‘’Production process improvement to reduce Work In Process and increase Delivery Performance’’

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Production process improvement to reduce WIP and increase Delivery Performance.

Thesis Master Business Administration – Track Innovation and Entrepreneurship.

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Preface

This master thesis is written to earn my Master degree in Business Administration, track Innovation and Entrepreneurship. The research was commissioned by and executed at Brinks Metaalbewerking B.V.. This research describes a stepwise bottleneck indication and solving method, executed in a practical case study.

I was not able to write this thesis without the help and guidance of several people and therefore I would like to thank first of all my supervisors, N.J. Pulles and P. Hofmann from the University of Twente for the input, enthusiasm, feedback and helpful meetings and discussions. Second I would like to thank W. Breukelman for the support and guidance at Brinks and also the guidance towards a deeper understanding of the link between the theoretical and practical side of business management issues.

Furthermore, I want to thank my family and friends, especially my girlfriend, sister, brother and parents for their support, advice and the discussions on difficult issues which helped to enlighten the topics.

I greatly enjoyed executing this research at the work floor of Brinks and appreciated the conversations and discussions with operators, team leaders and other personnel. Therefore, I thank the operators in Group 10, all project coordinators, managing board, planning and logistic department and all other personnel of Brinks for the instructive time.

The result of this research is a practical and feasible product which is valuable for Brinks and its employees. Also, several theories on bottleneck indication and solving are tested in this single case study.

Clemens Veldhuis

Vriezenveen, June 25, 2015

Management Summary

This research is executed in order to increase the delivery performance and decrease the work in process at Brinks Metaalbewerking. Brinks Metaalbewerking produces mostly valve units, hydraulic parts and towing bars. These are produced on milling machines and afterwards cleansed, deburred, packaged and expedited towards the customer.

During the preliminary research it became clear that there is one specific department which is related to the excessive work in process levels and the low delivery performance. Products which go through the cleansing, deburring and packaging department (called Group 10) have an average delivery performance of [redacted] instead of [redacted] and these products count for [redacted] of the sales. The preliminary research also showed that the throughput times of products which go through Group 10 are twice the times of the products which do not go through Group 10. It has been shown that this is not due to longer cycle times. Therefore, the focus of the research is on Group 10.

The goal of the research is to improve the production process at Group 10 to decrease work in process and increase the delivery performance. To improve the production process the Theory of Constraints from Goldratt (1986) is used. The bottleneck indication and solving method from Goldratt (1986) is the guideline for this research.

First, the bottleneck is identified using three different bottleneck methods based on; cycle times, queue lengths and workload. Based on these three methods the Cleanroom is considered to be the bottleneck. At the Cleanroom the cleansed and deburred products are visual inspected, restored when needed and packaged for the customer.

Second, the bottleneck is investigated to exploit it in the most efficient way, this is started by describing and measuring the current process at the Cleanroom. The activities are measured, categorized and labeled non-value adding or value adding. Non-value adding processes are considered waste. These types of waste are the basis for exploiting the bottleneck. The goal of this step was to eliminate the waste and thereby improve the capacity of the bottleneck with the current resources. To eliminate the waste within the bottleneck, recommendations are formed which are afterwards presented to and discussed with a board of experts. Implementing the improvement plan can lead to a grow in value added capacity of 49%. With an equal output there is approximately [redacted] per year, based on the labor cost paid for non-value adding activities, available for other value adding activities.

To accomplish the increase in capacity the following recommendations are formulated. The implementations done at time of writing are mentioned as well.

- Implementing pull instead of push in the Cleanroom using visual signs and make sure that no more than one order is send to one lane. This reduces jams, relocating products, searching for products and counting if orders are complete. In addition to implementing the pull system, also an adjustment in determining the order sizes is necessary, because the drop-off lanes have a maximum capacity of five product baskets. To exploit the Cleanroom, and the second bottleneck as efficiently as possible the available baskets need to be filled maximally and therefore the order quantities need to be determined based on the capacity of the baskets.

Implementation: the visual signs are programmed in the current system and the capacity of the lanes is increased towards six baskets.

- Information about the products and the inspection process needs to be delivered with the product. In the current situation the products are identified based on experience and the order ticket and work instructions are collected. In the new situation the order ticket is eliminated and replaced by a waterproof punch card and work instruction are showed on a screen. This makes sure that all information needed is available instantly and the start up time of the process is reduced.

  Implementation: external IT consultants are invited to discuss the possibilities of integrating the plan in the Cleanroom and the entire factory. A request for quotation is done for the database link and installing mobile screens in the Cleanroom.

- The (packaging) materials need to be delivered just in time, instead of being collected by a Cleanroom employee after receiving the products at the Cleanroom. A new function is added to the ERP system which signals were the upcoming orders are placed and therefore the needed packaging materials are visible and can be picked by an operator of a non bottleneck machine in the department. This makes sure that the packaging material is just in time at the right lane in the Cleanroom and therefore the employees of the bottleneck can start inspecting directly when the products arrive. This reduces, combined with the previous mentioned recommendation, the startup time of an order at the Cleanroom.

  Implementation: a screen is mounted at the Piller which shows the lanes, a timer and the upcoming products including the required packaging materials. The Piller operator collects the materials from a new placed pallet rack, which is replenished by the expedition department using Kanban cards. The materials are brought to the correct lane at the Cleanroom just in time by the Piller operator.

- After inspecting the products, random samples need to be carried out on orders inspected by new employees. This will only be done during their training program, afterwards the employees are certificated and there will not be any random samples. To create responsibility and traceability, each packaging needs to be provided with a card which identifies the inspector. This recommendation reduces the time spend on double inspections and improves the efficiency of the packaging process.

  Implementation: the superfluous random samples are abolished and random samples are only executed during a training program of six weeks. Cards with personnel numbers are introduced and added in each packaging material.

- Relocate the restore workstation and implement a conveyer belt or collection point towards the Drent machine. Due to pollution or minor damages some products need to be restored after the inspection. Afterwards the products need to be pickled again in the Drent, using the conveyer belt saves walking time and makes sure that the restored products are directly lead towards the Drent. Relocating the workstation reduces the walking towards this station.

  Implementation: the workstation is going to be relocated towards the empty office in the Cleanroom after the summer holiday and the restored products are placed on a collection point, from which the Piller operator collects the products and bring them towards the pickle baths.

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1. Introduction

Brinks Metaalbewerking is a Dutch company, located in Vriezenveen, which employs around 125 employees with a yearly turnover of approximately €17.000.000,-. Brinks Metaalbewerking mainly produces valve units for divers applications in the automotive and agricultural industry. Brinks states that her core business is Computer Numerical Control (CNC) producing products in large scale (1000 – 100.000 pieces/year). These parts are produced very accurately and precisely (tolerances up to 0,003mm). Furthermore the parts need to be clean and absolutely burr free. Brinks uses waterjet- and thermal deburring to assure high quality. Section 1.1. describes the products and markets of Brinks. Section 1.2. elaborates on the way those products are produced. Section 1.3. describes the problem situation and the motive for this research. The way this problem is handled is described in the methodology, Section 1.4..

1.1. Product and Market

Brinks Metaalbewerking produces several products for the automotive, agricultural, machine building and renewable energy market. These products are complicated to produce and require high-tech CNC machining to be manufactured. Brinks states that handling with extreme complexity and small tolerances can be seen as one of their core competences. That is why companies choose Brinks instead of producing the products their selves or elsewhere. Brinks claims that technology and knowledge are two of their unique selling points. There are products which Brinks produced for many years which are nowadays produced by foreign countries with lower wages, like Poland or China. That is why it is key to keep investing in new technologies and knowledge. That way, Brinks can keep the competitive advantage and to deliver the quality, knowledge and counseling the customers expect

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Figure 1: Products of Brinks with percentage of sales in 2014.

Figure 1 shows the three categories of products which Brinks produces: valve units and hydraulic engine parts, hydraulic cylinders, and detachable towing bars. The biggest category is the valve unit and hydraulic engine parts category, this is one of the specialties of Brinks. A valve unit functions as a dividing point for hydraulic fluid, water or air. This fluid can be used for opening and closing convertible tops from cars or to compensate body roll by pumping hydraulic fluid in shock absorbers during high speed cornering. In the agricultural industry these valve units are used for the controlling of several hydraulic devices like lifters, pumps and cutters. The second category products are hydraulic cylinders, these products require different machining steps on different machines. Brinks sees the demand decreasing, probably because other factories are also capable of producing these products. The third category is the detachable tow bar category. Brinks produces these products for high-class cars like [redacted]

The current market of Brinks can be divided in two main categories: hydraulic systems and automotive. The first category contains organizations which produce hydraulic systems for various applications. The automotive market is a broad market in which Brinks supplies several different types of products. This can be valve units, but also products like detachable towing bars and hydraulic cylinders for hydraulic convertible top systems. Both these markets are highly sensitive for economic fluctuations and they are demanding in terms of quality of the products. The customers of Brinks offer their products to the following smaller submarkets: construction, transport, agriculture, shipbuilding, windmill, solar energy and mobile home. In general, the quality demands for the different products are about the same. However, a small amount of customers ask for extra cleanness tests or are performing these tests themselves. This is more product specific rather than customer specific. The demand of different products fluctuates throughout the year. These fluctuations depend on the type of product rather than the customer. To moderate the fluctuations, Brinks has made arrangements with loyal customers about stock which can be produced with the guarantee that the stock will be purchased. Also, Vendor Management Inventory arrangements are made with three of the largest customers which cover about 25 percent of the total sales. In these cases Brinks produces stock and transports this stock to the customer, however the stock remains on the balance sheet of Brinks until the customer takes the product out of its own warehouses and uses it for production. These arrangements include both a minimum and maximum quantity of stock which needs to be available in the customers' warehouse. Although Brinks has customers worldwide, most customers are located in the Netherlands, Germany, Switzerland and Spain. Around 75 percent of the total production is going abroad.

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Figure 2: Sales and EBIT, based on consolidated financial information.

[redacted]

1.2. Production Processes

This section describes the several production process at Brinks with the help of figures. The machining departments operate in a 24/7 schedule, the deburring and packaging happens in two shifts. Brinks produces both Just In Time and Made to Stock, depending on the type of product and the annual demand. Arrangements are made with customers about the maximum quantity the customers guarantee to purchase. In the past the delivery performance of Brinks has been low, therefore they produce to stock. Brinks also chooses for this because of the demand fluctuations. In times of low demand, they produce to stock to keep a steady production output. If demand is going up, Brinks first sells the stock. All machining steps are kept in-house. Only highly specialized processes like electro galvanizing and anodizing are done by external parties. Figure 3 shows the lay-out of the factory.

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Figure 3: Lay-out of the Factory

For manufacturing the high tech products Brinks uses extensive machinery. This machinery includes lathes, milling machines, honing machines, lapping machines, cleansing machines, a waterjet deburring machine and thermal deburring machines. The lathes and milling machines are located in different production halls in the factory, clustered in production groups. Brinks uses several different types of milling machines, ranging from single spindle machines to four spindle machines. The type of milling machine which is used depends mainly on the type of product and the batch size. The lapping and honing machines are located in a smaller climate controlled production hall. In this climate controlled area Brinks can produce pieces with a tolerance of 0,003 millimeter. This will only be done if the customer needs this kind of small tolerances.

The deburring machines are located in the production facility called group 10. In this group the machined products are being cleansed and deburred. Deburring can be done with water under high pressure or with the thermal deburring machine, which burns the burrs from the work piece with an instant explosion. This thermal deburring is also an important competence of Brinks. After deburring and cleaning the product, it will undergo a last visual inspection. Hereafter, the product will be packed customer specific in the cleanroom. This room is slightly pressurized, which keeps dust or other dirt from entering the room. Appendix 7 till 10 show the most common paths within the factory. Figure 4 shows the most utilized departments in terms of ´´sales gone through´´. The departments are ranged based on number of products expressed in terms of sales which has passed the department. These data is gathered based on 489 different types of products sold in 2014. For each product the processing steps, from raw material to expedition, are indentified. The amounts sold and the selling price combined formed the amount of sales. With these data a database is formed. Figure 4 is composed based on the database.

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Figure 4: Heat vision map Brinks.

Figure 4 shows that more than 90% of sales goes through Group 10, Expedition and Raw Material. These departments have the highest ''go-through-rate'' of the factory. Machining group 8, group 15 and the measuring room have the lowest go-through-rate of sales, respectively 2, 3 and 9 %. This is because group 8 is the prototype group. The prototype group produces test series and other small series. These series are mostly not larger than 100 products. Group 15 has a low go-through-rate, because it is not been used at full capacity, due to the lack of orders. The measuring room also has a low go-through-rate, because they do not measure every single product. The measuring room only measures new orders and orders containing products which fluctuate in quality, due to the quality of raw materials, external processes or external suppliers. Group 2 and 6 combined and Group 4 also have a moderate go-through-rate of sales, both 15% , which is due to the capacity of the machinery in these groups. Group 5 has a relatively high go-through-rate of sales (33%), which is due to the extensive machinery park in this group. Group 3 is less extensive and has a slightly lower rate of 23%. The rate of Group 7 is 13%, this is due to the specific process which is not necessary for every product. The high rates of the expedition and raw material make sense, because the expedition processes every finished product in the factory and 91% of sales are products made out of raw material. The remaining 9% of the sales are assembly or deburring orders from external companies.

All machines of Brinks are scheduled by the planning department, except for the machines in Group 10 and 7. The planning of the milling machines and lathes in the other groups are based on demand forecasts and specific customer orders. The planned production date is based on the machining time and a safety net is calculated for processes done by external suppliers. The required cleansing, deburring, honing and lapping is not taken into account by the planning department. These process steps are controlled by a priority list, which is present at Group 10 and Group 7. This list is automatically composed by the Enterprise Resource Planning (ERP) system and the priorities are based among other things on the due dates of expedition. In theory, the operator picks the next order based on the list. However, the operator also chooses based on WIP at other machines in the group. He wants to make sure that the following workstation has enough work and he keeps track of the previous steps to know which workload he can aspect. The machines in Group 7 are controlled the same way as in Group 10.

1.3. Problem situation

As can be observed at the factory floor of Brinks there is a lot of WIP. At many places in the factory there are pallets stored with products which need another or multiple processing steps before being finished. These stored pallets can hinder the overview in the factory. Figure 5 shows the WIP in the factory. The red, solid crosses are places where WIP is stored for longer time. The bold edged crosses are WIP which is being processed the same day. The size of the cross indicates the amount of value in the particular department. In front of Group 10, there is the highest concentration work in process. The large solid red cross next to Group 10 is also WIP which is waiting to be processed by Group 10. The WIP in the machines groups are the bold edged crosses, they are relatively low compared to the WIP waiting for Group 10. This is because the WIP which is processed by the machining departments is brought almost directly to the WIP storage in front of Group 10. Within the machining groups there is not a lot of WIP, because the raw material is sawed on demand of the machining groups and therefore there is no excessive WIP created by the sawing department.

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Figure 5: WIP hotspots

1.3.1. Defects per Unit

The rejection rate of a product or product line is the number of products which are rejected divided by the number of products which are totally processed times 100, also called Defects Per Unit (DPU) (Slack et al, 2007, p. 567). At Brinks, the rejection rates depend on the type of product, because every product has its own specific machining steps. In Figure 6 the average rejection rate of the whole plant from the time period 2010-2014 is shown.

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Figure 6: DPU 2010-2014, based on data from Microsoft Navision ERP system.

The rejection rate is divided into two different types; rejections based on machining errors or rejections based on defects in the raw material. This distinction is made because rejections can have different origins and with that different solutions. What stands out in Figure 6 is that the rejection rate fluctuates. According to the quality manager the fluctuations are caused by the
defect is reported in the ERP system. This happens not consistently after the defe
the moment the defect is registered, it is visible in the ERP system. It happens t
weeks or even a month old are registered. This causes the fluctuations.

1.3.2. Delivery Performance

The delivery performance of a product is the percentage of how many orders delivered on time compared to the total orders delivered (Slack, Chambers, Johnston; 2007). Measurements for the delivery performance are according to Stewart (1995): delivery-to-request date and delivery-to-commit date. Figure 7 shows the delivery performance, based on delivery-to-commit date, from 2010 till 2014, based on data from the ERP system of Brinks which registers all shipments and link them with the requested and confirmed delivery date. The delivery performance in Figure 7 is based on the confirmed delivery date. This date is communicated with the customer by the planning department.

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Figure 7: Delivery Performance 2010-2014, based on data from Microsoft Navision ERP system.

Figure 7 shows that the delivery performance also fluctuates with considerable margins. Average dependability in 2014 was [redacted] that means [redacted] of all production orders were late. The increase of delivery performance around June 2012 is because Brinks began to produce Make to Stock at that moment. Hence, more orders are delivered directly from stock, instead of being produced to order. This way, the risk of having an error in the production system which could cause a delay became less. As a result, the delivery performance increased substantially.

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Figure 8: Delivery Performance Top 5 customers 2010 -2014

Figure 8 shows the delivery performance of the five largest customers of Brinks, based on annual sales. There is a large difference between the best delivered customer in 2014 [redacted] and the worst [redacted] This difference already exist in 2010, [redacted] had a delivery performance of [redacted] and [redacted] only [redacted] It seems that the delivery performance of the top 5 customers has increased, except for [redacted]This indicates that the delivery performance can depend on the type of customer and product.

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Table 1: Delivery Performance and percentage of sales 2014 of specific department

Table 1 shows the effect of specific departments on the delivery performance. Delivery performances are given both for orders that do not go through a specific department and for orders that do. The three departments shown are the departments with the highest amount of WIP waiting to be processed (see Figure 5). Orders which do not pass Group 10 have an average delivery performance of [redacted] Orders which pass Group 10 have an average delivery performance of [redacted] The average delivery performance for orders that go through the sawing department is [redacted] The percentage for order that do not go through the sawing department is [redacted] Orders that pass the Pre Inspection department somewhere along the way through the factory have a delivery performance of [redacted]orders that do not pass here have an average delivery performance of [redacted] Group 10 has the highest go-through-rate of sales compared to other departments of the factory (see also Figure 4).

1.3.3. Throughput Time

Throughput time is the duration which one product needs to move through the factory (Slack et al., 2007). In this case the throughput time is the time elapsed from cutting the raw material till the moment the order is shipped at expedition. The throughput time at Brinks is retrieved from the ERP system. At every process step, a barcode on the work ticket is scanned, the ERP system tracks all these recordings. Like this, the duration of each process is recorded and throughput time can be calculated by adding up the processing times. The average throughput time in 2014 was 95 hours, considering products which go through internal processes only, the go-through-rate of sales of products going through external processes is only 8%. Based on the delivery performance and the amount of work in process, the following groups may slow down the process: Group 10, Sawing and Pre Inspection. Therefore, the throughput times are expected to be higher if an order needs to go through these three departments. Table 2 shows the average throughput time of the whole process if the order goes through a specific department. Table 2 is based on data of 2014 which contains 8891 orders subjected to in-house production processes.

Table 2: Average Throughput Time 2014

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Table 2 shows that the throughput time is 50% less if an order does not go through Group 10. If an order goes through sawing department this is 35% and for Pre Inspection 28%. This difference is substantial but can explained based on the lead times of the processes. Hence, a relative long lead time results in a relative long throughput time. The lead time is the time elapsed from the start till the end of process. Hence, the lead time is an important indicator to judge the throughput times and therefore the lead times of different processing steps are gathered.

Table 3: Lead Times of process steps.

	Department	AVG Lead Time (m)	AVG Lead Time (h)
Machining	Group 4	332	5,53
	Group 5	282	4,70
	Group 3	328	5,47
	Group 2	222	3,70
	Group 6	326	5,43
	AVG Total	299	4,98
Deburring / Inspection	Group 10	101	1,68
	Pre Insp.	130	2,17

Table 3 shows the lead times of processing steps in different departments. In the machining groups the shown cycle time is the average time of all machines in the specific department. Because the machining processes often only takes places on one single machine. The lead time in Group 10 is the average lead time of the different machines/processes in Group 10. The lead time in the pre inspection department is the average of the cleansing machine (BVL) and the actual pre inspection process executed by inspectors. Based on these lead times the doubling of throughput time of orders gone through Group 10 (see Table 2) is not justified. Because the lead time within Group 10 has an average of 1,68 hours and the average lead time in the machining departments is almost 5 hours. Hence, the extensive throughput times for orders which go through Group 10 cannot be explained by the lead time.

1.3.4. Link between Throughput Time and Delivery Performance.

In the previous section the link between a high throughput time and Group 10 is shown and in Section 1.3.2. the indication is shown that delivery performance for products which go through Group 10 is lower than for products which do not go through Group 10. In this section the link between the throughput time and delivery performance is shown. The data on throughput time and delivery performance is based on the same 8891 orders produced as Table 2. The diagram indicates that orders with a low delivery performance have high throughput times. Orders with a high delivery performance tend to have an low average throughput time. Therefore, a high throughput time can be related to low delivery performance. Figure 9 indicates a relation between delivery performance and throughput time at Brinks. According to the figure the delivery performance decreases if the throughput times increases.

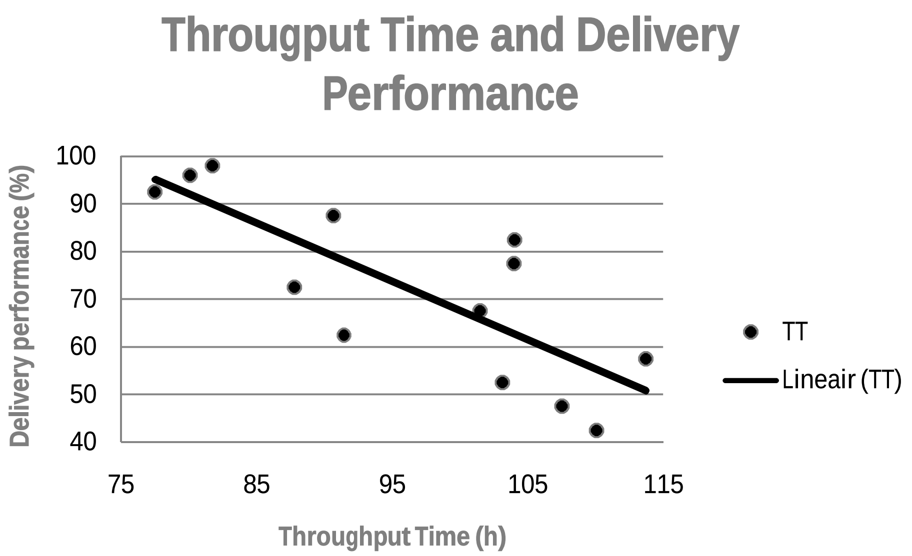

Figure 9: Throughput time and Delivery Performance.

1.3.5. Problem Statement

In the previous sections the following problems become clear: overall delivery performance is low, Brinks is not making a profit, there is excessive WIP on the work floor and rejection rates of products fluctuates. The previous sections indicate that the delivery performance and work in process are linked and that orders with low delivery performance also cope with long throughput times. Therefore the scope of the research will be on the delivery performance, WIP and throughput times. To maintain a clear overview of the research and because the fluctuations can be explained by the frequency of data input, the rejection rate is left out the research scope. The previous sections show that Group 10 is the most utilized department containing the most WIP. There is link found between Group 10 and the low delivery performance. Previous research also indicates a link between low delivery performance and long throughput times. The management of Brinks suspects Group 10 as the bottleneck in the factory, this suspicion seems to be the case based on the info in previous sections. Therefore, the focus of this research will be on Group 10 and the following problem statement is formulated:

''Brinks copes with excessive work in process, low delivery performance and high throughput times which can be related to one production group, Group 10.''

In order to structure this research, the following research question is formulated:

''How can the current production process of Group 10 be improved to decrease WIP and Throughput Times and increase the Delivery Performance?''

In order to answer the research question and structure the research, four sub questions are formed:

1) *''How are Work In Process, Throughput Times and Delivery Performance related at Brinks?''*
2) *''What are the current reasons for the high level of Work In Process and relatively long Lead Times of Group 10?''*
3) *''What can be done to reduce the Work In Process and Throughput Times?''*
4) *''How can the suggested improvements be implemented in the organisation of Brinks?''*

1.4. Methodology

To answer the questions formulated in Section 1.3.3. scientific research is done. The way data is gathered is described in Section 1.4.1. The methods for answering the research questions formulated in Section 1.3.4. are described in Section 1.4.2..

1.4.1. Data gathering

The research uses several methods for gathering information and data; observations, data analysis, qualitative interviews and a literature study. The research will focus on Group 10, as described in Section 1.3. There are three types of sources for information: data from observations, the ERP system and knowledge from the employees. Observations are done on the work floor of Group 10, all handlings are recorded and cycle times are measured. To gather valid data, the observations and timing is done on multiple products in both shifts. For the data analysis, data from the ERP system is analysed. This system contains valuable data on delivery performance, cycle times, throughput times, work in process, process paths and the machining steps. The interviews are held with operators, inspectors, managers, planners and logistics. These informal interviews will take place on the work floor, to obtain valuable information on the production processes. This way, information is gained on the reasons and motivations of (managerial) choices on the work floor. To gather the necessary theoretical background to reflect the findings of the qualitative research, scientific literature is studied.

1.4.2. Methodology

In this section the methods used to analyse the problem are discussed.

To find out how WIP, Throughput Times and DP are related the data on the link between Throughput Times and DP from Section 1.3.4. is used in combination with a theoretical background which is formed in Section 2.3.. The expected link based on the theoretical background and Section 1.3.4. is tested using data from the ERP system and an observation. This observation is executed for three workdays and included active involvement Interviewing is the second method to gain knowledge on the relation between WIP, Throughput Time and DP at Brinks. An informal interview is held with the chief expedition to gain more insight in the reasons for late deliveries and how this can be related to the excessive WIP and therefore high Throughput Times.

The second research question; ''What are the current reasons for the high level of WIP and relatively long Lead Times of Group 10?'' is answered by finding the cause of the WIP at Brinks. The first step is to visualize and measure the production path in Group 10. Therefore, bottleneck indication methods are used, which are further describer in Section 2.2.. These bottleneck indication methods are applied on the production paths of products with a low delivery performance and relative high contribution to the turnover. The to be observed products are chosen based on a delivery performance below or equal to 75% combined with a contribution to turnover of more than €100,000.-, this selection came up with ten products. The following measurements are done on each machine/process for different types of products: up-time en physical amount of WIP in front of the machine. Furthermore the cycle times and lead times of the processing steps in the production path are measured using a stopwatch during the observations. With these measurements it is possible to point out the bottleneck in the organisation. Interviewing is the second method to find the cause for the WIP at Brinks. Interviews are held with the line production manager. With the help of that interview earlier insights can be checked and further information can be gained.

The third research question; ''What can be done to reduce the WIP and Throughput Times'' can be answered by indicating how the capacity of the bottleneck can improved. The bottleneck is indicated in the previous sub research question and turns out to be the Cleanroom, where products are inspected and packaged. Increasing the capacity of the Cleanroom will lead towards a decrease in WIP and Throughput Times. To improve the capacity of the Cleanroom, without increasing costs considerably, a flow of activities, based on the Value Stream Map (Slack, 2007) principle, is constructed to identify the non-value adding movements. VSM is a tool to understand where waste is present in a process, specified for a single product or product family. In the areas where the non-value added movements take place there is the possibility to improve the capacity. The value stream map is based on observing the Cleanroom for three weeks. All activities done by employees in the Cleanroom are recorded and timed with help of a stopwatch during the observations, to reveal the non-value added activities performed by the Cleanroom staff.

The last research question; ''How can the suggested improvements be implemented in the organisation of Brinks'', can be answered using the answers on the previous questions. In this last part of the research the knowledge gathered by observing, studying literature, interviewing people and analysis of the activity flow map is used to point out the areas of improvement within the production process. For implementing these improvements, recommendations will be made. A board of experts is formed to find a technical and financial feasible implementation of the recommendations. This board will be multidisciplinary, containing the following members: production manager, director operations, logistic manager, quality manager, team leader Cleanroom, department supervisor Group 10 and a project coordinator. With this board a meeting is organised, during this meeting a short presentation of the research is held and the recommendations are discussed. The outcome of this meeting will be the basis for a practical implementation plan. After this meeting the initial recommendations with the outcome of the discussion are combined into a practical implementation plan. This plan contains multiple recommendations for which owners are allocated. Afterwards, the recommendations are implemented within Brinks.

2. Theoretical Background

In the following chapter the theoretical background is formed. Section 2.1. will focus on Little's Law and its applications in production processes. Little's Law describes the relation between WIP, cycle time and the throughput. Section 2.2. focuses on the theory of constraints, this theory describes techniques to find the bottleneck of an organisation. The third section, 2.3., focuses on the link between work in process and delivery performance. In Section 2.4. production techniques based on lean manufacturing philosophy are described. Section 2.5. describes methods to construct a value stream map.

2.1. Little's Law

Little's law is a mathematical relationship in queuing systems. It describes the relationship between the average number of items in the queuing system, average waiting time in the system for an item and the average number of items arriving per unit time (Little, 1961). The following relation is stated:

$L = \lambda * W$

L: Average number of items in the queuing system
λ: Average number of items arriving per unit time
W: Average waiting time in the system for an item

Little's law is often used in operations management. For its use in operations management the variables are named different. The underlying reasoning is the same, since a production process has great similarities to a queuing system. The derived version of Little's Law used in operations management is the mathematical relationship between throughput time, work in process and cycle time (Slack et al., 2007). The formula is formulated as follows:

Throughput Time = Work in Process * Cycle Time

Throughput Time; the time elapsed for a unit to move through a process
Work In Process; the number of units within a process waiting to be processed further
Cycle Time; the average time between units of output emerging from a process, also lead time

First the creation of WIP is shown in Figure 11 and further explained.

Figure 11: WIP and Inventory represented schematically

Figure 11 shows WIP and finished goods inventory within a production process. The cycle time (CT) in Stage 1 is one minute, the cycle time in Stage 2 is two minutes. Because the difference in cycle time is one minute, every minute there will be one minute of work waiting to be processed by Stage 2. This work is called work in process. Until Stage 1 shuts down for any reason, the WIP will be compiling. Stage 3 will run out of work because the cycle time is lower than the previous stage (Stage 2), therefore Stage 3 has to wait for Stage 2 to finish a product. At this situation, WIP3 is empty, Stage 3 is wasting production capacity and Stage 2 is the bottleneck in the production line.

Little's Law indicates that when WIP is increasing, the throughput time increases. When the CT increases, the throughput time increases as well. To decrease the throughput time, it is necessary to decrease the amount of WIP and/or the cycle time of the processing step. This law can be used in production processes in which one of the variables is difficult or time consuming to measure. Often two out of three variables can be measured or obtained easily, using the equation the missing variable can be calculated.

Little's law can be helpful for many departments of an organisation, for example for the planning department. According to Slack (2007), in operations management the output of a process is one of the key items. By using Little's Law the throughput time, representing the output of a process, can be calculated easily, which gives insight in the total time needed to produce a product. Based on this calculation the delivery dates can be promised to customers and the production capacity can be evaluated. The equation can be used for an entire production process from raw material till expedition but also for single production steps.

2.2. Theory of Constraints

The theory of constraints (TOC) is a management philosophy introduced by Eliyahu Goldratt in 1984. The goal of TOC is to reach the ultimate goal of a production organisation. According to Goldratt and Cox (1986) the goal of every commercial organisation is to make profit in the present as well as in the future. This goal is interdependent to some variables like: motivated employees, innovativeness, cash flows, return on investment and competitive advantage. To judge the day-to-day impact of the production process Goldratt and Cox (1986) mention the following three measurements:

- Operational Expense
- Throughput
- Inventory

Operational expense is the investment needed to turn raw material (inventory) into throughput (finished products). The throughput consist of the finished products that generate the sales. Inventory is the investment made in products which have the intention to be sold. Hence, the goal of the organisation (making profit in the present as well as in the future) can be reached by the more hands on goal: Increasing throughput while simultaneously reducing both inventory and operating expense. This statement can be used to compare the decisions made on the work floor with the goal of the organisation.

Constraints are issues which keep the organisation from achieving the goal. According to Goldratt and Cox (1986) organisations are networks of process steps which are dependent of each other. Each process event succeeds the previous event. Events could be machining steps, but also administrative processes like releases. Goldratt and Cox (1986) suggest the events in a process can be seen as a chain. In every chain one link is the weakest, this is the constraint. After strengthening the weakest link, another link in the chain will be the weakest. In Figure 11 (Section 2.1.), the constraint is Stage 2, based on the cycle time of the stages. Stage 2 slows the whole process down. If the cycle time in Stage 2 is brought down to 1 minute. The weakest link is not Stage 2 anymore, the next weakest link is than Stage 3. Therefore, solving the constraint relocates the weakest link the process.

Goldratt and Cox (1986) formulate the following five steps to cope with constraints in an organisation:

1. Identify the constraint

2. Determine the most effective means to exploit it

3. Subordinate everything else to the above decision

4. Elevate the constraint

5. If in the previous a constraint is broken, start over. But beware of “inertia”

The first step is to identify the constraint within the process. The constraint is the event in the process which determines the performance of the whole system, the weakest link (bottleneck). The constraint slows the whole process down, usually in a production process this is the machine with the longest cycle time. To find the bottleneck the production process has to be observed. The second step is to determine the most effective means to exploit the constraint. Exploitation of the constraint seeks to achieve the highest rate of throughput possible using the current resources of the organisation. TOC strives for utilizing the current resources more efficient instead of simply adding more capacity, because this would increase the operational expenses. The third step is to subordinate the other process steps, this is because the constraint determines the performance of the whole process. This way, waste due to improving other processes is avoided. The organisation only works on that which it can expect to turn into cash through sales in the near future. The fourth step is to elevate the capacity of the constraint to elevate the throughput of the whole line. This is only done if step 2 and 3 did not increase the capacity of constraint such that the constraint is broken. Elevating the capacity can be done by adding shifts, outsourcing work or investing in new machines. At the fifth step the constraint is broken and the process starts over, to improve the system continuously. While following the five steps, inertia as a constraint has to be avoided.

There are three types of constraints according to Watson, Blackstone & Gardiner (2006):

- Physical
- Market
- Policy

Physical constraints are bottlenecks based on the capacity of the resource. The capacity of the resource is less than the demand. In this case the capacity of the bottleneck needs to be improved to deliver to customers demand. The second form of constraints are the market constraints, in this case the demand from the market is lower than the capacity of the resource. The third form of constraints are policy constraints. Policy constraints are policies which limit the production capacity due to policy, like regulation or the mindset of operators (‘’we have always done it this way’’).

TOC also came up with a planning methodology which takes the bottleneck into account. This methodology is called optimized production technology (OPT). In OPT the bottleneck is the base for the planning. OPT uses the drum-buffer-rope technique (Slack et al., 2007). The bottleneck or constraint is the drum, this drum determine the pace of production. If the bottleneck almost runs out of material to produce, the rope releases material to the first operation at a pace determined by the bottleneck. Buffers are placed in front of the constraint and on other strategic chosen places to overcome lack of raw materials and to protect promised delivery dates. The drum-buffer-rope principle is shown in Figure 12, in which the circles show production processes. The crossed circle is the bottleneck and therefore the drum, which determines the pace of the production.

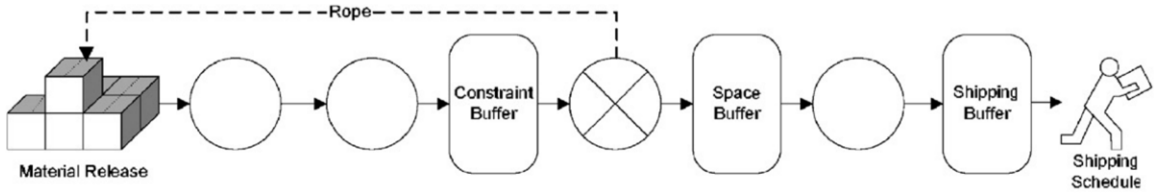

Figure 12: Drum Buffer Rope (Watson et al., 2006, pg 362).

Bottleneck knows multiple definitions, Lawrence and Buss (1995) mention the following different definitions for a bottleneck:

- Congestion points occur in product flowing
- The resource whose capacity is less than the demands placed upon it
- A process that limits throughput; Temporary blockades to increased output
- A facility or operator that impedes production
- Any operation that limits output

These definitions are roughly the same, they all indicate that there is one event which slows down the process. In the overview written by Whang, Zhao & Zeng (2005) several bottleneck indication methods are described. The most common methods are:

- Measuring average waiting time / queue length
- Measuring average workload
- Measuring average cycle times

Bottleneck indication based on average waiting time or the length of queues are based on little's law, which is discussed in Section 2.1.. The machine with the longest queue or the highest waiting time is considered the bottleneck. Applying bottleneck indication based on the average workload needs measurements of the average workload (up-time) of a machine. The machine with the highest average workload is considered the bottleneck. The third method is bottleneck indication based on the average cycle time. The machine with the highest cycle time is considered the bottleneck. TOC does not give a direction in which the bottlenecks can be solved, besides the indication that the production capacity of the constraining event needs to be increased. Increasing the performance of an event with the current resources can be done by reducing waste in the process or to radically change the way of working, called Kaikaku (Bhasin & Burcher, 2006).

2.3. Link Work in Process and Delivery Performance

According to Slack, Chambers and Johnston (2007) work in process (WIP) is the number of units within a process waiting to be processed further. WIP is a type of inventory, this type of inventory is located between raw material and finished goods. The delivery performance of a product is the percentage of how many orders delivered on time compared to the total orders delivered (Slack et al., 2007). Measurements for the delivery performance are according to Stewart (1995): delivery-to-request date and delivery-to-commit date. In practice the delivery performance rates are based on orders delivered on time, rather than single products. Delivery performance should be high, because it is a direct influence on customer satisfaction according to Towill (1997). Stewart (1995) confirmed that delivery performance can be improved by reducing the lead time of an order. Based on the research of Stewart (1995) the following variables influences the delivery performance of a delivery: Lead Time, reliability (machine/human errors causing delays), frequency of output and location of depots/machines (physical location of machines). Reducing lead time is a possibility to improve the delivery performance, doing so the planning can be done with a shorter forecasts and other problems can be prevented, such as lost orders or orders which need rework or repairs due to storage (Elfving, Tommelein & Ballard, 2002). Reliability of the production process also influences the delivery performance, break downs of machines can cause delays of orders. Frequency of output is also determining for delivery performance, large batches can mean a low output frequency, which can delay an order.

Considering Little's Law, throughput can be increased if WIP decreases. Larger lead times lead directly to proportionally larger WIP, as an elementary application of Little's law shows. Hence, the amount of WIP is directly linked with lead time. Long lead times increase the need for long term planning. Also, long lead times are accompanied by more uncertainties, which makes planning harder with are higher change of errors (Karmarkar, 1987). Acknowledging the fact that Stewart (1995) confirmed that delivery performance can be improved by reducing lead time, WIP and delivery performance are linked to each other through lead time. The connection is schematically shown in Figure 13.

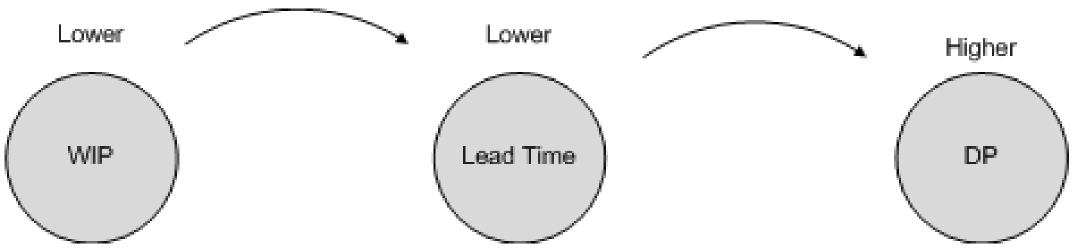

Figure 13: Link between WIP and delivery performance

Based on Section 1.3.3. there is an indication that at Brinks the link between lead times and delivery performance is also present. Considering Little's Law, there should be a relation between the WIP and the delivery performance at Brinks.

2.4. Lean manufacturing

To remove the constraint exposed by using the Theory of Constraint from Section 2.2. several techniques can be used, one of them is the drum-buffer-rope technique explained in Section 2.2.. A technique more focused on the exploitation of the current resources is the lean manufacturing technique. Lean manufacturing is a total management system rather than a list of techniques (Bhasin & Burcher, 2005). Lean manufacturing is based on the Toyota Production System invented by Eiji Toyoda and Taiichi Ohno (Womack and Jones, 1990). The essence of Lean manufacturing is according to Slack et al. (2007, pg 466) ''moving towards the elimination of all waste to develop an operation that is faster, more dependable, produces higher-quality products and services and , above all, operates at low cost''. According to Slack et al. (2007, pg 470) these seven types of waste are:

- Over-production. Producing more than is immediately needed by the next process in the operation is the greatest source of waste according to Toyota.
- Waiting time. Equipment efficiency and labour efficiency are two popular measures which are widely used to measure equipment and labour waiting time, respectively. Less obvious is the amount of waiting time of items, disguised by operates who are kept busy producing WIP which is not needed at the time.
- Transport. Moving items around the operation, together with the double and triple handling of WIP, does not add value. Layout changes which bring processes closer together, improvements in transport methods and workplace organisation can all reduce waste.
- Process. The process itself may be a source of waste. Some operations may exist only because of poor component design or poor maintenance and so could be eliminated.
- Inventory. All inventory should become a target for elimination. However, it is only by tackling the causes of inventory that it can be reduced.
- Motion. An operator may look busy but sometimes no value is being added by the work. Simplification of work is a rich source of reduction in the waste of motion.
- Defectives. Quality waste is often very significant in operations. Total costs of quality are much greater than has traditionally been considered and it is therefore more important to attack the causes of such costs.

To achieve reduction of waste, Lean developed several techniques which can be implemented in the production process. There are several lean techniques with their own field of application, but all techniques have the same goal; reducing waste. Bhasin and Burcher (2005) mention the following lean techniques:

- Kaizen: Kaizen is Japanese for continue improvement. In a lean organisation it is important to continue pursue improvement of quality, costs, delivery and design to reduce waste. This improvement is done at every level in the factory, both managerial and on the work floor (Slack et al., 2007). ''Kaizen epitomizes the mobilization of the workforce, providing the main channel for employees to contribute to their company's development.'' (Brunet & New, 2003, pg 1427)
- Cellular manufacturing*:* Manufacturing cellular instead of in lines helps reducing waste like transportation, waiting and process time. Cellular manufacturing usually works best in U-shapes. According to the research of Miltenburg (2000) lead time, WIP and defects are decreasing using u-shaped manufacturing cells.
- Kanban: In a Kanban controlled system, ''a stage is authorized to start working on a new part only when a production authorization card, called Kanban in Japanese, is available. A Kanban becomes available only when a finished part of the stage is transferred to the next or downstream stage. When a Kanban becomes available, it both transmits a demand for and authorizes the production of a new part. The advantage of this mechanism is that the number of parts in every stage is limited by the number of Kanbans of that stage. Its disadvantage is that the system may not respond instantly to demand.'' (Dallery & Liberopoulos, 2000, pg 370)
- Single piece flow*:* ''The one-piece flow principle means that single parts are transferred between different operations instead of complete lots. This enables short throughput times and therefore a quick response to changing market requirements.'' (Nyhuis & Vogel, 2005, pg 286)

- Single Minute Exchange of Dies (SMED): To reduce the lead-time and improve flow it is necessary to eliminate delays on change over times on machines (Slack et al., 2007, pg 477). SMED is a four-step method for reducing these set-up times.
- 5 S model: Sort, Straighten, Shine, Standardize and Sustain. Sort: eliminate what is not needed and keep what is needed. Straighten: position things in such a way that they can be easily reached whenever they are needed. Shine; keep things clean and tidy; no refuse or dirt in the work area. Standardize: maintain cleanliness and order- perpetual neatness. Sustain: develop a commitment and pride in keeping to standards (Slack et al, 2007, pg 470).
- Jidoka: Jidoka is a quality control method, in which every employee has the authority to stop the production line if the employee thinks it is necessary. Situations where Jidoka is used can be: a quality problem occurs; a machine problem occurs or processing is completed. (Miltenburg, 2007)

2.5. Value Stream Mapping.

Value stream mapping is a method to understand and visualize the flow of information and products within a process (Slack, 2007). In a Value Stream Map (VSM) the distinction between value adding (VA) processes and non-value adding (NVA) processes is made. With help of the VSM waste can be recognized, NVA processes can be seen as waste. The value stream map shows the amount of time spend VA and NVA and the areas were this occurs. Identifying the areas were NVA work is conducted is helpful in improving the efficiency in these areas. Value stream mapping consist of four steps:

1) Identifying the value stream within the process
2) Physically map the process
3) Diagnosing problems and suggest changes
4) Implement the changes

First two steps form the ''Current State Map'', the current state map described the current situation. In the current state map all process steps are visible, including the supporting documents or services. In the current state map the distinction between VA and NVA can be made visible. Step three is the ''Future State Map'', the purpose of this map is eliminate the NVA process steps of the current state map.

Creating the current state map can be done with the help of seven different tools according to Hines and Rich (1997), they state that a combination of tools is the best way to construct a value stream map. The following tools are explained by Hines and Rich (1997):

Process activity mapping: has its origins in industrial engineering and focuses on removing waste on the workplace and provide high quality goods and services easily and inexpensive. The five stages of process activity mapping are

1) The study of the flow of processes
2) The identification of waste
3) A consideration of whether the process can be rearranged in a more efficient sequence
4) A consideration of a better flow pattern, involving different flow layout or transport routing
5) A consideration of whether everything that is being done at each stage is really necessary and what would happen in superfluous tasks were removed.

Supply chain response matrix: has its origins in the time compression and logistics. This mapping approach seeks to portray in a simple diagram the critical lead-time constraints for a particular process. The supply chain response matrix is often used for logistic processes and lead time management.

Production variety funnel: This method is based on the degree of product variation of organisation. The method is similar to the IVAT model. The IVAT model classifies types of organisations based on the product variety. I-shaped organisations focuses on producing multiple identical items with a low variety in raw materials, such as a chemical plant. V-shaped organisations have low variety in raw material combined with a high variety of products produced. This is a typical shape for metal fabrication organisations. A-shaped organisations is the contrary of the V-shaped organisations, they have a high variety in raw material and only a couple different products. This is typical for major assembly plants, for instance an aircraft manufacturer. T-plants have a wide combination of products from a restricted number of components made into semi-processed parts held ready for a wide range of final versions. This is typical in electronics and household appliance industries. With the help of these classifications the way how the firm works and the way the supply chain operates is made visible. This approach can be helpful in deciding in which part of the process inventory should be reduced to be most effective.

Quality filter mapping: This method is focused on the quality issues within a multi-tier supply chain. Quality filter mapping operates with three variables; product defects, service defect and internal scrap. Product defects are quality issues which are not intercepted during the production process or at the end-of-line inspections and therefore are passed on to the customer. Service defects are defects which are not directly linked to the goods themselves, for instance late deliveries or deliveries with the wrong documentation. Internal scrap are faulty products produced and are noted during the production process or at the end-of-line inspection. Using the quality filter mapping method these defects are recorded and mapped along the supply chain. With the help of this map areas with defects can be identified, these areas can be used for improvement activities.

Demand amplification mapping: This method focuses on information and material flow within production processes and is based on the ''law of industrial dynamics''; ''if demand is transmitted along a series of inventories using stock control ordering, then the amplification of demand variation will increase with each transfer''(Burbidge, 1984). This results often in excess inventory, production, labour and capacity, which are all types of waste. Using the demand amplification mapping method, which sets out the actual demand and the orders placed, the ordering system can be improved. For instance by splitting up orders in necessary basic orders and exceptional orders.

Decision point analysis: This method is of particular use for T-shaped plants (see production variety funnel method). This method focuses on the decision point at which goods are produced. Gaining an understanding of where this decision point lies is useful to determine the strategy (push or pull), also several ''what if'' scenarios can be designed to improve the design of the value stream itself.

Physical structure mapping: This method is concerned with two types of visualizing the supply chain, based on number of firms involved and based on costs firms are adding. Based on these two types of visualization, the areas with the most added costs are visible and this can be compared with the added value this area delivers.

3. Bottleneck Identification

This chapter describes the analysis of the deburring, cleansing and packaging department of Brinks, called Group 10. In Section 3.2. the production processes in Group 10 are described. The chapter starts in Section 3.1. by explaining the issues described in Chapter 1 using the theoretical background formed at Chapter 2.

3.1. Analysis using the theoretical background

To explain the issues of Group 10 found in Chapter 1, the excessive WIP, relative long throughput times and low delivery performance are described and explained using the theoretical concepts described in Chapter 2. WIP is generated by production process which is not balanced. In balanced production process the cycle times of the machines are equal. This creates a continuous flow of products through the production process. WIP is created in front of the machine with the lowest cycle time, called the bottleneck, this machine cannot process the amount of products supplied by the previous machine in the chain. The products waiting to be processed by the bottleneck are called WIP. Hence, WIP is created by a bottleneck in the production process. Long throughput times are related to the WIP in a production system. According to Little´s Law, the throughput time of production process is related to the amount of WIP. The throughput time is the time elapsed for a product to move through the process. If WIP is absent, the throughput time is equal to the cycle times added with time for transport between the workstations. With the presence of WIP, the throughput time is the cycle time added to the transport time and the time in which the product is waiting to be processed further. Hence, if WIP increases the throughput times increases. The delivery performance is also related to the throughput time. A decrease in the throughput time is likely to cause an increase in the delivery performance. Hence, the mentioned issues are all related to each other and can be solved by improving one variable. For instance, decreasing the WIP leads to a decrease in the throughput time which in its turn is likely to improve the delivery performance.

3.2. Production Process in Group 10

Group 10 is a production group which clusters several different machines and work stations for deburring, cleaning, inspecting and packaging of products. The group controller is the floor manager of the group. He determines in which order the production orders are handled. This order is based on an Enterprise Resource Planning System, which gives the production orders a certain priority. It is possible that multiple, usually around five or six, items have the same priority. In this case the operator chooses based on WIP in previous and following producing steps. He wants to make sure that the following workgroups have enough work and he keeps track of the previous steps to know which workload he can aspect. The following machines and work stations are present in group 10:

- ''Durr''; this is a large degrease machine. This machine will degrease products which come from ''Group 7", this is the honing and lapping group. In these processes they use a special kind of oil which is being removed by the Durr machine. If the product is being degreased it will be transported by conveyer belt to the cleanroom.
- ''Piller''; this is a CNC deburring machine which uses a waterjet to deburr products. The products are being placed in the mold by a robot. This robot picks the product from a pallet, fits the product in the machine and the deburring process will start. The robot can only pick the products if the products are on a specific pallet in a specific order, therefore they have to be repacked. After being deburred, the product is taken out by the robot and placed in the drying machine. After the product is dried, the robot picks it up again and places it on a

pallet. If the pallet is full, the operator takes the pallet out of the cage and now the pallet is being covered, packed and made ready for shipment.

- ''MTM''; this is a cleansing machine. The products are loaded on the conveyer belt by hand or by crane, depending on the weight. The products are cleansed in the machine and then lead to a conveyer belt leading to the thermal deburring machines. At these conveyer belts the products are sorted based on the material type of the product, aluminum or steel.
- ''TEM''; This is the thermal deburring machine. Brinks has two of these thermal deburring machines. In this machine a product is being deburred by a short explosion under high pressure, all the burrs which are left after being cleansed are burned. To deburr the products they have to be packed on the TEM machine into molds or heavy duty round baskets. The type of mold depends on the type of product which needs to be deburred and needs to be changed if another type of product needs deburring. The TEM machine has five places were a mold with products can be placed, these five places are located on a rotating platform. The operator lets the platform turn and deburrs the products. If one product is ready, the product will be taken out of the TEM and put in a basket. Subsequently, a new product will be put back on the rotating platform to be deburred. If the basket with finished products is full, it will be send off into the Drent.
- ''Drent''; the Drent contains two lineups of several pickle baths were the thermal deburred products will be dipped into anti-corrosion fluids and preservatives. The operator of the TEM machine will launch the baskets with products into the machine. A moving crane above the different baths picks up the basket and dips the basket in the bath. It depends on the type of product which baths the product will be dipped in, this selection is done by the operator of the TEM machine. The operator also chooses the exit conveyer belt for the basket. This depends on which type of inspection and packaging the product needs.
- ''Clean Room"; this is a work station which is under constant air pressure, to make sure no dirt or dust is coming in. In this room the products are undergoing a visual inspection and are packed. In the cleanroom there are eight conveyer belts, six of them have an inspection plateau. The products are being transported on the conveyer belts onto the inspection plateau, here the inspector visually inspects the products. After the inspection, the approved products are at random inspected by another inspector. The rejected products are tried to restore manually, if this succeeds, the products are brought back to the pickle baths. Because during the restoring the product can collect dust or pollution. If the repair work on the product fails, it will be stored at the final rejections and they are thrown away.

Semi finished products machined by other groups follow several paths within group 10. This depends on which machining steps they have been subjected to, the material of which the product is made or the finish the product already has. For example; some cast products are supplied with a color coating. When this product is processed by the thermal deburring machine, the coating will be burned too. In this case these specific products will be deburred with use of the Piller machine, the waterjet. The most chosen paths are shown in Figure 14.

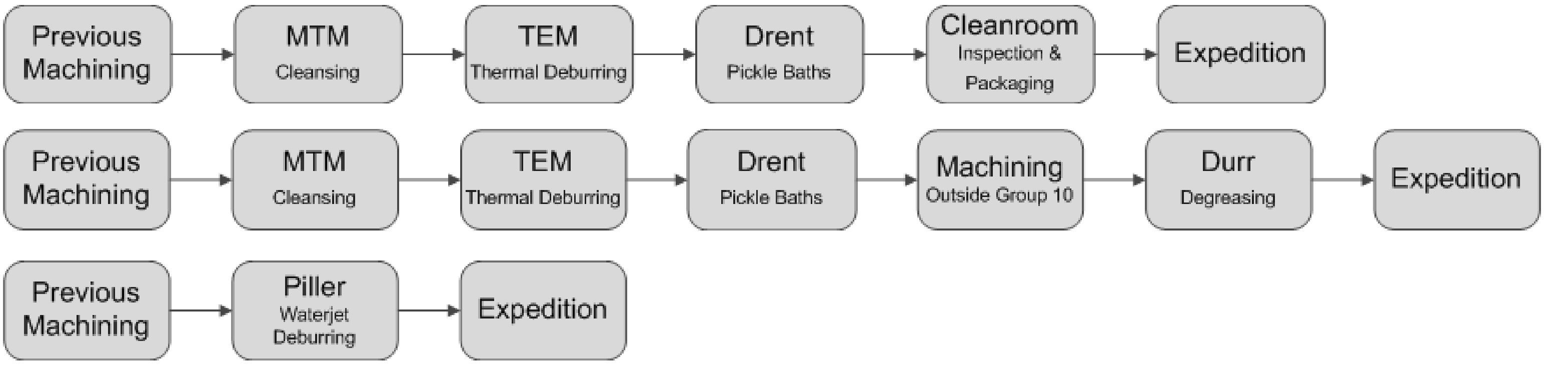

Figure 14: Different paths within Group 10.

In Appendix 1 till 6 the specific flowcharts of the different activities within group 10 can be found. Figure 15, on the next page, shows the lay-out of group 10. The different processing steps are connected by conveyer belts. The conveyer belts take care of all the logistic handlings in group 10 once the product is through the first machine. Products that need deburring are delivered by forklift trucks from the other production groups in the factory. Figure 15 shows that there are three operators within the group, excluding the Cleanroom. The Cleanroom is staffed with three operators as well, who execute the visual inspection and packaging of products. Logistics deliver pallets with raw material, these products are taken out and placed into baskets. These baskets fit the MTM (cleansing machine) and the Drent (pickle baths). Each of these baskets need to be covered, otherwise the products fall out the baskets while being cleansed or pickled. The thermal deburring machines do not accept the baskets, here the products are taken out manually and placed in a product specific mold. After the thermal deburring step the products are packed in the baskets again to be pickled in the Drent. In the Cleanroom the products are taken out and the operators do a final visual inspection and package the products. The packed products are picked by the logistic department and moved to the central finished goods inventory.

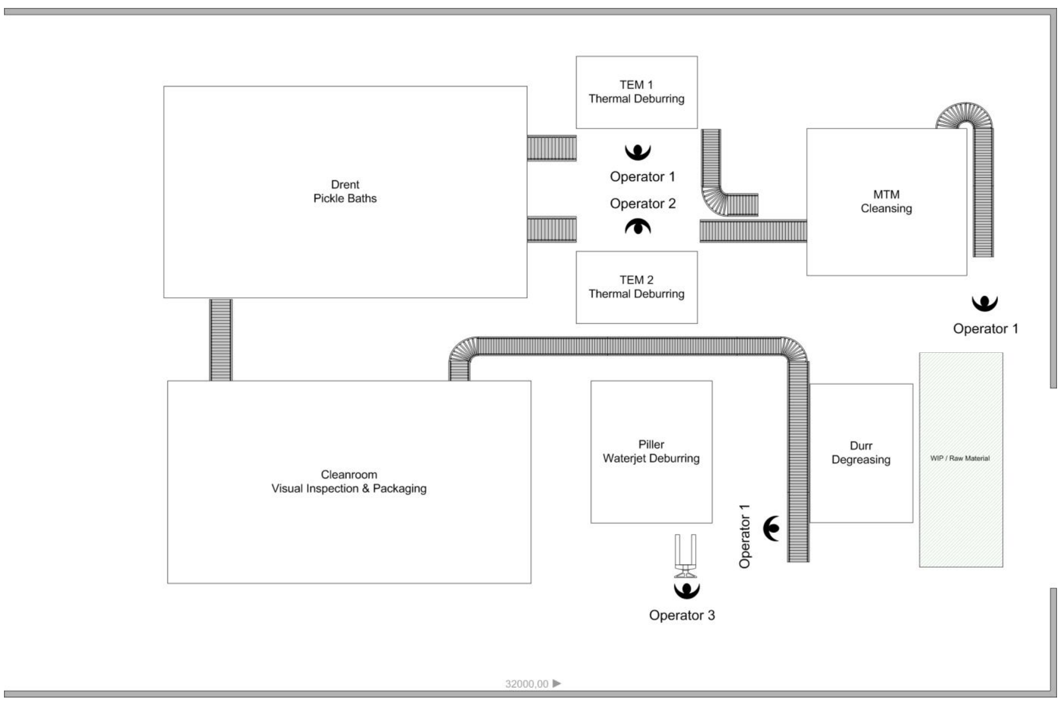

Figure 15: Map of Group 10

3.3. Link between WIP and delivery performance at Brinks

The theoretical link between WIP and delivery performance is described in Section 1.4.2.. High level of WIP increases the throughput times which in its turn decreases the delivery performance. This link is visible at Brinks by the relation between high throughput times and the low delivery performance, as found in Section 1.3.4.. During the three-day observation in Group 10 several reasons for orders delivered late are revealed; a first reason is that not enough products pass the visual inspection, therefore another batch needs to be inspected to complete the order. Often this batch is already produced but needs to undergo the cleansing and deburring process of Group 10, sometimes the product needs to be produced completely from raw material at the milling machines. Another reason is that a start-up product was produced in the machining groups and afterwards stood still for a few weeks in front of Group 10. When being processed in Group 10, an issue with residues of burrs in the thermal deburring machine occurred. These residues had to be removed and the surface restored, for this process the project coordinator was counseled, because of the rework and the counseling the product was not shipped in time. These are two examples which came up during the observation, the expectation is that there are several other reasons. Because these reasons are not stored in the ERP system an interview is held with the chief of expedition to gain more insights in the reasons for late deliveries. The chief expedition is responsible for the on time delivery for every order and during the observation it showed that if a product is expected to be late he tracks down the product in the factory and asks for clarification. During the interview with the Chief Expedition it came up that he could not pinpoint a single cause for the low delivery performance, however he stated that the products are usual still being processed in production. Therefore the focus will be on reducing the WIP in the production process.

3.4. Current reasons for the WIP at Group 10

In the following section the causes of WIP at Brinks are discussed. As discussed in Section 1.4.3. WIP is caused by a misalignment in the production process. Differences in cycle times causes batches of products which are waiting to be processed further, these batches are WIP. To indicate the cause of the WIP in group 10 there are ten products observed while being processed. During this observation the cycle times are measured and the workload of the machines is tracked to determine the bottleneck of group 10. Determining the bottleneck is the first step of the constraints solving Theory Of Constraints. To determine the bottleneck three types of bottleneck indication methods are used: measuring average cycle times, measuring average waiting time and queue length and measuring average workload. Table 4 shows the products chosen for observation based on the turnover and delivery performance. This selection based on delivery performance is made because of the suspected link between Group 10 being the bottleneck and the low delivery performance. The selection based on the yearly turnover is done to eliminate prototypes and small series and therefore the selection focuses on the daily activities of Brinks. The chosen products have delivery performance rates below or equal to 75% and a turnover of over €100.000,-. The combined sales of the observed products equals [redacted] of total sales. Ten products meet this selection criteria.

Table 4: Observation selection

Table removed for competitive considerations

Machining these products is done in group 2, 3, 4, 5 or 6 and afterwards the products are brought together at group 10 for deburring and packaging. The chosen observation selection tends to follow the same path; MTM – TEM – Drent – Cleanroom. Because the products with a low delivery performance, which represent [redacted] of total annual sales. Products with a DP below or equal to 75% which are processed by the Piller and Dürr are when added together only [redacted] of total annual sales. Therefore the Piller and Dürr are left out of the research scope. Within the above explained main path three different paths are distinguished, 1A, 1B and 2. These paths are visible in Figure 16. The first step of the main path is divided in two types: 1A and 1B. 1A is the path followed by products made out of steel and 1B for aluminum products. The difference between 1A and 1B is the program of the machines and the TEM machines. An aluminum product undergoes a specific cleansing program in the MTM, will go through TEM2 and is lead to the pickle baths for aluminum. The TEM machines cannot process aluminum and steel alternately, because steel products leave pollution in the TEM which can damage the aluminum parts. To process aluminum in the ''steel-TEM'' the machine needs to be cleaned thoroughly. Hence, the programs for cleansing and pickling steel and aluminum are different. Moreover, the cycle times of the processes are different. The cycle time for aluminum in the pickle baths is shorter than the cycle time for steel products. Path 2 is equal for every product within the observation selection, the products are lead from the pickle baths to the cleanroom. In the cleanroom the cycle times are not only depending on the type of material, but also the type of product. At the cleanroom the visual inspection checks products on scratches, burrs, contaminations and other damages. Some products are inspected more thorough, based on work instructions. These work instructions are product specific and contain information on how to inspect critical aspects of the products, for instance the presence of certain holes or engraving. Steel is inspected less preciously than aluminum, because the standards are less strict. Inspecting steel products is usually done by an operator of Group 10, which often simultaneously operate the Piller and Durr machine. Hence, in the Cleanroom only aluminum products are visually inspected by the cleanroom staff.

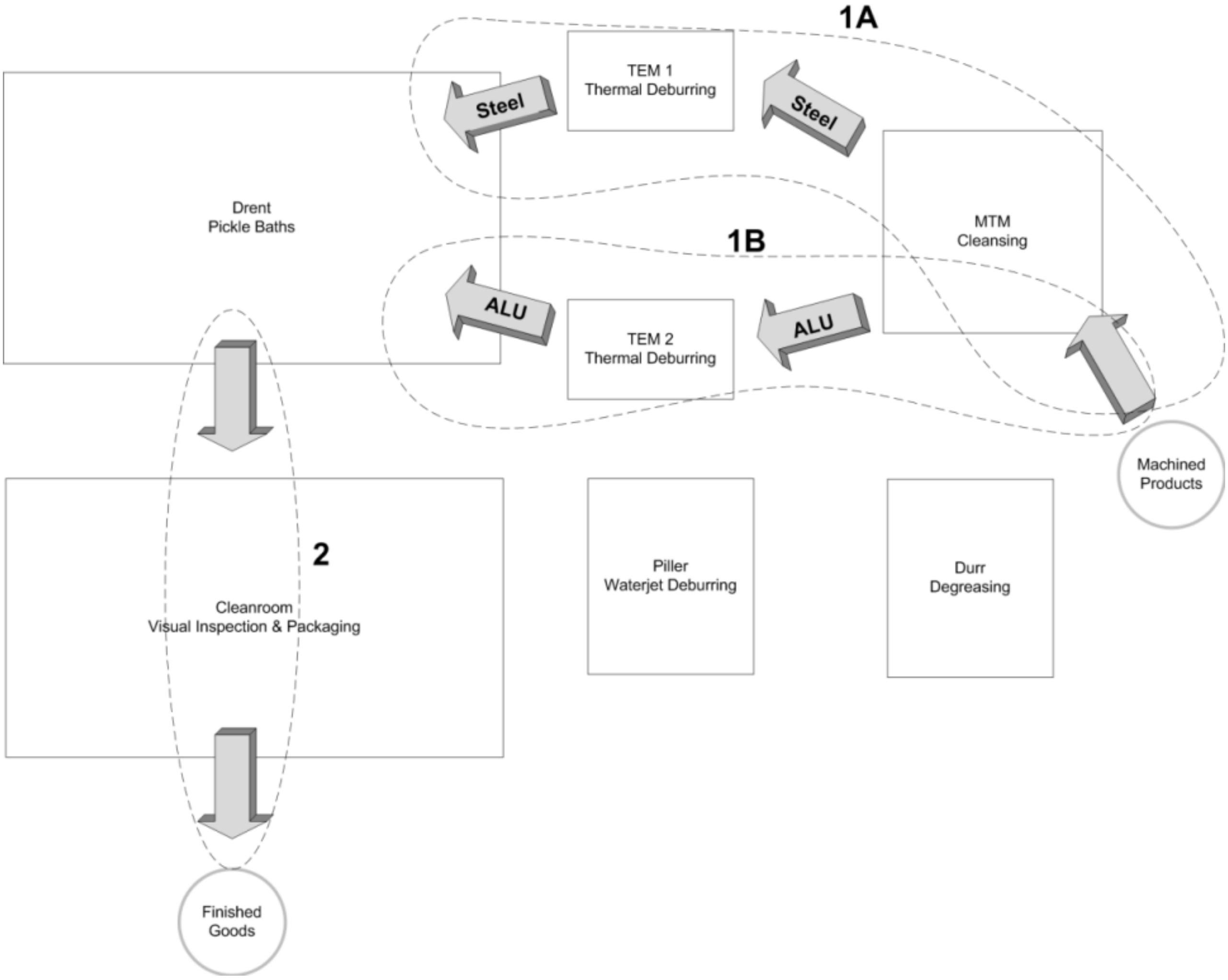

Figure 16: Flow of the observed products in group 10.

To determine the bottleneck of the machines within group 10 three bottleneck indication methods are used, based on Whang, Zhao & Zeng (2005). These methods use their own measuring variables, which are shown in Table 5.

Table 5. Bottleneck indication methods

Bottleneck indication method:	Variable:
1) Measuring cycle times	Cycle Time
2) Measuring average queue length	# Minutes WIP
3) Measuring average workload	% Active Time

The first method is based on the cycle times of the machine, the time that the machine or process can handle one product. The machine with the highest cycle time is considered to be the bottleneck. The second method focuses on the average length of the queue in front of machines. The longest queue indicates the bottleneck, because this machine apparently cannot keep up with the feed from the previous machines. The third method focuses on the up-time of the machines, the machine in the path with the highest up-time is considered to be the bottleneck, because other machines can handle the same amount of products in less time.

3.4.1. Cycle Times

The first bottleneck indication method is based on the individual cycle times of the workstations and machines in Group 10. The cycle times of ten products in the observation selection are measured being processed in Group 10. The cycle times are measured at the work floor with a stopwatch. The cycle time is the time elapsed to process one product. Products are often processed in baskets or molds, therefore the cycle time of the processed basket or mold is divided by the number of products in the basket or mold. The batch size varies from one per mold (TEM) till 80 per basket (MTM and Drent). The machine with the highest cycle time is considered to be the bottleneck. The cycle times of the machines and workstations which process the ten products from the observation selection are measured, these machines and workstations are; MTM, TEM (both), Drent (both lines) and the Cleanroom. A single order is processed by a single machine, even if there are multiple machines. For instance the TEM; Brinks has two TEM machines, but in practice there is no moment that both TEM machines process the same order or even the same type of product, see Figure 16. This also applies for the Drent. At the Cleanroom an order is handled by one employee, only a check based on a random sample is executed by a different Cleanroom employee. Although this indicates that the production is a linear process, group 10 handles multiple orders of different products with different flows (see Figure 16). Hence, the measured cycle times per product need to be corrected with the available to use the cycle times as comparison for the workstations. If these cycle times are not corrected this will imply that Group 10 is a linear production process, which is incorrect. Therefore, to get a clear overview of Group 10 the measured cycle times are corrected based on the capacity of each machine or workstation. The correction factors are shown in Table 6 and elaborated on in the subsection measurement methods below Table 6.

Table 6: Correction Factors for Cycle Times

Machine	Capacity	Correction Factor
MTM	1 Machine	1
TEM	2 Machines	2
Drent	2 Lines	2
Cleanroom	3 Employees, 1 in charge	2,5

Measurement methods:

Brinks has one MTM machine, therefore the cycle times measured on the MTM machine do not have to be corrected. Brinks has two TEM machines, which can work simultaneously on different orders. They cannot work on the same orders because there are not enough molds available for two machines. In Group 10 they often process multiple different orders, although both machines never produce the same products, so the theoretical capacity of the TEM machines is twice the capacity of a single machine. Therefore, the measured cycle times for the TEM machines are corrected with the factor 2. This also applies for the Drent, in practice both Drent lines do not process the same orders, but they can process simultaneously and therefore the theoretical capacity of the Drent lines is twice the capacity of one line. Hence, the cycle times measured at the Drent are corrected based on the capacity with factor 2. The Cleanroom consist of eight different conveyer belts, on these conveyer belts baskets with products arrives from the Drent and the Durr. The Cleanroom operates in two shifts, both shifts consist of usually three employees, with some exceptions. At the Cleanroom there is no distinction in the tasks, every employee can work on the whole product range of Brinks. The only exception is the team leader, she executes visual inspections and rework but also takes random tests and divides work among the rest of the team. According to both team leaders they spent 50% of their time instructing, dividing work or taking random samples. Taking into account the team leader and the presence of three employees the correction factor for the Cleanroom is determined at 2,5. The results of the research on cycle times are shown in Figure 17.

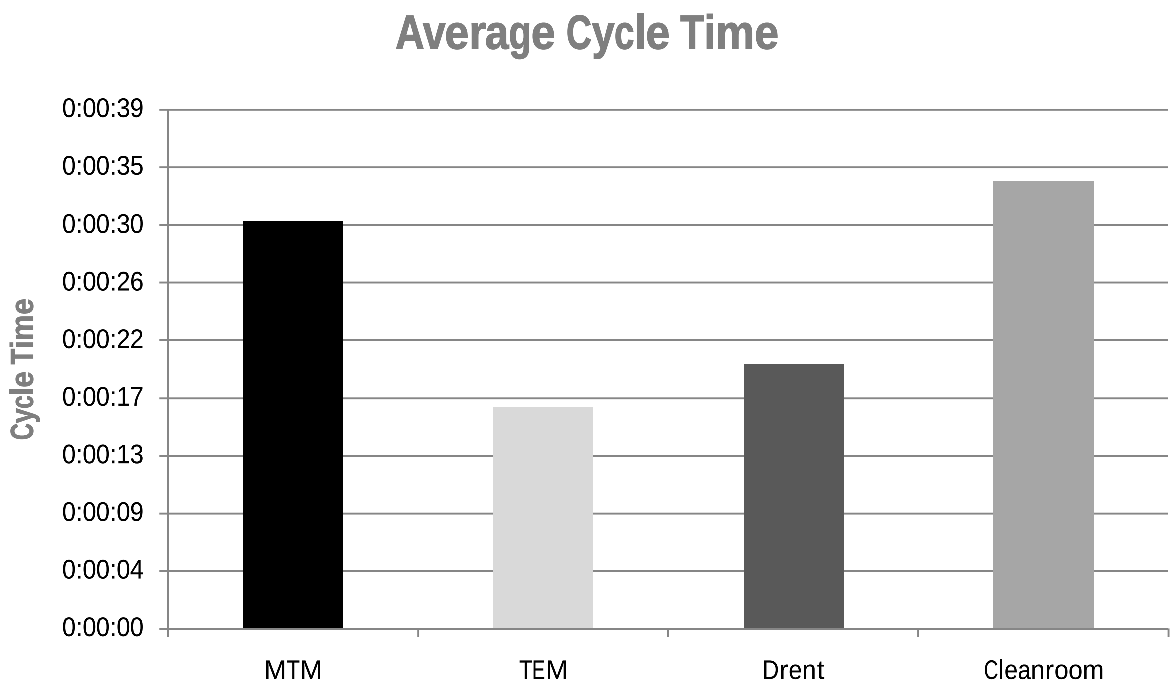

Figure 17: Average Cycle Time per Product in Group 10.

Figure 17 indicates that the Cleanroom is the bottleneck based on the average cycle time of 34 seconds, the MTM machine is a close second with an average cycle time of 30 seconds per product. The TEM and Drent machines have lower cycle times of respectively 17 and 20 seconds. Therefore, based on the observation with use of the cycle time based bottleneck indication method, the Cleanroom is the bottleneck in the process.

3.4.2. Average queue length

The second bottleneck indication method is based on the average queue length in front of the workstations and machines. The longest queue in front of a machine indicates the bottleneck in the process. The average queue length is recorded every working day (Monday till Friday) at 11:00 AM from 19-01-2015 till 03-04-2015. The queue lengths at the machines in group 10: MTM Machine, TEM, Drent and the Cleanroom are recorded. The queue lengths of the Cleanroom, TEM and Drent are compared to determine a bottleneck. The MTM machine is left out in the research because it is the first machine in the production path. Hence, the WIP in front of the MTM machine is seen as raw material inventory for Group 10 instead of WIP specific for the MTM machine. According to the interview held with the production manager at Brinks, not all products in front of Group 10 are being processed in the near future. These products are stored in front of the MTM machine and is also visible as such in the ERP system. Most of the products are produced based on forecasts from customers and Brinks to create value on the inventory and the balance sheet. The first reason for storage in front of group 10 is that processing in group 10 is the most expensive process of Brinks, due to power consumption, gas consumption and because the process is labor-intensive. Storing the semi-finished products in group 10 postpones these costs. The second reason for storing these products in front of the MTM is that milling the products adds more value to the product than the cleansing, deburring, inspecting and packaging department. Therefore, the MTM machine is excluded from the bottleneck indication method based on the average queue length. The queue length is represented by the number of hours WIP. This is based on the number of orders, products and the cycle time of the products. The number of minutes of WIP is based on the cycle times of the machines, measured in Section 3.4.1.. The queue data is gathered from the ERP system, in this system the WIP in front of every machine is shown. Orders are booked in the ERP system at every process step, if the order is booked out, the order is visible as WIP in front of the subsequent workstation The ERP system tracks the WIP individually for the Cleanroom but combines the WIP for both TEM machines and both Drent lines. In this chapter data of the Cleanroom and TEM and Drent combined is gathered and the results are shown in Figure 18 and 19. The number of hours WIP is based on the type of product and its cycle time. At the Cleanroom for every order there is five minutes time added to the WIP for scanning working tickets and collecting package material. This is done to give a clear representation of the reality. At the TEM/Drent for every order ten minutes is added for scanning working tickets and changing the molds of the TEM machine. Figure 18 and 19 shows the average WIP and the measured WIP at the Cleanroom and the TEM and Drent.

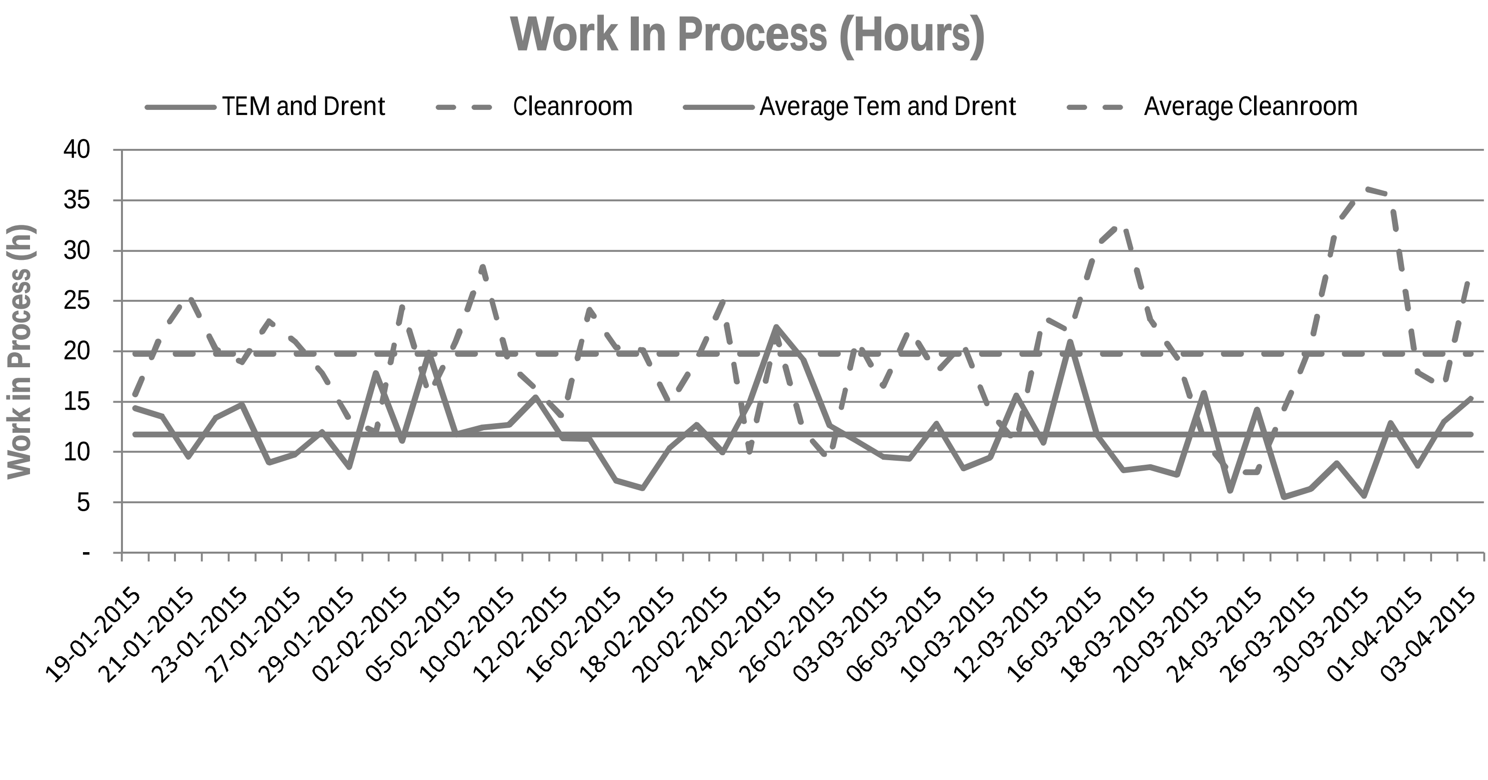

Figure 18: Work in Process (Hours) Cleanroom and TEM/Drent

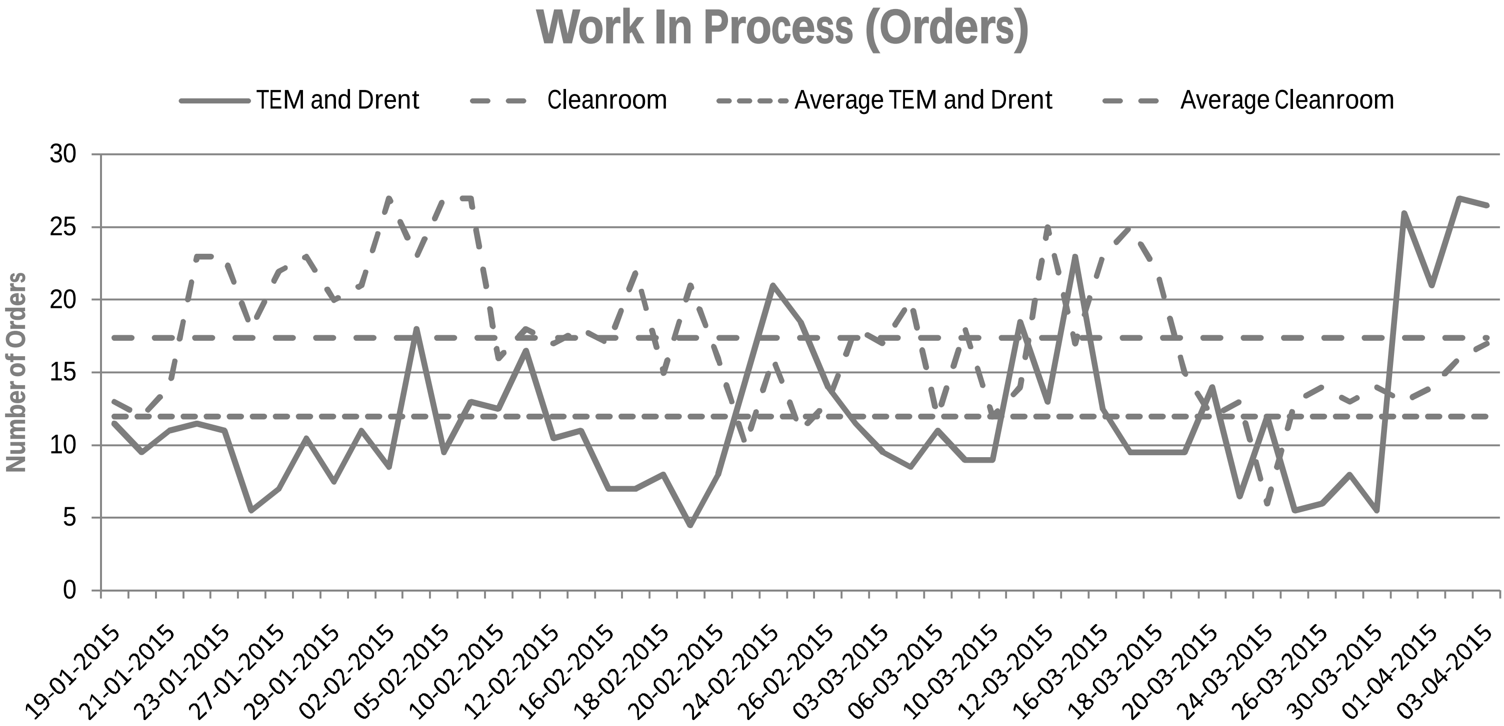

Figure 19: Work in Process (Orders) Cleanroom and TEM/Drent

Based on the average queue lengths as shown in Figure 18 and 19, the Cleanroom can be considered the bottleneck.

3.4.3. Workload

The third method concerning indicating the constraint is based on the workload of the workstations and machines. The workload is here defined as the difference between the active time and the available time, expressed in a percentage. The workload of the machines is measured by the machines themselves. The Drent is provided with an extensive counting mechanism which tracks the number of active minutes and baskets gone through. The MTM is provided with a less extensive system which only keeps track of the number of baskets gone through, the clock on the machine counts the time the machine is active, including idle time and standby time, which in practice is 24 hours a day. The thermal deburring machine does not have an operating hour clock, this machine is equipped with a counter that counts the number of shots fired, which is used to calculate the active time. The difference in active time relative to the maximum available time is the detrimental factor. To gain data on the active times, all clocks are reset Monday 16-03-2015 at 12:00 AM and data of every machine is retrieved every working day at 12:00 AM, until 03-04-2015. This period equals three working weeks and is identical to the observation period of the average queue length. To calculate the active time of the TEM machines the shots fired are multiplied with the average cycle time of one shot measured in Section 3.4.1.. The workload for the Drent is specified for both lines. The Drent is provided with a extensive counter program which counts the total active time of the machine, the number of baskets gone through, the time one basket is in the machine, the time two baskets are in the machine and the time elapsed with three baskets in process. The maximum capacity of both Drent lines is three baskets each. Therefore, the elapsed time with only one basket is multiplied with 1/3, because at that the moment the Drent only uses 1/3 of its capacity. The time elapsed with two baskets is multiplied with 2/3 and the time elapsed with three baskets is not multiplied because at that moment the line is running at full capacity. To calculate the active time for the MTM data from the ERP is used. The production orders which are processed by the MTM are extracted from the ERP system. The production order contains information on the type of product and the quantity of products. The quantity of products which can be processed by the MTM is product specific due to the different dimensions of products. Acknowledging, the number of products in a basket and the chosen washing program, the active time of the MTM is calculated. Based on the gathered active times of the machines, the percentage of active time relative to the maximum available time is calculated; the workload. That percentage is calculated through dividing the active time with the maximum available time. The maximum available time is for the MTM and Drent 960 minutes, which is based on two shifts without breaks, because it is possible to place products in a waiting queue to cover the break, these products are transported by conveyer belt into the machine. The TEM needs continuous supervision and operating by an employee, but because the machine has the capability to run 960 minutes a day, the maximum active time for the TEM is also set at 960 minutes. At the Cleanroom the employees work in two shifts, the first shift starts at 05:45 AM and the last shift finishes at 22:45 PM without overlapping or interception. During the observation all the cleanroom employees did not stood still or were waiting for products, this indicates that they were fully active all the time. However, the actual active time of the Cleanroom employees was not measured. Therefore, the Cleanroom is left out of this bottleneck indication method, due to a lack of workload data. The workload in the period from 16-03 until 03-04 is shown in Figure 20.

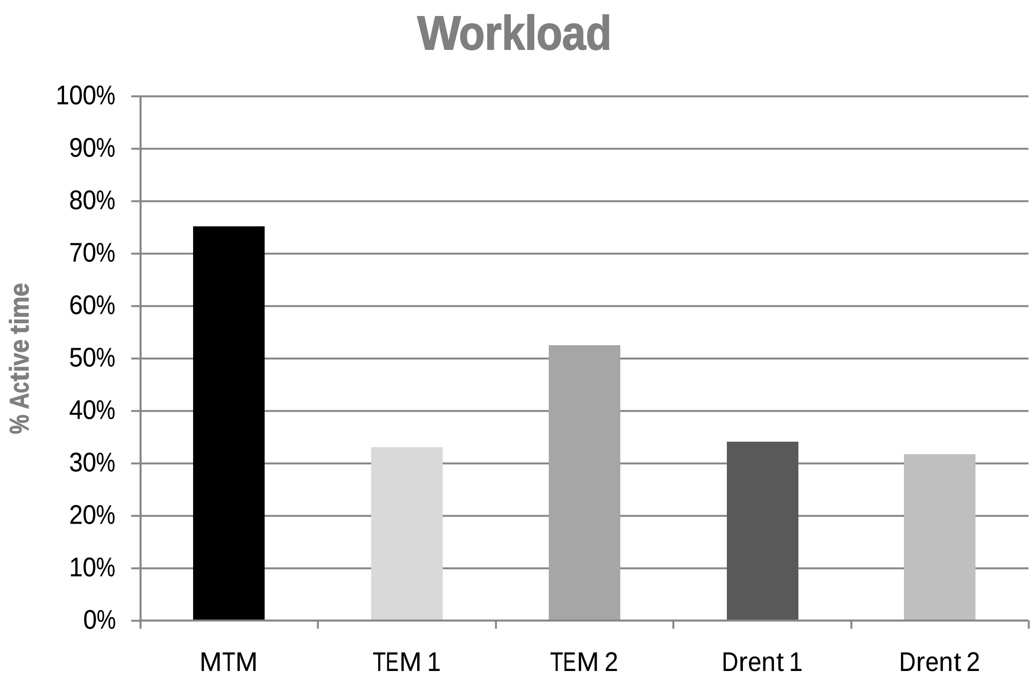

Figure 20: Workload

Figure 20 shows that none of the machines are active all the time, the MTM machine is active almost 75% of the available time, both Drent lines are active around 30% of the time and TEM1 en TEM2 respectively 33% and 52%. A bottleneck in a process has typically a workload towards 100%, which indicates that the machine is active all the time. Therefore, because none of the machines are active all the time, they are considered not to be the bottleneck.

3.5. Remarks observation

During the observation at Group 10, some things were remarkable. First, in six of the ten product observations the operators of the Drent machine could not lead the products in the Drent because the Cleanroom was full. The Drent does not accept baskets if the conveyer belts in the Cleanroom are full, this will jam the conveyer belt system. At this moment the operators of the TEM and Drent are noticeable slowing down to wait for space in the Cleanroom. Second, in nine out of ten observations the products of one order are spread across different lines in the Cleanroom because baskets only can be lead in the Drent if the room is available in the Cleanroom. Therefore, the operators at the Drent often lead baskets with products from one single order on to different lines in the Cleanroom. This subsequently results in employees of the Cleanroom relocating baskets between lines, because they have to package all products of one order. Third, a statement often heard by operators is that the operators at the Cleanroom can never keep up with their pace of deburring and therefore more Cleanroom employees must be hired.

3.6. Summary bottleneck analysis

The previous sections described three different bottleneck analysis, with different detrimental factors; Cycle Time, queue length and workload. Every method uses measurements to determine the bottleneck, based on these measurements bottlenecks are indicated. The findings of the previous sections and there analysis are summarized in Table 7.

Table 7: Summary Bottleneck Analysis.

Section	Method	Bottleneck
3.4.1.	Cycle Time	Cleanroom
3.4.2.	Queue Length	Cleanroom
3.4.3.	Workload	Not the machines

Based on the research conducted using three different bottleneck indication methods, and the remarks from Section 3.5., the Cleanroom is considered to be the bottleneck of Group 10. The further research will focus on improving the capacity of the Cleanroom, to move the bottleneck to another location. The new bottleneck location would be the MTM based on the first bottleneck analysis. Hence, step 1 of the roadmap concerning coping with constraints of Goldratt and Cox (1986) is completed, the constraint in the current production process is determined; the Cleanroom. In the following chapter step 2 is used to improve the current production process.

4. Bottleneck Waste Analysis

This chapter describes the analysis on the bottleneck in order determine the most effective way to exploit the Cleanroom, step 2 of the Theory of Constrains. Section 4.1. describes the analysis of the Cleanroom. Section 4.2. and its subsections deliver the basis for practical ways to determine the most effective way to exploit the Cleanroom.

4.1. Waste Analysis Cleanroom

Reducing the WIP is possible by removing the constraint in the production process. Removing the current constraint in a production process is step 2 of the five steps given by the Theory of Constraints. These steps focus on how the bottleneck can act more efficient with the current resources. In the theoretical background of Section 2.4. Lean manufacturing is introduced. Lean manufacturing is a practice based theory consisting out of several techniques to implement in an organisation to run processes more efficient. The foundation of Lean management is to reduce waste within processes. To reduce waste, the first step is to identify the waste within the process. Identifying waste can be done through observation on value added and non-value added activities, based on the principle of a Value Stream Map (VSM). During this analysis this principle is used to gain an overall view of the process of the Cleanroom. In the observation all activities of an operator are registered and timed preciously. Important in this observation is to identify the value of activities of operators. Operating and movement which do not add value, are waste. This time and energy (capacity) is more useful if used for value added processes.

At the Cleanroom products are visually inspected. This visual inspection focuses on damages and specific production faults which are visible with the human eye. Products are often damaged in the TEM machine, due to the explosion to remove burrs. During this explosion occasionally burr material attaches to the products. This residue of burrs needs to be removed from the product to meet customer standards. Removing residues is done by a Cleanroom employee. Other damage for example can be scratches or dents. Often these types of damage cannot be restored by the Cleanroom employees and the products will be rejected and scrapped. The Cleanroom is focused on visible shortcomings like previous mentioned failures rather than tolerances of diameters, depths, roughness and angles. This is done by the measuring room, which give clearance for a process. Inspected and where necessary restored products are inspected again based on a random sample by the team leader before the products are packed in customer specific containers, wrapping and boxes. To identify what is value added and what is non-value added, the definition ‘’value’’ has to be given for the Cleanroom. In this case, value at the Cleanroom is performing the desired tasks; visual inspecting and packaging of products. Other activities performed by Cleanroom staff are considered non value added (NVA). Activities which do not contain visual inspecting or packaging are not value added (VA), however they can be needed to perform the value added tasks. These activities are labeled indirect value adding (IVA). To improve the current capacity of value added activities at the Cleanroom the time spend on indirect value added and non-value added activities should be reduced.

The first step in reducing NVA is recording all activities performed by Cleanroom staff, timing these activities and label them NVA, IVA or VA. This mapping is done based on observation of the Cleanroom, all activities are followed and written down on the value information form (Appendix 8).

With help of this form, the types of movement and actions are labeled with a category. The observations are done during different working days during two weeks, at both shifts. Over 62 hours of observation are recorded in the Cleanroom and filled out in 88 value information forms. All activities performed are recorded and later on categorized in 18 different categories, which are presented in Table 8. During the observations general remarks are noted, which are elaborated in subsection 4.1.1.

Table 8: Activity categories in Cleanroom

	Categories:
1	Inspection
2	Restoring
3	Packaging
4	Scanning/collecting work tickets and procedures
5	Walking towards restore table
6	Collecting/arranging packaging materials
7	Storing/organizing empty baskets
8	Storing/organizing racks and covers
9	Product related questions/discussion
10	Relocating baskets/products
11	Executing random samples and waiting time
12	Counting products/baskets
13	Preparing for inspection and rework
14	Collecting/searching work instructions
15	Other, e.g. drinking coffee, toilet visits
16	Waiting time to restore products
17	Package rework and deliver to Drent
18	Handling finished products

The categories are combined into 7 main categories, as shown in Table 9. This is done to give a more clear overview of the situation, several categories are linked by the cause. The new categories are combined based on the causes for the activity, these reasons are determined during the observation period through interviewing operators and observation. These causes are appointed in Table 9.

Table 9: Combined activity categories of the Cleanroom.

Category:	Type of Activity	Sub-categories:	Category Description:	Cause of the activity:
1	VA	1 + 3	Inspection/Packaging	Customer demands packaging and looking for burrs and other malfunctions developed in the production process.
2	IVA	2 + 5 + 16 + 17	Restoring, walking towards restore location/Drent and waiting for space at restore location.	Contamination and damage originated in the previous processes has to be restored in order for approval for expedition.
3	IVA	4 + 9 + 13 + 14	Collecting work instruction and gathering extra information/materials	Not every work instruction is contains all information and often the knowledge is with the team leader. Work tickets need to be collected and scanned.
4	IVA	6 + 7 + 8 + 18	Handling packaging material and baskets	Cleanroom employees need to collect and store these materials themselves, expedition only delivers batches on request
5	IVA	11	Random sampling	Random sampling is done to guarantee quality, employees often wait on this process. The checks are executed by the team leaders.
6	IVA	10 + 12	Relocating products and counting products to complete the orders	Baskets of the same orders are spread around in the Cleanroom, the conveyer belt accepts a maximum of 4 baskets. Orders are often bigger, conveyer belts are not empty or the computer has false information due to relocating
7	NVA	15	Other: e.g. drinking coffee, toilet visits etc.	Different reasons, mostly private

These categories are dived in three types of activities, value adding (VA), indirect value adding (IVA) and not value adding (NVA). Restoring the products is an example of indirect value adding, during the observations over 15% of the time is spend on restoring products. The majority of these parts are restored because of contamination due to the thermal deburring process, during the deburring residue of burrs sticks on to the product. These residues are removed by the cleanroom employees using wire wool attached on drills. This is done at a workstation near the Cleanroom, at this workstation the cleanroom staff change their coats, to prevent dust and other pollution landing on the clothes of the cleanroom employees. The restoring category is marked as IVA because the products otherwise are not eligible for shipment, however restoring is not desirable because these products are relatively expensive compared to products which do not need restoring activities. The categories ''Gathering Information'', ''Handling (packaging) materials'', ''Random Sampling'' and

''Relocating'' are also IVA, because these activities are not directly rewarded and paid for by the customer, but are needed to perform the value added tasks. Category 1 is VA, because the customer only pays for visual inspected and packaged products. Category 7 is NVA, because it does not add value to the product and is not needed to perform a value adding activity. The goal is to eliminate categories 2, 3, 4, 5, 6 and 7 because these categories are not directly adding value. Figure 21 shows the percentages of time spend on the different activity categories.

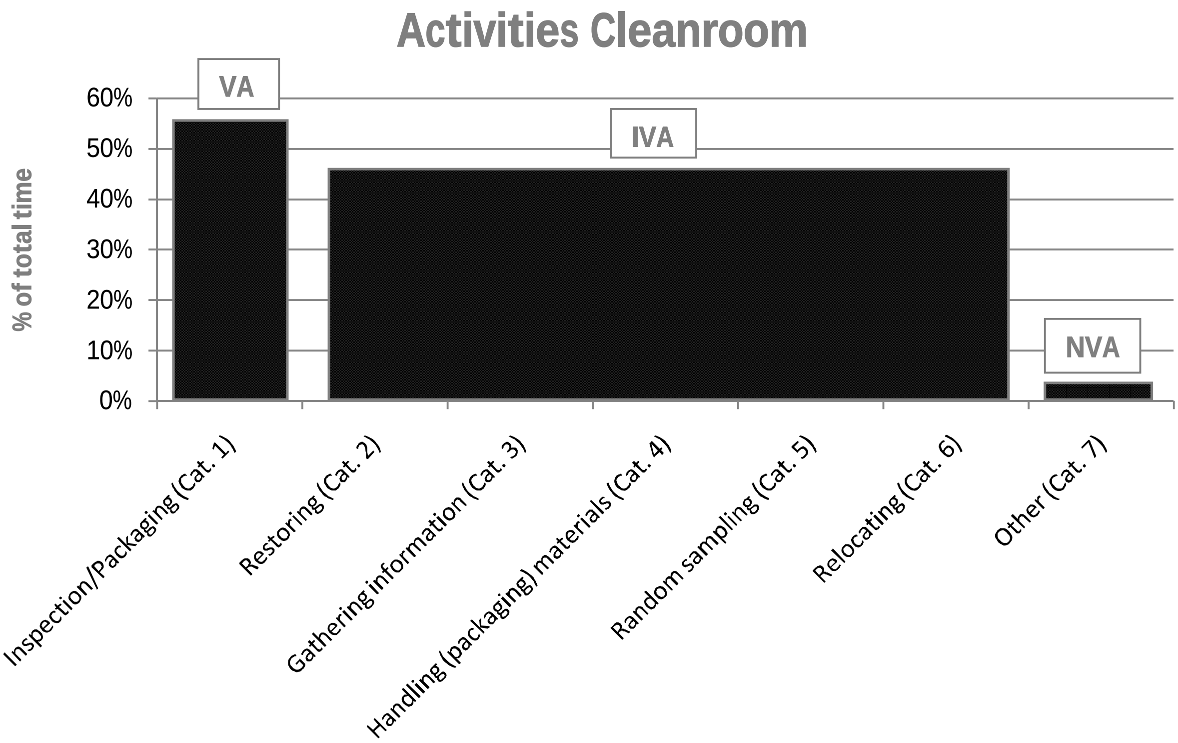

Figure 21: Activities Cleanroom

Figure 21 shows cleanroom employees spend 55% of their time with VA processes; inspecting and packaging products. One remark is that also within these VA processes waste can be present, due to other IVA or NVA processes. The remaining 45% is used IVA processes and NVA processes. As earlier mentioned 15% of the total available time is used for restoring products, which is a undesired but necessary process, therefore labeled as IVA. The remaining 30% of the time spend on IVA and NVA is not directly VA and therefore waste. Removing this waste from the process leads to a more efficient process. The biggest IVA category is category 4, handling (packaging) materials, with 10% of the time spend dedicated to this category. The next biggest IVA category is gathering information with 9%, category 'relocating'' and ''random sampling'' follow subsequently with respectively 4,5% and 4,3%. The category NVA is the category ''other'' which represents 3% of total time spend. These categories are elaborated on in Section 4.2., in which the basis for improving these categories are explained.

4.1.1. General remarks analysis

During the observations some general remarks came up, these can be found in Appendix 9. They are briefly explained in the following paragraph. The Cleanroom is designed to package products immediately after inspection, in this situation the packaging material is manually lead in the Cleanroom on a conveyer belt, which delivers the materials next to the Cleanroom employee. This process is the most efficient process. Currently all employees, except for the team leaders and two assistant team leaders, are checked again. Because the work of these employees is going to be checked again, they pack the products first in a crate instead of immediately in the packaging material. When the crate is full, several products are checked nv again, based on random samples, and afterwards the products are packaged in the Cleanroom. Another procedure is packaging the products outside the Cleanroom afterwards the inspection from the team leader. This procedure contains the most waste, because the products are first packed in the crate and moved outside the Cleanroom and subsequently the products are taken out of the crate and are packaged. This procedure is currently necessary because these products are packaged in materials which may not enter the Cleanroom because of pollution hazard. Another thing that stands out is that the team leaders are busy with ordering packaging materials and handling these materials, instead of managing the people and work along. Also remarkable is the assigning of baskets to different lanes/conveyer belts. Almost every order is spread over different lanes and the employees of the Cleanroom are therefore losing valuable time relocating products or themselves. Also time is lost in leading baskets properly on the conveyer belts, the Cleanroom is designed in such order that the employee stands at the workstation and the baskets are automatically lead to the workstation. In practice the employees are often using tricks, fooling sensors and holding baskets to not overload the lanes. This overloading occurs because the availability of the space is not visible in the computer, which is mainly caused by relocating baskets by cleanroom employees. This can be seen as an vicious cycle. The operators at the Drent manually adjust the number of vacant places at the conveyer belts to lead more baskets to the belt. The maximum capacity of the lanes are according to the computer system four baskets, but in practice six baskets is possible. Therefore it often occurs that lanes are stuffed with six or seven baskets.

4.2. Bottleneck Problem Areas

According to the activities measured and the general remarks during the observation there are six categories of non-value adding activities and non desired activities; restoring, gathering information, handling (packaging) materials, random sampling, relocating and other activities. In the following sections each of these activities are explained and elaborated to form a basis for practical ways to reduce the time spend at these activities. The activities are elaborated on to give more insights in the way the Cleanroom operates currently. For a better understanding, Figure 23 shows a schematically drawn map of the Cleanroom in which the lanes, workstations and employees are shown and Figure 22 shows the regular flow with the corresponding activities executed to fulfill an order at the Cleanroom. Figure 22 is based on the VSM principle, however a specific VSM, using the VSM-language, for a specific product or product family is not formed. Because multiple products and product families are observed. Therefore, Figure 22 does not contain the VSM-specific language and images, only the VA activities are distinguished and shown in the larger bold-edged frames.

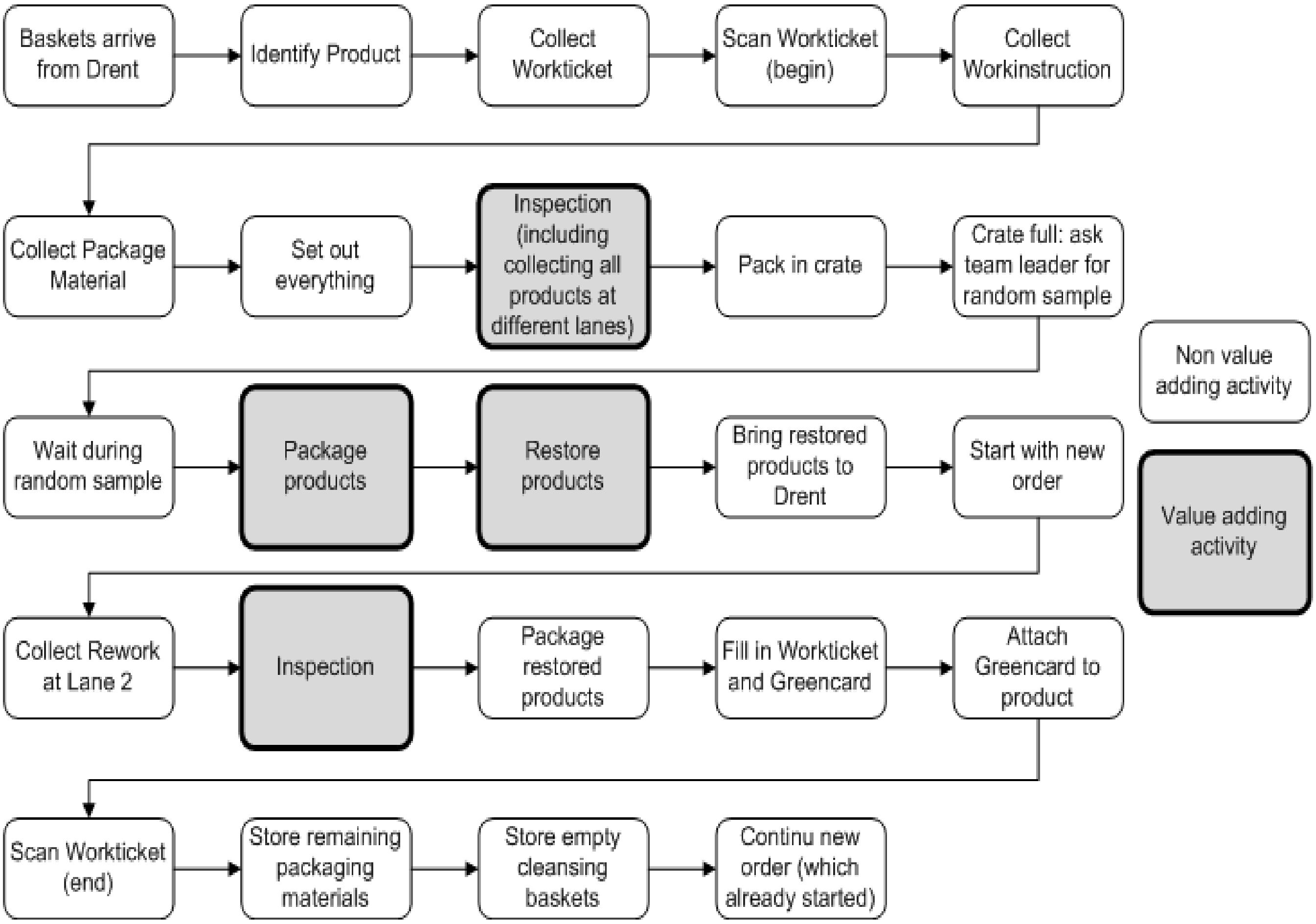

Figure 22: Activity flow in Cleanroom.

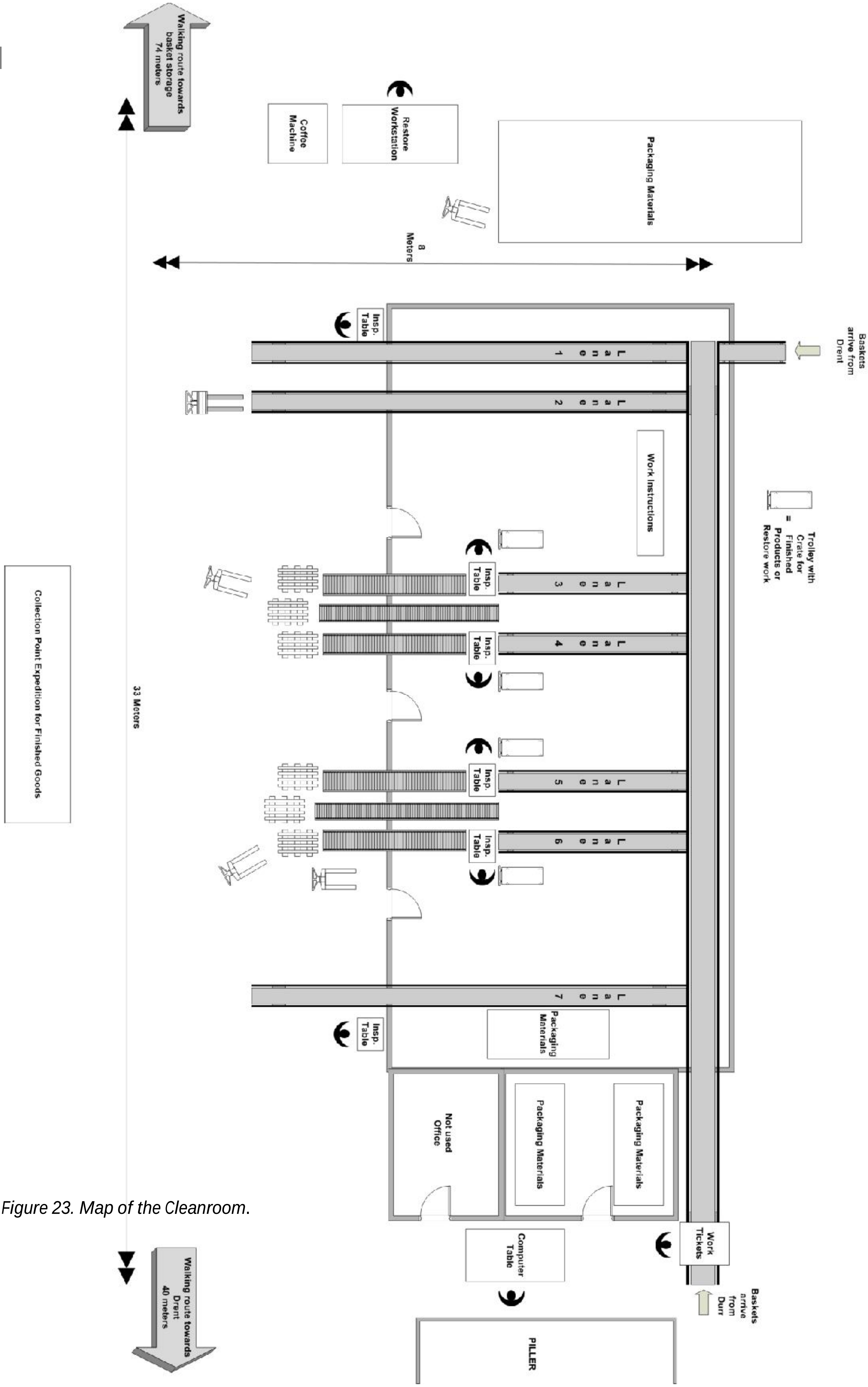

Figure 23. Map of the Cleanroom.

4.2.1. Restoring

Restoring products is a daily activity for the staff at the Cleanroom and takes up 15% of the total available time. The most interfering factors are: walking towards the workstation and Drent, confusion and discussion on the identity of baskets, interruption of the current activities if the restored products arrive. It is not technical feasible to design the thermal deburring process in such a way that no restoring is needed, therefore the focus of the recommendations will be on eliminating the waste in the restoring process. As described in Section 4.1. restoring the products is necessary because during the thermal deburring process residues of burrs attach themselves on the product. This contamination can be removed using wire wool or sandpaper. Sandpaper is also used to smooth rough edges or to remove minor scratches on surfaces. Restoring products is done after inspecting the products, the products which need restoring are collected in a crate during the inspection. When the inspection is finished, or when the crate is full, the crate is transported towards the restore workstation. This workstation is a table with a inspection light, sandpaper, wire wool and a drill used to mount wire wool on. Before restoring, the Cleanroom employee takes a dust coat and puts it on. After restoring, which can reach up to three or four minutes per product, the products are packed in a cleansing basket and this basket is brought to the Drent by the Cleanroom employee. The products are pickled in the Drent again because during the restoring the product collects dust and other pollution. The products are lead to a specific conveyer belt (number two) in the Cleanroom, but the products are not recognizable as restored products. This often leads to confusion and discussion, because it is hard to trace if the products are indeed restored. This confusion appears often if multiple orders of the same product are being processed in the Cleanroom, the employees take into account the possibility that products are send to a wrong conveyer belt. When the restored products arrive in the Cleanroom, the employee which restored the products stop their current activities and proceed with inspecting the restored products to complete the order. After the inspection of the restored products often a random sample takes place, subsequently the products are packaged. This restoring process is not recorded and so the time spend is not visible for project coordinators and other technical staff. The ERP contains the feature to record the restore activities by clocking on restore-work. Currently this feature is not used, the team leader explains that this clocking on restore-work takes much time. Based on the observations the restoring disturbs the flow of the inspection and packaging process in the Cleanroom.

4.2.2. Gathering information

Gathering product information takes up 9% of the time from the Cleanroom employees. There are four activities to focus on: walking to Lane 2 and 3 to collect work instructions, walking towards the computer and work ticket location, confusion about the products and corresponding orders and consulting team leaders for identification and information. Information on the product and the order is needed for the Cleanroom employees to perform their jobs correctly. At the Cleanroom two types of information can be distinguished; at first information regarding the product and aspects of the product which require additional focus, for instance a sealing surface, this can be found in the work instruction. Work instructions are located between lane two and three within the Cleanroom, see Figure 23. Second are the work tickets, these tickets contain information about the order, including the quantity of products within that order. These work tickets are dropped by the operators at the TEM and Drent on a designated place, see Figure 23, near the computer where the tickets are scanned. At this dropping point the different lanes are separated and indicated, the purpose of this separation is that work tickets are dropped on the correct location, despite this there is confusion about which products are part of which order. In practice the Cleanroom staff recognizes which products are on the lane and then search for the corresponding work ticket at the work ticket location. Often the team leader is consulted to identify the products at the conveyer belt, without knowledge of the products the corresponding ticket cannot be found. Another downside is that if two orders with the same products are in the Cleanroom, these orders cannot be distinguished and the orders are often mixed which results in bad traceability. After collecting and scanning the corresponding work ticket, the ticket is brought to the inspection table at the lane and the work instruction is collected at the work instruction location between lane two and three, which results in unnecessary walking if the order is placed on Lane 1, 4, 5, 6, or 7. Often the work instruction is not up to date or complete and the team leader or a colleague is consulted for additional information. With the right information gained the Cleanroom employee starts with collecting the additional goods, which will be elaborated on in Section 4.2.3.. Afterwards the inspection starts. Obviously, gaining the right information is necessary for the inspection, but the current way of gathering these information contains multiple types of waste.

4.2.3. Handling materials

Handling materials takes up 10% of the time from the Cleanroom employees. The following activities contain the most waste: collecting, returning and ordering packaging materials and cleansing baskets. These activities have nothing to do with neither inspecting nor packaging, these activities are usual logistic tasks. Handling material includes handling cleansing baskets and covers, packaging crates, plastic bags, foam, tape and pallets and requesting these items at expedition. The first materials which are handled by the Cleanroom employees are the cleansing baskets and the corresponding covers. Before the inspection is started the racks are removed from the cleansing baskets and brought outside the Cleanroom to a mobile storage unit for covers, racks and nets. The following step is to collect the necessary packaging materials for the order, these packaging materials need to be collected from different places in and around the Cleanroom, as visible in Figure 23. If one of these items is running low, the employees tell the team leader to order new items. This ordering is done by calling expedition, they deliver the requested items to the Cleanroom. These deliveries are usually complete pallets, except if just a single crate is ordered. After delivery, a Cleanroom employee, often the team leader, places the pallet with packaging materials to the designated place using a hand pallet truck. When an order is finished, the Cleanroom employee brings back the remaining packaging materials to the different packaging material locations. This is necessary because the Cleanroom staff do not pick the exact needed quantity of packaging materials. Subsequently, the Cleanroom staff pile up the baskets at a pallet and stores the cleansing baskets at the designated point in the production hall. This is done by traveling a distance of approximately 60 meters with a hand pallet truck and maneuvering the pallet at the storage place. Afterwards the Cleanroom employee walks back and stores the hand pallet truck.

At Brinks the work tickets contain a certain order with a specified quantity of products, this quantity is based on different factors and is determined by the planning department. These factors are: the number of products which can be cut out of one bar stock, the number of products in a mold on the milling machines and the number of products which fit the baskets used in Group 10. According to the manager planning and operations the number of products which can be cut out of one bar raw material is usual the detrimental factor. The reason for this is that the sawing department does not waste time by transporting remains of raw material. No clear arrangements are made on the detrimental factors within Brinks for the ‘’quantity-of-an-order-policy’’. Because the number of products which can be cut from one bar stock is usually the detrimental factor, orders in Group 10 often contain a incomplete basket, due to the order size. These not fully utilized baskets take up space and lead to unnecessary handlings of baskets, racks and nets by the Cleanroom staff. In short, inspecting products at the Cleanroom consist of some fixed handlings, which are applicable on every basket, both full and not entire utilized baskets. Furthermore, incomplete baskets result in a less efficient use of the other machines in Group 10, the Drent and MTM. Especially at the MTM, which is the second bottleneck in the process, cleansing incomplete baskets is waste. In the previous research the indication is made that Group 10 is the bottleneck of Brinks, and therefore everything else should be subordinated and the size of the orders should be based on the number of items fitting one basket. This will reduce the previous mentioned types of waste in handling these baskets.

4.2.4. Random sampling

Random sampling takes up over 4% of the available time at the Cleanroom. The focus for the recommendation contains the following activities: executing random samples, waiting on random samples and disturbing of the packaging process due to random samples. At the Cleanroom random samples are taken by the team leaders to audit the Cleanroom employees. Everybody except for the team leaders and the employees with firm contracts are audited by the team leaders. According to the Quality Manager and the team leaders themselves there are no guidelines for the selection of random sampling taking, this is done based on intuition of the team leaders. During the inspection the employees place inspected goods in a crate, when the crate is filled they ask the team leader for a random sample. During these random samples the employee is often waiting on the sample. There is no guideline for the sample size of the random sample, and therefore the sample sizes differs from one out three to one out of twelve. If a product is found which does not meet requirements, the product needs to be restored or rejected, but the remaining products in the crate are not necessarily inspected again. According to the team leaders this takes up to much time, this is only done if multiple faults are found. Thus, there is also no guideline for the consequences if faulty products are found. According to the team leaders the random samples are necessary to encourage the Cleanroom employees to inspect the products properly and to encourage a sense of responsibility for their work. This sense of responsibility is essential because it is very hard or even impossible to trace the employee which executed the inspection if faulty products are returned from the customer. Therefore, the employees cannot be approached to confront them with their faults. Thus, the random samples can be important in the current process, because traceability is low. The current way of random samples knows two drawbacks: the time lost in executing the random samples and waiting and the disturbance of the inspection and packaging process. This disturbing takes place because the inspected products are first packed in a crate and afterwards the products are repacked in a packaging crate, without the random samples the products can be packaged immediately. To determine the actual value of the random samples, the random samples executed by the team leaders are tracked for two weeks, using a form. This form can be found in Appendix 10. The number of executed random samples, number of faulty products found and the degree of the faults are recorded. Based on this data the value of the random samples can be determined and recommendations can be formed.

4.2.5. Relocating

The category ''relocating'' takes up over 4% of the time of the Cleanroom employees and contains waste due to: walking and relocating baskets and products and counting finished goods. The category ''relocating'' is the sum of relocating baskets and counting products, both activities are caused by the order sizes or the location of the baskets in the Cleanroom. Cleanroom employees inspect the quantity of products mentioned on the work ticket, which equals a single order. Waste due to relocating is the time spend on walking and repacking products in crate or baskets from different lanes in the Cleanroom, because one order is located at different lanes. Another aspect of relocating is counting the number of inspected and packaged goods to complete a work ticket, the observation has shown that this counting happens often when orders are spread around the Cleanroom and the baskets contain different quantities of products. The different quantities in the baskets combined with relocating products tend to confuse the Cleanroom employees and therefore rather count and check the quantities twice. This confusion tends to grow if multiple orders with the same products are present in the Cleanroom. At these situations the baskets with products, of multiple orders, are spread around the Cleanroom. The baskets are not visually or in another way labeled. Therefore the baskets cannot be recognized as part of specific order. This problem is even more complicated if multiple orders in the Cleanroom contain the same products but have different quantities. Counting and allocating baskets with products to meet a specific quantity of finished goods like specified on a work ticket comes with a lot of waste. In short, the main cause of relocating is that orders cannot be identified as such and the fact that orders are spread in the Cleanroom.

4.2.6. Other activities

The category other activities consist of mostly personal activities like visiting the toilet, drinking coffee and collecting personal items like reading glasses. Also work related activities are gathered among ''other'' activities like throwing away rejected parts or sweeping the floor. Usually these activities happen before the end of a shift, at moments when there is no time to inspect a new order. These activities are not part of the regular path within the Cleanroom. Because these activities are not part of the standard procedure/process, most of the activities are person related and based on the waste analysis the category is 3% of time spend, the category ''other'' will be left out of the research scope.

4.3. Summary improvements

This section gives a short summary of the waste analysis done in the previous sections and elaborates on the focus point for the implementations. The outcome of the observations in the Cleanroom resulted in focus points of different types of waste. This waste is the starting point for the implementations at Brinks as described in the following Chapter. The following issues are addressed;

- The restoring of products needed caused by technological processes is left out in the research, however the activities related with restoring products can be improved. These activities are the walking towards the restoring workstation and waiting due to an occupied workstation, also the time spend on restoring is not properly recorded and therefore improving the manufacturing process to reduce the amount of restore work is limited.

- The information provision on products and orders needs improvement. Products and orders are not visually identifiable, therefore time is spend discussing the identity of products, which baskets belong to which order, searching work tickets and afterwards time is wasted walking towards the other side of the Cleanroom collecting the work instruction.

- Handling of materials contains multiple types of waste. Collecting new and storing remaining package materials, which are located at three different places, is done by the Cleanroom employees. Also storing empty baskets is done by these employees, not every basket is filled completely with products, therefore more than necessary baskets are handled.

- Random sampling is done by the team leaders based on intuition, there are no guidelines for the sample size and the consequences. Waste caused by random samples is: waiting during the random sample, the interruption of the inspection and executing the random sample. However, the biggest waste of the random samples is that the inspection and packaging process is being disturbed because the products are packed in a crate and afterwards packed out of the crate in a packaging crate, instead of packaging the product directly after inspection in a single movement, this delays the overall process.

- Waste during relocating, searching and counting orders and products. Relocating products is done because the baskets with products are spread around the Cleanroom, products are gathered in crates and relocated to a inspection table. Counting the products is done to complete the quantities specified on the work ticket and is complicated by baskets with different quantities and relocating of baskets. These different quantities are caused by the planning, which determines the size of the orders on different factors, not only on the capacity of the baskets.

- Other activities are mostly personal or not part of the standard process, see Figure 22, therefore it will be left out of the research.

5. Solutions

Chapter 4 describes the analysis of the Cleanroom and the waste in the process. Chapter 5 focuses on this waste and introduces recommendations for Brinks to eliminate this waste. The routing of the implementations is based on the flow of activities in the current situation, see Figure 22. This chapter describes the plan to change from the current situation to the future situation, a situation containing less waste. Based on the theoretical background of Chapter 2 and the waste analysis executed in Chapter 4, several recommendations on eliminating waste at the Cleanroom are formed to structure a concept version of an improvement plan. The starting point of the concept version were the types of waste found in Chapter 4. Each waste needs to be eliminated and therefore a pragmatic solution, based on theories from Chapter 2, is formed to achieve that goal. The given solutions structure the concept version of the implementation plan which is presented to a board of experts, this presentation can be found in Appendix 11. The board of experts consist of: production manager, director operations, quality manager, logistic manager, team leader Cleanroom, department supervisor Group 10 and a project coordinator. During the presentation the recommendations are discussed with the experts and concrete implementations are formed and project owners are allocated. This practical implementation can be found in the following sections. Each section is provided with a recap which elaborates on the types of waste in the part of the process. Finally, Section 5.6. summarizes the future state of the process in the Cleanroom.

Figure 24, on the next page, presents the map of the Cleanroom in the future state. In this figure the recommendations are visually presented and these changes are linked to one of the sections from Chapter 5.

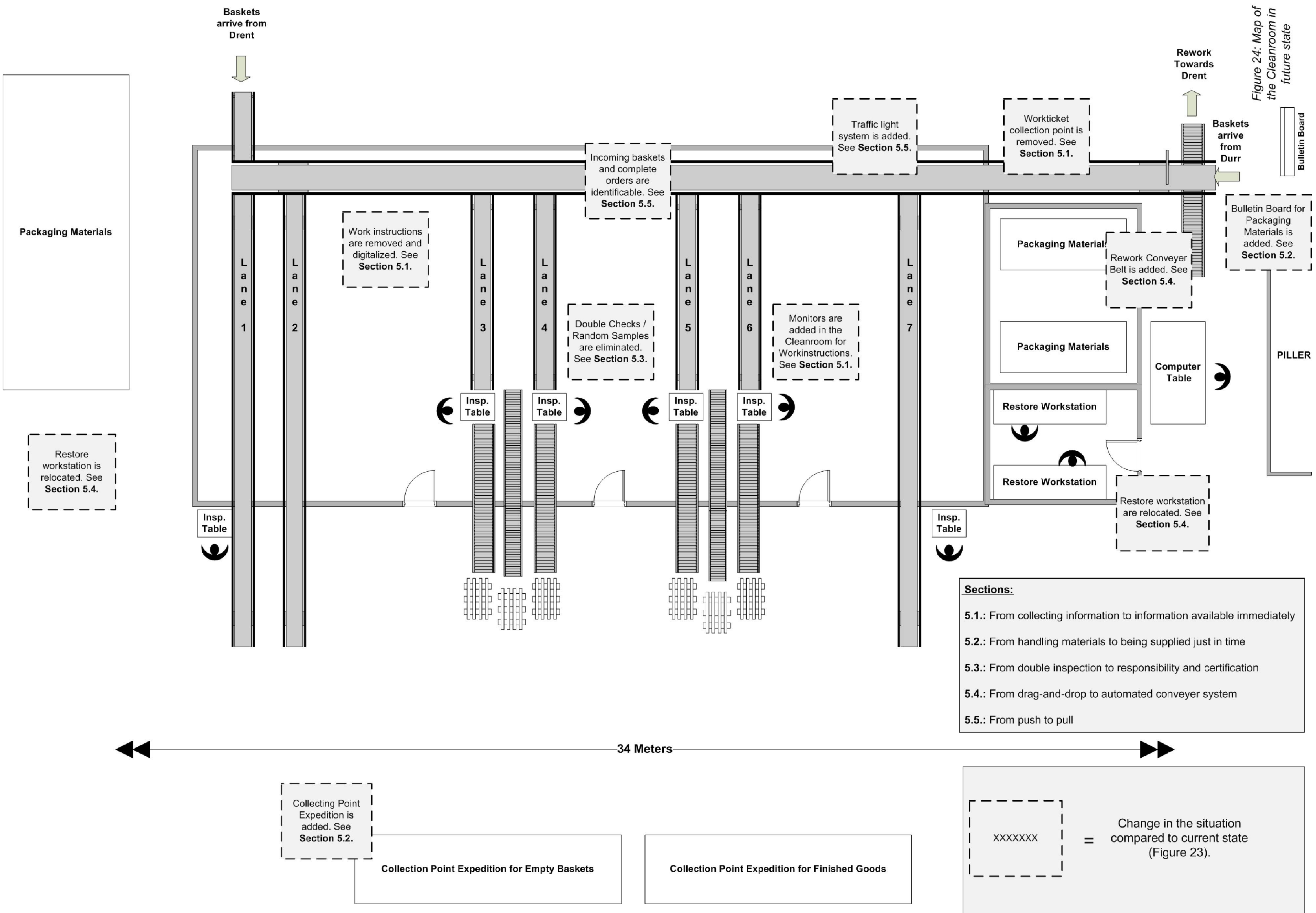

Figure 24: Map of the Cleanroom in future state

5.1. From collecting information to information available immediately

> **RECAP**: The first step in the process at the Cleanroom is to identify the products and to gather the necessary information to perform their job. Gathering information takes up 9% of the available time of the Cleanroom Employees. It contains waste through identifying and searching for work tickets and work instructions.

The information provision can be improved at Brinks. Waste through identifying and searching for work tickets can be eliminated. This can be done by attaching the work tickets to the baskets. In this situation the work tickets do not have to be searched at the drop point and the identity of the product is known instantly. Attaching the work tickets is possible by furling the work ticket and put it in a waterproof tube, which can be attached to the basket. Work instructions can also be attached to the baskets using this technique. Work tickets go through the whole process, from the sawing until the Cleanroom. These tickets move with the products in plastic folders during the process. Adding the work instructions to the work ticket ensures that the work instruction is available during the operations and eliminates waste by searching work instructions on paper or digitally. The work instructions for the whole process need to be joined together in a folder and added to the work ticket at the planning department or sawing department. In this way, the information at every production step is available and no time is wasted by searching. And by furling it into a waterproof tube all the information will be available immediately at the Cleanroom.

In the current situation the work tickets are collected and scanned at the computer table, recommended is to change the scanning procedure in such way that the operator at the Drent does the scanning and the Cleanroom employees only scan the work ticket when they are finished. This will eliminate the walk from the inspection lanes towards the computer and back. If the tickets are already scanned and the necessary information is provided with the basket, the Cleanroom employees can start with the inspection immediately if the packaging materials are set out. Setting out the packaging materials will be discussed in the next section.

Above mentioned method ensures that products are identified instantly and all information is available. Because an order often consists of multiple baskets, only a single basket contains all the information. During the observations is shown that orders are spread on different lanes, this complicates the identification because just one basket is provided with the information. Recommendations on this issue are further elaborated on in Section 5.5..

During the meeting with experts the idea came up to delete the work ticket from the entire production process and to add a punch card instead of a work ticket. This way there is no need for waterproof and acid resistant tubing and the improvement can be introduced in the whole factory. The additional benefit of the punch card with a work ticket number is that if changes in the production process occur, it can be changed digitally and not all open orders need to be replaced in the factory. The pre scanning can be done by joining the Cleanroom and Drent in the ERP system towards a single step, which is started by the Drent operator and closed by the Cleanroom employee. The work instruction is in the ERP system linked to the work ticket, therefore by using the work ticket all relevant work instructions are shown at a screen in the Cleanroom. A drawback of this system is that processing steps are not visually shown on the cards, however steps are visible if the cards are scanned at the computer, which is present at every processing step. The forklift drivers are equipped with a laptop, in order to scan the cards to expedite the products towards the right workstation.

During the discussion meeting it is agreed that the project coordinator and the supervisor of Group 10 are allocated to this project.

> **Implementation**: At time of writing appointments are made with external IT consultants to discuss the possibilities to place screens in the Cleanroom to display work instructions and make a link to the database for the booking orders. As well as the possibilities to introduce this in the entire factory. A quotation for a card printer which meets requirements is already present and approved, the cards are tested on their acid resistance in the pickle baths.

5.2. From handling materials to being supplied just in time

> **RECAP:** Waste in handling materials is collecting packaging materials and storing empty baskets, this waste takes up 10% of the available time of the Cleanroom employees. Collecting packaging materials by the Cleanroom employees enables them to start with the inspection immediately after arrival of the products. Eliminating collecting and returning these materials will improve the process at the Cleanroom.

To eliminate the waste the packaging materials need to be delivered to the Cleanroom, this can be facilitated by the Piller operator or expedition. The information about coming orders at the Cleanroom can be passed on using a bulletin board, the Drent operators write or use cards on the bulletin board to signal the expedition or Piller operator that a certain order is coming up and the packaging materials have to be collected. The information on the bulletin board contains the order, customer and the lane where the order is send to. The expedition or Piller operator collects the materials and drops them at the corresponding lane. This way, the Cleanroom employees can start with the inspection immediately after the products arrive. If certain packaging materials are not present in the packaging material storage areas, these materials can be ordered in advance instead of when the products are needed. This is an additional benefit if the materials are arranged by the Piller operator or by expedition.

The empty cleansing baskets are currently also returned and stored by the Cleanroom employees, which requires walking with a hand pallet truck and maneuvering, this type of waste can be eliminated by placing the empty baskets at collecting points. The empty baskets are collected by expedition from these collecting points and are subsequently stored and maneuvered by skilled personnel using forklifts.

Products in the baskets are covered with racks to prevent them from falling out. Releasing and storing these covers contains waste through walking in and out the Cleanroom. This can be eliminated efficiently by changing the work pattern. Often all racks of an order are released in once and stored before the inspection. Releasing the rack when the basket is first in queue and placing it on the subsequent basket will make it possible to use the roller conveyer to send the rack with the basket out after finishing the inspection of the basket.

During the meeting with the board of experts the idea of a bulletin board was discussed and also the idea of adjusting the ERP system in such a way that it gives a signal to the Piller operator if a work ticket is scanned at the Drent came up. Therefore, the practical recommendation is to implement the collecting point for the expedition and to add a function in the ERP system to signal the Piller operator when, which and where packaging materials are needed. A drawback of this system is the possibility for a late delivery from packaging materials by the Piller operator, however the minimum available time to deliver is 18 minutes, collecting the materials takes about three minutes. The logistic manager and production manager agreed on the ownership of this recommendation.

Implementation: A screen is mounted next to the Piller and a program is coded which shows the lanes and required packaging materials in the Cleanroom including the remaining time. This information is gathered out of the ERP system. Next to the Cleanroom a FIFO pallet rack is placed to distribute the packaging materials, expedition supplements this rack based on Kanban cards which are mounted on a bulletin board.

5.3. From double inspection to responsibility and certification

RECAP: Random sampling takes up over 4% of the available time at the Cleanroom. The focus for the recommendation contains the following activities: executing random samples, waiting on random samples and disturbing of the packaging process due to random samples. At the Cleanroom random samples are taken by the team leaders to audit the Cleanroom employees.

The team leaders from the Cleanroom recorded their random samples at five working days, spread over two weeks. The initial goal was to collect around 100 orders to gain insights on actual value of the random samples, however the partial results gained after five days combined with the previous observations held in the Cleanroom, it can be concluded that the random samples are useful in the current situation. In total 22 random samples are executed and in 9 cases the team leaders did not found faulty products. More than half of the 22 orders were not inspected good enough and products with burning marks and pollution were found. In the 13 cases where the inspection was not performed good enough in one situation the Cleanroom Employee had to inspect the order again. The other 12 orders the products were not inspected again and were packaged. Thus, the products were packaged without certainty that the products are of the right quality because during the inspection by the team leader products were found which did not meet quality standards. This indicates that the random samples taken from the orders by the team leaders are double inspections rather than random samples because orders will not be inspected again if faulty products are found. In the current situation the team leaders are performing double inspections rather than random samples, while executing these double inspections faulty products are still found. The team leaders emphasize that their double inspections are important to keep the Cleanroom employees focused, apparently the double inspection does not have the wanted result, namely zero faults. However, according to the quality manager there are not much rejections from the customer based on pollution or minor damages. Therefore it can be concluded that the current way of quality control is superfluous and the reason for current way of inspecting twice is to keep pressure on the Cleanroom employees. This pressure or responsibility can also be achieved by marking the boxes with finished goods with a color, stamp or card which is unique for a Cleanroom employee. Using this method the Cleanroom employees should feel responsibility because they can be traced and addressed if a customer files a rejection.

During the discussion with the board of experts the conclusion is drawn that the current way of doubling inspecting is superfluous because there is an acceptable number of rejections and it is a double control system instead of a random sample system. Also the need for creating responsibility was confirmed and the idea of adding personal cards in the packaging was accepted. Another point of the discussion was that employees working more than five years at the Cleanroom were double checked. This brought up the need for an training plan with a certification in the end of the program for new employees. The quality manager and production manager agreed on ownership of this issue and writing a new training plan and implementing the cards in consultation with the team leaders of the Cleanroom.

Implementation: The superfluous double inspections are abolished and cards with personnel numbers are added to the packaging.

5.4. From drag-and-drop to automated conveyer system

RECAP: Restoring products takes up 15% of the time from the Cleanroom employees, restoring products is waste, however in this case the restoring itself is value added because otherwise the goods cannot be sold. The causes of the contamination which need to be removed are left out the research, however the way of restoring can be improved. With this improvement the time spend at restoring can be reduced.

This can be done by reducing the time spend walking towards the restore workstation and the Drent. Two options are recommended for consideration. First; relocate the restore workstation from the current location to the empty office space. This space is closer to the inspection lanes and the walk to Drent is shorter. Distraction by other personnel is also less at this location, because it is not near the coffee machine. Second option is to restore the products in the empty office space and to establish a collecting point for the Piller operator. The operator of the Piller which is close to the empty office, can expedite the restored products towards the Drent.

The recommendation in the previous paragraph was the starting point at the discussion session with the board of experts. Relocating the restore workstation towards the empty office space was accepted, with the condition that a proper exhauster will be installed to ensure the health and safety of the Cleanroom employees. Instead of a collection point at the Piller a conveyer belt towards the Drent is introduced as solution to ensure that the rework reaches the Drent as fast as possible. This will relieve the Piller operator and the shortest route can be taken, this is underneath an existing conveyer belt from the Durr towards the Cleanroom, where the Piller operator has to walk around. A drawback of relocating the workstation are the costs for exhausters, which are needed because the products are restored in a closed space. The operational director and production manager agreed on implementing this recommendation.

Implementation: The restore workstation is going to be relocated towards the empty office space after the summer holidays and decided is to implement a collection point from which the Piller operator collects restored work and

5.5. From push to pull

RECAP: Waste in the category relocating is the time spend relocating and counting products to obtain the right quantity of products as described on the work tickets. This waste takes up over 4% of the time of the Cleanroom employees. This relocating and counting is necessary because the orders in the Cleanroom are spread on different lanes and the baskets contain different quantities. This waste is caused by the push attitude from the Drent operators, they want to keep all lanes filled with products. This results in spreading orders on different lanes and jams. These jams are caused by the operators at the Drent adjusting the capacity of the lanes in the Cleanroom manually to push more baskets towards the Cleanroom.

Using the pull technique can eliminate the waste of relocating, counting and fixing jams. Currently the Drent operators look in the Cleanroom to see where available space is on the lanes, often they do not consider the baskets already in the Drent, this causes the jams and overfull lanes. During this search for open spaces at the lane they also do not consider if an employee is working at an order at a specific lane. In practice some orders are standing hours before they are addressed. Sending baskets to lanes which are not occupied, leads to more inefficiency. The maximum capacity of the lanes is in practice six baskets, the system is limited to four baskets. This needs to be adjusted and the manual function to adjust the capacity has to be blocked. The delivery of baskets in the Cleanroom needs to be based on pull signals from the Cleanroom and they have to be delivered at a single lane. The recommendation to be successful at creating pull signals is to provide the lanes with signs in front of the glass, which can be turned by the Cleanroom employees to show; ''GO'' or ''NO GO''. If the signs says ''GO'', the Drent operator can send baskets to that specific lane. If the sign is on ''NO GO'', even if the lane is not filled completely, Drent operators do not send baskets to that lane. To keep the bottleneck at work and not idle, Cleanroom employees turn the sign on ''GO'' if they are finishing their current order and are finished within ten minutes, this is the average time needed to process a single basket in the Drent. To eliminate the need for counting, the last basket of an order is made visually identifiable, through an attached label. This label is attached by the Drent operator and indicates that it is the last basket of an order. To feed the Cleanroom when needed two changes have to be made to the current system. First, in the current situation line 2 of the Drent is used to feed the Cleanroom and is not very reliable, line 1 is more reliable based on the observations and the Mean Time Between Failure report of 2014. Based on this knowledge it is best to switch the lines. Second, currently it is not allowed to stack WIP between the TEM and Drent. When the Cleanroom is pulling orders from the Drent, it is best to stack at least one order as WIP in front of the Drent to guarantee supply to the Cleanroom.

Abovementioned also reduces the time spend on counting products because complete orders are pulled and inspected. Another reason which complicates the counting are the different quantities of products in the baskets and orders. The quantities of the orders are currently mostly based on the number of products which can be cut out of one bar stock. According to the third point of the Theory of Constrains; ''subordinate everything else'', the quantity of the orders should be a multiple of the maximum capacity of the baskets which results in a maximum of six baskets, which is the maximum capacity of the lanes in the Cleanroom. Basing the orders on a multiple of the capacity of cleansing baskets also relieves the second bottleneck in Group 10, the MTM machine. At the MTM every basket is processed equally long depending on the chosen program. Therefore, cleansing half-full baskets leads to wasting capacity of the MTM machine.

During the discussion session the previous paragraph is used as starting point to introduce pull system in the Cleanroom. During the discussion the question arises if the Cleanroom employees are able to determine the right moment to pull a new order from the Drent. This issue can be solved by introducing a traffic light system. This traffic light system uses a sensor to turn the light from red to orange if the last basket of an order is being processed, the Cleanroom employee than determines if the lane can be released for a new order or not. Cases when the lane is not being released can be if products need a lot of restore work or the Cleanroom employee stops working due to for instance the end of a shift or a break. In that case the traffic light will stay orange, only if an employee needs another order they turn the light into green. If lanes are empty without occupation of a Cleanroom employee the team leader can adjust the traffic light into green, to provide the upcoming employees with work. Possible drawbacks of this system are the adjustments to the current system which need to be done and the discipline which is needed to release the lane at the right moment. The director operations agreed on the ownership of this project in consultation with the automation and technical department.

Implementation: The monitor on which the capacity of the lanes can be adjusted manually is relocated to the Cleanroom, the operators at the Drent can only adjust capacity in consultation with the Cleanroom team leader if the reason is valid. The Cleanroom is provided with buttons to release the lanes and the traffic light system is integrated in the current system to send products into the pickle baths. Products cannot be pickled if the lane is full or not released by a Cleanroom employee in this new traffic light system. Also the capacity of the lanes is expanded to six baskets.

5.6. Summary recommendations

This section describes the summary of the recommendations. The basis for the recommendations is to transform the current situation from a push orientated process to a pull oriented process. This is done using traffic lights in the Cleanroom which indicate if an order can be send by the Drent operators. The order quantities are based on a multiple of the maximum capacity of the baskets which results in a maximum of six baskets, to use the lanes in the Cleanroom as efficiently as possible and also relieve the second bottleneck; the MTM machine. The orders also contain a punch card with the number of the work ticket, the paper work ticket will be eliminated from the whole factory. With this number the work instruction can be requested at the screen in the Cleanroom as well. The Drent and Cleanroom will be joined together in the ERP system which allows the Drent operator to start the work ticket and the Cleanroom employee to close it. The last basket of the order is visually identifiable due to an attached label. Because the Piller operator has received the signal from the ERP system that packaging materials need to be picked up and dropped off at the right lane, the Cleanroom employee can start the inspection immediately. Certified Cleanroom employees pack the products right away, without the intervening of a double inspection. In each packaging a personal card is packed to trace the inspector and create a larger sense of responsibility. Non-certificated employees pack the inspected products in a crate to let the team leader conduct a random sample according to the training program. Products which need restoring are restored at the new workstation which is located in the previous empty office space. After restoring the products at the new restoring location, the cleansing basket with restored products are placed at the conveyer belt which leads the basket directly to the Drent. Afterwards the Cleanroom employee starts with a new order, the Drent operator labels the basket to make sure the products are recognized as restored products. The punch card with the work ticket data will stay with the restored products to identify the products and order when the baskets arrive at the Cleanroom. The Drent operators use Line 1 instead of Line 2 to guarantee delivery if products are pulled by the Cleanroom, if necessary they deliver out of the WIP storage which contains a maximum of two orders. After receiving the restored products, the Cleanroom employee rounds up the order by closing the work ticket, filling in the green card and move the finished goods to the collection point for finished goods.

When the recommendations of the previous sections are implemented, Figure 25 shows the flow of activities in the Cleanroom if the recommendations are implemented within Brinks.

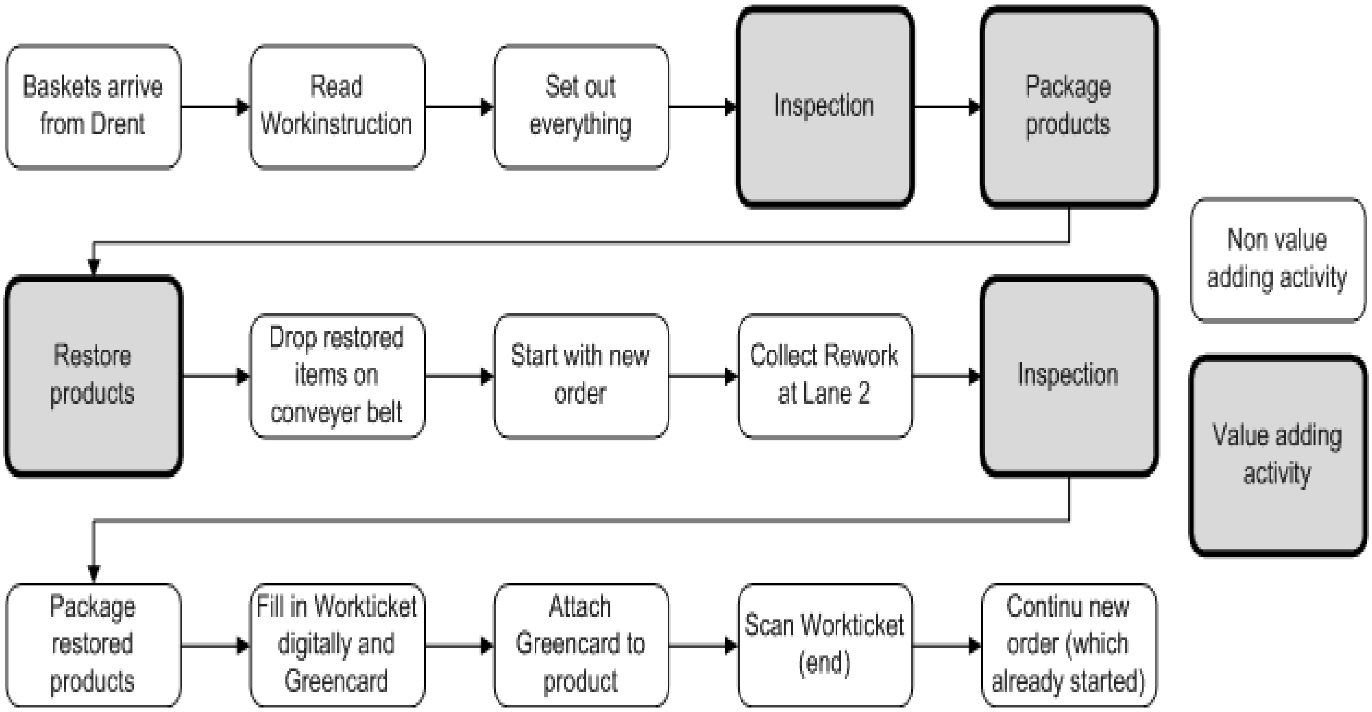

Figure 25: Activity flow in Cleanroom after implementing recommendations.

5.7. Results

This section describes the results of implementing the previous mentioned recommendations. The mentioned recommendations can lead to a reduction of the waste present in the current process. The waste is categorized and the time wasted performing these activities as a percentage of the total available time can be found in Table 10, a visual overview is shown in Figure 26.

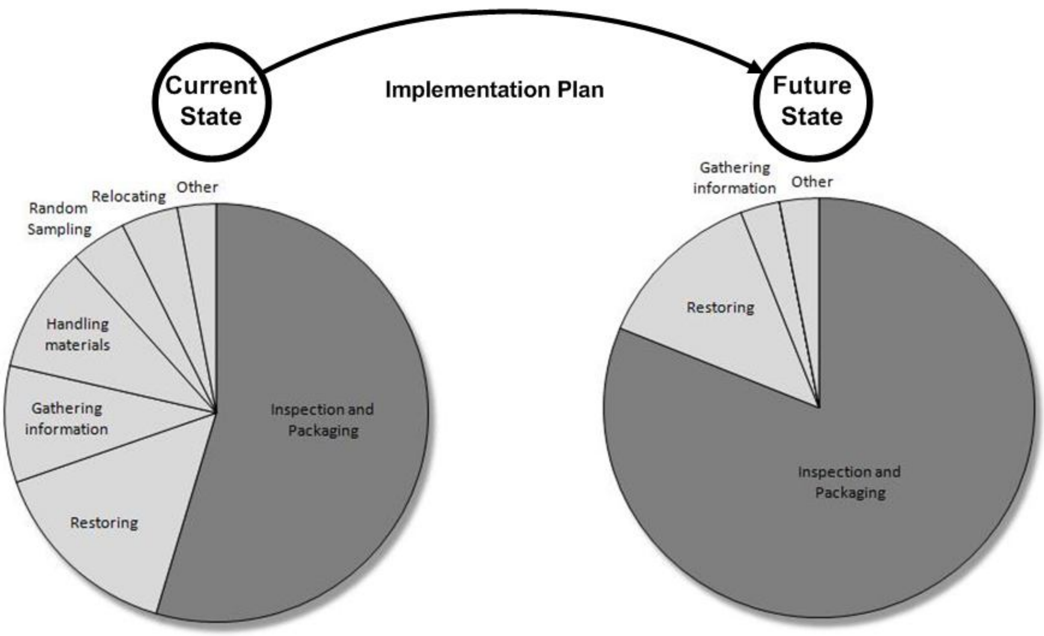

Figure 26: Current and future state time dividing Cleanroom visually.

Table 10. Current and future state time diving Cleanroom.

Activity	Current State	Future State
Inspection/packaging	55	82
Restoring	15	13
Gathering information	9	2
Handling (packaging) materials	10	0
Random sampling	4	0
Relocating	4	0
Other	3	3

Table 10 and Figure 26 show the current time division in the Cleanroom and the possible future state. The percentages as visible in Table 10 are based on the following factors. First, time spend at restoring will be less, because of relocating the workstation and eliminating walking towards the Drent, the reduction of time spend of 2% is an estimation, based on the time spend walking towards the Drent. Second, time spend at gathering information will decrease because information is available immediately. The time spend of 2% in the future situation for gathering information is the time spend asking team leaders for additional information. This time is measured during the observation of the Cleanroom and categorized as category 9, as seen in Table 8. Third, handling materials will be executed by the Piller operator and expedition, therefore the time spend on this activity by Cleanroom employees will be minimized and therefore determined at 0%. Fourth, the current double inspections will be eliminated, which saves 4% of time spend and increases efficiency in the packaging process. Fifth, relocating and counting products is minimized by introducing pull and labeling baskets, therefore the percentage of time spend by an Cleanroom employee at this activity is determined at 0%. The category ''other'' is not handled in this research, therefore the percentage of time spend at this activity will remain the same. Thus, if all recommendations are implemented successfully the time spend at value added processes, inspection and packaging, will increase from 55% to 82%. Therefore, in the future situation 49% more time spend can be used for value added processes instead of waste. Thus the value adding capacity rises with 49%. [redacted]

While determining the bottleneck three methods where used; based on cycle time, queue length and workload. This increase in capacity will lead to a reduced average cycle time in the Cleanroom, which is currently 34 seconds. The cycle time in the future situation is 49% less, resulting in a cycle time of 17 seconds. Therefore, based on the cycle time the bottleneck has been relocated towards the MTM machine, which has an average cycle time of 30 seconds. The second bottleneck method based on the queue length is in the future situation not applicable, because of the pull system. In a pull oriented system, the WIP is not a proper bottleneck indicator because products are moved from the previous workstation only if they are needed. The third method based on the workload excluded the Cleanroom, however with an increase of value adding capacity in the Cleanroom of 49% the total capacity of Group 10 will increase because the Cleanroom was the bottleneck. Due to this increase the MTM will also be utilized more. The current workload of the MTM is 75%, the expectation is that the workload in the future situation will reach 100% due to the capacity increase of the bottleneck, which equals a capacity increase for the entire process in Group 10. The workload of near 100% for the MTM indicates that this can be the bottleneck in the future situation. It can be concluded that based on the workload and cycle time in the future situation the bottleneck has been relocated towards the MTM. Three recommendations on exploiting the newly created bottleneck can be found in Appendix 12.

6. Conclusion

The goal of this research was to improve the production process to reduce WIP and improve the delivery performance at Brinks Metaalbewerking. The following main research question was formulated to structure the research: *''How can the current production process of Group 10 be improved, to decrease WIP and Throughput Times and increase the Delivery Performance?''*.

In order to answer the main research question four sub research questions were formed. The answer to the first research question: *''How are Work In Process, Throughput Times and Delivery Performance related at Brinks?''* is formulated; At Brinks the delivery performance decreases if throughput times increase and orders which are almost overdue are often still in WIP. The focus of the remaining research was therefore on reducing the WIP and throughput times. The second research question: *''What are the current reasons for the high level of Work in Process and relatively long lead times of Group 10?''* is answered using a bottleneck analysis in Group 10. This analysis showed that the Cleanroom is the current bottleneck in the process and therefore the reason for the high level of WIP and relatively long lead times of Group 10. The third research question: ''What can be done to reduce the Work in Process and Throughput Times?'' is answered by a waste analysis on the Cleanroom which indicated several areas containing waste: handling (packaging) materials, restoring products, random sampling, relocating products and gathering information. For each of these areas recommendations on improvements are introduced to answer the fourth research question: *''How can the suggested improvements be implemented in the organisation of Brinks?''.* The following improvements can be implemented to eliminate the waste in the Cleanroom:

- Implementing pull instead of push in the Cleanroom using visual signs and making sure that no more than one order is send to one lane. This reduces jams, relocating products, searching for products and counting if orders are complete. In addition to implementing the pull system, also an adjustment in determining the order sizes is necessary, because the drop-off lanes have a maximum capacity of six product baskets. To exploit the Cleanroom, and the second bottleneck as efficiently as possible the available baskets need to be filled maximally and therefore the order quantities need to be determined based on the capacity of the baskets.
- Information about the products and the inspection process needs to be delivered with the product. In the current situation the products are identified based on experience and the order ticket and work instructions are collected. In the new situation the order ticket is eliminated and replaced by a waterproof punch card and work instructions are showed on a screen. This makes sure that all information needed is available instantly and the start up time of the process is reduced.
- The (packaging) materials need to be delivered just in time, instead of being collected by a Cleanroom employee after receiving the products at the Cleanroom. A new function is added to the ERP system which signals were the upcoming orders are placed and therefore the needed packaging materials are visible and can be picked by an operator of a non bottleneck machine in the department. This makes sure that the packaging material is just in time at the right lane in the Cleanroom and therefore the employees of the bottleneck can start inspecting directly when the products arrive. This reduces, combined with the previous mentioned recommendation, the startup time of an order at the Cleanroom.

- After inspecting the products, random samples need to be carried out on orders inspected by new employees. This will only be done during their training program, afterwards the employees are certificated and there will not be any random samples. To create responsibility and traceability, each packaging needs to be provided with a card which identifies the inspector. This recommendation reduces the time spend on double inspections and improves the efficiency of the packaging process.
- Relocate the restore workstation and implement a conveyer belt towards the Drent machine. Due to pollution or minor damages some products need to be restored after the inspection. Afterwards the products need to be pickled again in the Drent, using the conveyer belt saves walking time and makes sure that the restored products are directly lead towards the Drent. Relocating the workstation reduces the walking towards this station.

Abovementioned improvements answer the main research question and the following summarizes the research and describes how the goal is achieved. The bottleneck in Group 10 was determined and an implementation plan is written in Chapter 5 to relocate the bottleneck towards a different machine or workstation by improving the capacity of the bottleneck. The time spend on inspecting and packaging at the Cleanroom, grows with 49% and therefore the bottleneck has been relocated towards the MTM machine. With an equal output there is approximately [redacted] per year, based on the labor costs paid for non-value adding activities, available for other value adding activities. Due to the increase of capacity at the bottleneck, the capacity of the department has grown towards the maximum capacity of the new bottleneck. The increase in capacity of the bottleneck department will lower the average cycle time which according to Little´s Law will lead to a decrease of WIP and increase the delivery performance. Therefore it can be concluded that the production process in Group 10 is improved to decrease WIP and increase delivery performance.

7. Discussion

The following chapter describes the limitations of this research in Section 7.1. and recommendations on further research are described in Section 7.2..

7.1. Limitations

The first limitation of this research is the observation period of some bottleneck indication methods, the cycle time and workload measurements are executed during four weeks, the queue lengths are recorded for three months. It is possible that due to certain conditions, as well internal, external as personal, in the four observation weeks the production capacity of the bottleneck was less than usual. Though, there are no indications that this is the case. During the observations the Cleanroom staff was stable and there were no personnel displacements. Based on the numerous informal conversations held with operators and team leaders there is nothing that gives reason to assume that the observation period did not provide a good representation of reality. Although, there a no indications that the observation period of four weeks had influence on the results of this research, an observation period of six months will overcome the possible influencing. Because of the time available for the research and writing the theses an observation period of four weeks is chosen.

The second limitation is that all observations are executed in the presence of the researcher, except for the workload indication and queue length indication. The presence of the researcher can influence the Cleanroom employees while performing their tasks. It is possible that they worked harder, were more motivated or better thought their activities through because they knew they were being observed. During the waste analysis the total amount of non-value added activities was 3%. Comparable research from O'Leary, Liebovitz and Baker (2006) found that their research group spend 4% of the time on personal activities. Research from Munyisia, Yu and Hailey (2011) observed six groups which spend the following percentages of their working time on personal activities: 5.3%, 2.5%, 5.1%, 7.9%, 5.0% and 3.9%. Therefore it is possible that the employees at the Cleanroom behaved different, however based on other research this seems not the case.

The third limitation is that by solving the current bottleneck, by increasing the capacity, a new bottleneck will be created. This can be considered to be limitation in such a way that it needs further research to solve the second bottleneck. Appendix 11 elaborates on the new bottleneck.

7.2. Future research

At first it is recommended to study the newly created bottleneck which emerged due to implementing the improvement plan in the Cleanroom. Section 5.7. already provides some recommendations on improving the newly created bottleneck. Future research is recommended to measure the situation after implementing the improvement plan as described in this research and investigate if the recommendations done in Appendix 11 are sufficient to relocate the bottleneck. Second recommendation for future research is to study the possibilities of implementing an automated visual inspection system based on comparing images of approved products and live camera footage. Implementing such a system will require large investments in hardware (robots and cameras), software and time for configuring the cameras and comparison images. For Brinks it will be interesting to study the possibility and the pay-off time of such a system because the human visual inspection is not very reliable, according to Smith (1993) at best only 80% and human visual inspection is labor intensive and therefore expensive. Third recommendation for future research is to investigate the results and outcomes of the improvement plan on several factors. At first the delivery performance because the delivery performance should increase due to the improvements. Second the rejection rates, because the quality control system is adjusted in the improvement plan. Lastly, the customer satisfaction, because high delivery performance is an indication that customer satisfaction is high as well. These three factors should be improved due to the improvements given by this research, therefore a research on the outcomes is recommended to measure if the implementations have the desired outcome. Such a research delivers important data for potential adjustments or possibilities to implement aspects not only in Group 10 but also factory wide.

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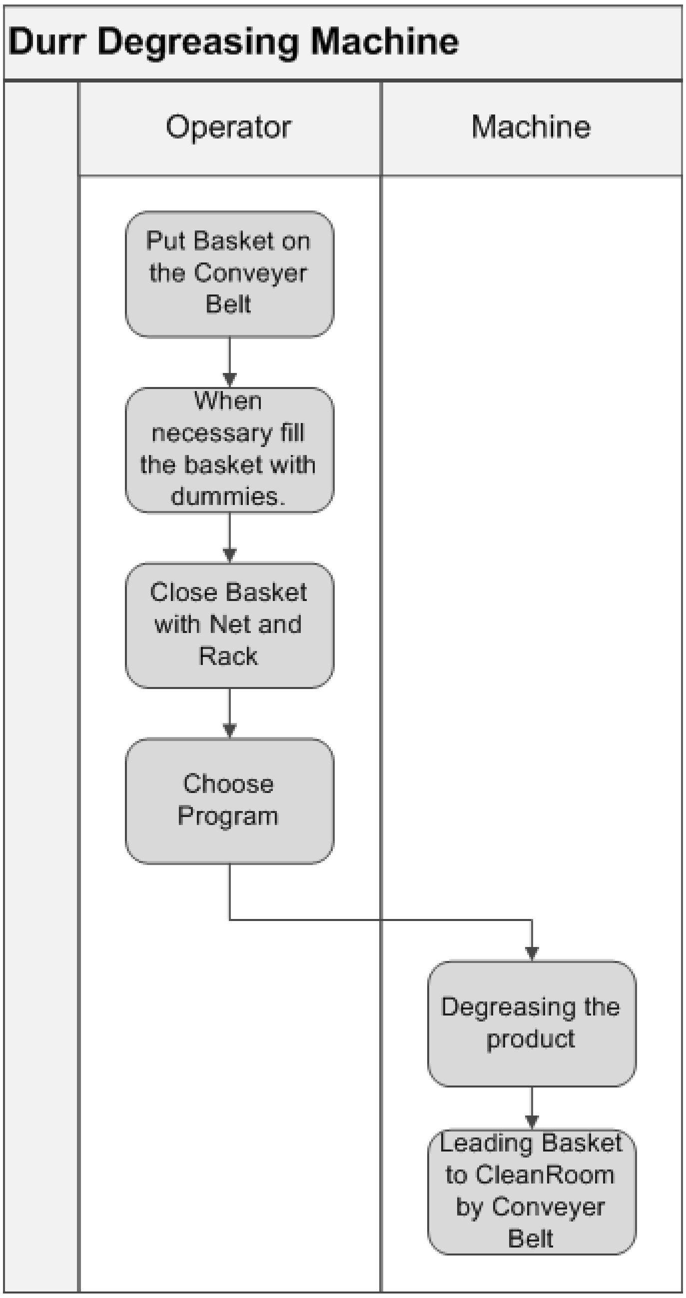
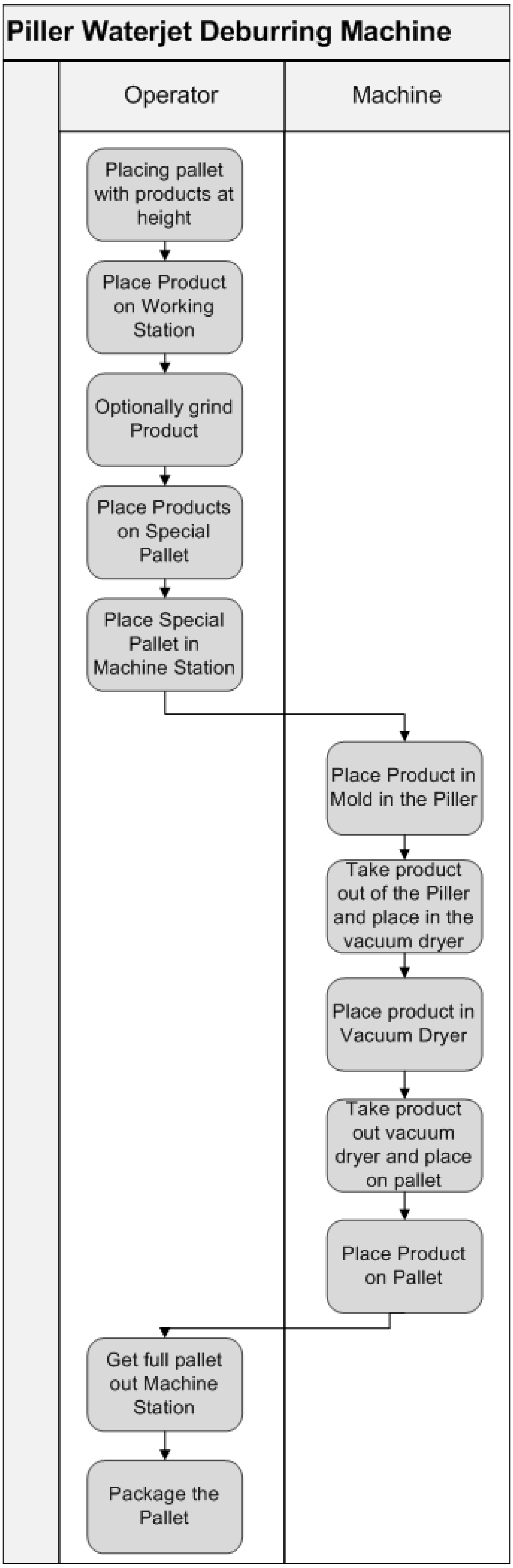
Appendix.

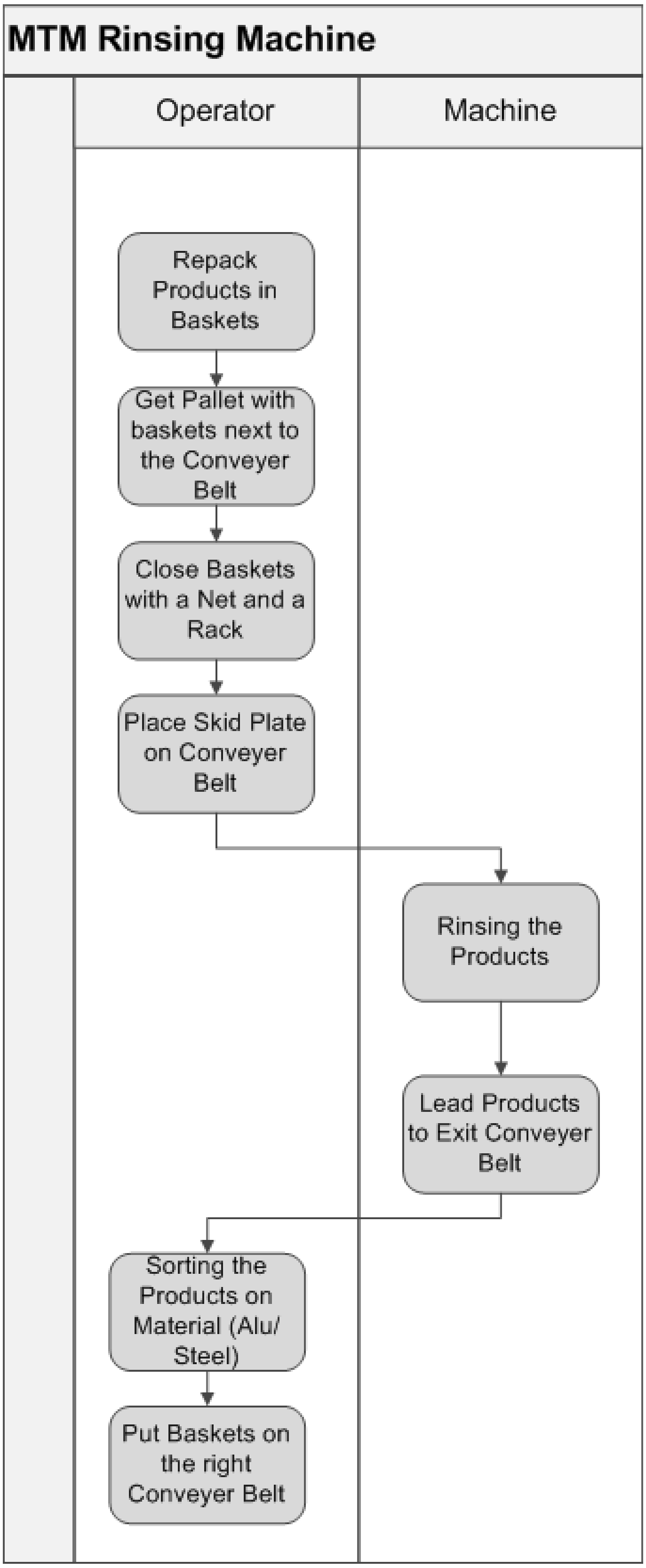
Appendix 1: Flowchart Durr



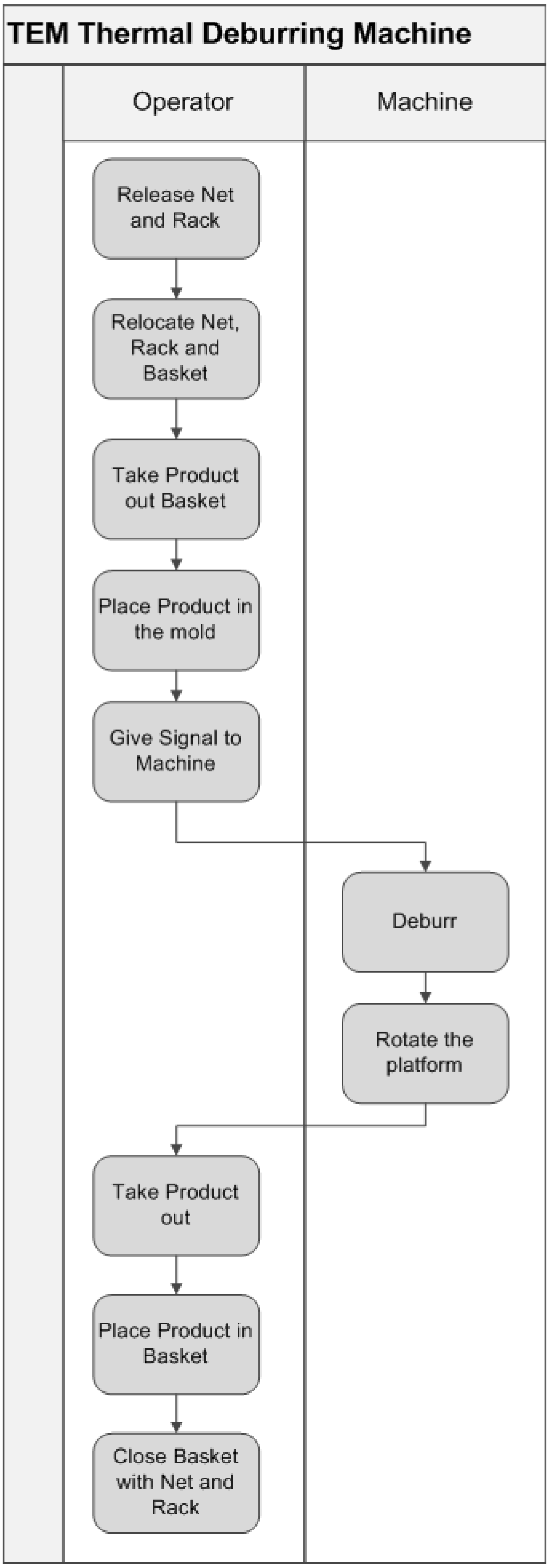
Appendix 2: Flowchart Piller



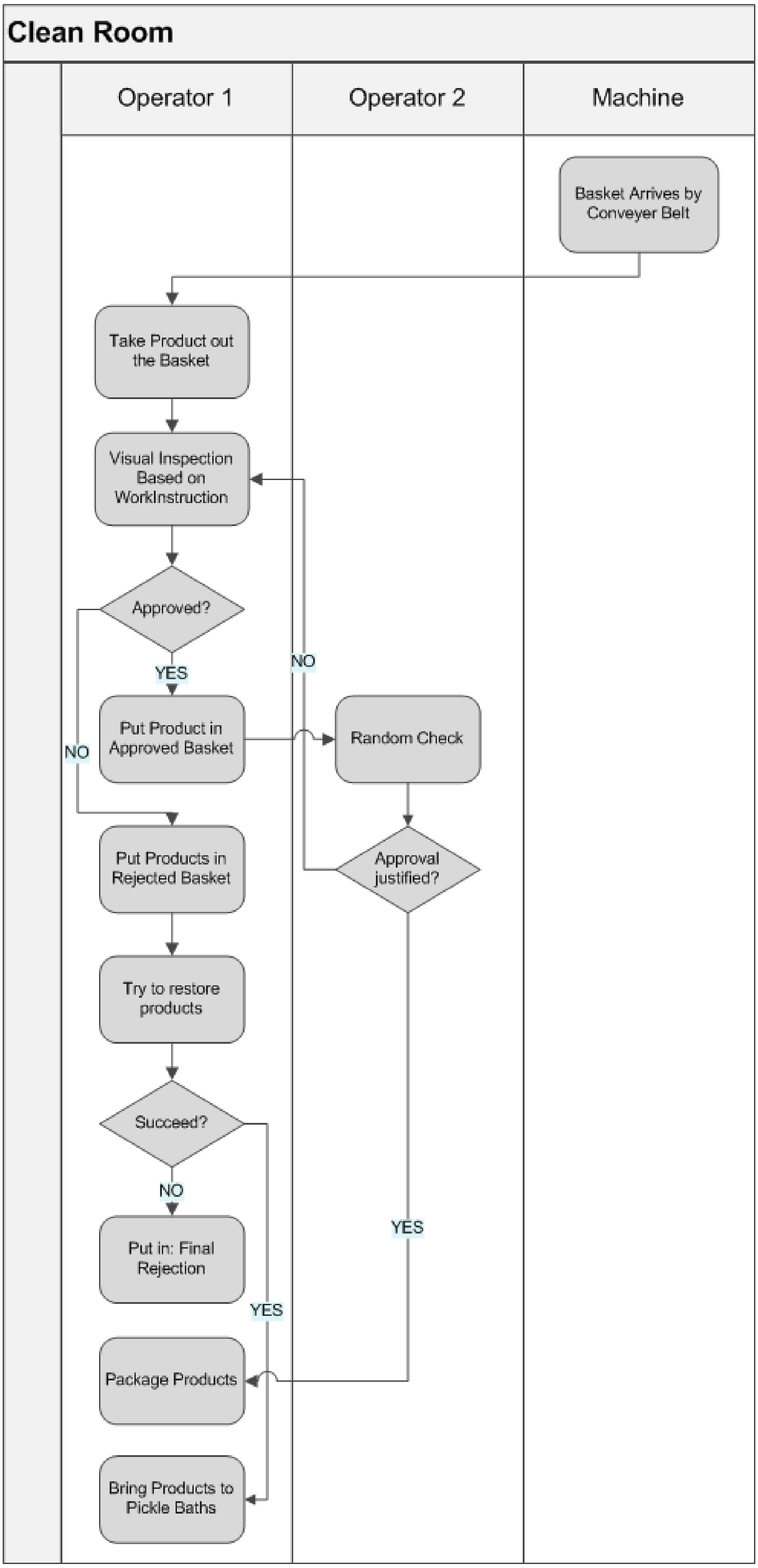
Appendix 3: Flowchart MTM



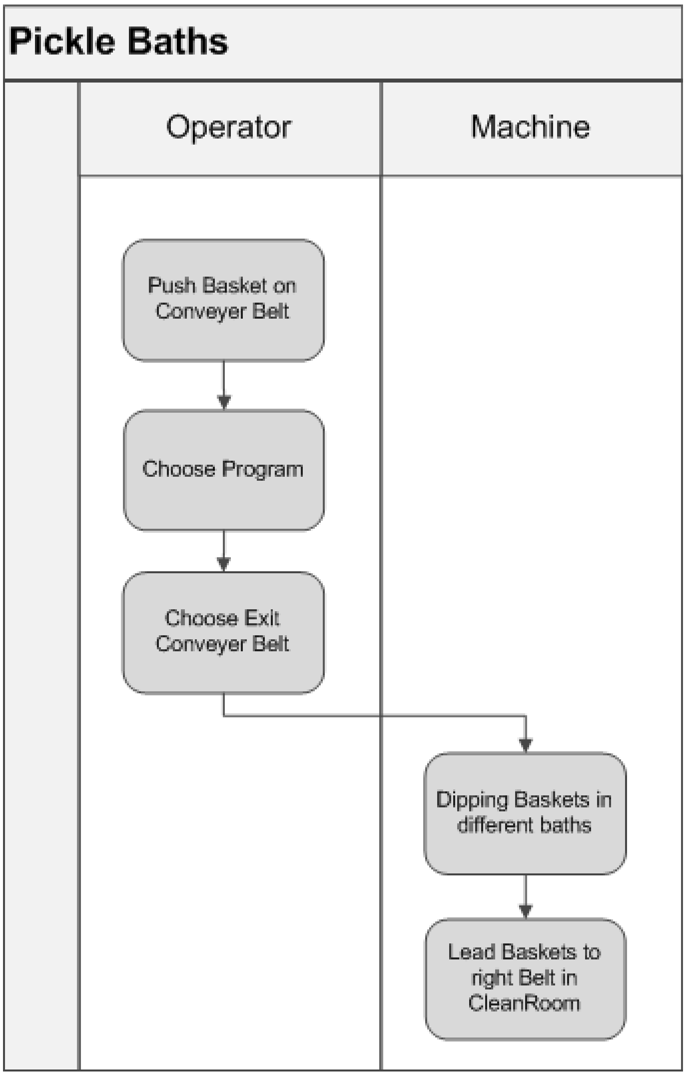
Appendix 4: Flowchart TEM



Appendix 5: Flowchart Clean Room



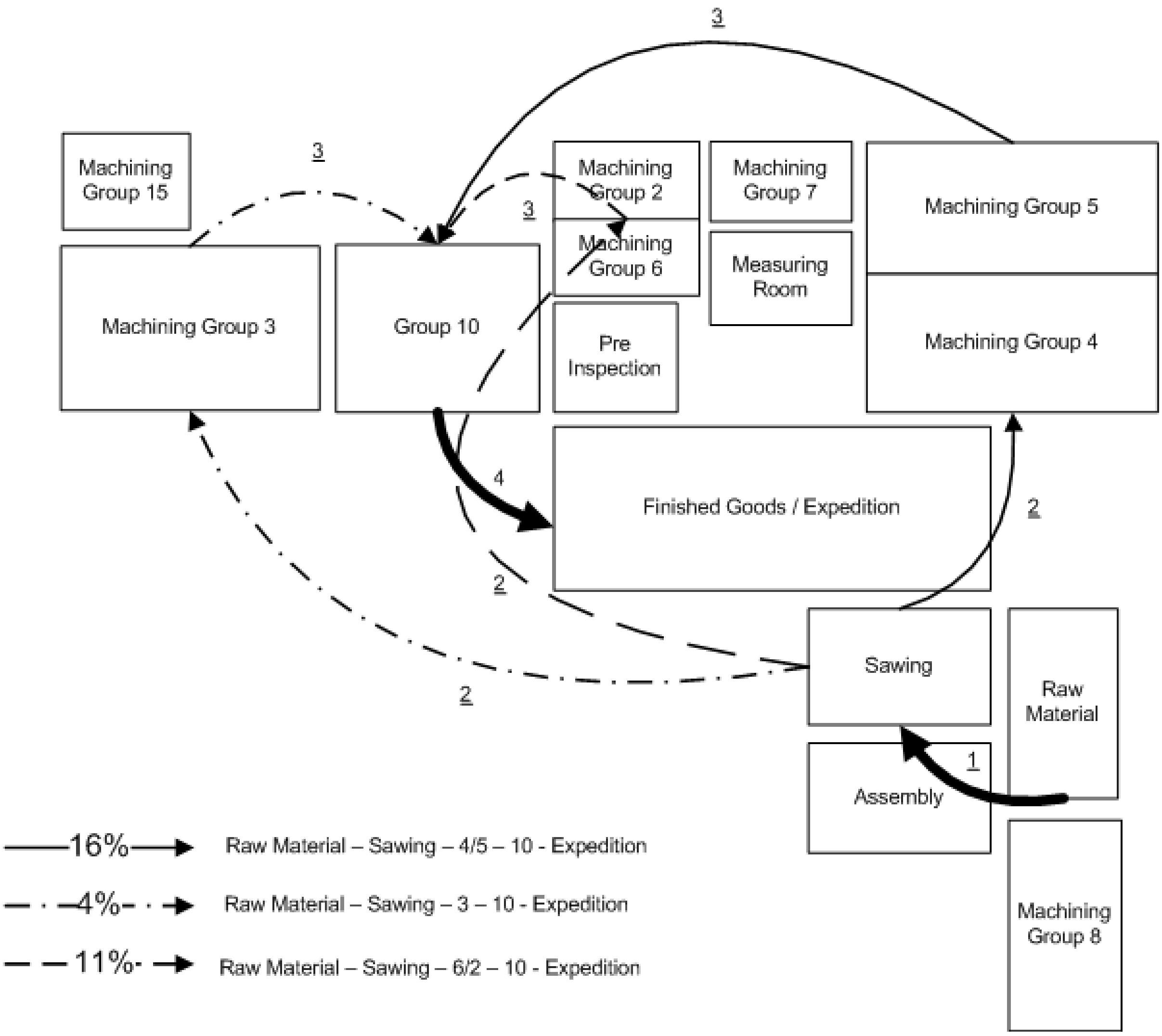
Appendix 6: Flowchart Drent Pickle Baths



Appendix 7: Flow paths within the factory

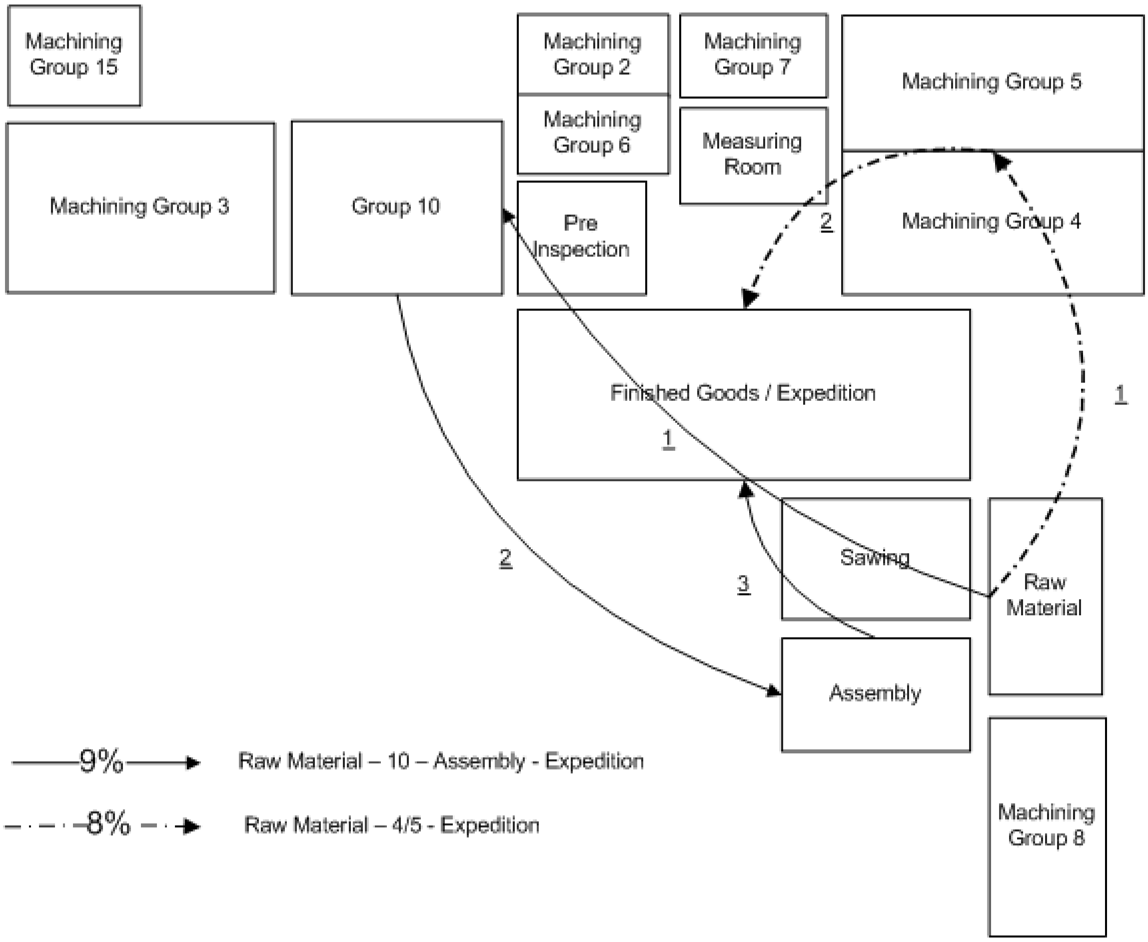
Appendix 7.1: Flow paths within the factory 1/4

The following figure shows three types of paths within the factory. The paths starts at raw material inventory, second is the sawing department. At the sawing department the paths are scattered. The arrows in combination with the numbers show the routing of the products. The given percentages are the rates of sales which follow the specific path.



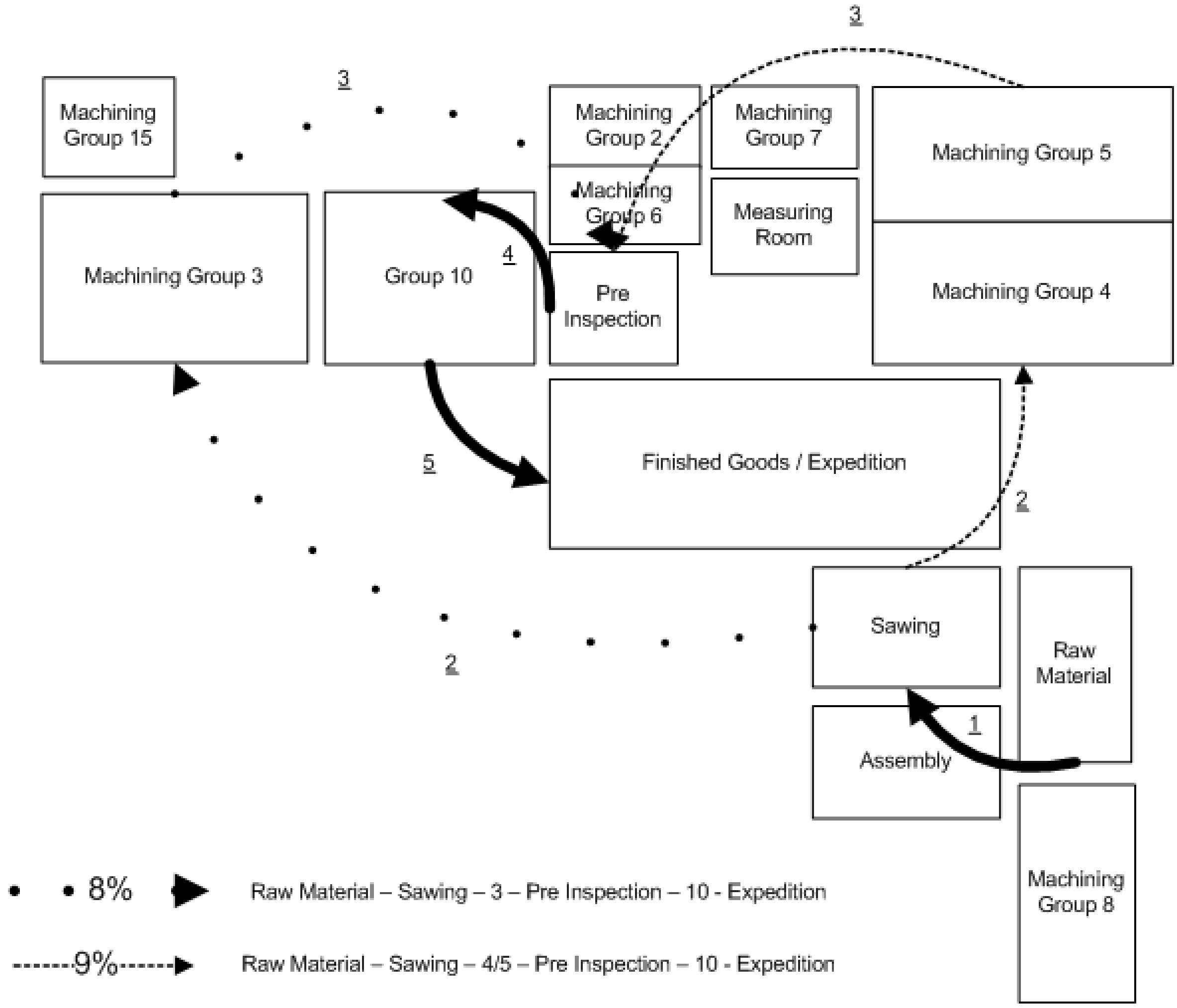
Appendix 7.2: Flow paths within the factory 2/4

The following figure shows two types of paths within the factory. The paths starts at raw material inventory. The arrows in combination with the numbers show the routing of the products. The given percentages are the rates of sales which follow the specific path.



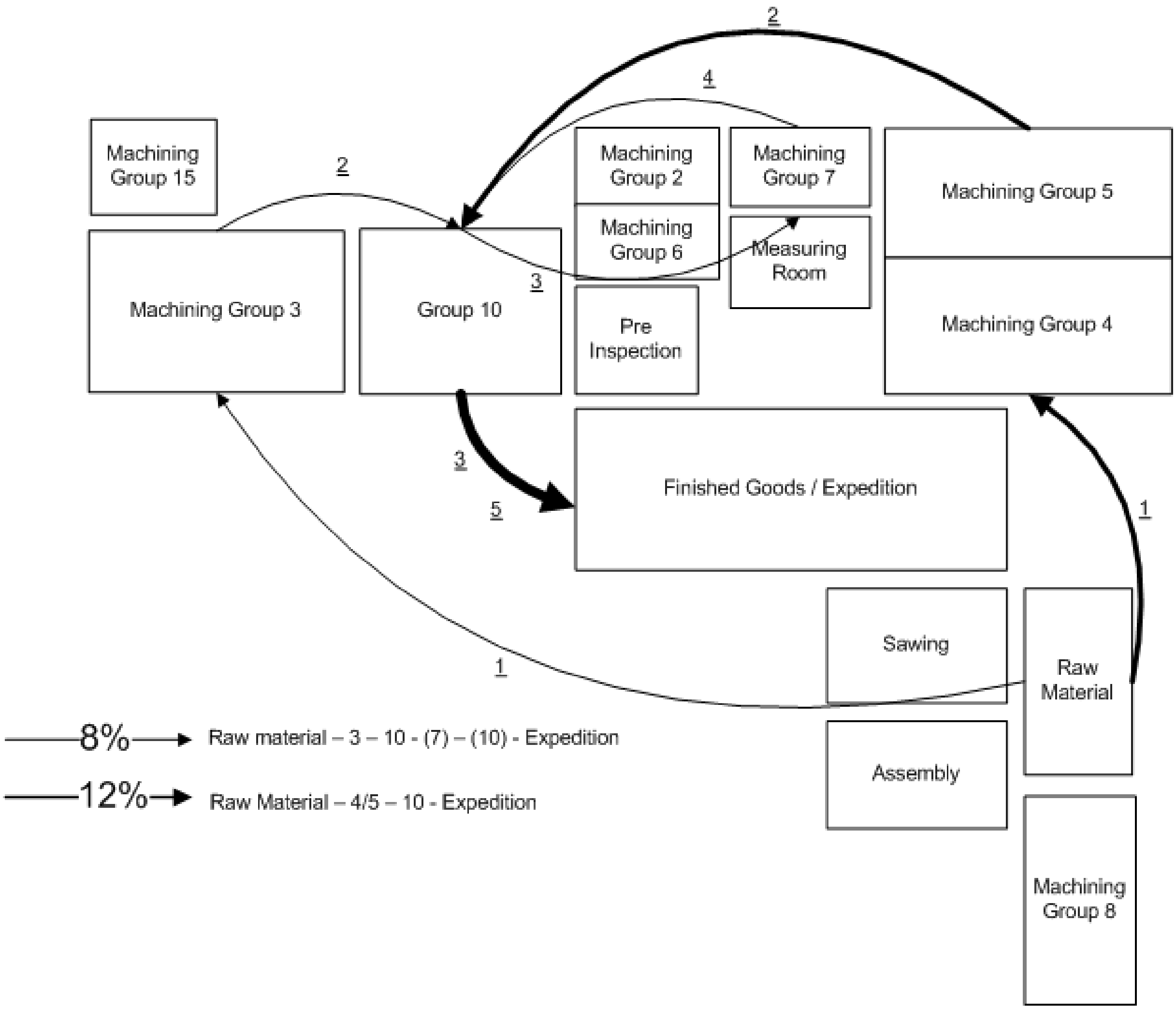
Appendix 7.3: Flow paths within the factory 3/4

The following figure shows two types of paths within the factory. The paths starts at raw material inventory, than through the sawing department. At the sawing department the paths are scattered and at the pre inspection department they gather again. The arrows in combination with the numbers shows the routing of the products. The given percentages are the rates of sales which follow the specific path.



Appendix 7.4: Flow paths within the factory 4/4

The following figure shows two types of paths within the factory. The paths starts at raw material inventory. From there the paths are diffused. The arrows in combination with the numbers shows the routing of the products. At Group 10 the paths are gathered again. The given percentages are the rates of sales which follow the specific path.



Appendix 8: Value Information Form

Value Information Form							
				Date:	*A*	Nr. :	*B*
				Time			
#	Activity	Cat.	VA	Start	Finish	(s)	People
1	*C*	*D*	*E*	*F*	*G*	*H*	*I*
2							
3							
4							
5							
6							
7							
8							
9							
10							

A: Date of the observation day
B: Observation form number
C: Short description of the activity (e.g. visual inspection, rework, grinding, walking, searching)
D: Category of the activity (Inspection, Packaging, Rework, Other)
E: Is the activity adding value?
F: Time the activity starts
G: Time the activity finishes
H: Elapsed time between start en finish
I: Number of people working on the activity, and their department

Appendix 9: General remarks observation period Cleanroom

General remarks Cleanroom, noted during observation period.

NB: only observations are noted which did not occur earlier.

9/4/2015:

- According to employee: waiting for place at the restoring table is time consuming
- Employee is searching for stickers for almost five minutes
- Employees are waiting on the random samples test

14/4/2015:

- Five employees at the Cleanroom, but they cannot keep up with the pace of the Drent, the lanes are kept filled
- Confusion about which baskets belong to which order, the searching is time consuming
- Employees are relocating products because they are spread over different conveyer belts
- Jam on the conveyer belt because a basket is lead to a conveyer belt which is full, employee has to relocate the basket which is very heavy.
- Two people are restoring products at the same time, with only one drill and lamp, so they wait on each other between handlings.
- Team leader is busy with collecting packaging materials for the employees.
- Confusion because restored products are lead to the wrong conveyer belt.
- A basket is lead to a different conveyer, but the conveyer belt with the rest of the order is not full.
- According to the computer lane 4 is empty, but in reality there are 3 baskets on that lane. Asked the operator at the Drent: ‘’we stuff it full’’.
- In the afternoon just two employees, instead of five in the morning
- Again confusion because the products cannot be identified
- A batch with packaging material is dumped in front of the Cleanroom, the team leader is almost 15 minutes busy with relocating the materials.

15/4/2015:

- Two times baskets of the same order are transported to different lanes, not because the lanes are full, there is room enough.
- Searching for work instructions from 09:43 till 09:47 with two employees.

16/4/2015:

- The Drent has a malfunction, therefore the delivery of baskets is shut down. The employees at the Cleanroom now that and are slowing down their pace.
- An order containing four baskets is spread over three different lanes. Asked the operator how that possibly can happen, he do not know the answer and certainly he do not care.

17/4/2015:

- Two employees are restoring at the same time, this does not work properly, a lot of time is wasted with waiting and maneuvering around each other.

22/4/2015:

- An employee is waiting in front of the restoring table, because is occupied.
- 3,5 of the 4 lanes are full with products for the firm Integral, but only the team leader has the skills to inspect these products. Therefore the other employees are slowing down the pace because they do not want to go to pre inspection.

23/4/2015:

- Team leader busy with requesting packaging materials at expedition.

24/4/2015:

- One employee is already three hours busy with deburring products of one order. Asked the team leader if this deburring cannot be done at the machine: ‘’that should be done at the machine, but they have not done it’’.

Appendix 10: Random Sample research form

Research Clemens

Date	Drawing number	# products checked	# products in order	# restore products	# faults and type of damage

Appendix 11: Concept improvement plan presentation

Figures removed for competitive considerations

Appendix 12: Recommendations improving new bottleneck

Three recommendations on improving the capacity of the bottleneck are introduced in this section. These recommendations are based on the observations done at Group 10 during the main research and recommendations introduced in Section 5.7.. The first recommendation is also mentioned in the research on the previous bottleneck, the Cleanroom. Recommended is to determine order quantities based on the maximum number of products which fit a cleansing basket and subordinate the other factors in the determination process. Cleansing only maximally filled basket results in a lower average cycle time and more products can be cleansed in the same amount of time. The second recommendation is to experiment with the cleansing times of the different programs, these programs are determined based on cleanness tests executed six years ago. The most used cleansing program takes seven minutes to cleans a basket, others take just five or two. To improve the capacity without investing in a second machine the cleansing times of the MTM machine needs to be lowered and tested for cleanness approval. The third recommendation is to include the MTM machine in the 24-7 production schedule instead of the two shift schedule, this will result in a capacity increase because the active time of the machine increases, the downside of this is that it is capital intensive.