Final Project Report

Extrusion Press Optimisation

By

Janelle Botha

13003161

Submitted in partial fulfillment of the requirements for the degree of

Bachelors of Industrial Engineer

In the faculty of Engineering, Built Environment and Information Technology

University of Pretoria

September 2016

DECLARATION OF ORIGINALITY
UNIVERSITY OF PRETORIA

The Department of ....Industrial Engineering................... places great emphasis upon integrity and ethical conduct in the preparation of all written work submitted for academic evaluation.

While academic staff teach you about referencing techniques and how to avoid plagiarism, you too have a responsibility in this regard. If you are at any stage uncertain as to what is required, you should speak to your lecturer before any written work is submitted.

You are guilty of plagiarism if you copy something from another author's work (eg a book, an article or a website) without acknowledging the source and pass it off as your own. In effect you are stealing something that belongs to someone else. This is not only the case when you copy work word-for-word (verbatim), but also when you submit someone else's work in a slightly altered form (paraphrase) or use a line of argument without acknowledging it. You are not allowed to use work previously produced by another student. You are also not allowed to let anybody copy your work with the intention of passing if off as his/her work.

Students who commit plagiarism will not be given any credit for plagiarised work. The matter may also be referred to the Disciplinary Committee (Students) for a ruling. Plagiarism is regarded as a serious contravention of the University's rules and can lead to expulsion from the University.

The declaration which follows must accompany all written work submitted while you are a student of the Department of ....Industrial Engineering............... No written work will be accepted unless the declaration has been completed and attached.
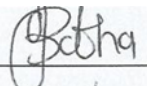
Full names of student: ......Janelle..

Student number: ......13003161...

Topic of work: ......Aluminium Extrusion Press Optimisation......................

Declaration

1. I understand what plagiarism is and am aware of the University's policy in this regard.

2. I declare that this Final Project report (eg essay, report, project, assignment, dissertation, thesis, etc) is my own original work. Where other people's work has been used (either from a printed source, Internet or any other source), this has been properly acknowledged and referenced in accordance with departmental requirements.

3. I have not used work previously produced by another student or any other person to hand in as my own.

4. I have not allowed, and will not allow, anyone to copy my work with the intention of passing it off as his or her own work.

SIGNATURE ....

i

Executive Summary

Wispeco is a leading aluminium extrusion company situated in Alberton. The direct aluminium extrusion process is a hot deformation process that produces aluminium profiles. A press is the machine used to transform a solid aluminium log into an aluminium product. This projects aims to increase the output of the company. The results of the production on the presses will be determined by a scheduling model.

An Operational Research model is created to develop a production schedule for the presses. This model has multiple objective functions to maximize the output and to minimize costs. This problem is classified as an NP-Hard problem and will have to use a metaheuristics model to solve it. A simulated annealing algorithm was developed to ensure the model will obtain able to obtain a high quality solution within a reasonable amount of time. This model will improve the production plan of the extrusion presses. This model can also be used to indicate if moving the problem dies to the smaller press will increase the output. This algorithm will develop the best schedule with regards to the cost of the production. Different scenarios can easily be compared with each other with the use of this algorithm, for example, the purchase of new presses. This schedule indicates the change in the production time and the impact on the cost of the production.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

The extrusion process can be described as squeezing toothpaste out of a tube. Pressure is applied at one point which causes the paste to flow through the opening at the other end. The paste takes the form of the opening. Different shapes can be produced by different openings. An everyday example for this is the shape nozzles used to decorate cakes. These openings are the dies and the toothpaste tube is the press machine that presses the melted aluminium through the dies.

Aluminium is the general material used for extrusion because it is cheap, light, corrosion resistant and formable. Aluminium extrusion profiles are used in various industries such as building, transport and agriculture.

1.1. Background

The direct aluminium extrusion process is a hot deformation process that produces aluminium profiles. These profiles are produced by performing multiple operations on multiple machines. Extrusion is performed under high pressure and temperature. The different steps in the process is shown in the figure 1 to 3. The extrusion process begins with melting the metal in the oven. The next step is transforming the molten aluminium into aluminium logs. This step is called continuous casting. The aluminium logs are cut into smaller sizes which are then referred to as billets. The billets are transported to the press machines. The billet is preheated to 450°C and the specific die is heated to 420°C. The hot aluminium is pressed through the container and then through the die's opening. The container is a hollow steel structure with one opening through which the billet is pressed and the other end is where the die is connected. Dies are classified in 2 groups, hollow or solid, and these two groups are sub-divided according to the number of cavities in the die. When referring to a die the abbreviation S6 is used, for example, where s=solid and 6 = number of cavities. The aluminium takes the form of the opening and an aluminium profile is produced. The profile is supported by a runout conveyor and stretched to ensure it is straight. The profile is cut into the specified commercial lengths. The profiles are then either powder coated or sent to the anodizing plant to get treated. These ageing processes ensure that the aluminium is not damaged.

Figure 1: Billets

Figure 2: Press
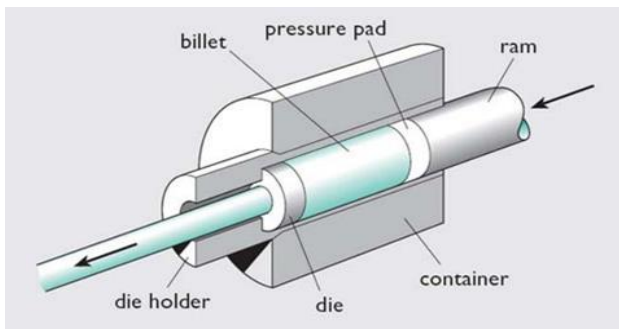
Figure 3: Container

This paper focusses on the presses and allocation of the dies to these presses. The optimization of the performance of the presses is considered. The plant has nine extrusion presses which vary in sizes. There are two 8-inch presses, five 7-inch presses, and two 5-inch presses. The 5-inch presses have less power or strength and produce less output than the 7-inch presses. The 7-inch presses are referred to as Ep1, EP2, EP3, EP4 and EP5. These presses are located at the plant in Alberton. The 5-inch presses are referred to as EP6 and EP8 and they are located at the

2

Vereeniging plant and Cape Town plant respectively. The 8-inch press is also located at the Cape Town plant.

The performance of these presses is highly influenced by the performance of a die. The die performance can be defined as the rate at which the profiles are extruded and the occurrences of die failures. The number of failures is expressed as a rate. Dies that have extremely high failure rates are referred to as problem dies. These dies have a big impact on the output of the press, because a lot of waste is generated by these dies. The speed at which the press can produce the profiles depends mostly on the characteristics/design of the die and the power of the press. A problem die is normally a slow runner. A low performing die will increase the production time for the job which normally causes late orders.

1.2. Problem statement

In 2015, a team from Wispeco, visited one of the largest aluminium extrusion plants in China. This manufacturing plant does not use dies with more than four cavities. When a die is identified as a problem die, they reduce the cavities and cut a smaller die and run this die on the smaller presses. The possibility of an increase in production, if dies with fewer cavities are used, should be investigated.

The Cape Town plant has two presses, a 5-inch and an 8-inch press, in operation. The plant has not been generating profits. The performance of the two presses were analyzed and it was decided that EP8 press is performing at such a loss that this press should be closed down. After structuring the work shifts in such a manner that there is no overtime, the plant experience an increase in profits even though they only use the one press. EP 8 is seen as a problem press because it does not produce high outputs and it generates a lot of scraps. This introduced the possibility of utilizing EP8 by only scheduling problem dies to this press. A problem die is a very low performing die which has a high failure rate. These dies have the most impact on the total output generated by the presses per period. The amount of waste created by these dies and the increase in production time causes these presses to produce less output than their capacity. The Cape Town plant will not be able to use the machine for the problem dies as they have already restructured their workforce, thus the press will have to be moved from Cape Town to Alberton. The company will incur high cost to move this press. The dies will also have to be cut smaller which is also very costly.

Currently, there is no fixed decision-making model for the allocation of dies to the different presses. The production plan of the presses, which refer to the allocation of dies to presses, is only based on the demand, press availability and two basic constraints, thus the opportunity

for a scheduling model was identified. Currently the dies are scheduled to the same presses as they believe the operators became accustomed to the die and the way to run the die. The scheduling does not incorporate the difference in production cost of the presses and their capabilities. It was also identified that they have a large number of late orders and thus there is a big need for the optimization of the presses. Table 1 indicates the total late orders, documented by Wispeco, per month. This graph represent the late orders over a period of two years.
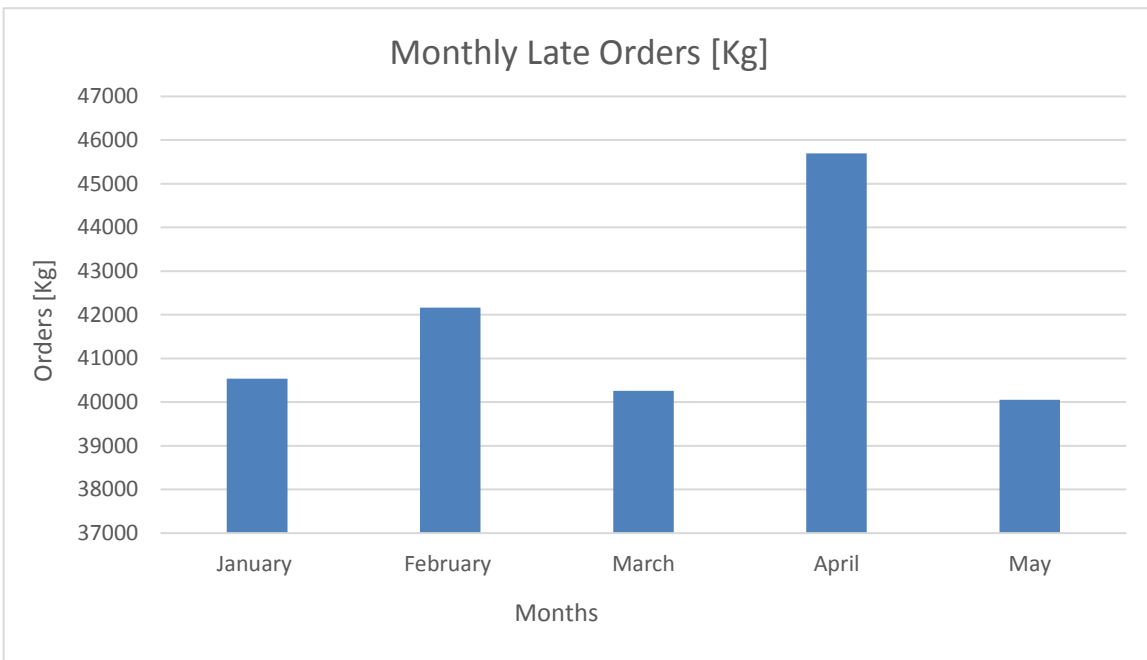

Figure 4: Late Orders

1.3. Project aim

This project aims to reduce the total production time which will reduce the number of late orders. This will be achieved by developing a scheduling model for the dies. This project should maximize the output of the company by implementing the scheduling model. The second objective is to improve the scheduling methods of the company and to indicate the key parameters to focus on when they do their production plan.

The final objective of the project is to determine whether it would be beneficial for the company to utilize EP8 located in Cape Town. The project will determine whether this will increase the output of the overall production output of the company. This paper will determine the benefit of removing problem dies from the bigger presses and running them on the problem presses (EP8) and the other 5 inch press (EP6).The 5-inch presses are currently at the other plants, one in Cape Town and the other one in Vereeniging. If this project indicates an increase in the production, the presses will be moved to the Alberton plant in order to provide the plant with the flexibility to run the bigger presses at full capacity.

1.5. Scope

This paper will only include EP1, EP2, EP4, Ep5, EP6 and EP8. The benefit should be determined if the problem dies are moved from the 7-inch presses and are run on EP6 and EP8.

The effects of the problem dies should be identified and analyzed. The change in capacity and production time should be calculated if these dies were to be moved to EP8. Preliminary cost implications should be determined to indicate if such a change is viable. This analysis has to incorporate the cost of moving EP8 from Cape Town to Alberton. If these calculations show this will increase the capacity and the profits, 4 of the problem dies will be cut into 5-inch dies and will run on the 5 inch-presses. The impact must be observed through time studies and data capturing.

Another aspect of this project is the current decision-making logic for the production plan of the presses. The reasoning behind the current production plan development is analyzed. A scheduling model is created with which the optimal allocation of dies to the presses will be determined. This schedule will ensure the shortest production time and lowest cost is met.

1.6. Research design and Deliverables

A full cost-benefit analysis will be calculated with economic calculations. During this project, it will also be determined which dies are the problem dies. The company can use the criteria matrix, shown in appendix B, to classify any new dies. The minimum speed, at which extrusion should occur in order to maintain profits, will be determined.

After the completion of the project, an operational research model will be delivered to the company. This model will help to maximize the output of the extrusion process and increase the profits. The aim of a production scheduling problem is to ensure that the resources used in

the manufacturing process are allocated in the most efficient way and that all the production constraints are followed. After researching similar scheduling problems, the conclusion was drawn that a mixed integer linear programming model will be used. This model will have a multi-objective that the total cost of the manufacturing is minimized and the output of the EP1, EP2, EP4 and EP5 are maximised.

The model should be used for different scenarios. The first one is to schedule the As-Is production plan, the second one is scheduling the problem dies to EP8, and the third a model that decides independently where the problem dies should be run.

1.7. Project Approach

The first step is to identify similar problems in the same industry and to identify which methods that were used in the literature could be used to solve our problem. Firstly, the problem specific literature is used to determine whether other extrusion companies have used scheduling models. Then we will look at what tools where used for scheduling models.

The impact of the problem dies will be calculated with three steps. The company requires the first two steps. A general production plan will be created with factor values that represent the utilization factor of the die. These values will ensure that the calculations consider the demand for the different product and that the dies that have higher demands, will contribute more to the outcome. The next step will be to manually identify 100 problem dies and calculating the impact on the system.

An operational research model will be developed and here the constraint will be identified. Because this is a complex problem it will be solved using metaheuristics. A simulated Annealing model will be developed in Python. Figure 5 is the activity break down structure for this project.
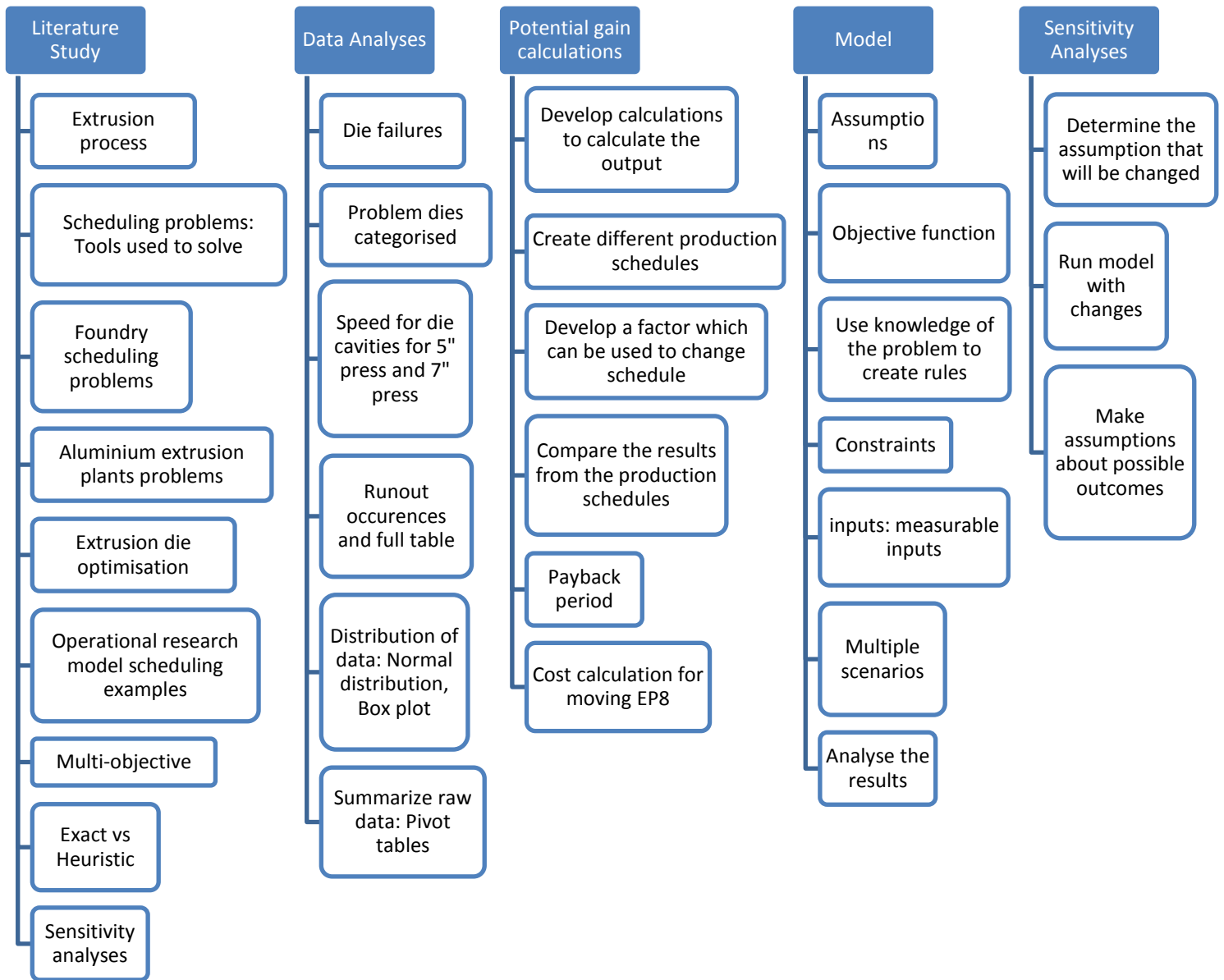
Figure 5: Work Breakdown Structure

1.8. Document Structure

Solution to similar problems in literature are reviewed in Chapter 2. The problem investigation is reviewed in Chapter 3. The analyses of the past production data is given in Chapter 4. The preliminary conceptual model developed to solve the scheduling problem is given in Chapter 5. The design of the simulated annealing pseudo code is given in Chapter 6. The results for the simulated annealing algorithm are shown in Chapter 7. The sensitivity of the model is tested in Chapter 8. The projected is concluded in Chapter 9.

Chapter 2: Literature Review

Scheduling can be implemented in numerous processes. The different scheduling problems will be discussed within foundries and other industries. The tools for these scheduling problems will also be discussed and it will show the similarities and the differences between our problem and previous literature.

2.1. Production process analyses

The type of production process has an impact on how the scheduling will be solved and with what resources.

A single machine scheduling problem involves a single machine that is used for production. This scheduling problem has to schedule different orders to that one machine and the machines perform a single task continuously. Noivo et al. (n.d.) presented a paper about solutions for one machine scheduling with sequence-dependent set-up times. In their paper, they described this problem as an NP-Complete. An NP-Complete problem is defined as a problem that does not have a fast solution. If any known algorithm were used the time it takes to solve the problem would increase if the scheduling items were to increase. The setup time for a die, is not sequence dependent. When a die change occurs the actions/operations/task to perform for the changeover is the same for all the dies. This paper production process has an average change over time during which the operators strive to perform these task.

Forrai and Kulcsar (2009) develop a model for flow shop or continuous production. The plant has multiple machines with different operations. These machines are placed in a sequence and these types of processes are used for mass production. The paper present a solution to the scheduling problems for this plant. They use a mixed integer linear model with heuristics to solve this problem. Bellabdaoui and Teghem (2006) also develop a model that schedules flow shop production lines. Hajeeh (2013) developed an optimisation model for an extrusion factory. This model selects the best cutting pattern of aluminium logs and billets with the objective to minimise the amount of scrap generated by the process. This model includes multiple machines that perform different task. The items that are produced has to follow the same sequence, for example the scrap metal has to be melted in the furnace before it can be cast. Our problem consists of different machines with different tasks that operate in parallel.

A job-shop production process consists of multiple machines that run a number of jobs, which are completed with a number of operations. Nonås and Olsen (2005) present paper on a scheduling problem that follows this principle. This foundry has limited resources, thus making it more complex than the simple job shop problem. In this paper, they use priority rules to schedule jobs to machines. The machines work in parallel with each other performing one

operation at a time thus, the operations are scheduled to the machines. Baki and Vickson (2004) describes a scheduling problem for N dies to a press as a one-operator (the press), N machine (the dies) open shop problem. An open shop production differs from a job shop in the sense that the order in which the different operations are scheduled are not determined by the previous operation completed. This scheduling is done more freely. Our scheduling does not take into account any other step in the extrusion plant, it only focuses on the profile extruding.

2.2. Scheduling problems

Scheduling problems in literature will be summarised and the tools used to solve these problems were identified.

2.2.1. Scheduling problems in other Industries

Bierwirth and Mattfeld (1999) develop a model for job shop scheduling. They develop a Generic Algorithm, which works for a dynamic production environment. This means that the number of jobs have different release dates. The mean flow-time of jobs is used and by minimising this the schedule will be generated, which will complete jobs as soon as possible. The different operations has to be completed in a certain sequence and this drives the scheduling.

Leung et al. (2007) proposes solutions for scheduling orders for multiple products produced with multiple dedicated machines, that works in parallel to each other. They developed a linear programming model and use heuristics because the model will not be able to calculate the exact optimal solution.

2.2.2. Scheduling problems for foundries

Hajeeh (2013) developed an optimization model for an extrusion factory. This model selects the best cutting pattern of aluminium logs and billets with the objective to minimise the amount of scrap generated by the processes. This job-shop production type is used for this foundry. A mixed integer problem is used to solve the scheduling problem. This model has a number of jobs to schedule to multiple machines. The items produced has to follow a certain sequence.

Dutta et al. (2009) develop model for an Aluminium extrusion company in India. The model is used to improve strategic planning within the company. The linear programming model optimizes five elements of this company, which is materials, facilities, activities, storage areas and time periods. The objective is to maximise the revenues from sales. The constraints considered for this model is the capacities of the facility and storage areas, the material balances and the bounds on the materials. This model is suitable to use for facilities that is in series, parallel or in more complex configuration.

De Araujo et al. (2008) proposes a solution for the scheduling of alloy production and the moulding of the aluminium logs. A mixed integer programming model to schedule these

processes is investigated but it is impractical to solve in a reasonable time frame. As a result, a faster relax-and-fix (RF) approach is developed. This approach reduces the number of integer values that needs to be scheduled by coding a series mixed integer programs that are relax to an extent. This was used on a rolling horizon basis, which schedules the items in detail for the first day and then relaxes the schedule for the rest of the workdays. The first day is divided into a number of sub-periods to be scheduled and the rest of the workdays only has one subsection.

Tang et al. (2000) developed a production schedule in a steelmaking-continuous casting foundry. A non-linear model with the objective function to minimise the lateness of orders is used. The objective function is achieved by minimising a cost function. This model is then converted into a linear programming model. This scheduling process consists of four steps. The machines used in the first three steps are fixed and thus, the model needs to decide what the starting and ending times are for a charge (a unit of production that consists of a sequence of operations) on a certain machine. A solution to our die scheduling can be derived from the scheduling method for the charges.

Nonås and Olsen (2005) discusses solutions for a scheduling problem for an engineer-to-order foundry that produces propeller blades. This is the same as the furnace and moulding processes but this company doesn't produce large numbers of items. They used a mixed integer linear model together with heuristic strategies to solve the scheduling problem. Simple heuristics were used to shuffle the jobs scheduled according to the due-date approach in order to get a new improved plan. A recursive algorithm, swopping a job finished ahead of time with a late job, gave the best results.

Dos Santos-Meza et al. (2002) focusses on developing a model to solve a lot-sizing problem in an automated foundry. This paper focuses on the furnace, which produces the melted aluminium which is then transported to several moulding machines. The decisions variables are the type of alloy produced in the furnace and the quantity of items to be produced in each moulding machine. They use an integer linear program to solve this problem. The objective function for this problem was to minimise the cost of production. The formulation for their objective function with their constraints can be used to formulate our second objective function.

2.3. Metaheuristics

The complexity of the problem determines whether the problem can be solved by an exact method or an approximate method. According to El-Ghazli Talbi, a complex problem cannot be solved using exact method. The exact model will not be able to solve the problem within a feasible period, thus approximation methods should be used. The scheduling problem for the aluminium foundry fits this criteria. If the MILP model were to be solved with an LP-solver the answer provided would be a local optimum.

Metaheuristics is an approximation method and it can be used to solve complex problems which are classified as NP-Hard and NP-Complete. Metaheuristics provide solution methods which are high quality in a reasonable time. Metaheuristics consist of different types of algorithms designed to solve these complex problems. Examples of these are Tabu search, Diminishing Neighborhood search and Simulated Annealing.

De Araujo et al. (2008) presented a paper on the scheduling of the alloy production and the moulding of the aluminium logs. A mixed integer programming model to schedule these processes is investigated but it is impractical to solve in a reasonable time frame. This paper discussed the use of relax-and-fix method, descent heuristics, diminishing search and simulated annealing to solve the complex scheduling problem. They find that the 3 neighborhood search method solutions improved as the sample size for the schedule increase. The simulated annealing achieved the best solution as this method escapes a local optimum by choosing a worse option and then generating a new schedule and converging to the minimum.

2.3.1. Simulated Anneailing

Talbi (2009) states that Simulated Annealing is based on the principles of statistical mechanics. The annealing process is described as the heating process of a substance and then slowly cooling a substance. This process results in a strong crystalline structure. The cooling rate is extremely important as the structure is largely impacted by this. The initial temperature should also be high enough to ensure the structure does not have imperfections. If the cooling rate is too high or the initial temperature is not high enough, the cooling solid will not reach thermal equilibrium at each temperature. The simulated annealing method compares the change in energy in the system until these results converge to an equilibrium state.

Simulated annealing is used to solve optimization problems. It has been found that this method can be used to solve real life problems because of the flexible nature of this algorithm and the ability to solve an NP-Hard problem in reasonable time. The objective of a simulated annealing algorithm is to escape a local optimum, as seen in Figure 6. The fundamental idea behind this algorithm is to accept a new solution with a worse answer than a previous store solution, with a certain probability.
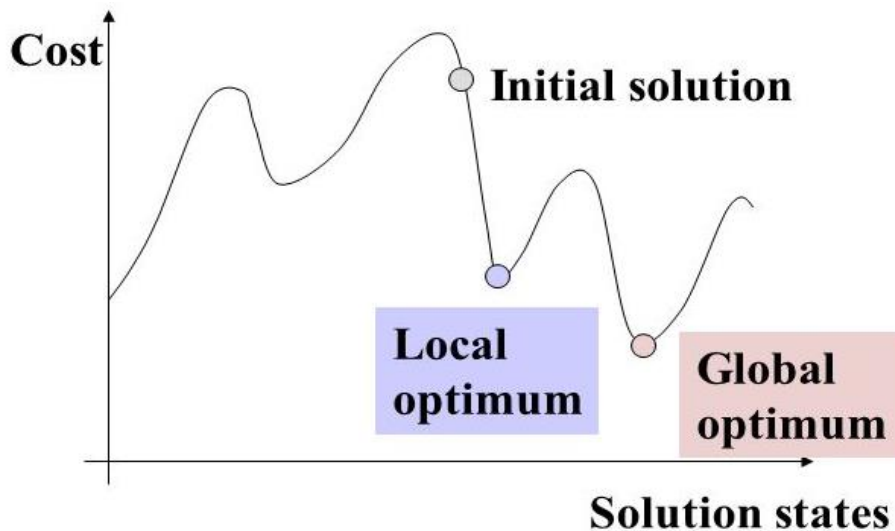
The algorithm starts with the initial solution. The initial solution can be generated randomly, calculated using an operational research model or calculated using historical data of the real life process. A new solution is generated with the use of a certain strategies. An example is swapping two jobs on two machines. The initial solution is compared to the new solution. If the new solution is better than the initial solution, this solution is then stored as the initial solution and the process continue. But if the initial solution is better than 'new solution', the new solution will be accepted with a certain probability. This probability will decrease as the number of iterations increases and thus the algorithm will accept fewer worse solutions.

The Simulated Annealing algorithm used to solve our problem, is displayed below provided by Talbi (2009):

Input: *Cooling Schedule*

> *Find a initial solution* (s)

> *Select an inital temperture*

> *Determine a temperature reduction strategy or function*

> *repeat*

>> *repeat*

>> *Generate a Neighbour* (s')

>> $\Delta E = F(s') - F(s)$

>> *if* $\Delta E \leq 0$ *Then* $s = s'$ *#Accept the neigbhbor solution*

Else *Accept s' with a probability* $e^{\frac{-\Delta E}{T}}$

Until *Equilibrium condition is reached*

Until *Stopping criteria is reached*

Output: *Best solution found*

Aycan and Ayav (2012) described a class scheduling problem as NP-complete. In this paper they used simulated annealing to solve the problem. In their model they developed hard and soft constraints. Examples of the hard constraints were that each instructor (teacher) can only be scheduled to one class and an example of a soft constraint is that the student conflicts with lectures should be minimized. The schedule satisfies all the hard constraints. Their paper used penalty scores when a constraint could not be satisfied. These penalty score functions were used to determine the cost calculation which were used to compare the different schedules. For the initial solution they developed a random initial schedule. The paper also described methods to develop a neighbor for the simulated annealing. The first was a simple searching neighborhood. This method randomly chooses one activity and one time slot and then assigns the activity with the starting time of the time slot. The second method, Swopping Neighborhoods, randomly selects two activities and swops their starting times. The third method, Simple Searching and Swopping, randomly selects two activities and two time slots and assign the activities to the respective time slots.

Yarkan and Dongara (2002) develop a scheduling model on a Computational Grid. When they analyse the results from the Simulated Annealing scheduler and the Ad-Hoc greedy scheduler, the simulated annealing algorithm generates a schedule that has a better *estimated* execution time than those returned by the Ad-Hoc greedy scheduler. FIdanova (2011) also developed an optimization model to schedule grid task. The author use a simulated annealing algorithm to solve the complex problem. For the initial solution the paper used greedy heuristics to schedule the task. This algorithm schedules the first task in the set to the first free machine, thus the machine with the shortest production time. The initial schedule needed to be approved by a feasibility study. The generation of the neighbor were also achieved by swopping two randomly selected task's starting times.

Chapter 3: Project Investigation

3.1. Press performance

The targets for each for the 7-inch presses were derived from past performance data. These values varied greatly for each press even though they have the same theoretical capacity and power. The targets for the EP1, EP2, EP3, EP4 and EP5 are shown in the figure 13. The presses are not even able to make the targets calculated for each of them. The actual capacity of the plant is not as high as it should be.
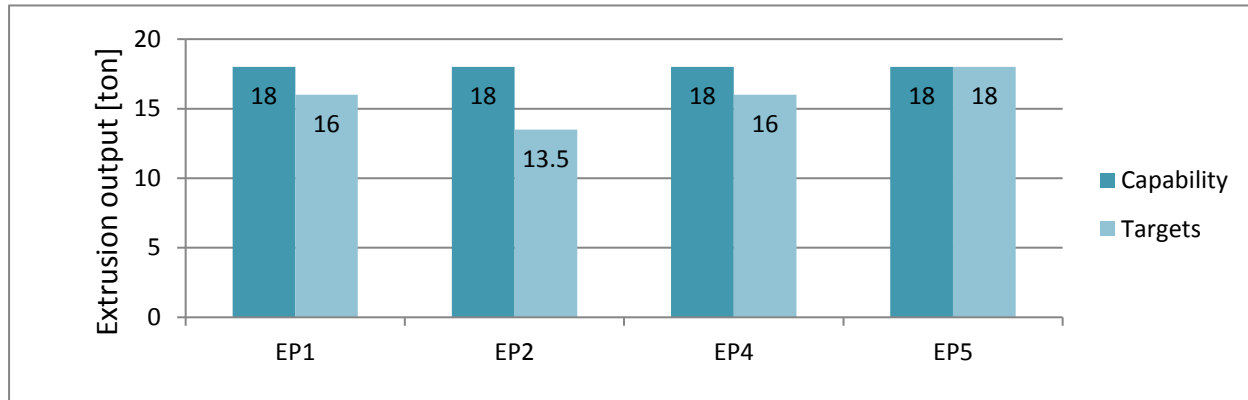
Figure 7: Press Performance

From the daily production information shown in Table 1, we can see that none of the presses reaches their target outputs for a day. The table also shows that each press generates high quantities of scrap material. The company profits are decreased largely by these presses. The performance of EP8 is extremely low in comparison to the other 5-inch press, EP5.

Press no.	Input [Kg]	Output [Kg]	Daily Output Target [Kg]	Waste [Kg]	Waste percentage of input
EP1	16 202	12 937	18 000	3 265	20%
EP2	17 027	13 438	13 500	3 589	21%
EP4	15 846	11 867	16 000	3 979	25%
EP5	25 049	22 260	23 000	2 789	11%
EP9	14 514	11 582	20 000	2 932	20%
Alrode	**88 638**	**72 084**	**110 500**	**16 554**	**19%**
EP6	14 609	12 175	13 500	2 434	17%
EP7	18 173	15 400	18 000	2 773	15%
EP8	2 751	2 087	4 500	664	24%
Total Company	**122 181**	**100 157**	**146 500**	**22 024**	**18%**

Table 1: Press Production daily data

The reason why the presses are underperforming is because of the amount of waste caused by die failures. The die failure causes a lot of down time. The past production information of EP5, indicated that this press runs the fast runners and thus produced more output than the other presses. This difference in the output produced by each press is displayed in the Table 1. The input for the presses is lower than the target values because the presses are not running at full speed. For problem dies and complex dies the presses needs to run at a slower speed.

3.2. Dies performance

The die performance is measured by the number of die failures, the speed at which the die extrudes the aluminium, the occurrences of run-out problems per die and the amount of down time caused by a full table. Each of these aspects has an impact on the output of the press.

The die failures for the different cavities are summarised in Table 2. The past schedules for each press were analysed and the percentages shown in this table indicates the number of times the dies are used on each press. The percentages values of the dies with a failure rate of 3 were added for each press. If we compare these values with the output for that press it indicates that if a press has a high percentage the output of that press is lower than the rest. The presses with the lower target values have a higher die failure occurrence.

Category	No of dies	No of failures	Failure/dies	EP1	EP2	EP3	EP4	EP5
S3	339	1275	3.76	4%	7%	2%	5%	2%
H4	290	1019	3.51	1%	3%	1%	**8%**	3%
H3	238	781	3.28	1%	2%	1%	6%	4%
S2	998	3260	3.27	**33%**	**15%**	4%	**8%**	6%
H6	118	365	3.09	0%	1%	1%	3%	2%
S8	88	271	3.08	0%	4%	1%	1%	0%
S4	643	1960	3.05	2%	**22%**	7%	**11%**	2%
S6	636	1924	3.03	1%	**20%**	6%	**12%**	2%
S5	4	12	3.00	0%	0%	0%	0%	0%
S1	1157	3407	2.94	**31%**	**11%**	**30%**	7%	6%
H2	784	2128	2.71	7%	6%	4%	**18%**	**21%**
H1	2500	6278	2.51	**20%**	9%	**43%**	**21%**	**54%**
S10	7	15	2.14	0%	0%	0%	0%	0%
H8	3	3	1.00	0%	0%	0%	0%	0%
Total				**42%**	**74%**	**23%**	**55%**	**19%**

Table 2 : Die failures

The performance of the die can also be analyzed by comparing the speed of production for that die. As seen in figure 14 the dies with higher number of cavities has a lower speed. Thus

running dies with more cavities compromises the speed. The amount of aluminium which can be produced per time unit is also higher for cavities one to four.
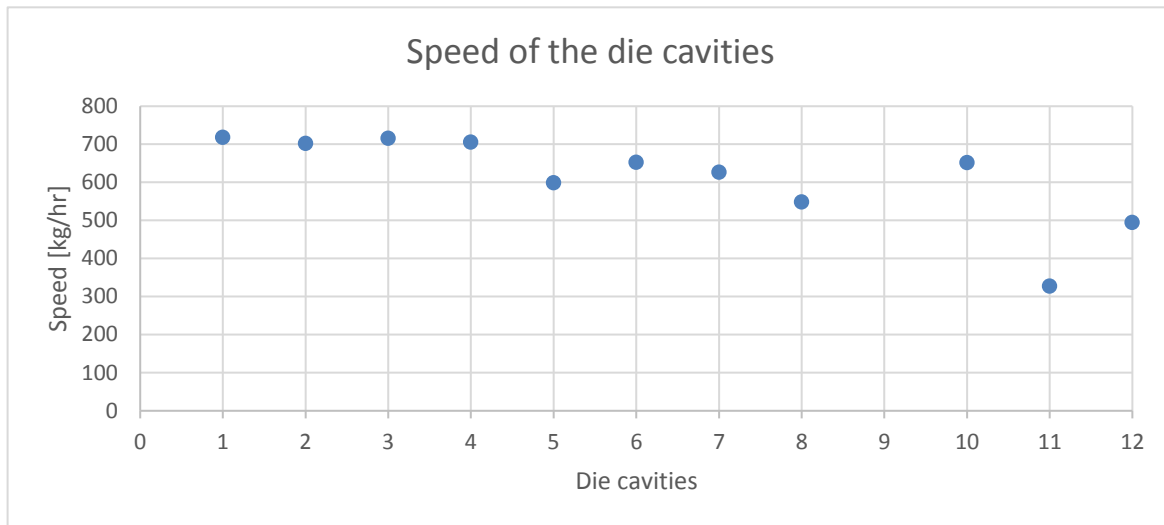
Figure 8: Die Cavities Speed

The dies with higher number of cavities have higher occurrences of runouts and a full table. A runout is when one or more of the profiles being produced is extruded at a higher speed as the other profiles. This causes a lot of scrap material. The die is then sent to the Die Room where the cavity(s) that caused the run out is analysed and improved. When a runout occurs the speed of extrusion is reduced in order to ensure the minimum damage is caused by the irregular extrusion speed. A full table normally occurs with higher cavities because there are more profiles produced per time unit. When the profiles are extruded it is stretched out on a conveyor table. When this table is full the production needs to stop in order for the operators to clear the table. Both these problems have a negative impact on the production time and speed.

We further looked at the distribution of the speed values for each die within a cavity group. This ensures the values that are used for the calculations are a good indication for the group. The distribution for the speed of the 7-inch dies is shown in the following graphs. The distributions of these values were plotted using the EasyFit program. The S2 dies speeds follow a normal distribution, but the variance for the dies within the S2 group is very big.
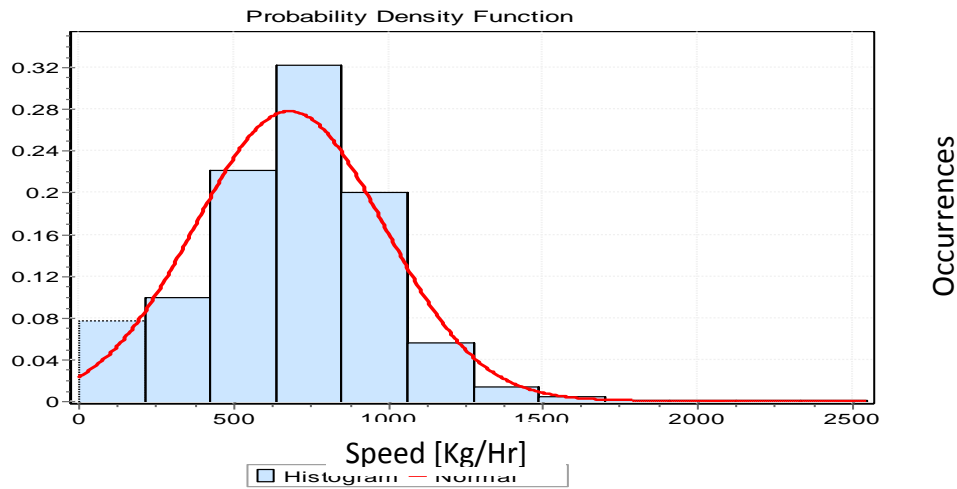
Figure 9: Speed Distribution

As seen in Table 4, the variance for the other cavities is also very big. This indicates that the average values for the dies cannot be used to determine the impact on the output of the presses.

Die Cavities	Mean	Variance
1	727.61	354.46
2	683.82	304.65
3	716.82	271.92
4	686.45	402.26
5	599.18	145.35
6	673.41	379.13
8	558.91	228.79

Table 3 : Mean and variance values for the 7" dies

3.3. Problem dies

The categories used to analyse the performance of the dies are the total number of failures, the output generated for the die, whether the dies have more than 5 failures in a short period and the amount of down time caused by the full table. A full table occurs when the aluminium profiles cannot be removed fast enough from the conveyor where the profiles are stretched and straighten after they exit the press. A full table normally occurs with dies with higher number of cavities, as there are more profiles produced per time unit.

Within this company a 100 problem dies were identified. Table 3 indicates the 30 dies with the highest number of failures. A problem die will mostly be identified among the group of dies which are used frequently. The sum of the failures are calculated over a period of 6 months.

When we analysed the performance of the dies it was the dies with high failure rates that had a huge impact on the production of the presses. Because the failure numbers are so high the total time wasted on die failures and the amount of scrap generated is extremely high. This loss in production time and production output is experienced across all the presses.

Die	Sum of Failures
14109	369
27921	128
28905	64
28974	64
29740	81
30607	196
30914	257
31106	121
31244	64
31271	208
34007	121
34398	64
34482	64
35175	169
35471	260
44088	247
53099	64
54318	209
55209	81
55253	98
55433	128
55434	228
56969	64
57305	64
57604	196
Grand Total	3609

Table 4: Problem dies

Chapter 4: Data Analysis

The following section indicates the type of data used as input to the algorithm. The production cost per press, speed, recovery rate and conditions per press is displayed in the tables below.

4.1. Cost

The production cost is which is also known as the conversion cost. This is the cost of converting a kilogram aluminum billet into a kilogram aluminium profile. Currently, the production cost of each press is equal. Table 7 shows the different components which is used to calculate production cost.

Per unit	Direct costs
Labour	1.00
Indirect material	0.50
Die costs	0.60
R & M	0.40
Energy	0.56
Other Factory Direct Costs	0.10
Own Distribution & Railage	0.47
Total	**4.1**

Table 5: Constant value of Production cost

After a close investigation of the production cost recorded in the past and the electricity consumption of each press it was determined that these values is different. It was also noted that the EP3 and EP4 uses gas billet heaters which is more expensive than the electric heaters used on the other presses. Table 8 displays the unique values determined for each press. The algorithm will use these values to determine the cost of producing the dies scheduled to applicable press.

Press	Constant	Gas Cost	Electricity component [R/Kg]	Total	Waste [R/Kg]
EP1	3.54	-	0.56	4.1	0.8
EP2	3.54	-	0.56	4.1	0.8
EP3	3.54	2.28	0.3	6.12	0.9
EP4	3.54	1.72	0.3	5.56	0.9
EP5	3.54	-	0.6	4.14	0.8
EP6	3.54	-	0.56	4.1	0.8

EP7	3.54	-	0.4	3.94	0.9
EP8	3.54	-	0.56	4.1	0.9
EP9	3.54	-	0.7	4.24	0.9

Table 6: Unique production cost per press

4.2. Die Input data

The input data is captured in excel and stored as a CSV (Comma-separated Values) file. Within the excel file, the production time and the amount of aluminium required as input, are calculated for each order. The following part will discuss this process.

The output required by the customer is the first parameter. This value is available in the order form and is inserted manually. Next the specific die that is used to produce the order will be inserted. The next step is to lookup the speed and recovery rate for the specific die. These values were determined by using past production information over a period of three years. The recovery rate for each die ensures the amount of material used in the planning is more than the ordered amount. This recovery rate refers to the amount of aluminium which forms at the end of the ram (steel cylinder that forces the aluminium through the die) and material that is scrapped when failures occur. Table 7 shows an extract from the excel file for the recovery rate of seven dies for each press.

			Recovery rate								
Die no.	Die Name	Output	EP1	EP2	EP3	EP4	EP5	EP6	EP7	EP8	EP9
0	99587	1200	0.96	0.96	0.94	0.96	0.96	0.92	0.96	0.98	0.8
1	65414	1000	0.96	0.96	0.94	0.96	0.96	0.92	0.96	0.98	0.8
2	95321	2000	0.96	0.96	0.94	0.96	0.96	0.92	0.96	0.98	0.8
3	54122	3000	0.96	0.96	0.94	0.96	0.96	0.92	0.96	0.98	0.8
4	87541	1800	0.84	0.86	0.94	0.85	0.96	0.92	0.96	0.98	0.8
5	65324	3500	0.82	0.8	0.82	0.81	0.84	0.82	0.8	0.85	0.6
6	22513	1000	0.96	0.96	0.94	0.96	0.96	0.92	0.96	0.98	0.8
7	84512	3200	0.96	0.96	0.94	0.96	0.96	0.92	0.96	0.98	0.8

Table 7: Recovery Rate

The recovery rate for the die is used to determine the amount of input required to ensure that the order quantity is satisfied. The amount of input required per order and the output required per order are used to calculate the expected waste. The input and waste data for five of the presses is shown in Table 8. These values are determined for each press and read into the algorithm to determine the production cost.

	Output	Input [Kg]					Waste [Kg]				
Die no.		EP1	EP2	EP3	EP4	EP5	EP1	EP2	EP3	EP4	EP5
0	1200	1250	1250	1277	1250	1250	50	50	76.59	50	50
1	1000	1042	1042	1064	1042	1042	41.66	41.66	63.89	41.66	41.66
2	2000	2083	2083	2128	2083	2083	83.33	83.33	127.65	83.33	83.33
3	3000	3125	3125	3191	3125	3125	125	125	191.48	125	125
4	1800	2143	2093	1915	2118	1875	342.85	293.02	114.89	317.64	75
5	3500	4268	4375	4268	4321	4167	768.29	875	768.29	820.98	666.66
6	1000	1042	1042	1064	1042	1042	41.66	41.66	63.89	41.66	41.66
7	3200	3333	3333	3404	3333	3333	133.33	133.33	204.23	133.33	133.33

Table 8: Input and waste data

The speed for the dies, which was determined from the past production data, is shown in Table 9. These values varies depending on the press the die is scheduled to. The reason for the difference is because of the power or strength difference of each press.

Die number	Speed [Kg/Hr]								
	EP1	EP2	EP3	EP4	EP5	EP6	EP7	EP9	EP8
0	1500	1550	1550	1530	1500	1200	1500	1700	950
1	1500	1600	1600	1530	1500	1100	1500	1700	1000
2	1500	1530	1530	1600	1500	1100	1500	1700	950
3	1500	1600	1600	1530	1500	1100	1500	1700	950
4	1500	1600	1600	1530	1500	1100	1500	1700	950
5	1500	1550	1550	1530	1500	1100	1500	1700	950
6	1500	1600	1600	1600	1500	1100	1500	1700	800
7	1500	1600	1600	1530	1500	1200	1500	1800	950

Table 9: Die Speed

The speed and the input values are used to calculate the total production time for each die. The algorithm uses this value and the duration of a die change (a constant value in the algorithm) to calculate the duration of the production schedule.

Production time								
Die no.	EP2	EP3	EP4	EP5	EP6	EP7	EP8	EP9
0	48.38	49.41	49.01	50	NA	50	43.23	94.73
1	39.06	39.89	40.84	41.66	NA	41.667	NA	75
2	81.69	83.43	78.12	83.33	NA	83.33	72.08	157.89
3	117.18	119.68	122.54	125	177.86	125	NA	236.84
4	78.48	71.80	83.04	75	106.71	75	64.82	142.13
5	169.35	165.22	169.45	166.66	232.81	175	145.33	294.73
6	39.06	39.89	39.06	41.66	NA	41.67	36.01	93.75
7	NA	NA	130.79	NA	NA	NA	108.84	252.63

Table 10: Production Time

21

The production time is shown in Table 10. As indicate in Table 10 some of the dies have NA as the production value. This stands for Not Applicable which indicates that that die can't be scheduled to that press. This table uses excels' built-in If-function too ensure the Production time table which is read into Python, incorporates the constraints of the dies and presses. The constraint of the dies are shown in Table 11. Within the conditions table, if the value of the die on the applicable press is zero, this means that the die cannot be scheduled to that press.

Die number	Conditions									Problem dies
	EP1	EP2	EP3	EP4	EP5	EP6	EP7	EP9	EP8	
0	1	1	1	1	1	0	1	1	1	0
1	1	1	1	1	1	0	1	1	1	0
2	1	1	1	1	1	0	1	1	1	0
3	1	1	1	1	1	1	1	1	1	0
4	1	1	1	1	1	1	1	1	1	0
5	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	0	1	1	1	0
7	0	0	0	1	0	0	0	1	1	0

Table 11: Conditions table

Factors to be taken into account when scheduling dies to a press include the die size, run-out length of a profile, and the cooling treatment that the profile requires. For example, the EP8 and EP6 presses are 5-inch presses, which means that dies with a circumference of 300mm or higher cannot be scheduled to them. Also, the run-out length of a die is determined by dividing the output per meter value of the die (kg/m) by the weight (kg) of the billet used. If the calculated run-out length is longer than the table length of a press, the die cannot be scheduled to run on this press. Finally, certain products are produced with hard alloys and the aluminium should be cooled quickly to ensure integrity of the metal. In these cases, the dies can only be scheduled to the EP3 and EP9 presses since they are the only presses that allow quick cooling.

Press	Table Length [m]	Conditions
EP1	41	-
EP2	44	-
EP3	42	Water Cooling/ Hard Alloys
EP4	41	-
EP5	45	Run out length
EP6	25	Die Sizes/Runout length
EP7	41	-
EP8	30	Die size/ runout length
EP9	42	Water Cooling/ Hard Alloys

Table 12: Conditions

Chapter 5: Conceptual design

This paper focus on the extrusion part of the plant. The aluminium billets are heated and the molted aluminium is then pushed through a steel die which forms the aluminium profile. The model takes into consideration the raw material available, the capacity of the presses, the delivery dates of these products and most importantly the dies. Each die has a different speed at which it produces aluminium profiles and this has a big impact on the output of the machines. The purpose of this project is to find the optimal schedule for the products.

The mixed integer linear program is developed to generate a production schedule for the presses. The mathematical model and algorithm are developed based on the algorithm of Maticevic, Majdandzic and Lovric (2008). The products produced will be scheduled in a manner to ensure the maximum output. The one will schedule the production for five presses and the press which is currently based at Cape Town. This version will have a multi-objective function where the output should be maximised and the cost should be minimised. This is a formal calculation to verify if the transportation of this press in viable.

5.1. Mixed Integer model

The model will use the following inputs:
- List of dies with the failure rate for each die.
- The orders for the certain period.
- The speed at which the die can extrude aluminium.
- The recovery rate for each press.
- The items and billets in inventory.

Tasks set to the production of aluminium casting products scheduling system are:
- The capacity of the presses for 24 hours are calculated. This is also one of the constraints that drive the objective function.
- A production plan is scheduled based on the work shifts
- A schedule for the daily production presses and available capacities needs to be generated.

This model has multi-objective functions. The model maximizes the output of the 7-inch presses and it wants to minimize the cost of the production.

Sets

Description	Sets
Press	$P = \{1,2,3,4,5,6,7,8,9\}$

Dies	$D = \{1,2,3, \ldots . n\}$
Production Orders	$O = \{1,2,3, \ldots . n\}$
Items	$I = \{1,2,3, \ldots . n\}$
Shift	$S = \{1,2\}$

Table 13: Sets

Parameter

$dd_{i,o}$	$\triangleq$	delivery date for item $i \in I$ and order $o \in O$
$K_{p,t}$	$\triangleq$	the capacity of press $p \in P$ for a day t [hours]
$K_{p,t}^{Cap}$	$\triangleq$	the capacity of press $p \in P$ per hour [kg/hours]
U_p	$\triangleq$	the utilisation factor of press $p \in P$
h_s	$\triangleq$	number of hours per shift $s \in S$
V	$\triangleq$	number of overtime hours
$Q_{i,o}$	$\triangleq$	the quantity of items $i \in I$ in production order $o \in O$ [pieces]
$B_{i,t}$	$\triangleq$	quantity of produced items $i \in I$ in period t [kilograms]
$Q_{i,t}^n$	$\triangleq$	ordered quantity of item $i \in I$ in period t [kilograms]
$I_{i,t}$	$\triangleq$	inventory of item $i \in I$ in period t
I_t^{raw}	$\triangleq$	the number of billets in inventory in period t
B_i^{raw}	$\triangleq$	the number of billets used for item i $\in$ I
P_d	$\triangleq$	processing time for die $d \in D$ [kg/minutes]
s_d^u	$\triangleq$	setup time for die d $\in$ D [minutes]
$b_{p,d,i}$	$\triangleq$	start time for processing item $i \in I$ die $d \in D$ in press $p \in P$
$f_{i,o}$	$\triangleq$	finish time of item $i \in I$ on production order $o \in O$
$R_{d,p}$	$\triangleq$	failure rate of die $d \in D$ on press $p \in P$
$Pr(i)$	$\triangleq$	priority of item $i \in I$
R_d	$\triangleq$	the recovery rate per die d $\in$ I
C_i	$\triangleq$	the production cost for item i $\in$ I
Y	$\triangleq$	the cost for moving EP8

Decision variables

$$x_{i,d} \triangleq \begin{cases} 1 \; if \; item \; i \in I \; \; is \; produced \; by \; die \; d \in D \\ \qquad\qquad 0 \; otherwise \end{cases}$$

$$z_{d,p} \triangleq \begin{cases} 1 \; if \; die \; d \in D \; \; is \; used \; on \; press \; p \in P \\ \qquad\qquad o \; otherwise \end{cases}$$

Objective function

Maximise

$$H = \sum_{p \in P} \sum_{i \in I} B_{i,p} \qquad\qquad (1)$$

Minimise

$$C = \sum_{p \in P} \sum_{i \in I} B_{i,p} \cdot C_i + \sum_{p \in P} \sum_{d \in D} P_d \cdot K_{p,d} (1 - R_d) + Y \qquad (2)$$

Constraints

$$\sum_{o \in O} Q_{i,o} \geq max\left(0, Q_{i,t}^n - I_{i,t}\right) \qquad \forall i \in I \qquad (3)$$

$$\sum_{t \in T} Q_{i,t} \geq \sum_{t,n} Q_{i,t}^n \qquad \forall i \in I \qquad (4)$$

$$\sum_{t \in T} \sum_{d \in D} t \cdot Q_i \cdot z_{d,p} \leq \sum_{t \in T} K_{p,t} \cdot K_{p,t}^{Cap} \qquad \forall p \in P \qquad (5)$$

$$\sum_{t \in T} K_{p,t} = \sum_{s \in S} \sum_{t \in T} (\delta_{s,t} \cdot h_s + V) \cdot U_p \qquad \forall p \in P \qquad (6)$$

$$\sum_{i \in I} B_i \leq \sum_{t \in T} I_t^{raw} \qquad \forall i \in I \qquad (7)$$

$$\sum_{i \in I} B_{i,p} = \sum_{d \in D} P_d \cdot R_d \cdot K_{p,d} \qquad \forall p \in P \qquad (8)$$

$$g \neq i, \mathrm{Pr}(g) \geq \mathrm{Pr}(i) \qquad \forall p \in P \qquad (9)$$

$$\sum_{d \in D} b_{p,d,i} \leq \mathrm{dd}_{i,o} - \sum_{d \in D} b_{p,d,i} \qquad \forall p \in P, i \in I \qquad (10)$$

$$\sum_{d \in D} x_{i,d} = 1 \qquad \forall i \in I \qquad (11)$$

$$\sum_{p \in P} z_{d,p} = 1 \qquad \forall p \in P \qquad (12)$$

Constraint (3) determines the order quantity of production order *o*. Constraint (4) ensures quantity of produced items in the planning horizon is at the least the ordered quantity. Constraint (5) ensures that the production is less than or equal to the available press capacity. Constraint (6) calculates the available capacity of presses *p* for the day *t*. Constraint (7) ensures that the number of billets used in production does not exceed the number of billets available. Constraint (8) calculates the production for a press. Constraint (9) ensures that the priority items are scheduled first. Constraint (10) ensures that the processing time for the presses is less than or equal to the difference between the due date and the starting time of item (*i*) on

the press *p.* Constraint (11) ensures that the item can only be produced from one die. Constraint (12) ensures that a die is not scheduled to multiple presses.

Chapter 6: Development of Supplementary Mechanism

The scheduling problem is too complex to solve with exact methods. When looking into solutions for similar scheduling problems with same complexity level it was determined that the use of metaheuristics were popular.

6.1. Simulated Annealing

Simulated annealing is used to solve optimization problems. It has been found that this method can be used to solve real life problems because of the flexible nature of this algorithm and the ability to solve an NP-Hard problem in reasonable time. The objective function of this algorithm is to escape a local minimum. The fundamental idea behind this method is to provide the opportunity for the algorithm to accept a solution with a worse answer than the initial solution or the previous solution stored. This enables algorithm to escape a local optimum solution.

The algorithms starts with the initial solution. The initial solution can be generated randomly, calculated using an operational research model or calculated using historical data of the real life process. The initial solution is compared to a new solution generated using a certain strategy. If the new solution is better than the initial solution, this solution is then stored. This solution will be used to compare the next neighbor with. But if the initial solution is better than 'new solution' there is a probability that the new solution will be accepted. This helps the algorithm escape a local optimum solution. This probability of acceptance decreases as the number of iterations increases. The Simulated Annealing algorithm structure, is displayed below:

Select an initial temperature

Choose temperature reduction function

Stopping Criteria T_{min}

Find an initial solution (s)

Feasibility Test

Calculate the cost of production $F(s)$

repeat

repeat

  Generate an Neighbour (s') by changing the schedule by swapping two dies

  Schedule's Feasibility test

  Repeat

    If *Schedule Feasibile store solution*

    Else *Generate new solution (s')*

    Until Schedule Feasible

  Calculate the cost of production F(s')

  $\Delta E = F(s') - F(s)$

  If $\Delta E \leq 0$ ***Then*** $s = s'$ *#Accept the neighbour solution*

  Else *Accept s' with a probability* $e^{\frac{-\Delta E}{T}}$

    if random generated value < than the probability

    Accept the worse solution

  Until *Equilibrium condition is reached*

  Update Temperature

Until *Stopping criteria is reached* $T < T_{min}$

Output: *Best solution found*

Plot the schedule

Calculate the reduction of production time.

The parameters of the simulated annealing algorithm, which is the initial temperature, cooling rate and search area parameters are problem specific. These values are different for each algorithm and are determined through trial and error. The performance of the algorithm can determined by the convergence of the costs accepted by the algorithm.

When a low initial temperature and a large cooling factor are used, the cost graph does not convergence. An example for this is shown in Figure 8 and Figure 9 and the parameter to calculate this is shown in Table 14.

Parameter	Value
Initial Temperature	600
Cooling Factor	0.7
Minimum Temperature	0.1
Equilibrium Condition	3

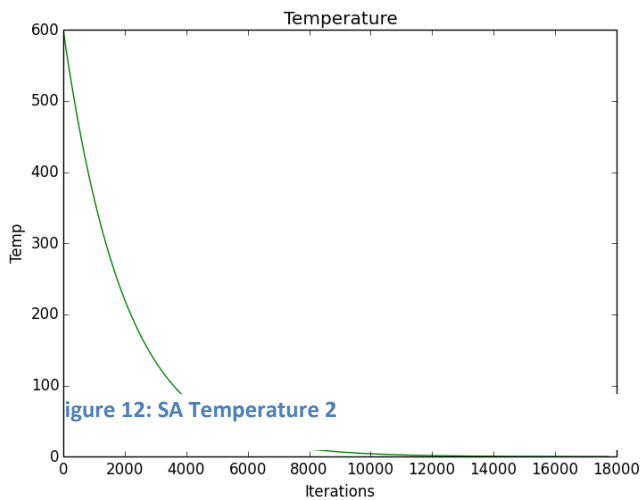Table 14: Cooling system's parameters 1

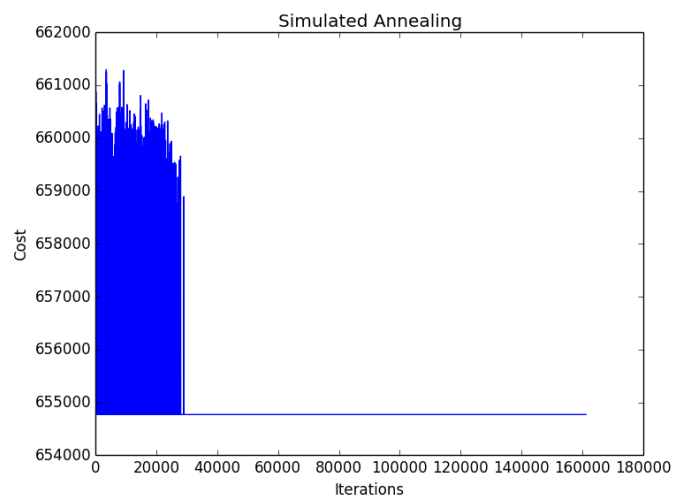Figure 11: Simulated Annealing Temperature1

Figure 12: SA Temperature 2

Figure 10: Simulated Annealing Cost 1

As Table 15 depicts, for the following next values. The initial temperature were increased. Different values for the cooling factor were tested. The cost graph, Figure 14, improved but the temperature graph, Figure 13, weren't visible.

Parameter	Value
Initial Temperature	700 000 000
Cooling Factor	0.99
Minimum Temperature	0.0001
Equilibrium Condition	200

Table 15: Cooling System's parameters 2
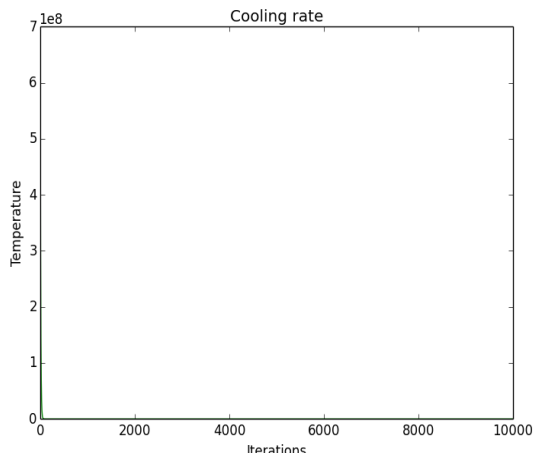
Figure 14: SA Temperature 2
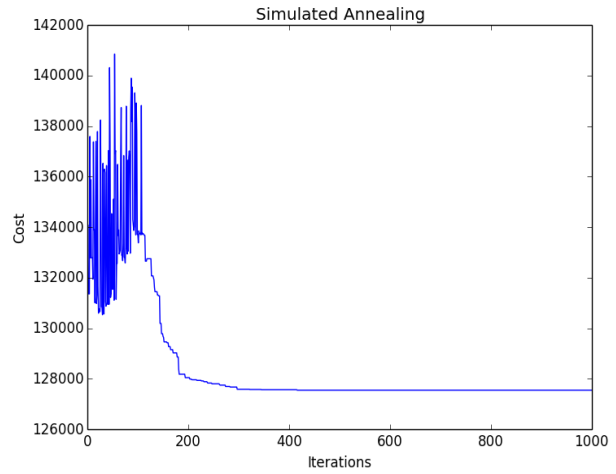
Figure 13: SA Cost 2

The next strategy was to increase the equilibrium values. This increased the number of iterations which the algorithm performs before the temperature were updated and the cooling rate is shown in Figure 15. The Figure 16 depicts that the cost graph performed a wider search within the search area but at 2000 iterations the cost graph decreased too quickly. With performing more test it was apparent that this drop occurs at the same temperature value.

Parameter	Value
Initial Temperature	7 000 000
Cooling Factor	0.99
Minimum Temperature	0.0001
Equilibrium Condition	1000

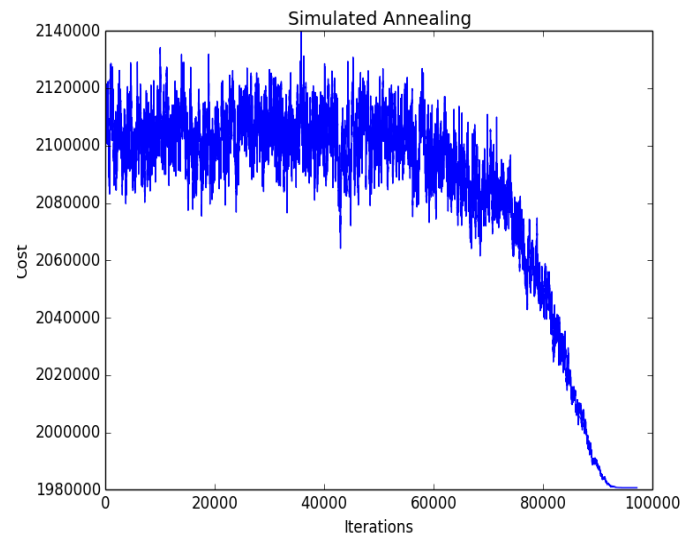Table 16: Cooling System Parameters 3
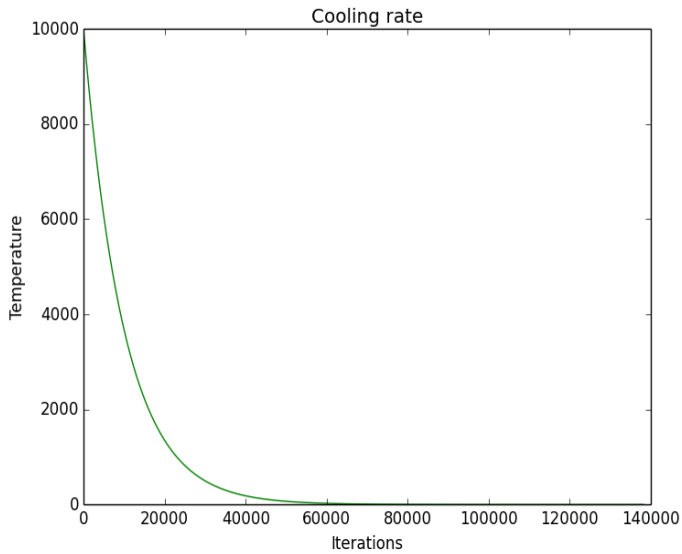
Figure 15: SA Temperature 3

Figure 16: SA Cost 3

The method used to cool the temperature is responsible for the quick drop in the cost. An alternative way of reducing the temperature were investigated. The temperature update formula were changed to reduce this value with a constant value. Figure 17 depicts the cooling rate for the number of iterations performed by the algorithm.
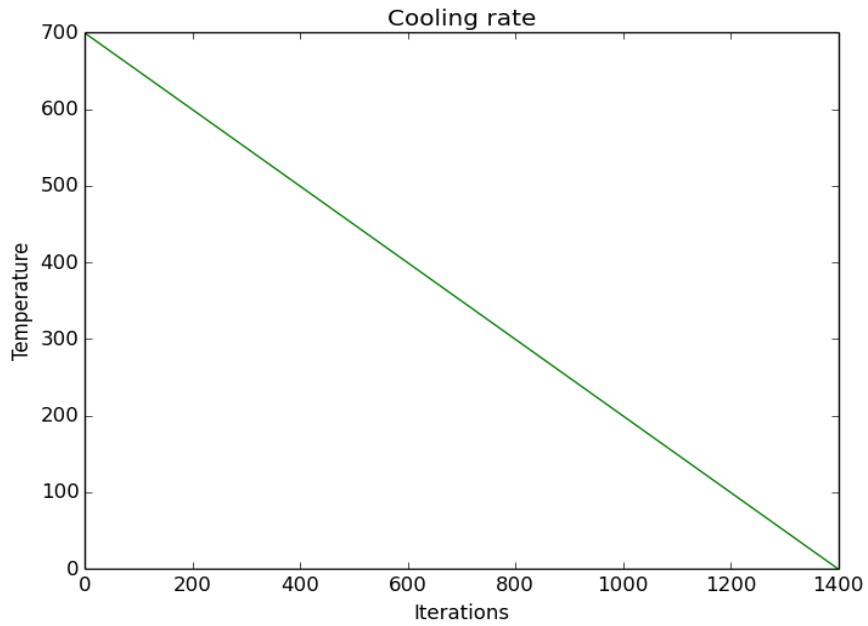
Figure 17: Simulated Annealing Cooling rate 4

Figure 18 depicts the cost convergence graph achieve through the linear reduction rate of the temperature. The simulated annealing algorithm were able to achieve significantly lower cost.
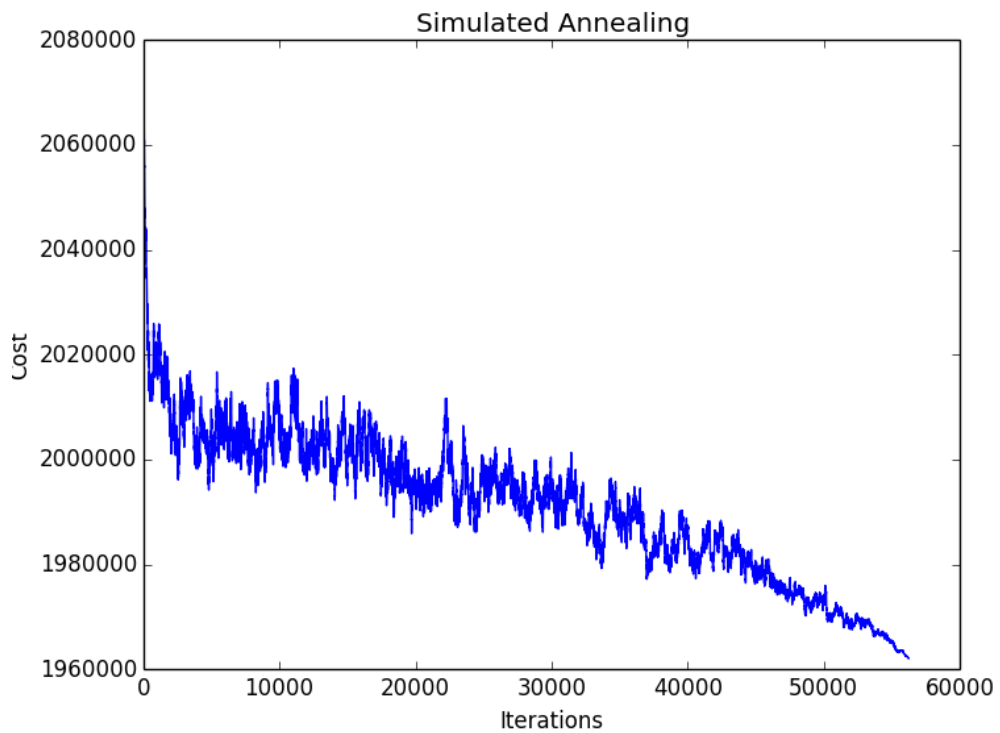

Figure 18: Simulated Annealing Cost 4

6.2. My scheduling problem

The initial solution and the way that the neighbor is generated should be programmed in such a way that the constraints of the company is adhered to.

Initial solution

The current scheduling is done by assigning a certain die category of a press. For example the fast runners, dies with one or two cavities with simple shapes, are scheduled to EP5. This indicates that the scheduling of these dies will not have a wide variety of dies for the presses. The historical data of the production plans for the presses can be used to schedule the initial solution and this can be used as a benchmark to compare the schedule generated by the algorithm. The only problem is that this might take more iterations to achieve the global optimum. The initial schedule is an important part of the simulated annealing and can have a big impact on the execution time of the algorithm. It was decided to use greedy heuristics to assign the dies to the presses. This means that the die will be scheduled to the press with the shortest total production time at that point in the loop. It was identified that the execution time of the algorithm is reduced when this scheduling method was used. The execution time for the past production scheduled is longer because each press contains dies with similar characteristics. Figure # is the structure which shows the generation of the initial schedule. The following part shows the section of the algorithm that determines the initial solution.

Create empty list for each press

Assign a die to each press

Repeat

    Repeat

        If *problem die* ***then***

            Assign die to Press[8]

            Calculate the production time for the press

        Eliff *Press*[i] *has shortest production time* ***then***

            Assign die to Press[i]

            Calculate the total production time for Press[i]

    Until *the press with the shortest production time is established*

    Feasibility test

***If** feasibility test = True*

   Store scheduling move

Else

   Reject scheduling move

__Until__ each die is scheduled

The production time of each die is used to determine the makespan of the scheduled dies. The production time is calculated by using the speed of the die, the failure time and the time it takes for a changeover (if applicable). The production time is calculated by using equation 2.

$$\boldsymbol{Ptime = Input \cdot Die\ Speed + FailProb \cdot FailTime + Die\ Change\ overs} \quad (2)$$

Speed: The speed of the die depends on which press it runs on. The speed is measured in Kg/min and this is multiplied by the Output needed per die.

Die failure: The failure probability of each die was derived from historical data over a period of a year. Each die has a unique value. This value is multiplied by a constant time which represents the average time wasted with die failures. This value was derived from historical data.

Die change overs: A die has a production constraint of 2000 kg per run. If an order requires an input of more than that, time associated with a die changeover needs to be incorporated in the production time. The changeover times on all the presses and the dies should be constant. An average value was determined through time studies

Generating new solution

The Simulated Annealing algorithm requires the generation of a new solution. This is called neighborhood searching. In order to perform this, a neighborhood structure needs to be defined. This structure is the boundaries for the searching area for the new solution. The method used to generate the new solution is called the Swapping Neighborhoods. This involves randomly selecting two presses and randomly select a press scheduled to each of the selected presses. The dies selected are then swapped. This means die1 will have die2's starting time on press2 and die2 will have die1's starting time on press1. The new production time for this schedule is determined.

Selectpress1 = random(1,9)

__Repeat__

$Selectpress2 = random(1,9)$

End Selectpress2 does not equal Selectpress1

Select a random die on press 1

Select a random die on press 2

Feasibility test

*For Selectpress*1 and Selectpress2

　　　Update the list of the dies for that press

　　　Calculate the new production time for this press

　　　Calculate the cost for the schedule on the specific press

Add the cost of the other dies

Update the list of the two presses which were rescheduled

Feasibility test

When scheduling dies to presses there are constraints that the model needs to adhere to. The feasibility test ensures that the new solution does not result in an unfeasible solution. There are few dies (products) which use hard alloys when manufactured. These alloys can only be used on EP9 because this press has more strength than the others. When such a die shows up in the list of dies that needs to be scheduled, this die will not follow the scheduling rules and will be scheduled to EP9. The new solution that was generated also need to be approved by the feasibility test. A new solution will be generated if the solution was not approved. The input data will have the information of the alloy used for the specific die and with a simple 'if loop' this constraint will be incorporated into the model. The following constraint ensures that the products that need to be water treated are only scheduled to EP3. This method will use the same method to ensure the constraint is followed when scheduling the dies. The last constraint ensures that the problem dies are scheduled to EP8 and that these dies are not used to generate a new solution.

Cost Calculation

The cost calculation of the schedule is determined per press as the presses have different production costs. Equation 3 depicts the cost calculations.

$$Cost = Input \cdot Production\ Cost + Waste \cdot Waste\ cost \qquad (3)$$

This calculation will be performed for each press and this will be a summation of all the dies scheduled to the press. The input and waste values are determined prior to importing it into Python. These values are then stored in list with a unique value that is used to indicate which die it is link to. These calculations are calculated by using a 'for loop' for each press.

Chapter 7: Solution

7.1. Different Objective Functions

The algorithm can be used to compare different scenarios in order to determine the best way forward. For each scenario the production cost, production time per press and production output can be recorded.

7.1.1. Minimise Cost

The first objective of this project is to show what improvements could be achieved by utilising a scheduling algorithm. For this purpose, a single objective of minimising total production cost was used in the algorithm. Total production cost consist of the production cost of each press' schedule. This calculation uses a production cost per kilogram and cost of waste to determine the cost of each schedule.

Actual orders for a period of 1 month totaled R2 076 519 and were used to determine the potential reduction in production costs when using the algorithm. Figure 20 depicts the comparison between the actual production costs during this period and reduced the production cost delivered by the algorithm. A total reduction of R 114 435 in production cost could be realised, which could result in annual savings in the region of R 1 373 220.
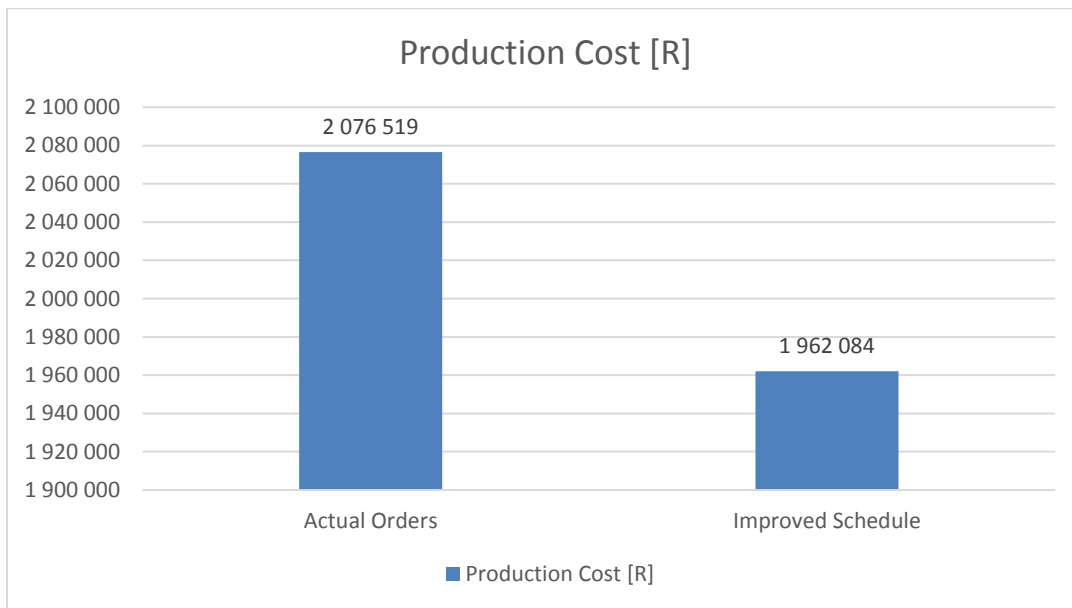

Figure 19: Decrease in Production Cost

7.1.2.　　　Increase Output

The second objective of this project is to increase the production output of the company.

Scheduling Results: Problem dies Restriction

An alternative method to increase the output of the dies were to restrict the scheduling of the problem dies to EP8. This is the first scenario that will be modelled with regards to the output. The scheduling model should determine what impact this will have on the production of the presses.

The algorithm was adjusted to restrict the scheduling of problem dies to EP8, which is the lowest performer. In theory this should allow the production of the other presses to be reduced as the dies that will be scheduled to these presses have higher recovery rates and higher speeds. Table 18 depicts the comparison between the normal schedule method and the Problem Die restriction method.
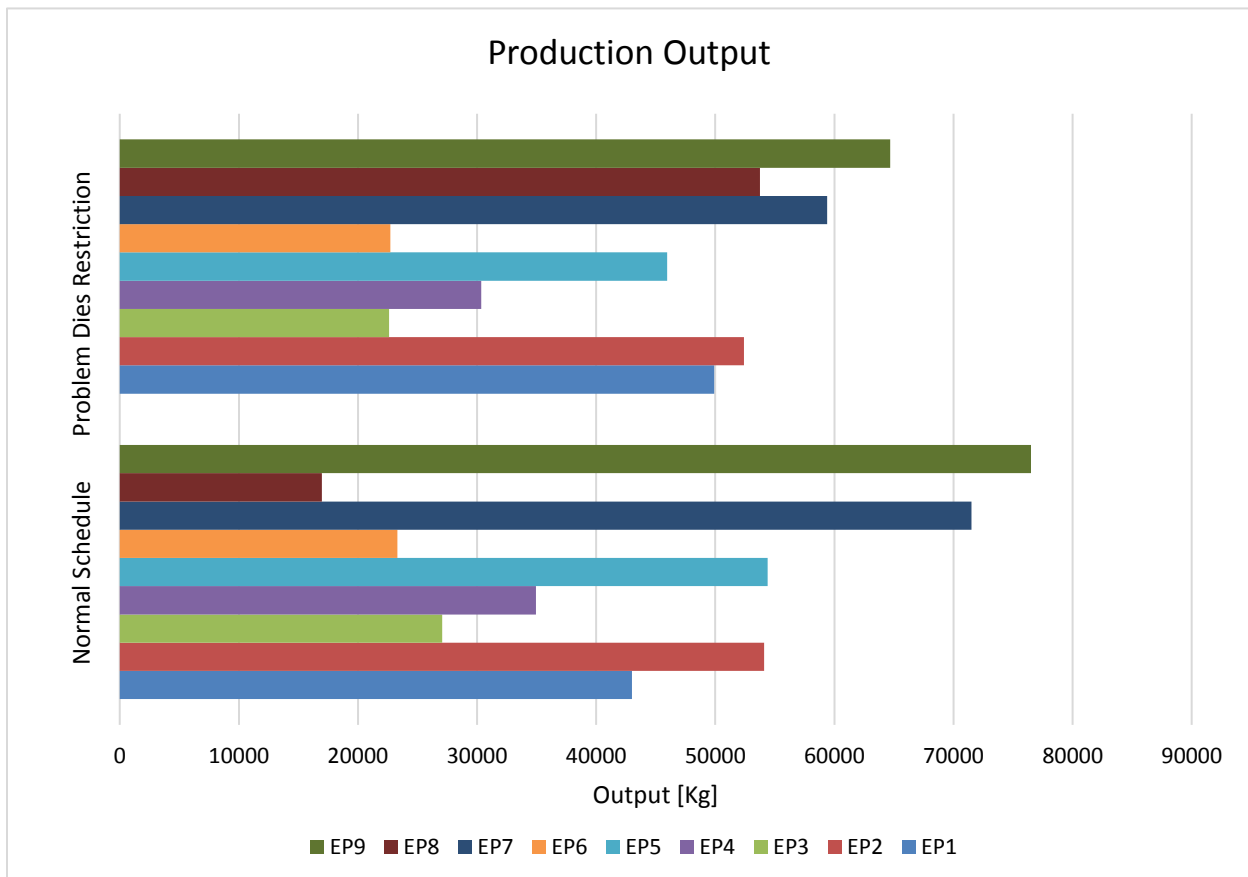

Figure 20: Production Output schedule

The restriction of the problem dies to EP8 resulted in open capacity of **36809.26 kg** on the other presses. The waste produced by EP8, increased significantly. This resulted in an overall

increase between the different schedules with 20496 kg. Figure 21 depicts the increase in waste. The problem die scheduling increased the production cost with R21 563. This analysis concludes that restricting the problem dies to EP8, will not be beneficial to the production output of the company.
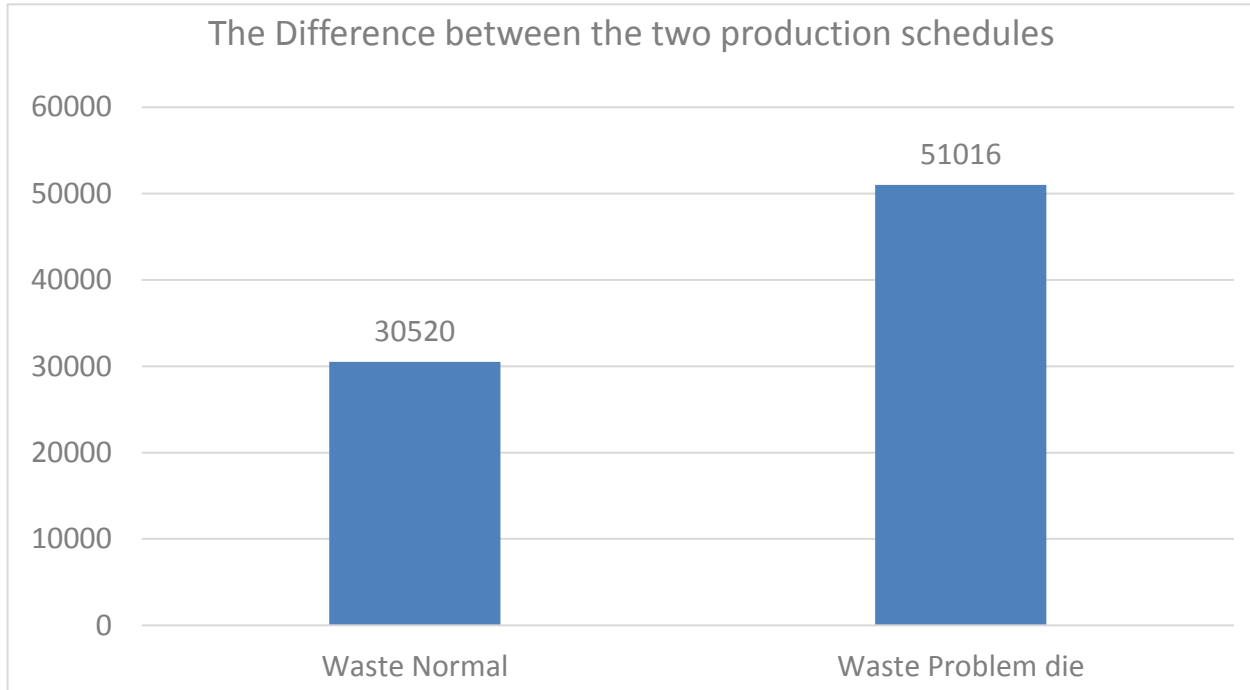

The Difference between the two production schedules

Waste Normal: 30520
Waste Problem die: 51016

New Machine

For the second scenario, Ep8 is scrapped and a new machine is purchased which has the same capabilities as Ep7. The dies' speed on this press will be faster than EP8 and have higher recovery rates. The new machine reduced the overall waste generated by the schedule and total production time.
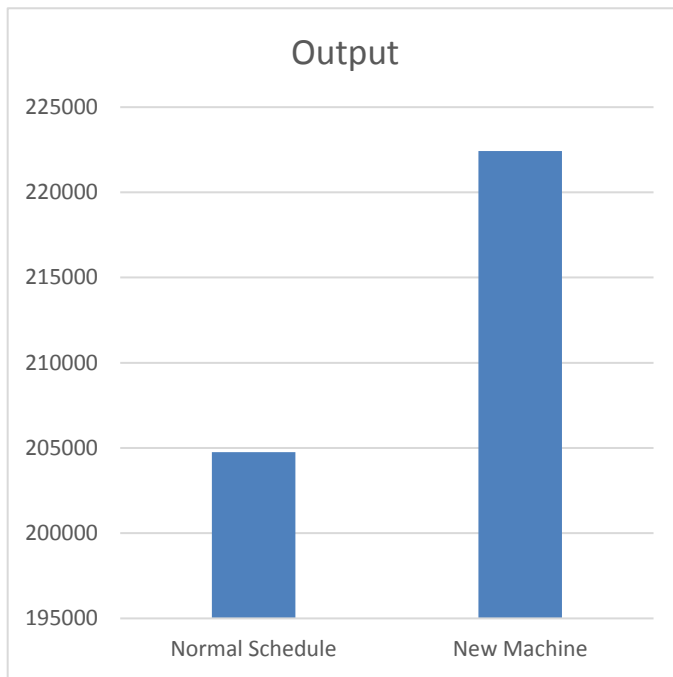
Figure 22: New Machine Output

Figure 22 and Figure 23 depicts the results of a week's schedule. The output of the production schedule was increased by 15 000 kg for the week. This means that the company will be able to improve their production output with 60 000kg per month and 720 000 kg per year.
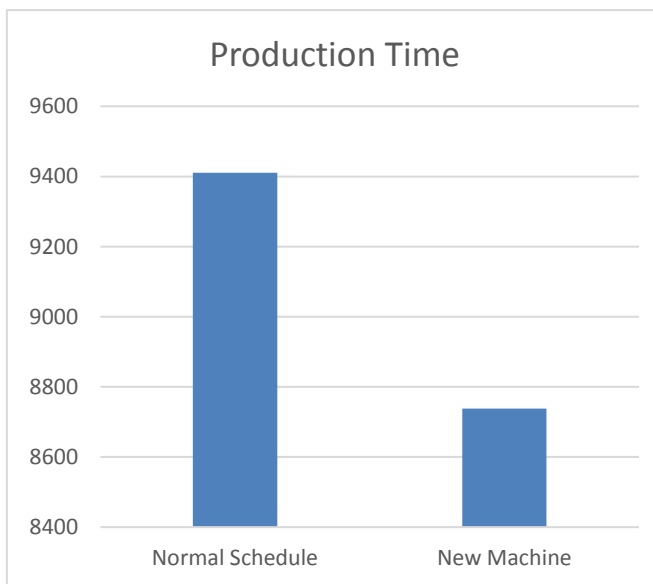

Figure 23: New Machine Production time

The the price to buy a new 7" press is R10 million. The company will earn a profit of R5 per kilogram for the extra output produced by this press which result in an increase of R3 600 00 per year. This means that the payback period for this machine will be 3 years. From this point the company's profits will increase.

7.1.3. Minimise Make span

The second objective of this project is to reduce number of late orders the company documents. To achieve this, the model has to be adjusted a bit in order to incorporate the due date of the orders. The due date of the orders are read into the algorithm and constantly compared to the finishing time of the die on the schedule. A simple strategy to include the due date in algorithm is to assign a Penalty factor to any late orders. This strategy is also proposed by Aycan and Ayav (2008) as a solution to a Course scheduling problem. This when a new neighbor is generated and the swapping strategy of this step causes the order to be late, a penalty factor will be added to the production cost calculation.

The past production schedule of 200 dies were used as a benchmark the results of the algorithms. The 200 dies total production time extended over 5 days. The algorithm reduced the production time with 400 minutes. This will result a decrease of 1200 minutes per month, which is 9 days (1200minutes /1340 minutes production per day). The company will be able to reduce the number of late orders and reduce the number of lead days.

7.2. Improve Scheduling

The current production schedulers does not incorporate the different production cost and the difference in the ability of the presses, when they plan the production schedules. The final deliverable of this project to show what important factors influences the scheduling distribution of dies between the presses. A production list of 200 dies were scheduled with the algorithm. The scheduled were analysed in detail and rough scheduling guidelines were drawn from these results. Table 17 depict the production output and production time determined for each press. Figure 24 depict further detail of the schedules of the presses which can be used to analyse the specific die characteristics of dies scheduled to a press. The schedule graph uses the production time calculated for the die to display the duration of the order assigned to the press.

Presses	Production cost	Production time [min]	Output [Kg]	Problem dies
EP1	4.92	1117	25500.	3
EP2	4.92	965	21246.	4
EP3	7.1	677	15260	0
EP4	6.84	886	14521	0
EP5	5.22	688	14511	0

EP6	4.82	**1054**	16517	1
EP7	4.92	1443	**33905**	0
EP8	4.92	**938**	13255	0
EP9	5.02	1640	**33033**	4

Table 17: Scenario 1 results

From the results of the algorithm, the impact of the production cost and the capabilities of the presses with regards to the scheduling is evident/visible. The following rules can be concluded from this:

- Ep1, EP2 and EP9 should have the highest utilization factor.
- EP6 and EP8 should handle short jobs, in terms of kilograms required. Dies with high recovery rates and high speeds were scheduled to these presses.
- Dies with high recovery rates should be scheduled to Ep3, EP4 and EP5 because they have the highest production cost. No problem dies should run on these presses.

- Ep3, EP4 and EP5 should have the lowest production time when possible.
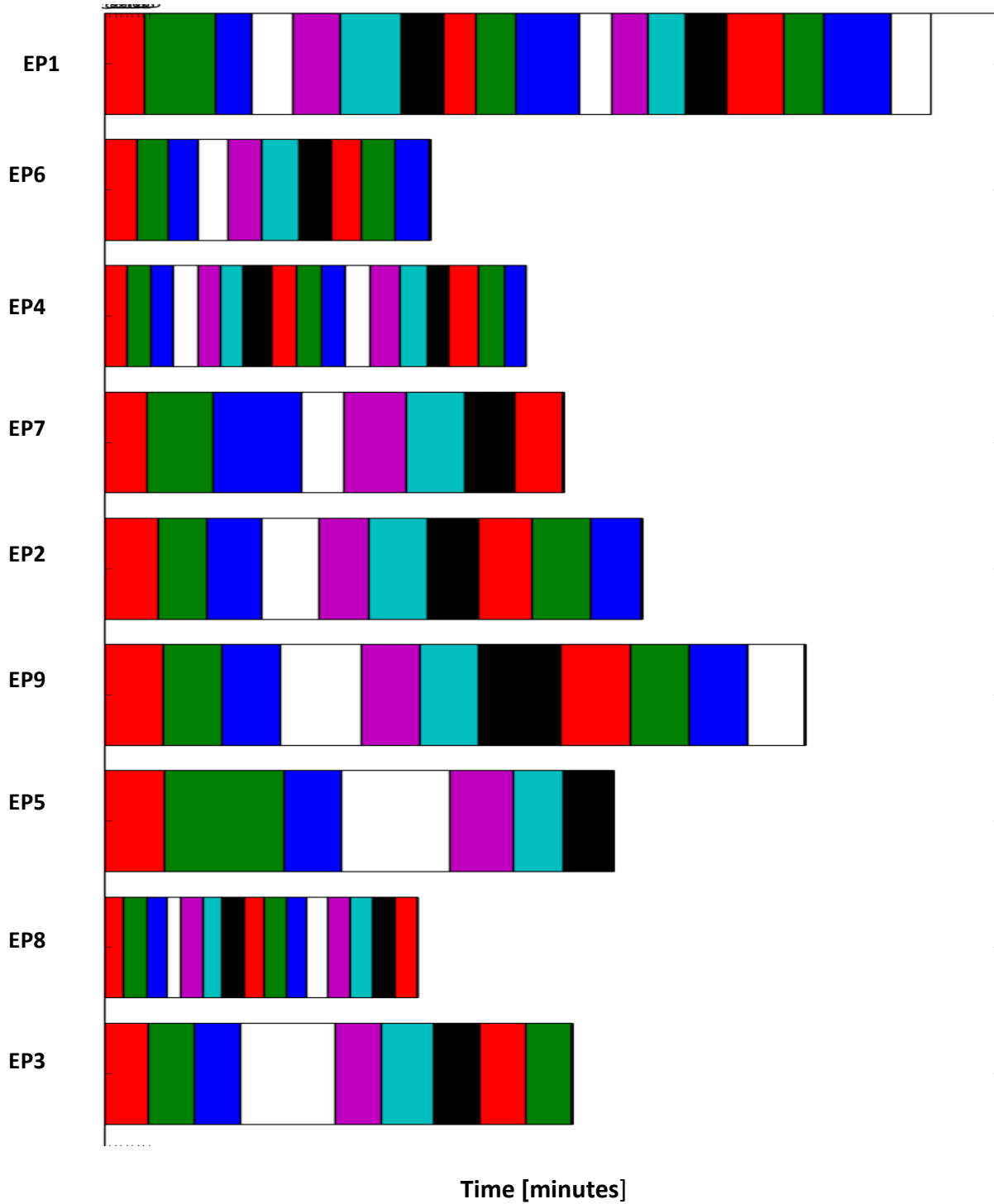

Time [minutes]

7.3. Validation

The model can be validated by the use of a benchmarking scheduling problem. Within the document they provide input data which can be used as input to our scheduling model. The results calculated by our model can be compared to the articles results, in order to determine the accuracy. The following code is built into my model:

$Initial\ solution\ and\ constraint$: $X_0 = 50$

$Modify\ the\ seed$: $k = X_i/b$

$$X_{i+1} = a\left(\frac{X_i}{b}\right) - kc$$

$New\ solution$: X_{i+1}

$Gnerate\ Processing\ time$: $P_{ij} = U[1,99]$

For $i\ in\ range(1, n)$

   For $j\ range(1, m)$

      $Generate\ new\ solution$

$Calculate\ lower\ bound$ $= max\{max, (\sum_i d_{ij}), max(\sum_{j,k} d_{kj})\}$

The scheduling used the input values and was able to calculate to their results.

Chapter 8: Sensitivity Analysis

Sensitivity analysis in which key quantitative assumptions and computations (underlying a decision, estimate, or project) are changed systematically to assess their effect on the final outcome. Local sensitivity analysis is a *one-at-a-time* (OAT) technique. OAT technique analyze the effect of one parameter on the cost function at a time, keeping the other parameters fixed. Thus, you test how robust the cost function is to small changes in the values of optimized parameter. Sensitivity analysis can help the reviewer to determine which parameters are the key drivers of a model's results

8.1. Production cost

The production cost of the different presses to see what the effect on the production output, production time and the production cost would be. The cost value of a single die were changed. The motivation behind this analysis of this parameter is to determine if there is a specific press that drives the model.

The production cost for each of the dies were change were changed in increments of 10%. Figure ## depicts the change this had on the production output for EP3, EP7 and EP9. The change in the production cost did not really influence EP7 because this press has the lowest production cost. With the decrease in in production cost the output stayed the same, since this press already has a high utilization factor. The increase in production cost the press did not experience a big drop in production because this press is still cheaper than the other presses. The Ep3, EP4 and EP5 which has the highest production rates had a big effect on the production output when the cost was increased. EP4 and EP3 followed the same trend EP3 in Figure ##.
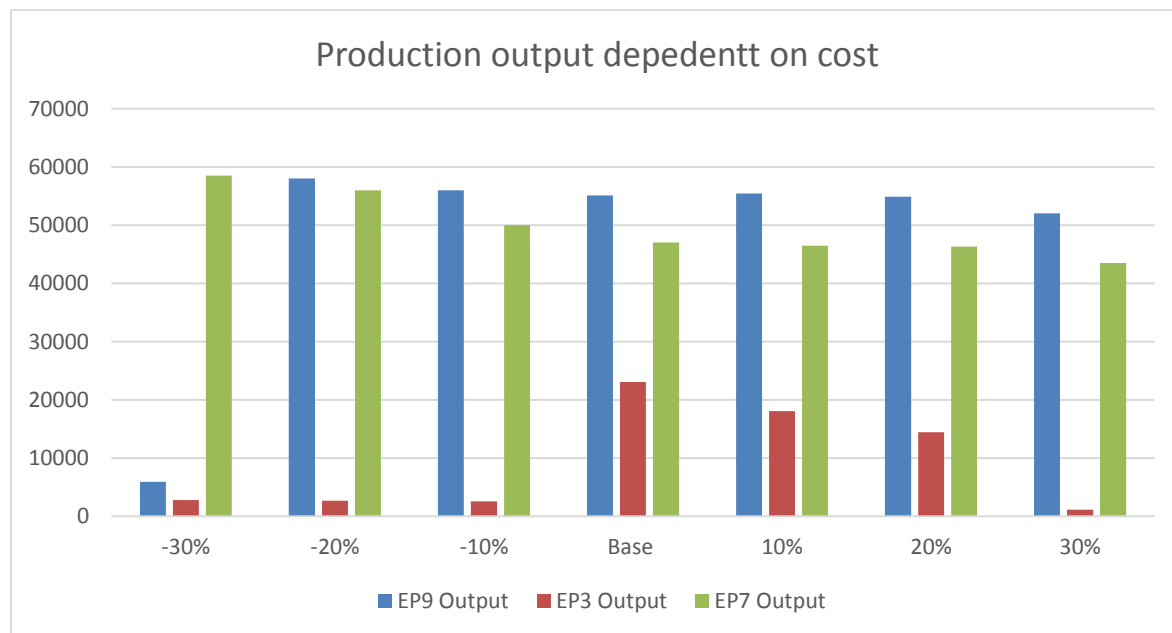

Figure 25: Cost Sensitivity Analyses

8.2. Demand

The final variable which will be analysed is the decrease or increase of the demand. This variable is chosen to determine whether the die scheduling is rigid. The impact on the overall distribution of the dies, which can be depicted from the production times of the schedules, is documented. The demand of the dies were increased and decreased with 10% increments.

As seen in the graph the distribution of the dies/work did not change by a large margin. The production time for the press increased or decreased as the demand was increased or decreased.
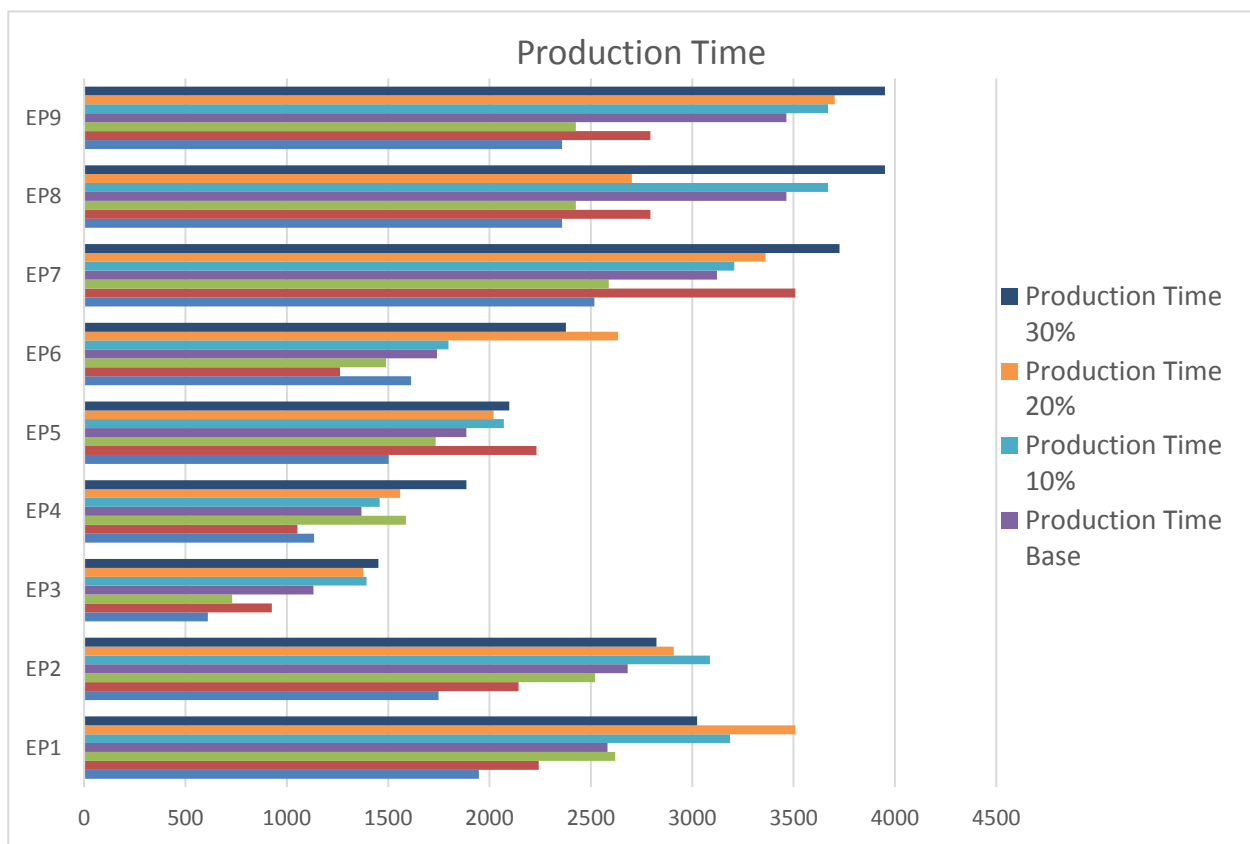

Figure 26: Production Time Analyses

Chapter 9: Conclusion

The simulated annealing algorithm developed, used the constraints of the OR Model to ensure the schedules generated by this algorithm are feasible. The algorithm was able to determine an optimal solution in a short period. The algorithm was able to reduce the cost of production by R 114 435, which could result in annual savings in the region of R 1 373 220. This schedule is driven by the production cost of the different presses.

The scheduling models was used to analyse two scenarios that might increase the production of the press. The impact of restricting the problem to EP8 was computed. This resulted in high production cost and an increase in the total waste generated by the presses. The second scenario proved to be a potential investment for the company. The new machine were able to improve the production output for the company by 720 000 kg per year

The scheduling model can use penalty factor **i**ncorporate the due date of the dies. The schedule provided by the algorithm will have the lowest production cost as well as lower lead times.

References

Aycan, E. and Ayav, T. (2008). Solving the Course Scheduling Problem Using Simulated Annealing. *Metaheuristics*, 2.

Bierwirth, C. and Mattfeld, D. (1999). Production Scheduling and Rescheduling with Genetic Algorithm. *Evolutionary Computation*, 1(7), pp.1-17.

Bellabdaoui, A. and Teghem, J. (2006). A mixed-integer linear programming model for the continuous casting planning. *International Journal of Production Economics*, 104(2), pp.260-270.

Baki, M. and Vickson†, R. (2004). One-operator, two-machine open shop and flow shop problems with setup times for machines and weighted number of tardy jobs objective. *Optimization Methods and Software*, 19(2), pp.165-178.

Duba, J. and Osyczka, A. (2005). Multiple criteria lot-sizing in a foundry using evolutionary algorithms. *Evolutionary Multi-Criterion Optimization*, 7, pp.651-663.

Dutta, G., Gupta, N. and Fourer, R. (2009). *An Optimization-Based Decision Support System for Strategic Planning in a Process Industry*. Working Paper Series. Ahmedabad: Indian Institute of Management.

de Araujo, S., Arenales, M. and Clark, A. (2008). Lot sizing and furnace scheduling in small foundries. *Computers & Operations Research*, 35(3), pp.916-932.

dos Santos-Meza, E., Oliveira dos Santos, M. and Nereu Arenales, M. (2002). A lot-sizing problem in an automated foundry. *European Journal of Operational Research*, 139(3), pp.490-500

Forrai, M. and Kulcsar, G. (2009). SOLVING MULTI-OBJECTIVE PRODUCTION SCHEDULING PROBLEMS USING A NEW APPROACH. *Production Systems and Information Engineering*, 5, pp.81-94

Fidanova, S. (2004). Simulated Annealing for Grid Scheduling Problem. *Approximation Methods*.

Hajeeh, (2013). OPTIMIZING AN ALUMINUM EXTRUSION PROCESS. *Journal of Mathematics and Statistics*, 9(2), pp.77-83

Leung, J., Li, H. and Pinedo, M. (2007). Scheduling orders for multiple product types to minimize total weighted completion time. *Discrete Applied Mathematics*, 155(8), pp.945-970.

Nonås, S. and Olsen, K. (2005). Optimal and heuristic solutions for a scheduling problem arising in a foundry. *Computers & Operations Research*, 32(9), pp.2351-2382.

Noivo, J. and Ramalhinho Dias Lourenço, H. (n.d.). Solving Two Production Scheduling Problems with Sequence-Dependent Set-Up Times. *SSRN Electronic Journal*.

Maticevic, G., Majdandzic, N. and Iovric, T. (2007). Production Scheduling Model in Aluminium Foundry. *Journal of Mechanical Engineering*, 54, pp.37-48.

Mathworks.com. (2016). *Multiobjective Optimization - MATLAB*. [online] Available at: http://www.mathworks.com/discovery/multiobjective-optimization.html?requestedDomain=www.mathworks.com [Accessed 13 May 2016].

Tang, L., Liu, J., Rong, A. and Yang, Z. (2000). A mathematical programming model for scheduling steelmaking-continuous casting production. *European Journal of Operational Research*, 120(2), pp.423-435

Tang, L. and Wang, G. (2008). Decision support system for the batching problems of steelmaking and continuous-casting production. *Omega*, 36(6), pp.976-991.

A   Sponsorship Form

Department of Industrial & Systems Engineering
Final Year Projects
Identification and Responsibility of Project Sponsors

Final Year Projects may be published by the University of Pretoria on *UPSpace* and may thus be freely available on the Internet. These publications portray the quality of education at the University, but they have the potential of exposing sensitive company information. It is important that both students and company representatives or sponsors are aware of such implications.

Key responsibilities of Project Sponsors:

A project sponsor is the key contact person within the company. This person should thus be able to provide guidance to the student throughout the project. The sponsor is also very likely to gain from the success of the project. The project sponsor has the following important responsibilities:

1. Confirm his/her role as project sponsor, duly authorised by the company. Multiple sponsors can be appointed, but this is not advised. The duly completed form will considered as acceptance of sponsor role.
2. Review and approve the Project Proposal, ensuring that it clearly defines the problem to be investigated by the student and that the project aim, scope, deliverables and approach is acceptable from the company's perspective.
3. Review the Final Project Report (delivered during the second semester), ensuring that information is accurate and that the solution addresses the problems and/or design requirements of the defined project.
4. Acknowledges the intended publication of the Project Report on UP Space.
5. Ensures that any sensitive, confidential information or intellectual property of the company is not disclosed in the Final Project Report.

Project Sponsor Details:

Company:	Wispeco (Pty) Ltd
Project Description:	The total optimisation of extrusion presses
Student Name:	Janelle
Student number:	13003161
Student Signature:	[signature]
Sponsor Name:	Esbé du Toit
Designation:	Organisational Improvement Manager
E-mail:	esbe@wispeco.co.za
Tel No:	0113890034
Cell No:	0845841110
Fax No:	
Sponsor Signature:	EduToit