A contingency framework of the manufacturing bottleneck of manholes and the improvement of half round channel production

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University of Pretoria
UP Student 28007809

Executive Summary

This is a report on the production improvement at Rocla, a precast concrete company specializing in large concrete products. There are two sections to this project. The first section concentrates on the entire process improvement of the Half round channel production by increasing the throughput in a way that the demand per month can be met. The other section concerns the manholes post stripping process and eliminating the bottleneck. The report focuses mainly on the tools that will be used to find the problem and solve it. The quality defects of the products have been inspected too.

Table of Contents

Executive Summary 2

Table of Figures 5

CHAPTER 1 6

1.1 Introduction 6
1.1.1 Background of Products 6
1.1.2 Problem that occurs with product 6

1.2 Problem Definition 6

1.3 Project aim 6

1.4 Project Scope 7

1.5 Deliverables 7

1.6 Project plan 7
1.6.1 Activities and Task 7
1.6.2 Resources 7
1.6.3 Budget 7

CHAPTER 2 8

2.1 Literature Review 8
2.1.1 Lean Manufacturing 8
2.1.2 Value chain 8
2.1.3 Theory of Constraints 9
2.1.4 Quality control 10
2.1.5 Simulation 10

2.2 Conclusion 10

CHAPTER 3 11

3.1 Project environment 11

3.2 Data Analysis 13
3.2.1 Value chain analysis 15
3.2.2 Quality Control 19
3.2.3 Simulation 20
3.2.4 HRC monthly demand and production 21

CHAPTER 4 23

4.1 Recommendation 23
4.1.1 Manholes 23
4.1.2 HRC process 26
4.2.3 Quality 26

CHAPTER 5 27

5.1 Conclusion **27**

Appendix **28**
Appendix A: Gantt chart 28
Appendix B: Time Studies 29
Appendix C: Simulation data 30
Appendix D: HRC Invoiced and Produced data 31

References **32**

Table of Figures

TABLE 1: ACTIVITIES AND TASK 7
TABLE 2: BUDGET 7
TABLE 3: ACTIVITIES IN MANUFACTURING 9
TABLE 4: QUANTITY HRC PRODUCED AND SCRAPPED. 19
TABLE 6: ADVANTAGES AND DISADVANTAGES OF THE SHAFT PYLOP MECHANISM AND CHAIN GRIP BEAM. 24

FIGURE 1: THE PRODUCT FLOW AREA LAYOUT OF THE HRC 11
FIGURE 2: FLOW LAYOUT OF THE MANHOLE FINISHING AREA 12
FIGURE 3: AFTER THE PREVIOUS NIGHT'S SHIFT THE WORKER IS GREETED BY A LOT OF PRODUCTS. 13
FIGURE 4: VALUE CHAIN ANALYSIS OF THE STRIPPING AND ASSEMBLY PROCESS OF THE HRC. 16
FIGURE 5: VALUE CHAIN ANALYSIS OF THE CASTING PROCESS. 17
FIGURE 6: VALUE CHAIN ANALYSIS OF THE CUTTING PROCESS. 18
FIGURE 7: THE HANDLE ON THE SIDE OF THE HRC. 19
FIGURE 8: DEFECTS CAUSED BY THE HANDLE PART INSIDE THE MOULD. 19
FIGURE 9: ARENA PROCESS FLOW MODEL USED TO FIND OPTIMUM OUTPUT. 20
FIGURE 10: CHAIN GRIP BEAM 23
FIGURE 11: SHAFT PYLOP MECHANISM 23
FIGURE 12: PRODUCT STACKING EXAMPLE. 24
FIGURE 13: PROPOSED LAYOUT FOR MANHOLE PRODUCTION. 25
FIGURE 14: CURRENT AND PROPOSED HANDLES. 26

GRAPH 1: AVERAGE PROCESS TIMES ON THE MAIN PROCESS OF THE HALVE ROUND CHANNEL PRODUCTION. 13
GRAPH 2: AVERAGE PROCESS TIMES AFTER THE STRIPPING OF THE MANHOLES. 14
GRAPH 3: THE CRANE PROCESS DIVIDED INTO ITS OPERATION TIMES AND COMPARED TO EACH OTHER. 14
GRAPH 4: THE CASTING PROCESS DIVIDED INTO ITS OPERATION TIMES AND COMPARED TO EACH OTHER. 15
GRAPH 5: THE GRAPHED DATA FROM THE SIMULATION 20
GRAPH 6: THE AMOUNT OF 300MM HRC UNITS INVOICED AND PRODUCED MONTHLY. 22
GRAPH 7: THE AMOUNT OF 375MM HRC UNITS INVOICED AND PRODUCED MONTHLY. 22

Chapter 1

1.1 Introduction

1.1.1 Background of Products

Rocla is currently producing manholes for various clients. The manholes they produce act as compartments which are installed on regular intervals together with a pipeline to provide an opening to enter for any relevant reason, if inspection or work on the pipeline is needed. The manholes are produced from Reinforced Precast Concrete and work with an interlocking joint profile for fast and effective installation on site. The joints can be sealed with a sealant in order to make them watertight. Iron steps can also be moulded into the manhole for easy entering and exiting of big enough manholes. The standard sizes for a manhole ranges from lengths of 250mm, 500mm and 1000mm and diameters of 750mm, 1000mm, 1250mm, 1500mm and 1800mm. Special order sizes can be accommodated. These products are usually designed and constructed by Rocla's own technical team on an ad hoc basis. The demand for manholes is roughly about 400 a month depending on the economy and the contracts Rocla has to fulfil. The most popular at present is the 1000mmx1000mm manhole and a variation of the original design has been made to supply an order to a company.

The half round channel (HRC) is produced for customers for the use of guiding excess water alongside roads and buildings. It uses the same joint as an IJ(interlocking joint) which makes it easy to join these channels into an existing pipeline. The HRC are available on standard in the following sizes: 300x1220, 375x1220, 450x2440 and 600x2440. If needed be, they can be ordered and made in any size necessary. They are manufactured in the same manner as normal IJ pipes but a vertical divider ring separates the product in the middle when casted. A V-form is welded into the mould horizontally in order to ease the cutting process. So in short one IJ pipe can produce four HRC. The HRC is in huge demand and the amount averages at 3000 units per month. But at present there is 7000 on order.

1.1.2 Problem that occurs with product

Because the manholes are produced in a normal IJ pipe it is possible to make multiple products in one mould. After the product has been stripped it is moved to the finishing area. The product then gets washed, patched and a number of other finishing process before sent to the yard. The finishing process is always packed with products and decreases the throughput. The process should be evaluated and the bottleneck should be eliminated.

The HRC was always mainly produced at the Orkney branch but head office felt that due to its close positioning to the Roodepoort branch (which is a much bigger branch) it has to be closed down and the production for the HRC has been shifted to the Roodepoort branch. The production can presently not keep up with the existing demand and the addition of the Orkney demand.

1.2 Problem Definition

The company is currently experiencing the following two problems:

- Manholes throughput time post stripping is too high.
- HRC production amount is too low.

1.3 Project aim

The project aim can be stated by the following three points:

- To evaluate the process of the manholes entering the finishing area and finding a method to improve the throughput and eliminate the bottleneck.

- To inspect the current production process of the HRC and increase the production output.
- Both should be done at minimal cost

1.4 Project Scope

The evaluation of the Half Round Channel production process together with the improvement of Manhole product flow after stripping. For both an in-depth study will be executed to evaluate the current process times. The process will then be simulated and the result studied in order to determine where the problem/s are and where they might be located. If the problem/s are resolved improved production and quality of products will be expected.

1.5 Deliverables

- Alternative methods that can be used for the production of HRC
- An improved post stripping process for Manhole section

1.6 Project plan

1.6.1 Activities and Task

Activity and Task	Reason
Taking time studies	For data collecting purposes
Following Process Step by step	To understand flow of process and note the value being added by every worker
Collecting HRC scrap amount	For quality management purpose
Simulate studies	To find the problems
Apply Problem Solving Techniques	To find and solve problems

Table 1: Activities and Task

1.6.2 Resources

- Rocla facility
- Transport vehicle
- Stop watch and time study sheets
- Arena Simulation
- Quality sheets

1.6.3 Budget

Activity	Amount
Fuel	R 1200
Stationary	R 250
Printing and Binding	R 800
Internet	R 150

Table 2: Budget

Chapter 2

2.1 Literature Review

2.1.1 Lean Manufacturing

The main and most important purpose of the Toyota Production System (TPS) according to Taiichi Ohno (President of Japan Industrial Management Association in 1983) is to increase productivity and reduce costs (Monden, 1983). This system was started after World War II by Toyota to get ahead of the Western Nations' automotive industries seeing that they did not have the advantage of funds or facilities. This system used the Just-in-Time approach which is an integrated set of activities designed to achieve high-volume production using minimal inventories of parts that arrive at the workstation exactly when they are needed(Jacobs, 2009). But lean manufacturing (LM) does not work for every company that wants to increase their production and throughput. According to Gurumurthy & Kodali (2009) there is not only a lack of employee education on what lean production entails but managers also fail to understand the following:

- How to implement LM;
- What changes will happen in the organisation when it gets transformed by the implementation of LM;
- How LM will affect the performance measures of an organisation.

One of the effects LM has is inventory turnover. In a study done by Demeter and Matyusz (2008) it is founded that lean companies keep fewer inventories of any type. This means for a company to go lean the availability and lead time of certain inventories should be assured.
Another valuable part in LM is the Just-In-Time production system. The JIT production systems means that only what is needed is produced and it is produced when it is needed, no more and no less. This applies for repetitive products that are produced similar and one after another. JIT does not require large volumes and can be applied to any repetitive segments of a business regardless of where they appear (Jacobs, 2009). This in the other hand leaves no room for faulty products when they arrive at the next station. Quality at source is very important. If a product is faulty it will slow down the whole production line because there is no extra products to fill the defective part's position.
Uniform Plant Loading or also known as heijunka is smoothing the production flow to dampen the reaction waves that normally occur in response to schedule variations (Jacobs, 2009). Toyota found that producing small batches makes it easier to adjust the final assembly without sending magnified changes through the whole production and supply line.

2.1.2 Value chain

The usage of the Value chain approach was a method that was first introduced by Michael E. Porter who used it as a tool for identifying ways to create and add customer value. The idea of Value chain analysis is to identify the activity areas where value gets added or reduced in a process of producing products or delivering services and then to compare them with the business's performance (Nieman, 2002). This view point is a very business perspective view but by altering the tool it can be applied to any engineered process. The idea is to develop a detailed diagram of a process that clearly shows those activities that add value, activities that do not add value and the steps that just involve waiting (Jacobs, 2009).
As stated by Langley (2003) the value chain concept has been developed as a tool for competitive analysis and strategy but adapting this idea it can be used to explain to everybody how they are involved in the business. The Japanese edited the Value chain concept into Value stream mapping (VSM) or Value chain mapping (VCM). Value stream mapping described by Jacobs (2009) is widely used as a means of eliminating waste in a supply chain. According to Monden (1993) there are three types of activities in an manufacturing process when demonstrated in VSM:

Type of Activity	Explanation and Example
Non-Value adding (NVA)	Unnecessary actions that have no effect on the value of the product, ex. Waiting time.
Necessary but non-Value adding (NNVA)	Actions that have to take place but have no effect on the value of the product, ex. Unpacking deliveries.
Value Adding (VA)	This is the evolving of raw or semi-finished goods by the use of manual labour, ex. Sub-assembly of parts.

Table 3: Activities in Manufacturing

The first two activities (NVA & NNVA) should be eliminated completely. Also identified by the VC is wastes. There are seven common accepted wastes in the TPS according to Hines & Rich (1997). They are:

- Overproduction
- Waiting
- Transport
- Inappropriate processing
- Unnecessary inventory
- Unnecessary motion
- Defects

These seven wastes are easily highlighted by the VC and if the chain is targeted at the floor workers their mistakes can easily be seen and fixed internally.

2.1.3 Theory of Constraints

The TOC concept has been introduced by Eli Goldratt in the 1980 and the framework of this concept is the fact that in any organisation there are constraints that limits them from achieving their goals (Motwani & Vogelsang, 1996). Goldratt's five-step focussing process for improving a company's overall productivity are:

1) Identify the system's constraint(s).
2) Decide how to exploit the system's constraint(s).
3) Subordinate everything else to that decision.
4) Elevate the system's constraint(s).
5) If a constraint has been broken in the previous step, go back to step 1.

TOC together with Six sigma and lean manufacturing is part of continuous improvement (Jacobs, 2009). TOC is different in the way that it concentrates its improvement efforts only on the operation that is constraining a critical process or on the weakest component that is limiting the performance of the system as a whole. These elements must be properly manage in order to ensure that the whole system is synchronized and flows. A system consist of a few elements or processes working in a specific order towards a goal. According to Blanchard (1981) a system is a set of interrelated components functioning together toward some common objective or purpose. In order to reach that common goal the focus should be on the optimization of the entire system and not singular element in the system.

The process must be in harmony and flow without favouring one element even the final one. Therefore when a system is measure it must be measured as a total system, but when the one element is constraining the system that whole system, focus should be placed on that element to optimize it into the system and not on its own. One tool that is used to identify the process's constraining element is line balancing. This tool is used to identify the slowest activity which acts as a constraint for the production cycle time.

2.1.4 Quality control

Quality control is the use of techniques and activities to achieve, sustain, and improve the quality of a product or service (Besterfield, 1986). Due to the increase in today's global market quality control is mostly seen as a part in a product life cycle that needs to be done in order to keep customers happy. But accordingly Gitlow (2005) stated that a company increased their production by merely decreasing the amount of defected products that were produced. Statistical quality control is a subdivision of quality control. Besterfield (1986) describes it as the collection, analysis and interpretation of data for the use in quality control activities. Statistical studies make use of attribute and variable control charts. Attribute charts are used for situations where the data is based on counts or the number of times we observe a particular event (Gitlow, 2005). Variable charts are based on data that can vary with each observation, numerical measurements like time, speed and length.

The influence of the improvement of quality is underestimated or unknown to many companies. Many companies believe in order to increase production the need for producing more products are necessary but this is not always the case. A factor that played a role in the TPS is the quality of the products at every section. This is where the term Quality at the source was first practised. Quality at the source means that the person that does the work takes responsibility for making sure that his or her output meets specifications (Jacobs, 2009). A case study in Gitlow (2005) has proven that by only minimising the defected products produced the production increased. The study also showed that when the amount of products produced was increase more products needed to be scraped and production declined. The problem was identified by making use of the control charts. This goes to show that by using Quality control to find faults and fixing them can increase production.

2.1.5 Simulation

Simulation according to Kelton (2010) was first done by hand in the 1700-1800. It has naturally developed into a more complex tool even developing its own language. But with the complexity comes a great benefit doing simulation modelling. If done accurately simulation can result in a company saving money by highlighting problems without influencing a process. Simulation is particularly appropriate to situations in which the size or complexity of the problem makes the use of optimizing techniques difficult or impossible (Jacobs, 2009). Different process flow can also be tried and results can be listed saving money and time. Although the results are not certain the modelling gives an estimate to the company that is very accurate. Many companies tend to simulate projects early on in the product life cycle where it could have the greatest effect (Kelton, 2010).

For many years Arena was the main simulating program for many Industrial Engineers, but other programs like Simio and AnyLogic has come into play. Arena uses SIMAN code language and can be present in 2D animation. Arena is typically used for facility design/configuration, scheduling and passenger and bag handling processes. AnyLogic is more used for forecasting, strategic planning, process analysis and process optimization. Both AnyLogic and Simio is presented in 3D which makes the presentation much more capable to win people over because of the impressive look. Presenting a project with animation helps a engineer to sell the project as well cause the managers can follow the process and actually see how the project has improved a system.

2.2 Conclusion

From the literature it can be seen that the problem can be solved by making use of Value chain analysis, simulation, theory of constraint principles and applying lean manufacturing principles.

Chapter 3

3.1 Project environment

There are two areas that are relevant to the project. The manholes post-production area and the HRC production area.

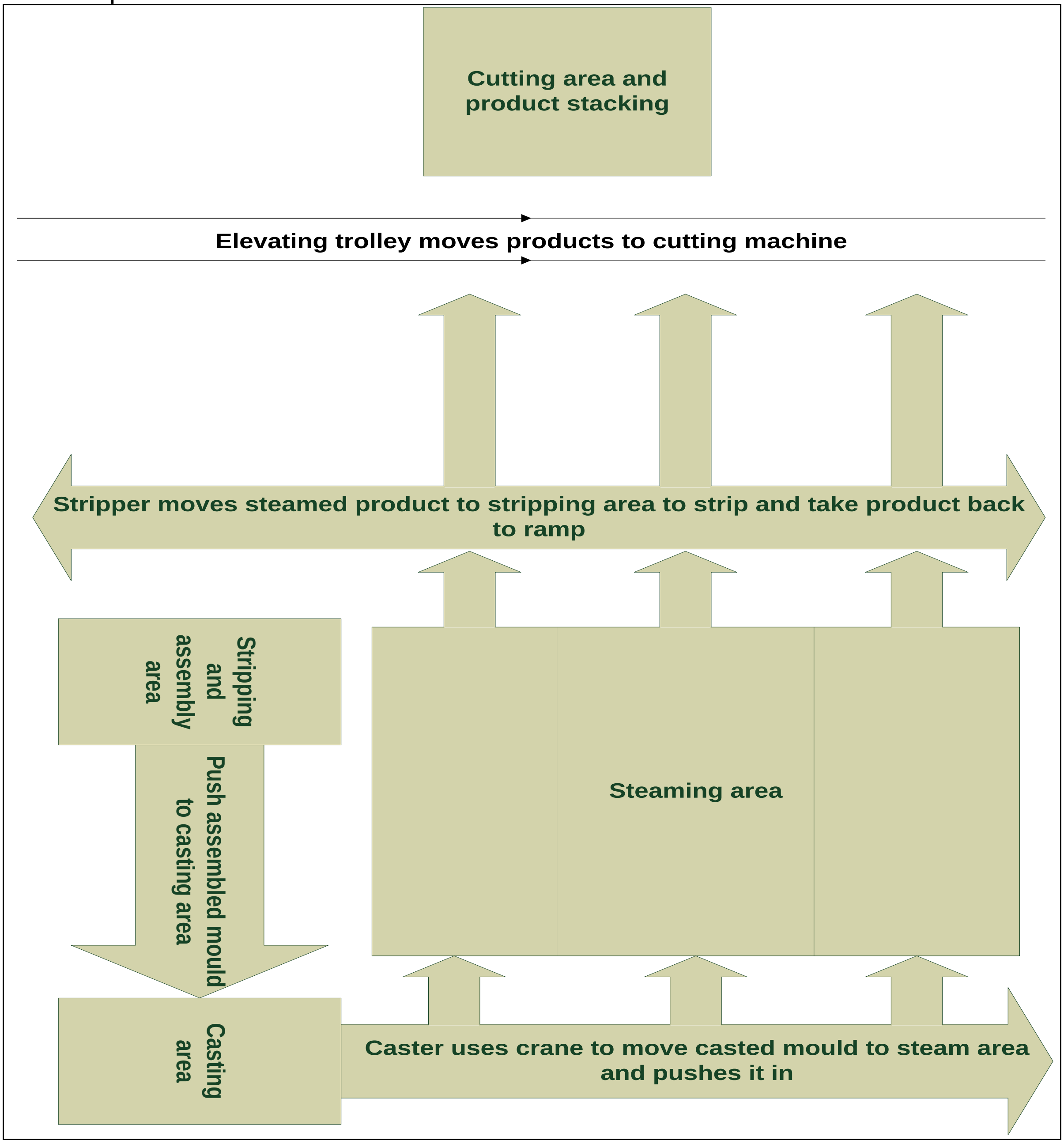


Figure 1: The product flow area layout of the HRC

The HRC moulds are moved around on a rail with skates which makes it easy to push to the next section. The skates are loose so they must be handled externally from the mould. When the last product is pushed into the steam area they are left there for the next shift to remove them and start the stripping, assembling and casting process.

The manhole finishing area is not a very large area but it is more than efficient enough to host the manholes for the finishing process. The finishing area involves scraping, patching, washing, grinding, as well as stencilling the product. After this is done the product is moved by hand to the tilting machine. The products may not exceed 2m in height for safety reasons, because of this reason the tilting device can only stack up to 2m. The manholes are tilted onto skates and then pushed into the yard. When the yard's rail is full the products are moved by the overhead crane to their relevant stacking area.

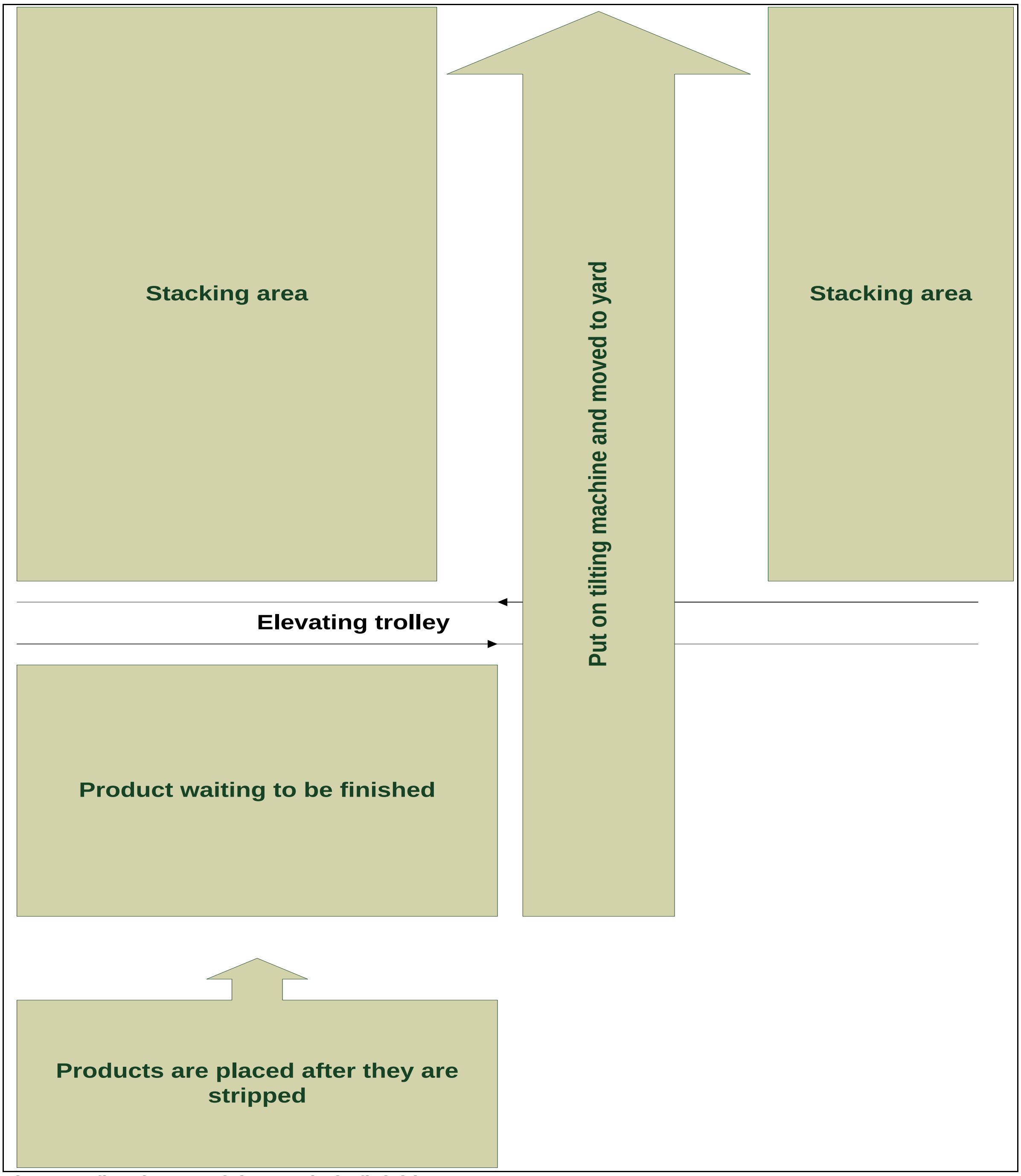


Figure 2: flow layout of the Manhole finishing area

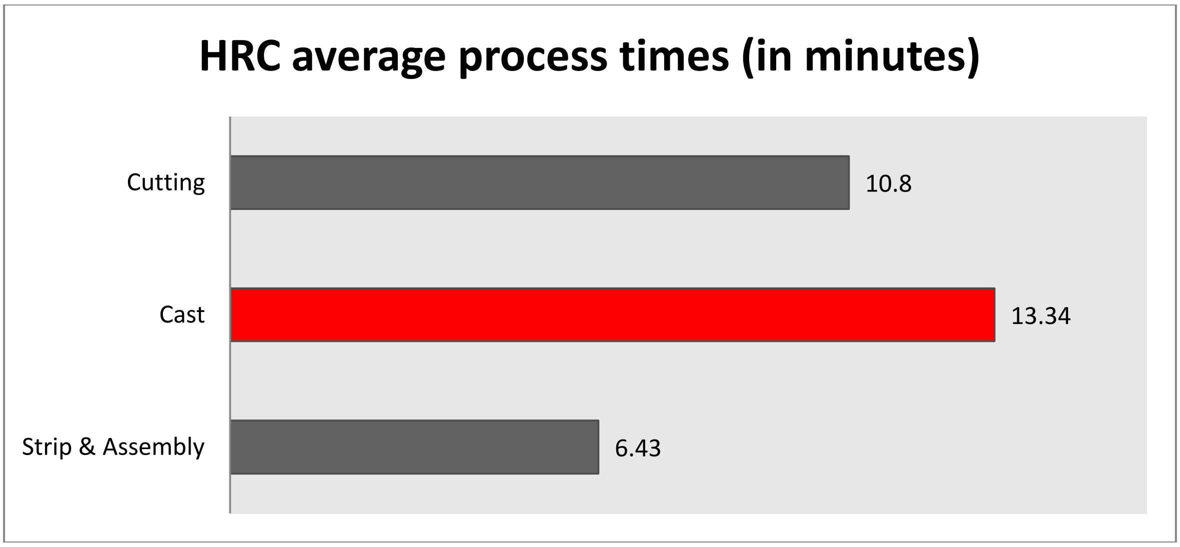
The manhole area is always stacked with the previous shift's product after they have been stripped and a bottleneck is formed as can be seen in figure 3.

Figure 3: After the previous night's shift the worker is greeted by a lot of products.

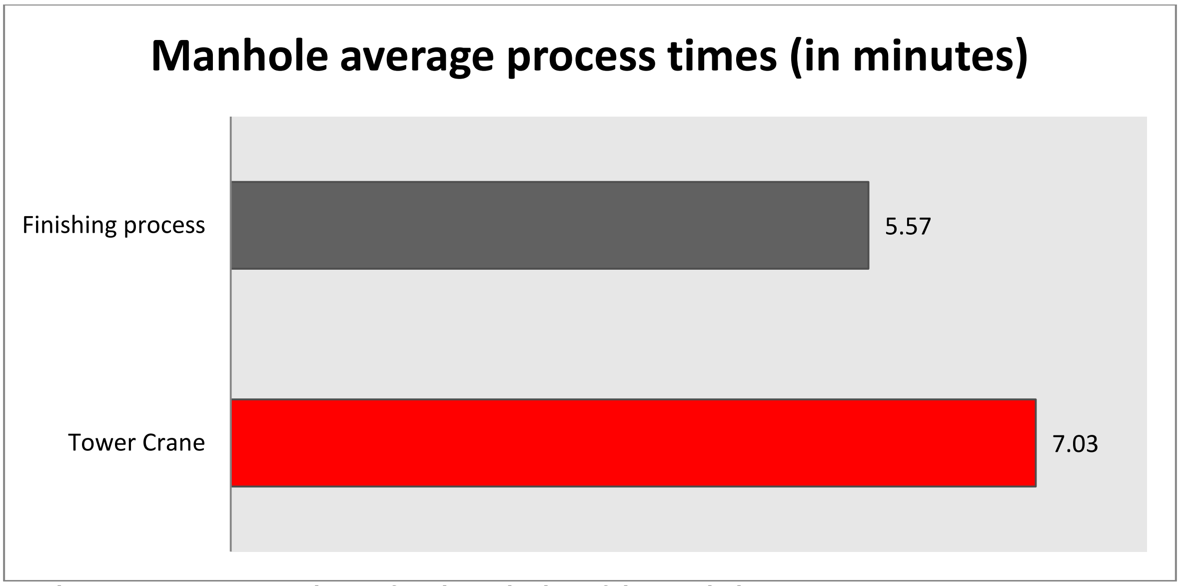
The worker struggles to work in this environment because he cannot move around freely to do what is required from him. This bottleneck slows down the throughput because the product cannot be loaded onto any transport vehicle from the finishing area.

3.2 Data Analysis

Data has been capture by making use of Time study methods. A minimum of 10 studies was taken and the sheets are included in the Appendix. All the times were then converted to charts (Figure 1.1 and 1.2) to better express and spot the time that is constraining the whole process. The times are compiled of the total time of each process

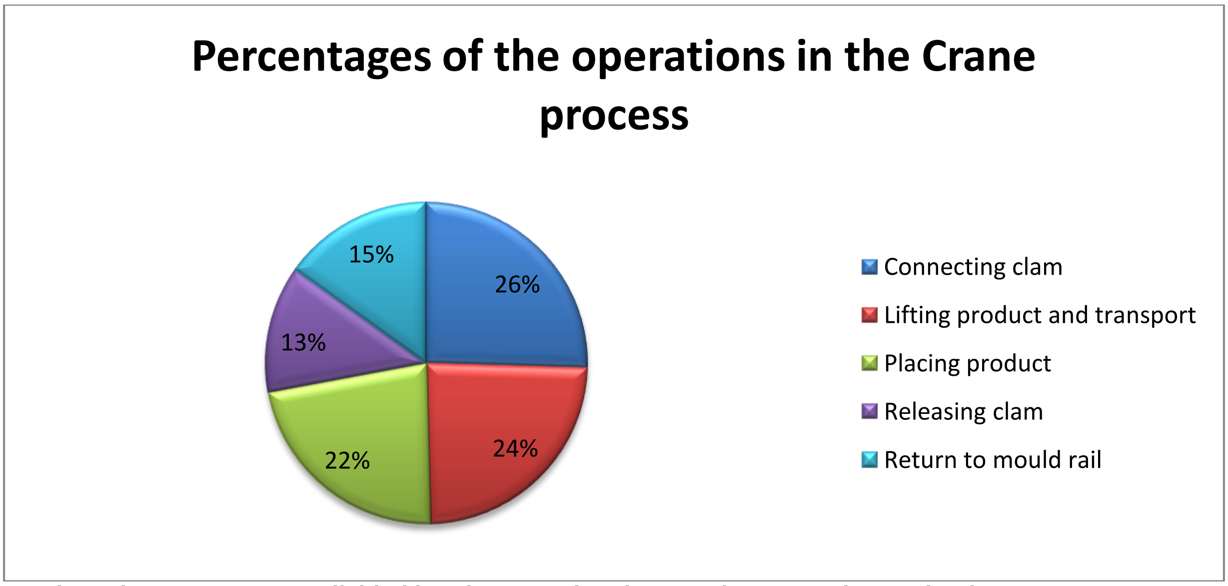


Graph 1: Average process times on the main process of the halve round channel production.



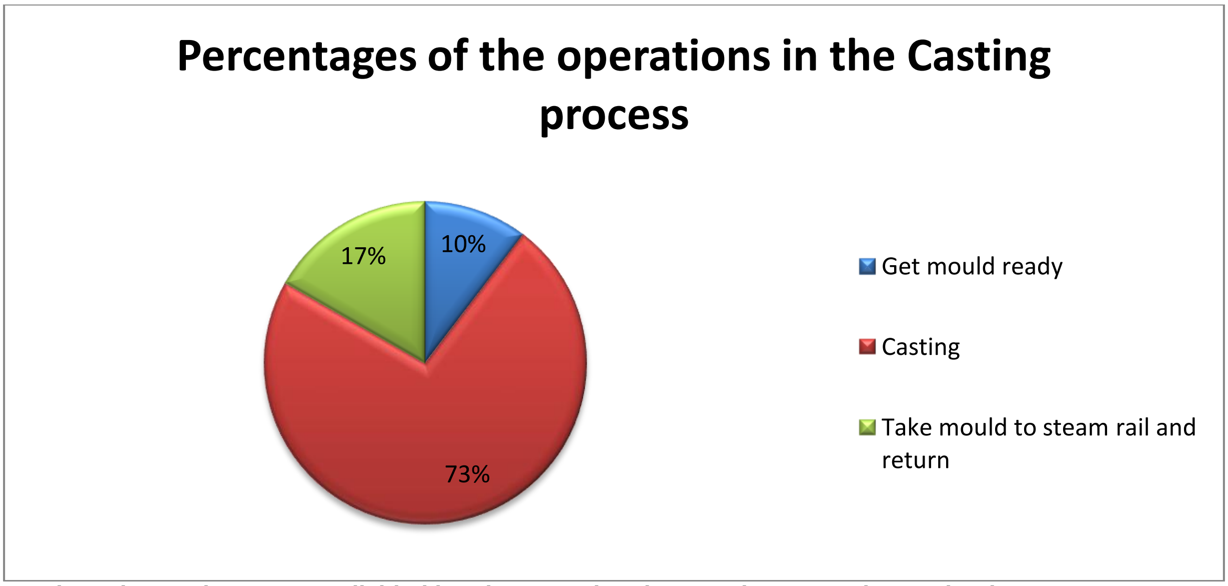
Graph 2: Average process times after the stripping of the manholes.

The constraining times have been put under attention to find the constraints in each process. The following data has been captured.



Graph 3: The crane process divided into its operation times and compared to each other.

As can be seen in graph 3 the connecting as well as the lifting and transporting of the product takes the longest and up to 50% of the total time of the whole process. The apparatus used for the transporting of the product is a c-clamp. The c-clamp is two big c shaped clamps that can be adjusted to the specific diameter, it is limited to one meter products in height. This clamp works with only the point friction when lifting the products. This concept has been used for a while and is designed by Rocla themselves.



Graph 4: The casting process divided into its operation times and compared to each other.

Graph 4 shows that the casting itself is the constraint. The casting process takes the longest and because of this it is also the constraint of the whole process. This limits the whole production line to the maximum of 128 HRC per shift.

3.2.1 Value chain analysis

The data is shown in a value chain description so it can be made clear where the value is added and not.

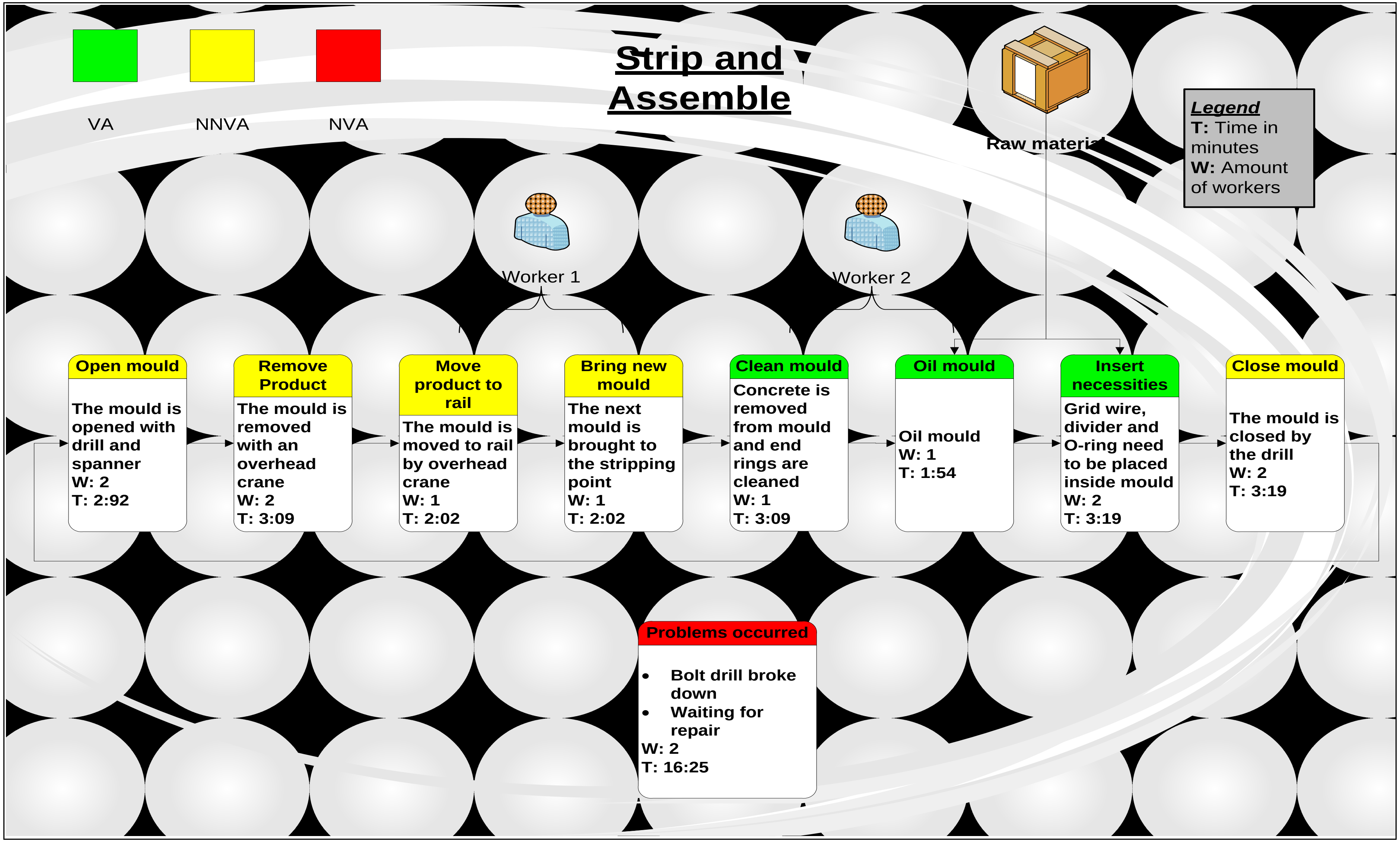


Figure 4: Value chain analysis of the stripping and assembly process of the HRC.

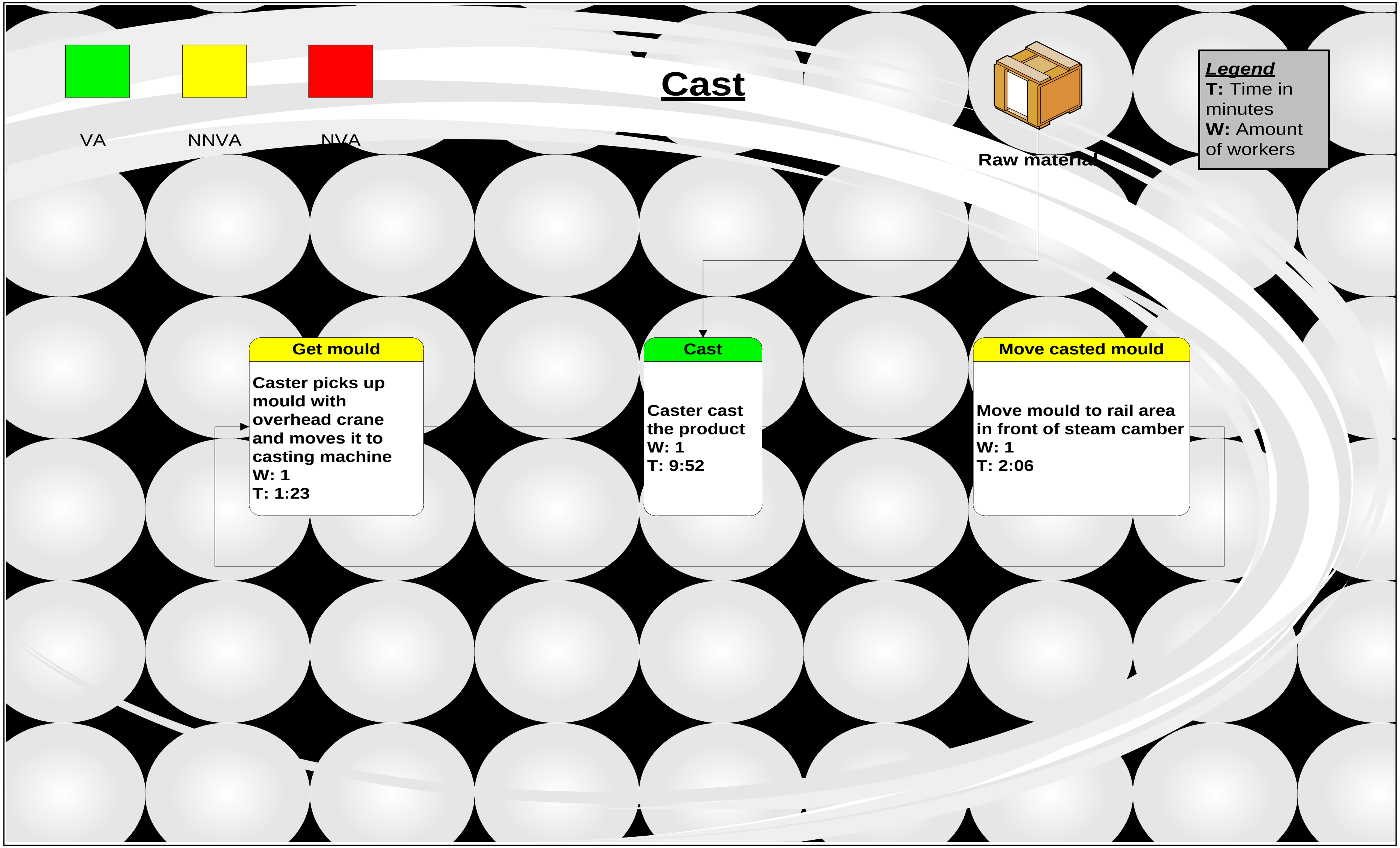


Figure 5: Value chain analysis of the casting process.

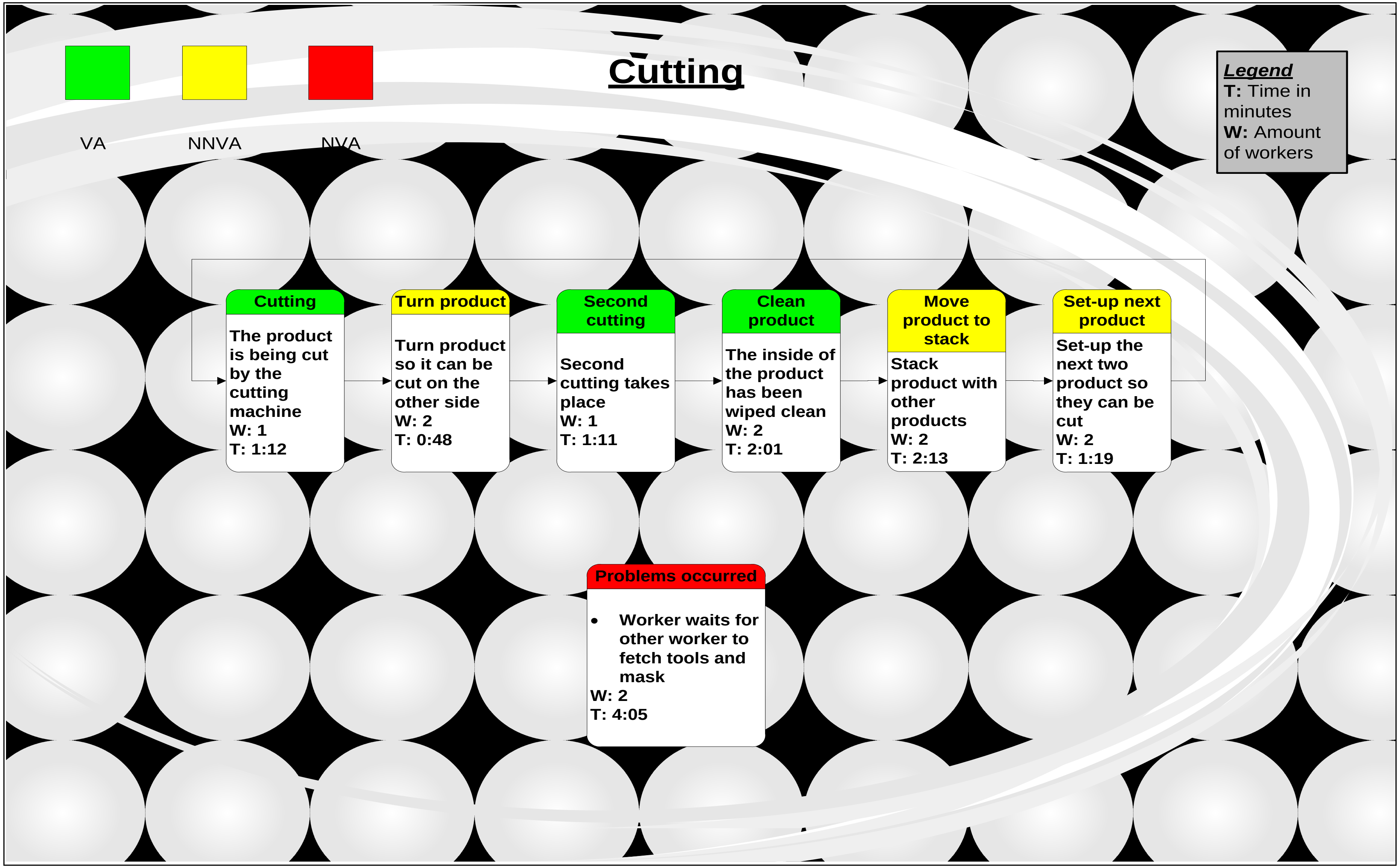


Figure 6: Value chain analysis of the cutting process.

As can be seen in the casting value chain there is no NVA activity. The same cannot be said about the cutting and stripping process. These problems can be solved but do not add to the synchronisation of the entire process. The optimization of these areas does not necessarily mean the optimization of the entire process (Gitlow, 2005). Although the problems that occurred should not be ignored they must be looked at and resolved. Here are a few suggestions.

Strip and Assemble problems occurred: The impact wrench used to unbolt the bolts has broken down a few times. It would be better if the impact wrench was fixed properly and if there was an extra impact wrench for when one breaks down production can continue to carry on.

Cutting: The needed tools can be placed in a tool closet close to the site of work and this then minimises the non value adding time spent on searching for tools and equipment.

3.2.2 Quality Control

The amount of scrap or defected HRC has not been regulated due to vast amount that is being produced. It has been asked that the amount must be documented and the amount of HRC scrap is as follows:

Month	Produced	Scraped	Percentage of scrap
July	5460	24	0.5
August	9102	208	2.28

Table 4: Quantity HRC produced and scrapped.

Just because the amount produced increases it is not a reason for the scrap amount to increase. With closer inspection it was found that the main problem for the defected products is the concrete rips pieces off because it gets stuck on the part that is used to mould a handle for the HRC. The moulded handle can be seen in figure 7. The defects caused by this can be seen in figure 8.

Figure 7: The handle on the side of the HRC.

Figure 8: Defects caused by the handle part inside the mould.

3.2.3 Simulation

The simulation is done in order to obtain necessary data for the manhole production in order to find the optimised output capacity of a single worker with the current process. Each process has been combined in order to use the process modelling blocks in Arena and keep the process very simple. This is done in order to get more data out of the simulation rather than animating the whole process. However, even though the time study data has been used there is still an estimate and may vary depending on situation at that time. Also the data that is being used is the average times and the risk of experiencing the phenomenon "the flaw of averages" also exist. Regardless of the risk the data will be more than reliable because of the small deviations. The process is shown in figure 9.

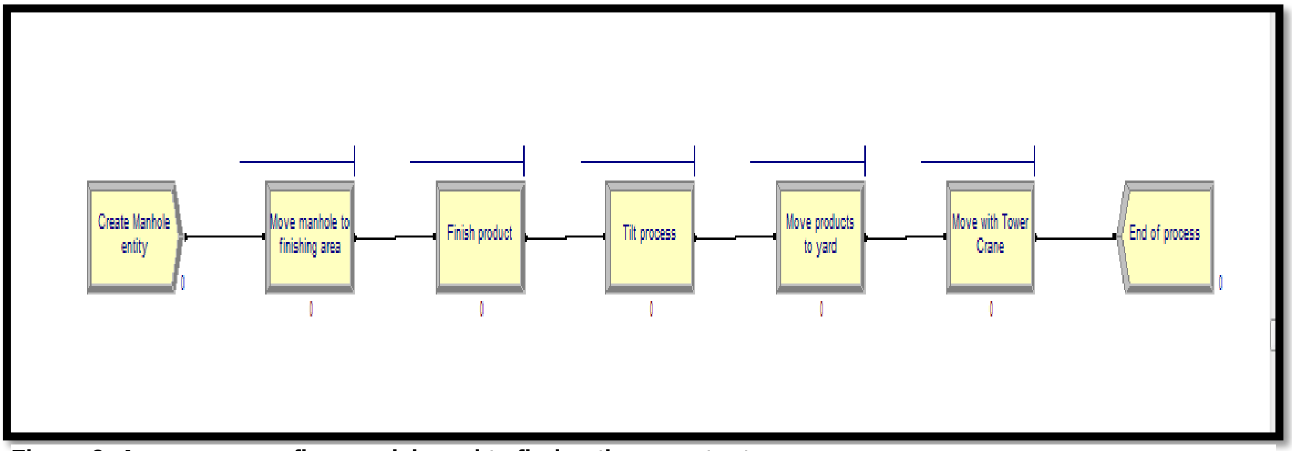
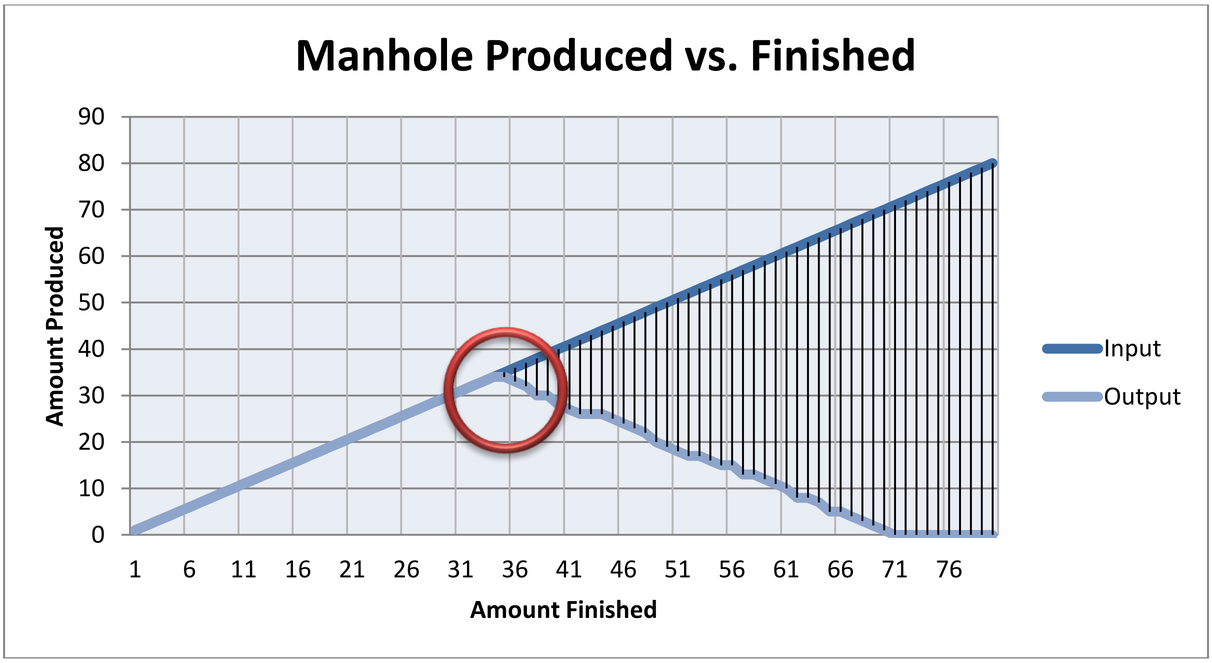


Figure 9: Arena process flow model used to find optimum output.

The data gathered is shown in appendix C.

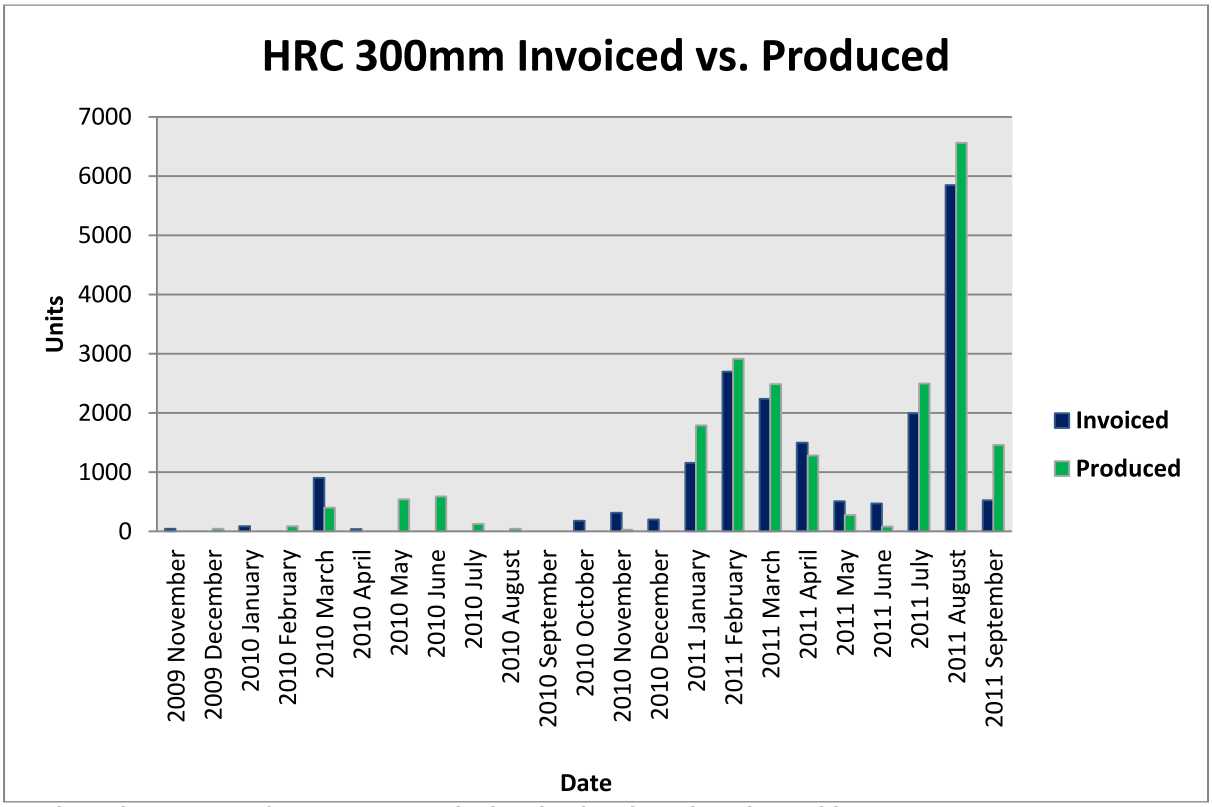


Graph 5: The graphed data from the simulation

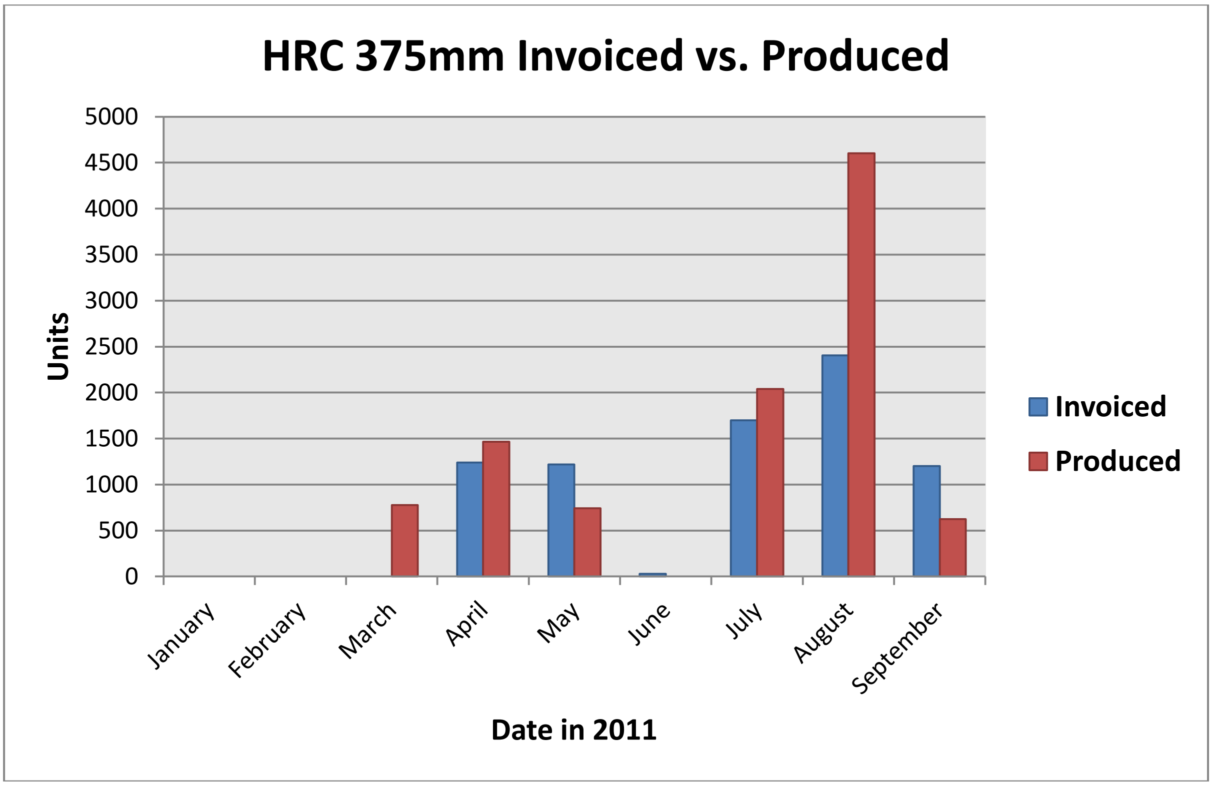
As the can be seen in graph 5 the data states that the break point is 34. This implies that the if a single worker is used which is currently the policy of the company the maximum number of products he can manage is 34. If this number is exceeded then the productiveness of the worker will decrease and less products will be finished at the end of the day. It can also be seen that the higher the amount above 34 is the bigger the area gets between the two graph When the amount reaches 70 the output of finished products reaches 0.

3.2.4 HRC monthly demand and production

The company has been using the JDE system to record their data regarding their everyday business. This system was started in 2008/2009 and is still relatively new to the business. The system has the data of the 300mm and 375mm HRC invoiced(sold) and produced but only from the when the system was started. In graph 6 and 7 it can be seen that there is a demand increase over February and August 2011. The closing down of the Virginia plant is the main cause responsible for the increase in demand at the Roodepoort branch. Due to this recent event there is no way of finding a consistency in the demand or produced products at the Roodepoort plant. The data must first be capture for the next two years with the new demand in order to make a estimation on the trend. The reason for finding the consistency in the demand and trying to point out where the fluctuations occur is so that a safety stock can be compiled for the months when the demand is high and production cannot keep up. When production is pushed into overtime more defects occur due to improper cleaning of moulds and extra cost is spend on the overtime workers.



Graph 6: The amount of 300mm HRC units invoiced and produced monthly.



Graph 7: The amount of 375mm HRC units invoiced and produced monthly.

Chapter 4

4.1 Recommendation

4.1.1 Manholes

With the manholes it was seen that the maximum number that can be produced with the current process in place is 34 due to the workload being designated to only one worker. There is no reason to increase the workers seeing that output will rarely reach higher than 34. The main problem that was singled out by the time studies is the tower crane's operating time. There are two reasons for this problem to have occurred. One being the lack of the tower crane operator being present the whole time and second the inferior equipment used to move the manholes. Firstly it would be recommended that the rail for the manholes towards the yard should be extended towards the back of the plant. Currently the rail is a 25m long rail which limits the products that can be stacked in the yard. This rail must be extended towards the back, and the area must be cleared and reassigned as the manhole yard. The reason for this is so that the overhead crane already in the yard can be used to empty the rail and not the Tower crane that is mainly used for moving products onto trucks transporting them to their relative destination. The rail will be crossing the road, it is very important that when the manholes are moved into the yard they do not obstruct the trucks. The new layout for manholes are given in figure 13. With the extended rail the finisher operator can continue with his work and stack the rail full with the shift's production. There would be no need to wait for the rail to be emptied because the yard supervisor at the manhole yard can clear the rail during the day with the overhead crane therefore eliminating need to wait for the tower crane operator. When using the overhead crane the option of moving equipment comes down to two that can be considered. The shaft pylop mechanism or chain grip beam.

Figure 11: Shaft pylop mechanism

Figure 10: Chain grip beam

Equipment	Advantages	Disadvantages
Shaft pylop	Quick connect and release method	Amount of products it can lift is limited by the products height
	Only one worker needed	Needs more maintenance than the chain grip
	Can fit on forklift	More expensive
Chain grip beam	Lifts more products with one go	Products need to be evenly stacked
	Not limited to the products height	Needs more than worker to connect chain
	Less expensive and chain easy to replace	Connecting chain can be time consuming

Table 5: Advantages and disadvantages of the Shaft pylop mechanism and chain grip beam.

The new layout proposed also involves the finishing area. The finishing area will be divided into the three diameter sizes 750mm, 1000mm and 1250mm. The worker needs to organise all the input products so that each diameter product is in his relevant section. He then finishes one section at a time. The spraying of the company brand will be done after the products have been tilted. Reason for this would be for the brand to be neat and straight beneath each other. This then gives a good impression and it is good for advertisement when the products stand at the relevant sites. An example is given in figure 12.

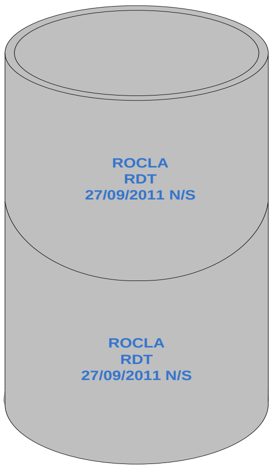


Figure 12: Product stacking example.

The old stacking area can be cleared and turned into an extended pipe storage area.

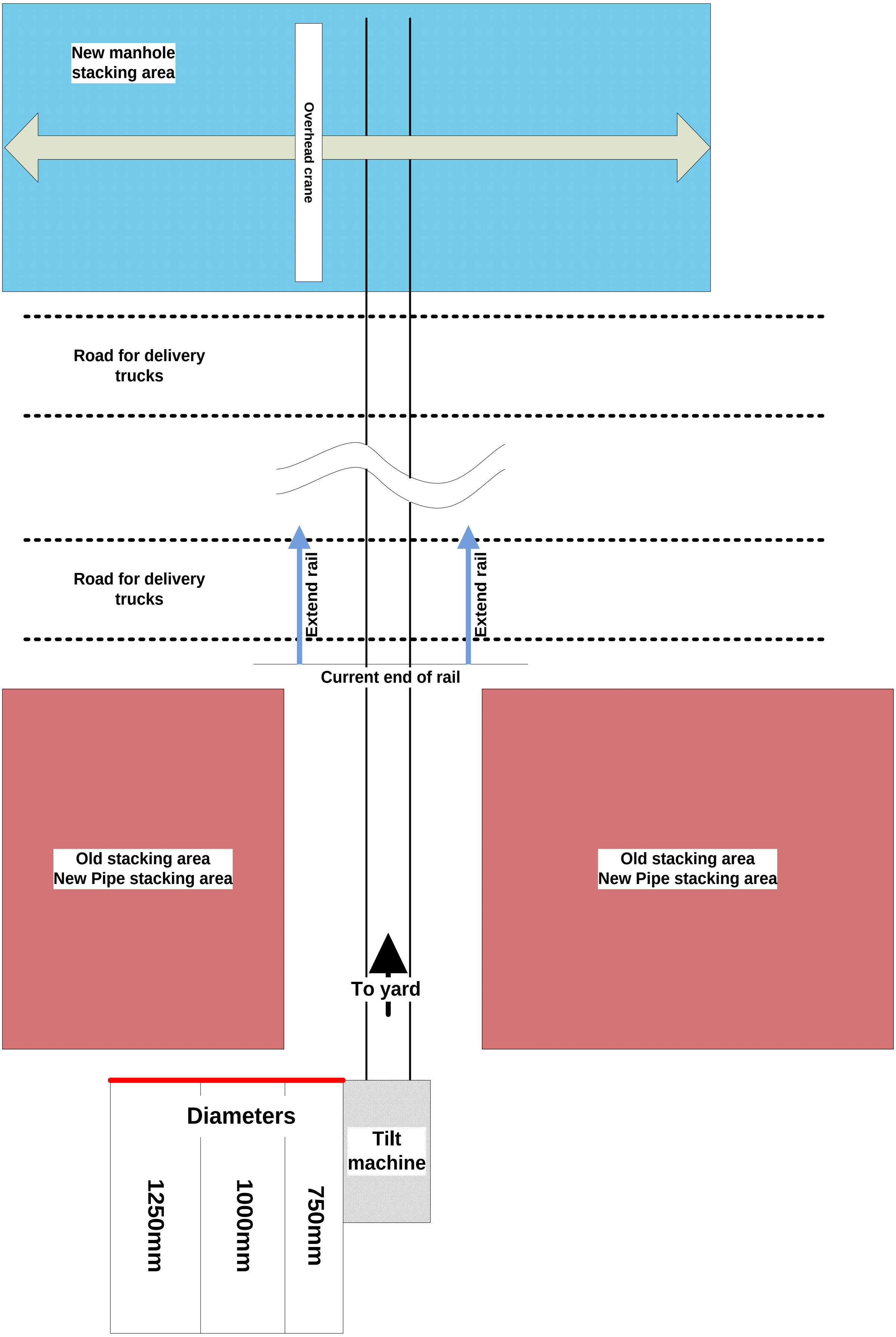


Figure 13: Proposed layout for manhole production.

4.1.2 HRC process

The time studies showed that the critical process is the casting process. The casting process can be automated which will cut the time of casting but will be expensive to install and due to the low rand per ton value of the HRC products produced it will not be feasible to go forth with the automated process. The process can be improved with the strip and assembly part. This process can make sure that there are already moulds ready for the next shift. Working with the idea of a push system. This can be done by putting two extra moulds in production even though they will not be casted. This makes it then possible for the caster to start casting immediately when his shift starts. The next recommendation would be to find a trend in the demand for the HRC and produce a safety stock amount for the high demand times. This will in turn lessen the load from the production plant. Due to the closing of the Virginia branch the demand for the Roodepoort branch has been altered and a sufficient trend cannot be established from the data at hand.

4.2.3 Quality

After inspection of the scraped HRC products it was found that the handles' corners that are edged into the product was the main cause of the defects. The reason for this is that mix gets caught in the corners of the handles inside the mould and when the product gets stripped the mix gets torn away from the product causing the defects. This defect increases if the production rises due to inadequate cleaning of the handles. The recommended handle is shown in the figure 14.

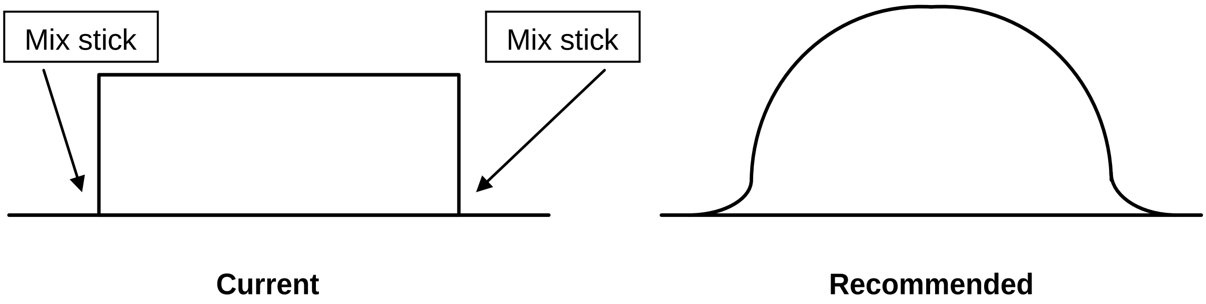


Figure 14: Current and proposed handles.

With the recommended method the mix cannot stick in the corners because they have been rounded which lessen the point corners.

Chapter 5

5.1 Conclusion

The aim of the project was to improve the process of both the manhole and HRC production. By using the appropriate industrial engineering tools the problems were identified and mended. It was seen that the entire manhole process was unorganised and that a bottleneck is formed after they are stripped. The process has been organised and formulated in such a way that it will improve the output but only if the worker works at the standard pace he should. By organising the work area in such a way that the same size diameter products are together it forces the worker to tilt them together. This makes the unloading into the yard easier because there is no changing the size over and over again. By making use of equipment already in place no disbursement took place. The extending of the rail can be done with little expense. The production of the HRC is limited to the time it takes to cast a product. Thus when big orders come production has to go into overtime in order to meet the demand. To prevent the extra cost of overtime a buffer stock must be produced in the off season. This is not in the line of lean manufacturing but it is found that the plant's equipment is not fit for lean manufacturing process. The trend of the sales for HRC needs to be formulated in order to compile the correct amount of buffer stock. The data at hand is insufficient because of the orders from the Virginia branch adding in to the orders of the Roodepoort branch. For future the data must be captured and the buffer stock must be compiled. The introducing of the new handles will improve the quality and minimise the amount of scrapped HRC products because it eliminates the problem of mix stick in the corners. For the future the whole process should be looked at to see if the entire system as a whole is working to its optimal capacity and not only subsection processes.

Appendix

Appendix A: Gantt chart

ID	Task Name	Start	Finish	Duration
1	Collect Data on pipe process	2011/06/23	2011/07/15	17d
2	Develop new suggestion on pipe production process	2011/06/23	2011/06/23	1d
3	Have meeting to find alternative half round channel process	2011/06/23	2011/07/01	7d
4	Investigate stacking of manholes	2011/06/23	2011/06/23	1d
5	Implement chosen proposal for half round channels	2011/06/27	2011/07/04	6d
6	Give results from new process	2011/07/06	2011/07/06	1d
7	Report back on current progress with project and findings on Data	2011/07/11	2011/07/15	5d
8	Visit to be made in intervals during varsity	2011/07/18	2011/10/11	62d
9	Process data and report finding	2011/08/11	2011/10/11	44d
10	Hand in Project proposal	2011/08/11	2011/08/11	1d
11	Hand in Interim Project Report	2011/09/13	2011/09/13	1d
12	Hand in Final Project document	2011/10/11	2011/10/11	1d

Appendix B: Time Studies

Process/M HRC casting | Observer: | Date: 05/072011 | Page: of
Time Star 08:00 | Time End: 16:00 | Information Code:

No.	Element	Obs	Req	Do	%	Tot	Avg	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Get mould ready	10	44	34	23%	12.30	1.23	2.19	1.50	1.50	1.16	1.15	1.05	0.54	1.01	1.11	1.09						
2	Casting	10	10	0	100%	95.18	9.52	8.44	10.08	12.57	8.47	10.37	7.03	10.55	8.34	9.15	10.18						
3	Take mould to steam rail and return	10	7	0	100%	20.59	2.06	2.21	2.42	2.14	2.02	2.10	2.26	1.56	1.55	2.07	2.26						
4		0	0	0	0%	0.00	0.00																
5		0	0	0	0%	0.00	0.00																

Process HRC strip and Assembly | Observer: | Date: 4/07/2011 | Page:
Time St 08:00 | Time End: 16:00 | Information C

No.	Element	Obs	Req	Do	%	Tot	Avg	1	2	3	4	5	6	7	8	9	10	11	12	13
1	**Without product**	0	0	0	0%	0.00	0.00													
2	Oiling	10	101	91	10%	15.35	1.54	1.30	1.17	2.00	3.55	1.20	0.41	1.48	1.22	1.44	1.58			
3	Put in Grids, devider and O-ring	10	9	0	100%	55.13	5.51	4.59	6.46	6.33	6.05	4.60	6.39	4.56	4.48	5.49	6.18			
4	Move mould, close while getting next mould	10	25	15	40%	16.19	1.62	1.58	1.50	1.23	1.14	1.15	2.20	2.23	1.53	1.48	2.15			
5	Clean mould	10	127	117	8%	15.51	1.55	3.48	1.48	2.30	1.20	0.46	0.27	1.50	1.23	2.10	1.49			
6	Non value Adding	3	31	28	10%	48.75	16.25	22.26	11.29	15.20										
7		0	0	0	0%	0.00	0.00													
8	**With Product**	0	0	0	0%	0.00	0.00													
9	Open Mould	10	9	0	100%	29.24	2.92	3.56	3.15	2.57	2.43	3.02	2.19	3.06	3.20	3.48	2.58			
10	Remove Product	10	10	0	96%	30.94	3.09	3.32	4.12	2.31	2.56	3.23	3.22	3.10	3.48	3.07	2.53			
11		0	0	0	0%	0.00	0.00													
12		0	0	0	0%	0.00	0.00													

Process/M HRC cutting | Observer: | Date: 28/06/2011 | Page: of
Time Star 08:00 | Time End: 16:00 | Information Code:

No.	Element	Obs	Req	Do	%	Tot	Avg	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Cutting	10	39	29	26%	9.53	0.95	1.27	0.49	1.10	1.17	1.19	1.04	1.16	0.56	0.48	1.07					
2	Turning product	10	22	12	46%	2.90	0.29	0.26	0.25	0.32	0.28	0.48	0.24	0.27	0.26	0.30	0.24					
3	Cutting second time	10	66	56	15%	8.68	0.87	1.17	0.56	1.29	1.15	0.57	1.14	1.32	0.49	0.45	0.54					
4	Clean product	10	3	0	100%	13.65	1.37	1.22	1.35	1.18	1.35	1.50	1.30	1.55	1.39	1.51	1.30					
5	Move product to stack	10	39	29	26%	15.56	1.56	1.19	2.14	1.29	1.48	2.10	2.00	2.02	1.58	1.17	0.59					
6	Set-up next product	10	83	73	12%	5.53	0.55	1.06	0.31	1.00	0.53	0.45	0.49	0.58	0.39	0.35	0.37					
7	Non-Value Adding time	4	153	149	3%	15.32	3.83	3.24	5.56	0.22	6.30											
8		0	0	0	0%	0.00	0.00															
9		0	0	0	0%	0.00	0.00															

Process/M Finishing | Observer: | Date: 27/06/2011 | Page: of
Time Star 08:00 | Time End: 16:00 | Information Code:

No.	Element	Obs	Req	Do	%	Tot	Avg	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Scraping	10	617	607	2%	10.78	1.08	3.01	0.27	0.36	0.55	0.23	4.19	0.14	1.48	0.34	0.21					
2	Applying cement	10	216	206	5%	18.55	1.86	0.39	0.34	1.57	1.27	3.09	2.58	1.28	0.33	4.56	3.14					
3	Wash	10	140	130	7%	1.86	0.19	0.07	0.10	0.15	0.11	0.45	0.27	0.28	0.18	0.12	0.13					
4	Spraying	10	166	156	6%	5.09	0.51	0.24	0.33	0.32	1.07	0.30	0.27	0.34	0.47	1.21	0.54					
5	Move onto tilt machine	10	222	212	5%	5.24	0.52	0.39	0.38	0.48	0.44	1.30	0.28	0.20	0.23	1.27	0.27					
6	Tilt	10	5	0	100%	2.72	0.27	0.33	0.28	0.28	0.26	0.28	0.24	0.22	0.29	0.24	0.30					
7		0	0	0	0%	0.00	0.00															
8		0	0	0	0%	0.00	0.00															

Process/M Tower crane moving manholes | Observer: | Date: | Page: of
Time Start: | Time End: | Information Code:

No.	Element	Obs	Req	Do	%	Tot	Avg	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Connecting clam	10	26	16	38%	15.95	1.60	1.24	1.09	2.39	2.01	1.23	1.48	1.34	2.10	1.57	1.50					
2	Lifting product and transport	10	31	21	32%	15.39	1.54	1.06	1.39	1.04	1.58	1.31	1.05	2.10	2.21	1.58	2.07					
3	Placing product	10	48	38	21%	14.28	1.43	1.07	2.14	1.11	2.13	0.58	1.09	1.52	1.38	1.24	2.02					
4	Releasing clam	10	72	62	14%	6.62	0.66	1.01	1.17	0.54	0.36	0.47	0.58	1.04	0.37	0.58	0.50					
5	Return to mould rail	10	41	31	24%	8.77	0.88	1.12	1.17	0.57	0.43	0.58	1.03	1.10	1.17	0.59	1.01					
6		0	0	0	0%	0.00	0.00															
7		0	0	0	0%	0.00	0.00															

Appendix C: Simulation data

Simulation	Input	Output
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	6
7	7	7
8	8	8
9	9	9
10	10	10
11	11	11
12	12	12
13	13	13
14	14	14
15	15	15
16	16	16
17	17	17
18	18	18
19	19	19
20	20	20
21	21	21
22	22	22
23	23	23
24	24	24
25	25	25
26	26	26
27	27	27
28	28	28
29	29	29
30	30	30
31	31	31
32	32	32
33	33	33
34	34	34
35	35	34
36	36	33
37	37	32
38	38	30
39	39	30
40	40	28

Simulation	Input	Output
41	41	27
42	42	26
43	43	26
44	44	26
45	45	25
46	46	24
47	47	23
48	48	22
49	49	20
50	50	19
51	51	18
52	52	17
53	53	17
54	54	16
55	55	15
56	56	15
57	57	13
58	58	13
59	59	12
60	60	11
61	61	10
62	62	8
63	63	8
64	64	7
65	65	5
66	66	5
67	67	4
68	68	3
69	69	2
70	70	1
71	71	0
72	72	0
73	73	0
74	74	0
75	75	0
76	76	0
77	77	0
78	78	0
79	79	0
80	80	0

Appendix D: HRC Invoiced and Produced data

HRC 300mm		
Date	**Invoiced**	**Produced**
2009 November	45	0
2009 December	0	45
2010 January	90	0
2010 February	0	90
2010 March	903	400
2010 April	40	0
2010 May	0	543
2010 June	0	589
2010 July	0	125
2010 August	0	46
2010 September	0	0
2010 October	183	0
2010 November	318	32
2010 December	204	0
2011 January	1157	1792
2011 February	2700	2913
2011 March	2238	2490
2011 April	1500	1284
2011 May	510	276
2011 June	471	83
2011 July	1998	2498
2011 August	5849	6561
2011 September	526	1460

HRC 375mm		
Date	**Invoiced**	**Produced**
2011 January	0	0
2011 February	0	0
2011 March	0	778
2011 April	1240	1464
2011 May	1220	742
2011 June	28	0
2011 July	1700	2040
2011 August	2403	4602
2011 September	1200	624

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