaning machine. Also, the whole transport line in front of the moulding machine was used, before buffering moulds. Only these two improvements are simulated, because these related to ‘normal’ production. Meaning, not improvements which correspond with variability in processing times or breakdowns. A picture of the simulation of the improved system is given in figure 32. In this simulation also no lids were taken out. The production output of the moulding machine in this model was 12,133 cheeses per day. Meaning, an increase of 19.1% compared the current system in simulation. This, only due to less time waiting on moulds for the moulding machine. The cleaning machine in this simulation gives a 0% blocking time.
Figure 32: Picture of the improved mould handling system in simulation. Example with addition of a lid-buffer and a replacement of the mould turner after the mould-buffer (could also be done with placing only a stopper instead). The two symbols in the upper left corner and the M’s (methods) are required to run the simulation properly.
5 Conclusion & Discussion

This research investigates the possibilities to increase the maximum production capacity of the mould handling circuit of the Royal Bel Leerdammer cheese manufacturing plant in Dalfsen. The DMAIC cycle [7] is used, comparable to the regulative cycle [10], to answer the main research question:

What are the factors influencing the production output of the mould handling system?

A main requirement for this system is that the first machine, the moulding machine, continuously produce cheese in order to reduce risks of quality issues. This machine operates with three fixed speeds (450, 466 and 506 cheeses per hour), dependant on the type of cheese. Hence, the other machines in the system should process moulds with these speeds or higher.

The results showed two main factors influencing the production output of the mould handling system. The first factor is large variations in processing time of different machines in the mould handling circuit. In particular, the (line before) presses and the remoulder. Four out of the five presses could be supplied with a speed lower than the desired lower boundary of the system, which is 506 moulds per hour. Respectively, 3% to 34% of the measurements were below 506 moulds per hour (measured at maximum supply). On the other hand, the remoulder processes 31% to 97% of the measurements under 506 moulds per hour, for respectively four different types of cheese. Here should be named that 18% to 32% of the measurements were below the setting speed of the moulding machine, respectively for the same type of cheese. However changing type of cheese still causes variations in the system.

The second factor is a varying amount in the availability of supplement equipment (moulds and lids) at the moulding machine: This is caused by the amount of moulds and lids in the system and the settings of the mould buffering machine. All these variations lead to unnecessary stops of the moulding machine, which results in a lower production output of the mould handling circuit (measured at the moulding machine).

To reduce the influence of these factors on the mould handling circuit, two corresponding design questions were formulated:

• How to enable an all time availability of moulds and lids in the beginning of the system (at the moulding machine and the lidplacer)?

• How to reduce the variability in the required time to handle moulds at the presses and the remoulder?

Recommended improvements related to the first design question are a standardized amount of moulds and lids in the system, together with enabling more
moulds in front of the moulding machine by adding just one stopper and replacing a sensor. Furthermore, a lid buffering machine is recommended due to its capability to continuously balance the number of lids in the system. All together, these improvements will costs €103,000. With these improvements (based on data of 2018), the average production speed will increase to 8.19 cheeses per minute and the total downtime will decrease with 4,889 minutes per year, resulting in an expected production output of 40,766 tons of cheese per year.

In relation to the second design question, suggested is that another €15,000 should be invested in the improvement of the presses. With this investment the software of all the presses should be equalized, stoppers should be added at the transport line and the chains need to be 'ensured'. This will decrease the total downtime further with 369 minutes per year, compared with 2018. Other proposed improvements need elaboration or their effects could not be quantified.

All in all, these recommended improvements have the potential to increase the production output of the mould handling system to 40,801 tons of cheese. An total investment of €118,000 is required, which will result in a saving of €280,175 in comparison to 2018. This expected production output of the mould handling system satisfies the desired production output of 2023, a stated in the goal of this project.

Aimed was: To increase the production capacity of the mould handling system of Royal Bel Leerdammer in Dalfsen, by re-designing the system and validating it in 18 weeks, that will give an improvement plan to increase efficiency and/or capacity, in order to be able to produce the company’s desired outputs of 40,200 tons and 40,789 tons of cheese in 2019 and 2023, respectively.
6 Generalization

The proposed solutions will help the cheese manufacturing plant of Royal Bel Leerdammer in Dalfsen. However, this research could also help other factories. Many factories, like this one, developed throughout the years. Therefore, facility layouts occur often not in the most efficient way. Still, replacing machines (space) or building a new factory are often costly and illusive solutions. Most problems stem for a reconfiguration instead of a new installation [22]. Frequently is mentioned that researchers are not considering 'true' world problems and that the scientific results could not be transferred back to practical problems [23]. Partly by, most papers treat the case of a first time installation [24, 25] or simple assembly line balancing problems [23, 26–28]. Recently, the focus evolved towards formulating and solving more realistic generalized problems [29]. The research of N. Boysen et al. in 2008 [24] classified line balancing problems in a clear way, also taken into account complex assembly line balancing problems. Multi- or mixed models often occur in assembly lines, due to different manual or automated processes. In the research three different lines are given.

The first one is the 'paced line'. Assembly lines with a paced line have one common cycle time. The pace could be kept with a conveyor, so each station has to finish the process before the end of the conveyor. Or, by a full stop at every workstation and automatic transportation whenever the given time is over. Secondly, an unpaced asynchronous line is explained. In these type of assembly lines products are transferred when the process is completed, rather than being bound to a fixed cycle time. Products are always moved when the process is ready, unless the output is blocked. For this reason, buffers are installed in these types of system to minimize waiting time. Boysen argues that buffers are only useful for temporary deviations in task times. If one machine is always faster than the other machine, the buffer soon will be filled to its capacity and loose their function. The last named line is an unpaced synchronous line. In this line workstations wait for the slowest process to be finished where after the product is moved. Buffers in this type of assembly line are not needed.

The mould handling circuit of Royal Bel Leerdammer can be subjected as an unpaced asynchronous line. The circuit consists of a value adding part, which then actually is a line, and a ‘returning’ part of supplement equipment (moulds and lids) (figure 2). The survey of Boysen, which covers around 150 papers, misses actually these kinds of systems. Thereby, the level of importance of each station is the same for simple assembly line balancing problems [24, 26, 27]. O. Battaia in her survey, covering around 300 papers, addresses in the discussion that re-balancing a line with machine having different levels of flexibility seemed very little explored [26]. The survey by O. Hazir in 2013 was a pioneering work which incorporated uncertainty, like variability in operation times, resource usage or availability’s [30]. Another paper, by V.N. Vasilev in 1989, described to minimize downtime due to the lack of machined parts [31].
The current research will help as an addition to Boysen’s paper and the paper of V.N. Vasilev. Especially when an unpaced asynchronous line is supported by a supplement equipment circuit. These types of systems could occur for example in cheese factories, flower industry (crates), vegetable industry (crates) or in distribution centers. Machines or workplaces where products are placed in the supplement equipment should always be able to continue, when products are available. Compared with Boysen [24] a buffer, ideally empty, indeed could be placed after this machine or workplace in order to minimize waiting time. The remaining machines and workplaces should at least process above the fastest process time of that machine or workplace. Therefore, to achieve line balancing, a buffer of supplement equipment (in this case moulds and lids) in front of the machine is also needed to minimize waiting time [31]. Ideally, with a capacity to store all the supplement equipment, in order to keep the value adding assembly line running independent of the processing time of the first machine.

These type of lines could be added to the ones classified by Boysen as an extended unpaced synchronous line. In which the first machine in the system is the speed determining factor and where the remaining machines always process with a speed at least equal to the highest production speed of this machine. Therefore, in case the first machine produces at a different lower speed, a buffer in front of the first machine is needed to balance the system. To investigate such a system the next steps can be used.

- Check total circulate time of products on transport lines - T (time)
- Check capacity of products in value-adding machines - M (products)
- Check if the first machine in the system is the rate determining machine, in order to always have a pull-effect in the system - rate = R (time/product)
- Check the extra buffering capacity of the non value-adding part of the system - B (products)

Each step is a focus point for research, whether they can be optimized. The ideal amount of products or supplement equipment (N) in such a system can be determined by equation 1:

\[ N = \frac{T}{R} + B + M \]  

All in all, this research could help closing the gap between theories and the practical assembly line balancing problems.
References


Appendices

Appendix A

Coagulation process in cheese manufacturing

It is commonly known that cheese is made from milk. However, what really is milk? Roughly, milk consists of five main components: Water, lactose, protein, fat and salts. Around 85% of the milk is water in which the other compounds are dispersed. Water molecules are attracted to each other through hydrogen bonds, because they are strong dipoles. The solid contents in milk stay dispersed because their molecules interact also with the water molecules, due to polar molecules of the solid contents.

Milk fat, consisting of non polar triglycerides, remains dispersed because those molecules are wrapped up in macromolecular structures. These emulsions are droplets with a polar surface layer, enabling the interaction with water [32]. During the first main step of cheese making, coagulation, the proteins in milk convert from a polar to a non polar form. The proteins separate from the water phase, causing simultaneously a coagulation of the milk. Water, fats and other substances are trapped by the proteins. When this gel or coagulum is cut, solid flakes (curd) in water with dissolved substances (whey) can be observed [33].

One of the substances that is soluble in water is lactose. Milk contains approximately 4.5% of lactose [34]. Lactose is a disaccharide, used as a substrate by lactic acid bacteria. These bacteria digest lactose to lactic acid. Therefore, lactose is an important substance in cheese manufacturing. However, due to the separation of curd and whey, only a small portion of the lactose is trapped in the curd [32].

The proteins in milk can be considered as two groups: Caseins and whey proteins [35]. It depends on the type of coagulation process if both groups coagulate. Mostly, only the caseins (the major group, around 82% of total proteins [33]) coagulate. In milk, whey proteins exist as monomers or dimers folded in a globular form. These micelles have polar outer surfaces composed of the amino acid backbones of the protein. This polar surface ensures that whey proteins remain dispersed in water (or whey).

Four fundamental construction parts of casein proteins can be distinguished, namely: αs1-, αs-, β- and κ-casein. Casein proteins are phosphoproteins, which means that in the molecules up to thirteen negatively charged phosphate groups occur. These groups form ionic bonds with calcium ions [32]. Subsequently, calcium ions form nanocrystals with phosphate ions, which are also present in large amounts in milk. Through the bonds with calcium phosphate nanocrystals, thousands of casein molecules form casein micelles. κ-casein rich casein molecules appear at the surface of the micelles, due to their hydrophilic behavior [36]. 66% of the total calcium and 57% of the total phosphorus present in milk are incorporated in colloids [33]. These undissolved salts could sometimes
include sodium, potassium, magnesium or citrate [2, 33].

As said before, in the coagulation step the (casein) proteins in milk convert from a polar to a non polar form. This step is initiated by the lactic acid bacteria. These bacteria grow and multiply rapidly, while digesting lactose into lactic acid. Due to this formation of lactic acid, the pH of the milk starts to drop. Whenever the critical pH of 4.6 is reached, the hydrogen ions actually neutralize the polar casein micelles [32]. As a consequence, the micelles cannot interact with water molecules anymore. Continuously, chains of these micelles start to form, resulting in a large matrix trapping all the water and components.

Appendix B

Time loss and production speed
The company’s reports started tracking the OEE at the 3th of March 2017. The period until the 1st of January 2018 had 23,807.42 minutes of machine effectiveness and short stop losses. The utilization and organization losses were 49,977.33 minutes. In the same period 2,907,377 cheeses were produced, which makes the time loss per day 4.05 hours and the production speed 7.99 cheese per minute. Note, the reports started at 03-03-2017, so data of January and February 2017 is not available. See figure 33.

![Figure 33: OEE summary from company’s report, time frame: 03-03-2017 till 01-01-2018, 303 days](image)
In 2018 the time loss while producing was 37,526 minutes. The utilization and organization losses were 63,652 minutes. However, 4502 minutes are subjected to 'no production, but operators available' and 780 minutes were utilization losses. These standstills occur when demand is low (production was possible). In total 3,449,863 cheeses (11.45 kg) were produced. Concluding, in 2018 the average time loss per day is 4.38 hours and the production speed is 8.13 cheeses per minute. See figure 34.

![Figure 34](image_url)

**Figure 34:** OEE summary from company’s report, time frame: 01-01-2018 till 01-01-2019, 365 days
Appendix C

Part from interview with Marcel Vendrig – Master Planning Manager – Supply chain - 03-12-2018

How are the cheese orders for the factory in Dalfsen established? On which points is the forecast founded?
Forecasts are made in the headquarters in Paris. Via different systems the planning for the amount of cheeses and the amount of packed cheeses is transferred. In the supply chain office in Schoonrewoerd they know what the stock of cheese is in each factory in the Netherlands. The planning for the plant in Dalfsen is based on the storage of cheese and the production capacity. Ideally, they want to have a stock of one week production. When stock is growing, the production need to slow down. Also, they have to act on different ripening times. For example the Caractère cheese need six weeks of ripening. For those type of cheese the storage will increase to two weeks. In essence this is too much. Now, storage is also outsourced. Around 30,000 cheese are stored externally. The intention is to reduce the stock again, to avoid external storage. For this reason the demand also dropped in the second half of 2018. The planning also anticipates on a new process in Dalfsen, which reduces ripening time.

Thereby, planning is also based on what the factory is able to produce. Information about the expected provided fats and proteins in the milk are known. These numbers give a maximum production. Marcel sometimes adjust the orders with help of his experience, for example more light cheese in the beginning of the year. In that time, more people ask for fat-reduced food. The planning also know the demanded B2B cheeses and those cheese are added to the planning if there is space left.

What is expected for the future? Headed to the vision of 40,789 tons of cheese in 2023? And, will the proportions of cheeses in the orders change?
Still uncertain. If 2017 is compared with 2018 the orders for Caractere, Delacreme and Light cheese seemed steady. This is also expected for the upcoming years. The total amount slightly grows. This means that the beginning of 2019 again could lead to problems. In the future also an extra line in Schoonrewoerd will be installed, which could ease the production in Dalfsen. Also, the demand is often dependant on the market in Germany. Here, they sell mixed boxes of Leerdammer Original, Leerdammer Light and Caractere. So, expected is that the proportions stay the same.
Appendix D

**Figure 35:** GANTT chart with the time planning of this research. The total time of the research was 4.5 months.
Appendix E

Data gathering explanation
All data is gathered when the machines had a maximum supply of moulds. So, the machines had to work at their full capacity. In this section the way of measuring is explained. Used was a simple stopwatch and writing equipment to register the measurements. Also, a laser distance meter was used.

Press
The data for the input/output speed at the presses can be gathered at different places. At the inserting point, time between inserting two trains is measured, so one cycle. This time is the same as the time between assembling two trains at the beginning point of the transport line before the presses. The assembly/inserting of five trains in a row is measured and after each assembly the time is noted. These measurements are repeated at least three times on the same day and on different days to acquire reliable results.

Remoulders
Measurement at the remoulders were performed when a buffer of moulds occurred in front of the remoulder. The machine operates in line, so every cycle consists of one speed (determined by the bottleneck). After three cycles the time is registered and later on the average speed per cycle is determined. These measurements are repeated at least three times on the same day and on different days to acquire reliable results. For this machine also the different types of cheese are incorporated.

Holding tables
The procedure for measuring the speed at the holding tables can be compared with the ‘presses’. Here, supply is determined by the remoulder. So, maximum supply is hard to measure. Still, on different days the measurements are performed.

Demoulder
Measurements at the demoulder consist of three or eleven cycles in a row. The lid taker, the vacuum plate and a mould turner all work together at the ‘demoulder’, so each cycle has the same speed. When possible these measurements were also repeated on the same and different days, for every type of cheese.

Remaining machines
The procedure for all other machine were the same. The cycle time of each machine is measured at least three times each day and again on different days. When machines had full supply of moulds, more cycles in a row could be measured, to acquire even more reliable results.

Transport lines
Every transport line was measured for their length with a laser distance meter.
Distances were measured from turns to machines, from machines to machines, from machines to turns or from transport line to transport line. Indicated by the name of the measurement is which place is measured. With the time needed by moulds to overpass a certain distance on the conveyor, the speed of that conveyor could be determined.

Appendix F

General weekly order
These are examples of weekly orders.

<table>
<thead>
<tr>
<th>Week</th>
<th>Cheeses</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>32294</td>
<td>0,52</td>
</tr>
<tr>
<td>42</td>
<td>36716</td>
<td>0,57</td>
</tr>
<tr>
<td>43</td>
<td>31624</td>
<td>0,51</td>
</tr>
<tr>
<td>44</td>
<td>32562</td>
<td>0,52</td>
</tr>
<tr>
<td>45</td>
<td>32026</td>
<td>0,53</td>
</tr>
<tr>
<td>46</td>
<td>45292</td>
<td>0,67</td>
</tr>
</tbody>
</table>

Figure 36: Weekly orders of cheese of week 41 until 46 in 2018. The first type of cheese is Leerdammer 45+. This type of cheese is demanded for most.

In the IDS loss model of the cheese manufacturing plant in Dalfsen the used ratio between the different ‘moulding’ times is: 73% for cheeses with a moulding time of 64s, 18% for 72s and 9% for 69.5s. See section 3.1 under ‘moulding machine’ for more information.

Appendix G

Raw data
The next table gives a summary of some observations and tests in the mould handling circuit. The cause of different sst’s registered in company reports are indicated. Also, the number of moulds in the system is indicated. Only the sst’s are described of which the cause is known. Other observations are not given here.
<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Causes and number of moulds</th>
<th>SST’s (or BKD’s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19-11-18’</td>
<td>9.00-9.50</td>
<td>Mould-buffer was full. Stop of cleaning machine. Mould-buffer empties. Not enough lids, so moulds on bufferlines. Due to slow emptying mould-buffer two sst’s.</td>
<td>3x sst’s, 2x: mould-buffer</td>
</tr>
<tr>
<td>20-11-18’</td>
<td>14.45-15.15</td>
<td>15.00 disruption somewhere Line before Lid placer full Mould-buffer need to empty</td>
<td>5x sst 4x: mould-buffer</td>
</tr>
<tr>
<td>04-12-18’</td>
<td>after 13.30</td>
<td>Lid placer breakdown Line of lids full Moulding machine blocked 4 mould in moulding machine 14 in front of moulding machine Caractere, so moulds not on time later</td>
<td>a lot sst’s</td>
</tr>
<tr>
<td>10-12-18’</td>
<td>8.00-9.15</td>
<td>8.55 demoulder stop Caractere leger at remould Caractere produced, all lines full buffering moulds, later too late</td>
<td>1x sst a lot sst’s</td>
</tr>
<tr>
<td>12-12-18’</td>
<td>after 8.00</td>
<td>L45 after Leli supply slow because of remoulder</td>
<td>a lot sst’s</td>
</tr>
<tr>
<td>18-12-18’</td>
<td>10.30-11.15</td>
<td>After daily cleaning, Leli 10.55 no lids/moulds from cleaning machine 13.30 1327 moulds in system</td>
<td></td>
</tr>
<tr>
<td>19-12-18’</td>
<td>14.40-16.15</td>
<td>14.55 1327 in system 16.00 10 extra moulds lines after HT full</td>
<td></td>
</tr>
<tr>
<td>20-12-18’</td>
<td>15.00-16.45</td>
<td>15.35, test 1292 moulds Delacreme. amount without mould-buffer Disruptions demoulder. TC3. moulds on bufferlines, sst’s 16.30 demoulder stop, stuck cheese, sst</td>
<td></td>
</tr>
<tr>
<td>21-12-18’</td>
<td>13.35-14.35</td>
<td>Caractere test 1297 moulds After 14.30 1318 moulds moulds on bufferlines line of lids full mould-buffer empties, slow</td>
<td></td>
</tr>
<tr>
<td>27-12-18’</td>
<td>11.00-13.45</td>
<td>after daily cleaning already moulds and lids enough, lids out L45, 1322 in system</td>
<td>no sst’s</td>
</tr>
<tr>
<td>Date</td>
<td>Time</td>
<td>Notes</td>
<td></td>
</tr>
<tr>
<td>------------</td>
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<td>----------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>03-01-19'</td>
<td>11.50-14.40</td>
<td>13.18 TC3 stop, blocked Moulding</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cleaning machine stop due to lids</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>13.45 1331 mould in system, Carac, L45</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>43 lids out</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>sst due to lids</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>sst due to space</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>after 14.00 good</td>
<td></td>
</tr>
<tr>
<td>07-01-19'</td>
<td>15.00-15.30</td>
<td>Demoulding stuck and 1307 moulds</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>not enough, also lack of lids</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>moulds at the wrong place to buffer</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>a lot sst’s</td>
<td></td>
</tr>
<tr>
<td>08-01-19'</td>
<td>8.35</td>
<td>1329 moulds, a lot at remoulder</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maasdam</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>a lot sst’s</td>
<td></td>
</tr>
<tr>
<td>10-01-19'</td>
<td>13.30-15.00</td>
<td>1327 moulds in system</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Caractere and Beldammer, good</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>sst’s because of emptying mould-buffer</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2x sst</td>
<td></td>
</tr>
<tr>
<td>11-01-19'</td>
<td>14.45-15.45</td>
<td>14.52 sst, cleaning machine stop, due to lids</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>14.54 next also moulds too late</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>lid placer stuck, line stop, no moulds, sst</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1314 moulds in system, caracter</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>15.13 gap placer, now sst, next also</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>15.20 not enough lids, mould on bufferlines</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>13x sst</td>
<td></td>
</tr>
<tr>
<td>21-01-19'</td>
<td>8.30-9.35</td>
<td>1316 mould in system, L45</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>could more in mould-buffer</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>good</td>
<td></td>
</tr>
<tr>
<td>23-01-19'</td>
<td>8.00-9.33</td>
<td>1322 in system, L45, one bkd</td>
<td></td>
</tr>
<tr>
<td>11.00-11.40</td>
<td></td>
<td>11.18 TC3 stuck, lids full, mould-buffer empties slow, gaps</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>11.33 gap from 11.18 now sst</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1x sst</td>
<td></td>
</tr>
<tr>
<td>24-01-19'</td>
<td>8.30-9.00</td>
<td>1322 moulds in system, L45</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>good</td>
<td></td>
</tr>
<tr>
<td>25-01-19'</td>
<td>8.30-9.30</td>
<td>1322 in system, L45, Demoulding cause a lot sst’s</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>a lot sst’s</td>
<td></td>
</tr>
<tr>
<td>28-01-19'</td>
<td>14.00-14.30</td>
<td>after cleaning, no lids out yet</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>demoulding gives sst</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>therefore, lid placer no moulds, cleaning machine stop</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>14.12 again sst</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2x sst</td>
<td></td>
</tr>
<tr>
<td>30-01-19'</td>
<td>8.00-9.00</td>
<td>L45, 1321 moulds in system</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>01-02-19'</td>
<td>14.50-15.30</td>
<td>1317 moulds in system</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>All inserted 14.15. Before a lot sst’s</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.45 leli cheese out press</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>so, less moulds for production</td>
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<td></td>
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<td>14.50 lids out 49. until 15.30 good</td>
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<td></td>
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<td>10.44-14.21 18 sst’s</td>
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<tr>
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<td></td>
<td>14.21- 1.00 (02-02), 15 sst’s</td>
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<tr>
<td>06-02-19'</td>
<td>8.00-9.00</td>
<td>1317 in system, leli</td>
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<td></td>
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<td>demoulder not good, and TC3, BKD</td>
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<td></td>
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<td>51 lids out, so no extra sst’s</td>
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<td>1x bkd</td>
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Appendix H

Instruction improvement: counter

The counter will be placed after the inserting point of moulds from the attic. External options for the counter are one reset button and a switch between three presets: three different moulding times. The moulding machine operator needs to know which type of cheese will be produced after the daily planned cleaning. When during this cleaning, all moulds are paused in either the presses, the holding tables or the attic, the counter should be reset to zero. Also, the preset (1, 2 or 3) should be set to the right number indicating the cheese type produced after the daily planned cleaning.

After the end of the daily planned cleaning all moulds will pass the counter one time. Even inserted moulds from the attic. When the right number is reached, a signal will warn the operator to stop inserting new moulds. Now, the counter could be turned off. If later that day another type of cheese is produced, moulds should be added or reduced. The operators already need to stick blue print to 'change' cheeses. Hereafter, the operator should balance the number of moulds, taken into account that moulds need to be available at the moulding machine. Balancing between the different types of cheese are fixed numbers of moulds. This balancing should be done each time a type of cheese is changed.

Take into account that this improvement may not be necessary if only one fixed number of moulds and lids in the system is chosen. This may only possible if the transport line before the moulding machine is completely used as a buffer (accumulate). Then, one time all the moulds should be counted and a new mould may only be taken from a storage if one mould is taken out (broken for example).