Cable Manufacturing: Meeting the Demand

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Submitted in partial fulfilment of the requirements for the degree of

BACHELORS OF INDUSTRIAL ENGINEERING

in the

FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY

UNIVERSITY OF PRETORIA

October 2011

Executive Summary

Company ABC is a cable manufacturing company with 4 different product groups, Electronic Detonator Communication cables; UTP cables; Telephone cables; and Twin wire, the focus of this project is on the Electronic Detonator Communication cables. The products in the product group are the current Blastwire-A and the soon to be in production Blastwire-B. The production of the cable runs 5 days a week, with 2 shifts a day and 12 hours a shift.

With a steadily increasing demand for Blastwire-A and the introduction of the new cable Blastwire-B, the demand will rise to more than double the current amount. By using numerous industrial engineering methods and tools the most effective and cost efficient solution to meeting the new demand will be found.

By looking at the results of the analysis it is clear to see that if all 4 sheathing machines are operational and run at an OEE level of 75% the company's current production capacity is close to 1 836 000 metres of finished product. When setting up the production schedule two option are available, LINGO and excel solver, and both do the job as required but because the excel solver is free with a copy of Microsoft Office it will be the best option for the company.

When trying to meet the rise in demand 4 alternatives were identified to increase the capacity to 2 400 000 metres: an additional machine, an additional day of labour, using UTP product capacity, production speed increase. Out of these 4 the second alternative was identified as the one with the lowest cost/benefit ratio, but unfortunately this alternative will not enable them to meet the demand and thus making alternative 1 the best option, and it is recommended that the company install a new machine to meet the new demand.

Table of Contents

List of Figures

List of Tables

Chapter 1 – Introduction and Background

1.1. Introduction

Company ABC is a cable manufacturing company based in Pretoria that was established in 2004. They are currently operating from a 5000m^2 factory, operating 12 hours a shift, with 2 shifts a day and operating for 5 days a week. With the two shifts combined the company employs over 65 employees.

The company has 4 different product groups, namely: Electronic Detonator Communication cables; UTP cables; Telephone cables; and Twin wire. Each product group has a number of different product variations available. In this project, emphasis will be placed on the Electronic Detonator Communication cables; the product line has been running for some time and has a promising and steadily increasing demand.

The Blastwire-A cable has been performing well and the company has been able to meet the demand up until now. Recently the product's demand from their biggest customer has increased, also the company is in the process of finalising a new contract for a product similar to the current Blastwire-A cable with a similar demand and thus the new demand will be more than double the current demand for detonation cables.

This project will use numerous industrial engineering methods and tools, such as Flow Diagrams, Production Capacity Calculations, Cost-Benefit Analysis, Financial Analysis, and Linear Programming models to investigate and find possible solutions to enable the company to meet their demand in the most effective and cost efficient way.

1.2. Background

1.2.1.The Blastwire Cable

The detonator communication cable is an extremely accurate and robust cable used wherever an electronic signal needs to be sent through within milliseconds. The Blastwire-A cable has two steel cores that are insulated with a plastic sheathing over that. The cable is mostly used in mines or quarries where a lot of small detonations need to be detonated in a specific order and with specific time intervals between each for the rubble to go exactly where they want it to.

Blastwire-A can send different electronic signals within 0.2 milliseconds of each other compared to older cables that can only do it at 1 millisecond. It is thus clear that the superior Blastwire-A can do what is necessary in a fraction of the time that it takes older cables.

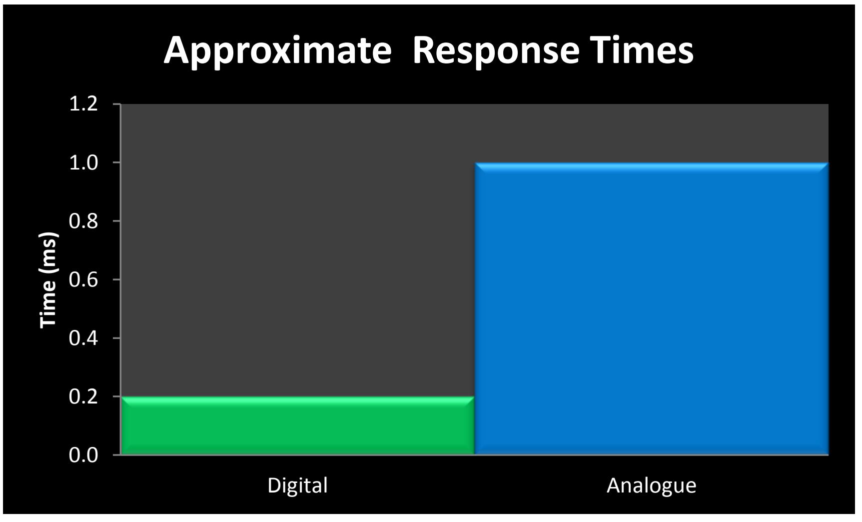

Figure 1. Comparison between Digital and Analogue Response Times

1.2.2.The Cable Manufacturing Process

The complete process of getting the raw materials to final product that is sellable to the customer is split up into two big phases, first the production of the initial cable and then the finishing (adding the plugs, etc.) and packaging it. Only the first process is done by the company and the latter is done by another company with whom they have an agreement to do the finishing and then deliver to the supplier.

The process then ends up being simpler; and it only has two main processes that it goes through from raw material to product that gets sent to the next phase. The steel wire cores in the cable must first be insulated. In this process the steel wire's diameter is first drawn down to the required diameter, and is then sent through an extrusion die where it gets a plastic coating over it.

The next process is the Sheathing process, also like the insulating it is a plastic extrusion, but in this case it is not only over the raw steel core but over the 2 insulated steel cores.

Both the Insulating and Sheathing process are done by pulling the product along the length of the machine where the plastic gets extruded over the wires when it passes through the die. Once through the die and with the coating over it, it is cooled down and at the end of the machine placed on smaller bobbins.

The new detonation cable, Blastwire-B, that will come into production soon is similar to Blastwire-A cable, but is also unique with its own specifications. The biggest difference in the manufacturing process is that with Blastwire-B the core does not need to be drawn down and also does not need to be insulated before getting the final coat sheathed over it.

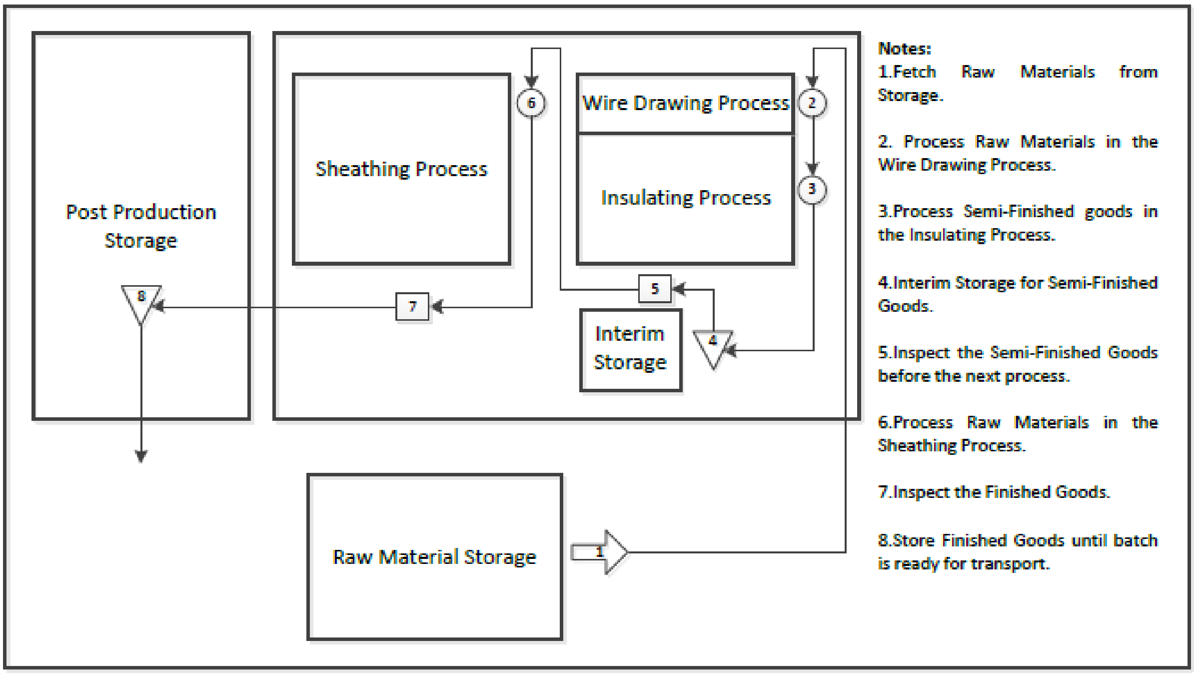

Figure 2. Flow Diagram – Blastwire-A

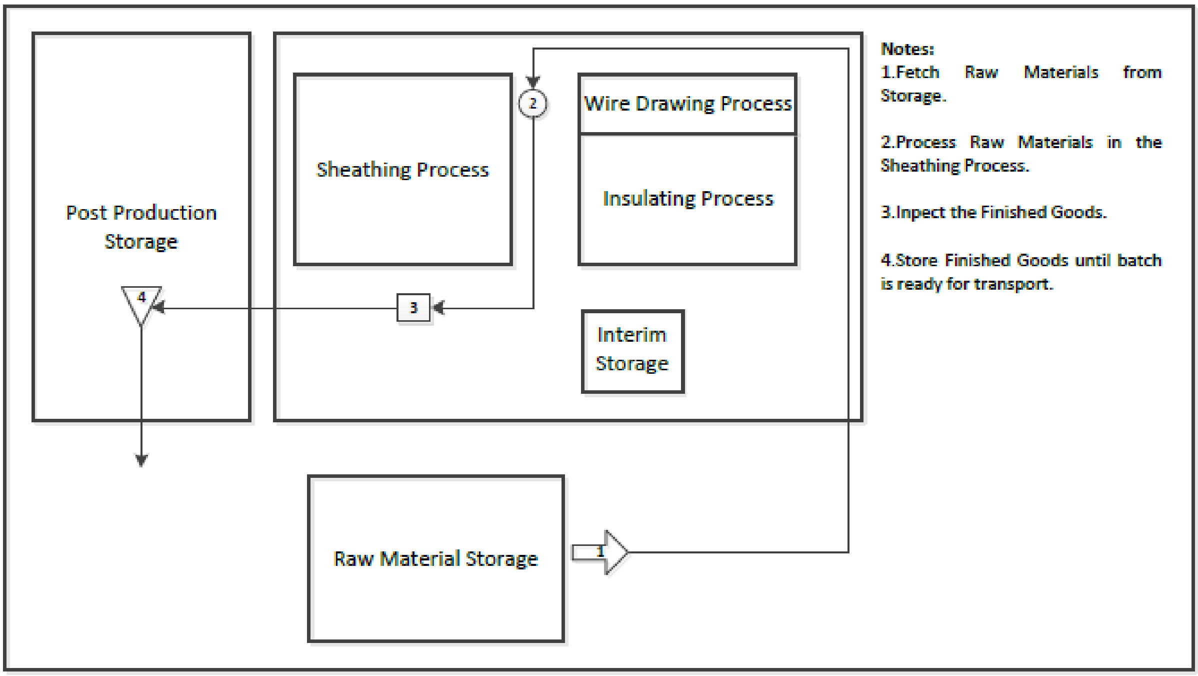

Figure 3. Flow Diagram – Blastwire-B

1.2.3.Demand

The current demand for Blastwire-A is 900 000m per week, but it has gone as low as 500 000m and as high as 1 200 000m. It is expected that the demand will steadily increase for this product from the current standard of 900 000m to 1 200 000m. As for Blastwire-B it is not known how high the demand might go in the future, as it is a specialised product made for one customer, but the customer requested that for at least the first period they will want anywhere between 800 000m and 1 200 000m as well. This then takes the demand for the Blastwires to between 1 600 000m and 2 400 000m per week.

1.3. Project Aim

The aim of the project is to enable the company to find the most effective and cost efficient solution for meeting the rise in demand. This will be done by using the following methods:

- Overall Equipment Effectiveness (OEE).
- Cost-Benefit Analysis.
- Financial Analysis.
- Linear Programming Model.

By doing so the company will benefit from this project in the following ways:

- The company will have a clearer understanding of their current process capacity.
- Certain solutions to circumvent problems and enhance productions in order to meet the rise in demand.
- The company will have a production schedule that will enable them to meet the demand.

1.4. Project Scope

The process of making the Blastwire-A cable involves Insulating and Sheathing processes and in order to meet the demand of the finished product, both these processes must meet the demand. If the Insulating process does not meet the demand, then neither will the Sheathing process.

To ensure the processes meet their demand, firstly all factors, such as quality of the products produced and actual production times, that might bring its capacity down must be investigated to ensure that they are running at their best possible levels. Then if the demand is still not met, all possible alternatives to increase the capacity need to be investigated. The alternatives range from new machine installations, changes in the production schedule, additional production hours, etc. The alternatives will be judged on their cost efficiency and effectiveness to find the best solution to the situation.

Chapter 2 – Literature Review

2.1. Labour Standards

A section of the labour standards applicable in this report that is applicable on all the employees in the factory according to the Employment act (Basic Conditions of Employment Act, No 75 of 1997) are summarized in to the following points:

- Ordinary hours of work for a worker is no more than :
    - 45 hours a week.
    - 9 hours a day if the worker works for 5 days or less in a week.
    - 8 hours a day if the worker works for more than 5 days in a week.
- Overtime:
    - Is not permitted except by an agreement.
    - A worker cannot work longer than 10 hours overtime in any week.
    - An agreement may not require a worker to work more than 12 hours on any day.
    - An agreement may increase overtime to 15 hours per week for up to 2 months in any 12 month period.
    - Must be paid at 1.5 times the worker's normal wage.
- Compressed working week:
    - An employee may agree in writing to work up to 12 hours in a day without any overtime pay.
    - In this agreement the previous standards of ordinary hours still stand and the worker may not work more than 45 ordinary hours a week, 10 hours overtime a week, or more than 5 days in a week.
- Averaging of hours of work:
    - An agreement may permit the hours of work to be averaged over a period up to 4 months.
    - Previous standards still stand and the worker is still not permitted to work more than an average of 45 ordinary hours a week, and an average of 5 hours overtime a week in the agreed period.
- Meal intervals:
    - The worker must have a meal interval of 60 minutes after every 5 hours of work.
    - A written agreement may reduce the meal interval to 30 minutes, or fall away for workers that work less than 6 hours a day.

- Rest Periods:
    - A worker must receive a daily rest period of 12 consecutive hours,
    - And a weekly rest period of 36 consecutive hours which must include Sunday, unless agreed on different terms.
- Work on Sundays:
    - If the worker only works on a Sunday on occasion the worker must receive double pay.
    - I the worker always work on a Sunday the worker must receive 1.5 times the normal wage.
    - Paid time off for working on a Sunday is allowed if agreed upon.
- Night work:
    - Workers working at night must be compensated by payment of an allowance or by a reduction of working hours.
    - Transport must be available.
    - If a worker works regularly after 23:00 and before 06:00 the next day, they must be informed of any health and safety hazards,
    - And have the right to undergo a medical examination.

2.2. Methods

2.2.1.Wire drawing

To draw a wire is to reduce the diameter of the wire by plastically deforming it when it passes through one or more dies with a diameter smaller than the wire's current diameter. Steel wire hardens during the process and the tensile strength of the wire increases but at the price of reducing its ductility.

The degree of diameter reduction is dependent upon the quality of the steel wire as well as the amount of dies it is sent through; it is possible to reduce the wires cross sectional area by as much as 95%.

2.2.2.Plastic extrusion

This is the process where small pieces of plastic (or plastic pellets) are melted down at very high temperatures to create a continuous plastic coating that can then be extruded over the product. A screw inside the extruder rotates which then forces the molten plastic material out of the extruder and through the die.

There is almost no limit to the different colours of coatings that can be produced and this is done by using coloured pellets or by adding some type of colorant into the extruder. To increase the quality of the plastic coating UV inhibitors are added to minimize the effect of UV rays on the wire.

2.2.3.Financial Analysis – Contribution Margin

$Contribution = Sales - Variable\ Expenses$

The contribution margin is the amount remaining from sales after the variable expenses have been deducted from it. This amount comprised of the amount used to cover the fixed expenses of the company and the profit made for that period. If the fixed expenses are larger than the contribution margin then there will be no profits and the company will have recorded a loss for that period. Where the contribution margin and the fixed costs equal each other is the break-even point where the company makes no loss but no profit either.

To improve the company's profits one needs to increase the contribution margin, this can be done by many different methods like:

- Decreasing variable costs.
- Increasing the contribution margin per unit.
- Decreasing the selling price, and therefore increase the volume of sales.
- Increasing the fixed cost (such as advertising) and therefore increase the volume of sales.

2.3. Tools and Techniques

2.3.1.Flow Diagram

This diagram is a pictorial plan of all the areas involved in the process being investigated. By means of symbols, lines and arrows, it can be seen exactly what the material goes through when and where. The material will go through different stations and states during the flow through the factory, the symbols used to depict the stations and states are:

- Operation - Circle
- Transportation - Arrow
- Storage – Upside-down triangle
- Delay – "D" shape
- Inspection – Square

This diagram is usually used together with the flow process chart where the chart will describe the process in detail and the flow diagram will illustrate it. The chart is also helpful to get a picture of how the material will flow and allows the manufacturer to identify where possible congestion areas might be.

2.3.2.Process Capacity

Capacity is any process, machine, factory or product's ability to produce some type of output in a given period of time, whether it is an hour, a shift, day, month or production year. Unfortunately most companies either do not understand the term properly or they just ignore the most basic measurements available to them.

There are many different variations of capacity calculations, some using the input variables, other the output variables and other a combination of the two, all dependant on the nature of the product. Further two main measures of capacity is used, theoretical capacity which is the maximum possible output from a process and does not account for any downtimes or rejects incurred, and rated capacity which is the actual capacity of the process after analysing the process and calculating figures.

One method used to work out the percentage of total capacity achieved is OEE (Overall Equipment Effectiveness), this method accounts for all factors that will affect the total capacity of a process and will be used in this project as such. Below are the calculations to be used in calculating process capacity:

Theoretical Capacity = Planned Operating Time x Cycle Time

OEE (Overall Equipment Effectiveness) = Availability x Performance x Quality

-- Availability = Operational Time / Planned Production Time

Operational Time = (Planned Production Time – Planned and Unplanned Downtime)

-- Performance = Cycle Time / (Operational Time / Total Pieces)

-- Quality = (Total Pieces – Rejects) / Total Pieces

2.3.3.OEE Standards

In order to assess the processes' OEE levels there has to be a set of standards to compare the values to. These OEE standards are defined by Vorne Industries Inc. in 4 different categories:

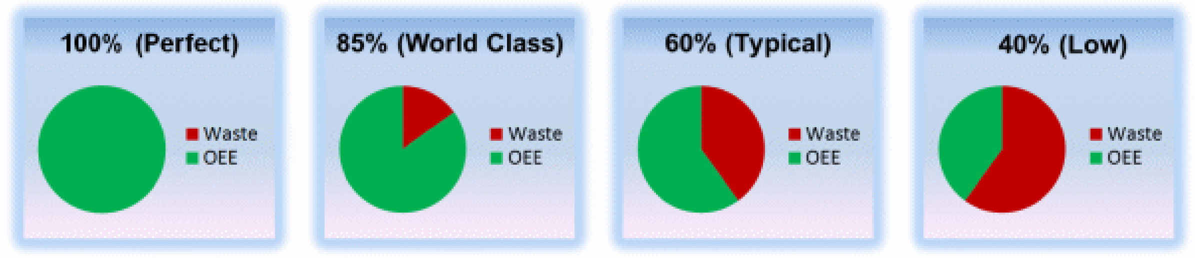

Figure 4. OEE Standards (Vorne Industries Inc, 2010)

- Perfect – This standard is when there are no downtimes, no breakdowns, nor any scrap produced by the process; in reality this is an unreachable standard.
- World Class – This standard is what all manufacturers in the world need to strive towards, the details of how the OEE of 85% can be achieved is shown in the table below:

OEE Factor	World Class
Availability	90.0%
Performance	95.0%
Quality	99.9%
Overall OEE	85.0%

Table 1. World Class OEE (Vorne Industries Inc, 2002)

- Typical – This is the average OEE achieved by most processes in the world, even if this is the most common OEE level it shows that there is still a lot of room for improvement.
- Low – This is a level where the process is running at less than half its actual capabilities, this leaves a lot of room for improvement.

2.3.4.Cost-Benefit Analysis

According to Niebel (Freivalds & Niebel, Proposed Method Implementation, 2009) the Cost-Benefit Analysis is a tool used to determine which alternative is best by comparing each other on terms of how much benefit the alternative will give if implemented and the cost that comes with that benefit. The analysis has 5 steps:

1. What change the alternative will give, increased productivity, better quality, decreased injuries, increased capacity, and so on.
2. Quantify these benefits into monetary units.
3. Determine the cost required to implement the changes.
4. Divide the cost by the benefit for each alternative, to get a ratio.
5. Then the alternative with the smallest ratio is the best option.

Another aspect that will be included when doing this analysis is to see if the alternative will do enough to actually bring up the capacity in order to meet the demand.

2.3.5.Linear Programming

Linear programming (LP) was developed as a simplex algorithm that needed to solve optimization problems. It was developed by George Dantzig in 1947 and since then the algorithm has been used by a large group of industries from banking to education, to trucking. In fact 85% of the respondents of a large survey replied that their company had used linear programming somewhere. (Winston & Venkataramanan, 2003)

There are a number of different variations of an LP that have been developed and used to solve different types of problems, these are:

- Linear Programming
- Integer Programming
- Nonlinear Programming
- Deterministic Dynamic Programming

The one particular from that was used for this LP model was that of integer programming (IP) which makes use of integer or binary variables and enables the additional aspect of decision making in the optimization process.

In order to formulate and solve the model a specific computer program is needed, and there are numerous different programs available to do this. These programs range in their capabilities and in their price. In this report the two programs that will be used are LINGO and Excel Solver.

2.3.6.Linear Programming Program - LINGO 13.0

LINGO is a comprehensive tool created by Lindo Systems that is designed to make and solve models faster, easier and more efficient. The program uses its powerful programming language and features to solve a big range of different models, namely:

- Linear,
- Nonlinear
- Quadratic,
- Quadratically Constrained,
- Second Order Cone,
- Stochastic, and
- Integer optimization

(LINDO SYSTEMS INC, 2011)

The key benefits of the new LINGO 13.0 program are:

- Easy Model Expression
- Convenient Data Options
- Powerful Solvers
- Model Interactively or Create Turn-key Applications
- Extensive Documentation and Help

2.3.7.Linear Programming Program - Excel Solver

A free version of Frontline's Premium Solver Free that is available as an add-in on Microsoft Office's Excel. Premium Solver Platform is a very powerful and versatile program used to optimize numerous linear problems. Key features and benefits of the solver program are:

- Able to solve virtually any type or size of problem.
- Use any existing models.
- Make use of any VBA code
- Works seamlessly in Excel and the Excel program recognises the solver as part of its own functions.

Chapter 3 – Data Analysis

3.1. Production Capacity

All current capacity data is only on the Blastwire-A product, but when the Blastwire-B product is introduced into production it will only affect the Sheathing process.

The theoretical capacity for each machine, as can be seen in Appendix A, was calculated by taking the available time to produce and multiplying it with the production speed of the machine. This gives a benchmark of what can be produced in the most perfect situation with no downtimes, no breakdowns and no production scrap. Because this will never be achieved an acceptable percentage of the benchmark must be established. As stated in the literature review, the average OEE level for manufacturing companies is 60% and the world class standard is 80%, so an acceptable OEE level to aim for would be between 75% and 80%.

By using the OEE method that looks at the availability, performance and quality; the current OEE levels could be calculated. This was done for 3 separate weeks to get a more accurate result of the current OEE levels. The 3 weeks that were chosen are all exactly 4 weeks apart and these were: week 21 (Appendix B), week 25 (Appendix C), and week 29 (Appendix D).

The tables below shows a summary of all the weeks together and their overall OEE levels achieved, to see the levels achieved in each area see the production week in question's Appendix page.

	Theoretical Capacity	OEE - Week 21	OEE - Week 25	OEE - Week 29	OEE - Average
AI03	1 440 000	75.85%	79.16%	78.04%	**77.68%**
AI05	518 400	72.58%	77.46%	78.42%	**76.16%**
AI06	921 600	77.87%	77.87%	74.63%	**76.79%**
Total	**2 880 000**	**2 186 115**	**2 259 067**	**2 218 067**	
Total Output	**1 440 000**	**1 093 058**	**1 129 534**	**1 109 034**	

Table 2. OEE Summary - Insulation Process

	Theoretical Capacity	OEE - Week 21	OEE - Week 25	OEE - Week 29	OEE - Average
SE01	612 000	0.00%	0.00%	0.00%	**0.00%**
AI04	612 000	63.07%	80.39%	62.03%	**68.50%**
SE05	612 000	73.20%	43.14%	0.00%	**58.17%**
SE06	612 000	48.20%	73.04%	76.62%	**65.95%**
Total Output	**2 448 000**	**1 129 000**	**1 203 000**	**848 510**	

Table 3. OEE Summary - Sheathing Process

Looking at the Insulating table it is clear that it all the machines are running at a constant and acceptable level and it will not be necessary to attempt to improve those levels further, due to the fact that the process is between the set acceptable standards already. To attempt to improve these levels will be very costly with only a small improvement on the overall capacity levels. At an expected production level of 1 080 000 metres per week it only just falls short with 120 000 metres of the needed 1 200 000 metres. Thus some steps have to be taken to make up that shortfall. This can be easily be done by working one additional shift to produce the necessary amount.

The Sheathing table shows a lot of variation in the OEE levels for all the machines with one line at 0% for all the weeks. But the below par OEE levels of these machines are not a true picture of the current state, this is because the demand for the Blastwire-A was only what was produced and the company did not want to stockpile the product. In all the weeks depicted above the SE01 machine did not have to run and was merely shutdown for that period and the cases where low OEE levels were achieved was when the machines only operated for a few days and not the whole week, this can be seen clearly in the Appendices. Unlike the Insulating process where only a slight increase is needed to meet the increase in demand the Sheathing process will have to increase its capacity by some means.

After analysing the above tables it is clear that in order to increase the production capacity, the focus must not be placed on how to improve the current OEE levels but rather how to increase the capacity.

Below is a table that depicts the production levels that can be expected from the manufacturing process if all the machines are operational and an average OEE level of 75% is achieved by all.

	Theoretical Capacity	OEE	Expected Prodcution
Insulating Process	1 440 000	75.00%	**1 080 000**
Sheating Process	2 448 000	75.00%	**1 836 000**

Table 4. Expected Production Levels

These levels can be increased by more than one alternative; all the alternatives will be compared and assessed by using the Cost-Benefit Analysis.

Chapter 4 – Development of Conceptual Design

4.1. Production Schedule

4.1.1.Linear Programming Model

In order to create a production schedule, a linear programing model was created. This model is based on two separate binary variables that depicts if the product needs to be produced on that day, that shift and that machine in order to meet the user defined demand.

The sets defined for this LP model is set ***I*** that is the different days that the production can run, set ***J*** that is the 2 different shifts available for production per day, set ***K*** that is the number of machines available for production and set ***P*** that is the 2 different products that need to be produced.

$$Let\ \boldsymbol{I}\ \in \begin{cases} 1.Monday \\ 2.Tuesday \\ 3.Wednesday \\ 4.Thursday \\ 5.Friday \\ 6.Saturday \end{cases}$$

$$Let\ \boldsymbol{J}\ \in \begin{cases} 1.Day \\ 2.Night \end{cases}$$

$$Let\ \boldsymbol{K}\ \in \begin{cases} 1.SE01 \\ 2.SE05 \\ 3.SE06 \\ 4.AI04 \end{cases}$$

$$Let\ \boldsymbol{P}\ \in \begin{cases} 1.Blastwire\_A \\ 2.Blastwire\_B \end{cases}$$

A_{ijk} = The binary variable if Blastwire-A is produced on day $i \in \boldsymbol{I}$, shift $j \in \boldsymbol{J}$, machine $k \in \boldsymbol{K}$.

B_{ijk} = The binary variable if Blastwire-B is produced on day $i \in \boldsymbol{I}$, shift $j \in \boldsymbol{J}$, machine $k \in \boldsymbol{K}$.

$Demand_p$ = The demand for Product $p \in \boldsymbol{P}$ for the given period.

$Produce_{pk}$ = The amount of Product $p \in \boldsymbol{P}$ that can be produced in a single shift on Machine $k \in \boldsymbol{K}$.

Day = The amount of days available to produce the products.

MachineOp = The amount of machines available to produce the products on.

Min $Z = \sum_k (Produce_{1k} \times (\sum_i \sum_j A_{ijk})) + \sum_k (Produce_{2k} \times (\sum_i \sum_j B_{ijk}))$ *(1)*

s.t.

$$A_{ijk} + B_{ijk} \leq 1 \qquad \forall\, i \in \boldsymbol{I}, j \in \boldsymbol{J}, k \in \boldsymbol{K} \qquad (2)$$

$$\sum_k (Produce_{pk} \times (\sum_i \sum_j A_{ijk})) \geq Demand_p \qquad \forall\, p \in \boldsymbol{P} \qquad (3)$$

$$A_{ijk}, B_{ijk} \in \{0, 1\} \qquad \forall\, i \in \boldsymbol{I}, j \in \boldsymbol{J}, k \in \boldsymbol{K} \qquad (4)$$

Notes:

The $Demand_p$, $Produce_{pk}$, Day and MachineOp variables are user defined.

Set ***I*** is limited by the Day variable that defines the number of days available for production.

Set ***K*** is limited by the MachineOp variable that defines the number of machines available to produce the products in the set time period.

(1) This is the total number of units produced during the set time period and number of machines, the Produce variable is the number of units that can be produced per shift on the specified machine. This sum is minimized to not over produce and it will still meet the set demand for the fact that the constraint (3) forces it to.
(2) This constraint enforces the logic that one machine cannot produce two different products on the same shift on the same day.
(3) This constraint ensures that set period's demand for each product is met.
(4) The last constraint enforces that both the A_{ijk} and the B_{ijk} variables are binary variables.

4.1.2.Running the Model

In order to run the model a linear program solver is needed, and a number of different products are available to do this. The first choice was LINGO 13.0 which is a very powerful program and is very capable of running the model and finding a solution for it, but the program is also an expensive program. For this reason other programs with a smaller price tag that can also possibly run the model need to be investigated, the first alternative is Excel Solver which is a free version of solver that comes with Microsoft's Office product.

Chapter 5 – Problem Solving and Results

5.1. Production Schedule – LINGO

The LINGO code, Appendix E, was executed with test data to test the functionality of the program and how the results could be presented. The model was solved with no problems when the following data was used:

- Machines Operational: 4
- Days available: 5
- Blastwire-A Demand: 800 000m
- Blastwire-B Demand: 800 000m

To display the data, a bar graph was generated for both products' production schedules showing on what day, shift and machine each product had to be run in order to meet both demands.

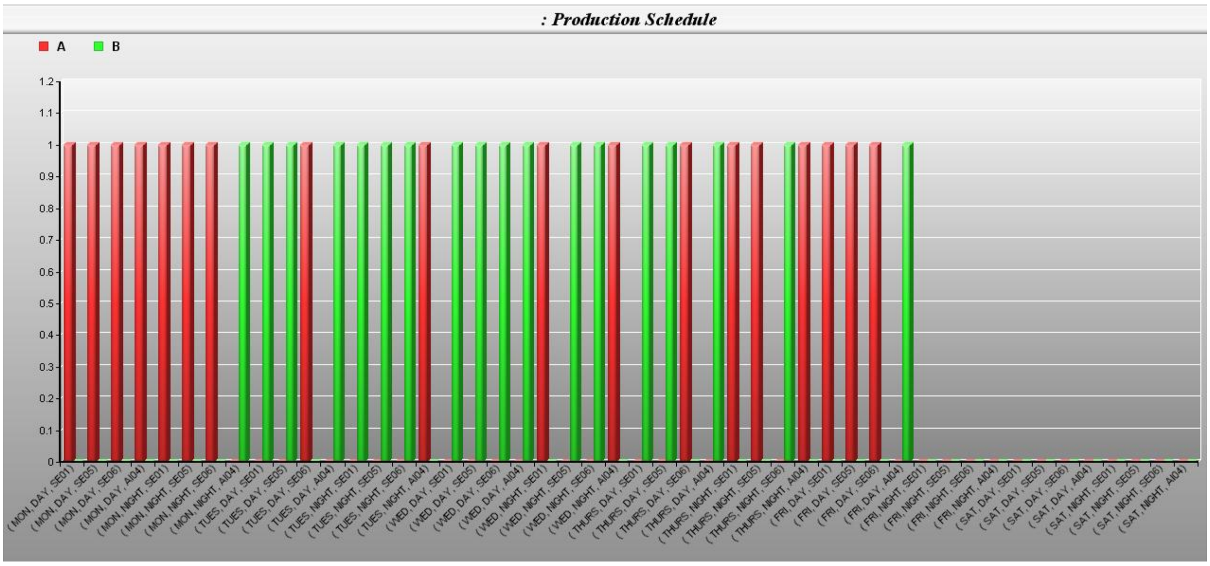

Figure 5. LINGO Production Schedule

This schedule is also represented in a table below for easier interpretation and daily use of the schedule:

Mon			**Wed**			**Fri**		
Day			Day			Day		
	SE01	A		SE01	B		SE01	A
	SE05	A		SE05	B		SE05	A
	SE06	A		SE06	B		SE06	A
	AI04	A		AI04	B		AI04	B
Night			Night			Night		
	SE01	A		SE01	A		SE01	N/A
	SE05	A		SE05	B		SE05	N/A
	SE06	A		SE06	B		SE06	N/A
	AI04	B		AI04	A		AI04	N/A
Tues			**Thurs**			**Sat**		
Day			Day			Day		
	SE01	B		SE01	B		SE01	N/A
	SE05	B		SE05	B		SE05	N/A
	SE06	A		SE06	A		SE06	N/A
	AI04	B		AI04	B		AI04	N/A
Night			Night			Night		
	SE01	B		SE01	A		SE01	N/A
	SE05	B		SE05	A		SE05	N/A
	SE06	B		SE06	B		SE06	N/A
	AI04	A		AI04	A		AI04	N/A

Table 5. LINGO Production Schedule

5.2. Production Schedule – Excel Solver

In order to use the Excel Solver, Appendix F, the LP model had to be adjusted slightly, and made use of the following functions:

- IF Statement
- Sum Function
- Data Validation – Whole numbers between 0 and 1

Furthermore the model still has the same constraints as that of the LINGO model and still solving the same objective. But because Excel is not a specialised Linear Program solver there are some flaws in it. But even with some flaws Excel Solver can still be used to model the Production Schedule if desired.

Product A Demand	800 000	Days Available	5	Total_A	826 200	Speed	5 100 m/hour
Product B Demand	800 000	Machines Operation:	4	Total_B	826 200	Hours	12
				Total	1 652 400	Efficiency	0.75

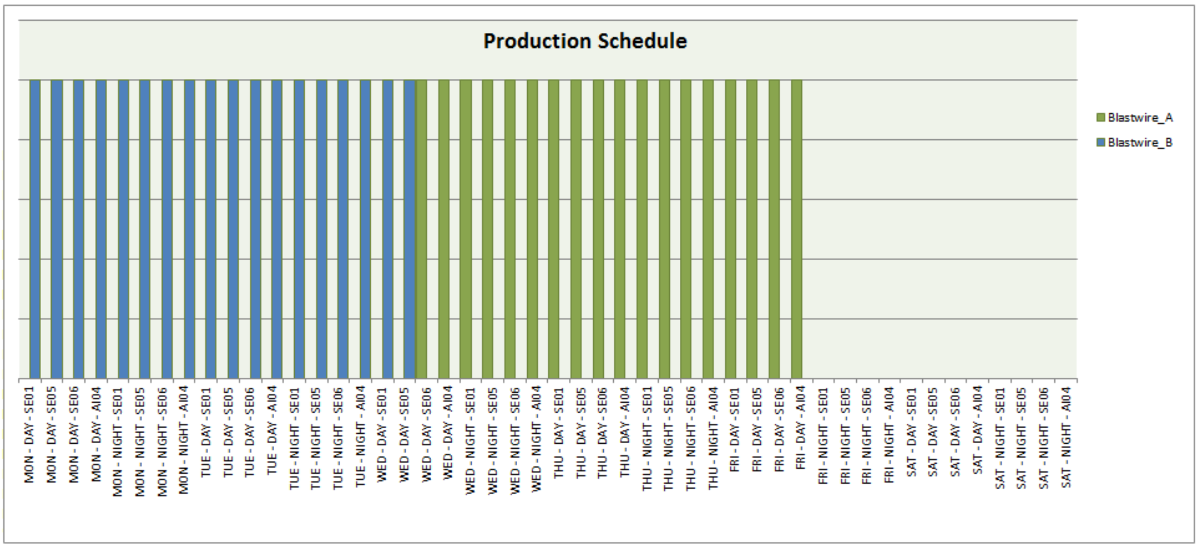

Figure 6. Excel Solver Production Schedule

This schedule is also represented in a table below for easier interpretation and daily use of the schedule:

Mon			**Wed**			**Fri**		
Day			Day			Day		
	SE01	**B**		SE01	**B**		SE01	**A**
	SE05	**B**		SE05	**B**		SE05	**A**
	SE06	**B**		SE06	**A**		SE06	**A**
	AI04	B		AI04	**A**		AI04	**A**
Night			Night			Night		
	SE01	**B**		SE01	**A**		SE01	**N/A**
	SE05	**B**		SE05	**A**		SE05	**N/A**
	SE06	**B**		SE06	**A**		SE06	**N/A**
	AI04	B		AI04	**A**		AI04	**N/A**
Tues			**Thurs**			**Sat**		
Day			Day			Day		
	SE01	**B**		SE01	**A**		SE01	**N/A**
	SE05	**B**		SE05	**A**		SE05	**N/A**
	SE06	**B**		SE06	**A**		SE06	**N/A**
	AI04	**B**		AI04	**A**		AI04	**N/A**
Night			Night			Night		
	SE01	**B**		SE01	**A**		SE01	**N/A**
	SE05	**B**		SE05	**A**		SE05	**N/A**
	SE06	**B**		SE06	**A**		SE06	**N/A**
	AI04	**B**		AI04	**A**		AI04	**N/A**

Table 6. Excel Solver Production Schedule

5.3. Cost-Benefit Analysis

Before the Cost-Benefit Analysis can start all the financial data had to be gathered, all the data needed for any of the alternatives are given in the tables below:

Cost	R 1 560 000.00
Depreciation	20%
Book life	5 years

Table 7. Machine Details

Cost (per Hour)	R	104.00
Daily Hours		24
Total	**R**	**2 496.00**

Table 8. Labour Details

The labour costs in the table above is the labour cost per machine, each machine only needs a single operator to operate the machine but the cost above includes the cost for the additional workers in the lab that have to do the inspections and tests on the products.

CAT 5	400 000
CAT 6	200 000
Total	**600 000**

Table 9. UTP Demand Details

The UTP product is produced on two Sheathing machines, SE02 and SE03, on the SE02 machine the UTP product is the sole product produced but on the SE03 machine the Tel products share the capacity and the UTP product only gets 60% of the capacity.

	Selling Price (per Metre)		**Variable Cost (per Metre)**		**Contribution**	
Blastwires	R	0.93	R	0.56	R	0.37
UTP	R	2.47	R	1.82	R	0.65

Table 10. Product Pricing Details

Using this table to putt the benefit into monetary terms the contribution from the Blastwire products will be used, as this is the benefit gained from selling the product. When the cost needs to be calculated in the 3rd alternative where the UTP product sales will be lost then the cost will be calculated by what the contribution is that they are losing out on.

5.3.1.Alternative 1 – Additional Machine

In order to get the initial capital investment needed to procure the new machine in a form to be able to compare it to a weekly cost, the machine's depreciation data had to be investigated. The company uses the straight line depreciation method at 20% per annum with a service life time of 5 years. The cost is then calculated as follows with 48 production weeks a year:

Initial Investment	R	1 560 000.00
Depreciation Rate (Per Annum)		20%
Yearly Cost	R	312 000.00
Production Week per Year		48
Weekly Cost	R	6 500.00
Labour	R	12 480.00
Total	**R**	**18 980.00**

Table 11. Alternative 1 – Costs

The benefit from the additional machine is calculated by assuming the new machine will be operational for the whole 5 day production week, and also operate at an OEE level of 75%. In order to get the benefit into a monetary form, as stated above, the increase in capacity will be multiplied with the Blastwires' contribution:

Benefit	**Days Operational**	**Theoretical Capacity Per Machine**	**OEE**	**Actual Capacity Per Machine**	**Machines Operational**		**Total Production**
Current	5	612 000	75%	459 000	4		1 836 000
New	5	612 000	75%	459 000	5		2 295 000
					Benefit (units)		459 000
					Contribution per unit	R	0.37
					Benefit (R)	**R**	**169 830.00**

Table 12. Alternative 1 – Benefit

5.3.2.Alternative 2 – Additional Day of Labour

This alternative is by increasing the production week from 5 days to 6 days by including both a day shift and a night shift on the Saturday. The cost is calculated by taking the labour cost per machine and then multiplying it by the number of machines operational:

Labour (Per Hour, Per Machine)	R	104.00
Machines Operational		4
Production Hours		24
Total	**R**	**9 984.00**

Table 13. Alternative 2 – Cost

The benefit is the difference between what is produced by 4 machines in a 5 day production week and what is produced by 4 machines in a 6 day production week:

Benefit	Days Operational	Theoretical Capacity Per Machine	OEE	Actual Capacity Per Machine	Machines Operational	Total Production
Current	5	612 000	75%	459 000	4	1 836 000
New	6	734 400	75%	550 800	4	2 203 200
					Benefit (units)	367 200
					Contribution per unit	R 0.37
					Benefit (R)	**R 135 864.00**

Table 14. Alternative 2 – Benefit

5.3.3.Alternative 3 – Using UTP Capacity

When it comes to using another product's capacity on a different machine there are a few factors to consider:

- The different speeds that the products will run.
- The amount of capacity gets taken up by a different product on one of the machines; in this case on SE03 the Tel product takes 40% of the capacity.
- The cost of the loss of production of the UTP product calculated by the UTP product's contribution per unit.

	SE02	SE03
Capacity Available	100%	60%
UTP Production Speed	65	65
Blastwire Production Speed	85	85

Table 15. Machine Details

Calculating how much needs to be produced in order to meet the rise in demand is a simple subtraction calculation between the new demand and the current production levels:

	Production Amount
Current	1 836 000
Required	2 400 000
Needed	**564 000**

Table 16. Production Amount Needed

By taking all the capacity from SE02 and 25% from SE03 the needed production will be met and the benefit from the additional production is calculated from the Blastwires' contribution:

UTP

	Days Operational	Theoretical Capacity Per Machine	OEE	Actual Capacity Per Machine	Percentage of Capacity	Total Production
SE02	5	468 000	75%	351 000	0%	-
SE03	5	468 000	75%	351 000	35%	122 850
					Total	**122 850**

Blastwires

	Days Operational	Theoretical Capacity Per Machine	OEE	Actual Capacity Per Machine	Percentage of Capacity	Total Production
SE02	5	612 000	75%	459 000	100%	459 000
SE03	5	612 000	75%	459 000	25%	114 750
					Total	**573 750**
					Contribution per Unit	R 0.37
					Total Benefit	**R 212 287.50**

Table 17. Alternative 3 – Benefit

The cost of this alternative is calculated by taking the lost production of the UTP product and then multiplying it with the product's contribution and getting a monetary value for it:

	Amount
Curren Demand	600 000
New Available Production	122 850
Production Lost	**477 150**

Table 18. UTP Production Loss

	Amount
Production Lost	477 150
UTP Product Contribution	R 0.65
Total Cost	**R 310 147.50**

Table 19. Alternative 3 – Cost

5.3.4.Alternative 4 – Production Speed Increase

The company has done previous tests in regard with the relationship between the speed of production and the amount of scrap produced. The tests have shown that the relationship is approximately 1 to 5; therefore if the speed is increased by 10% then the scrap produced will increase by 50%.

	Current	Percentage Increase	New
Speed (m/min)	85	30.59%	111.00
Average Scrap Produced	4 554	152.95%	11519.34

Table 20. Speed / Scrap Relationship

The cost is calculated by the difference between the current scrap levels produced and the expected scrap levels if the speed is increased, the difference is then multiplied by the selling price for the Blastwires to get the cost of the scrap produced as it the cost of production of the scrap and also the contribution of those materials that they lose out on:

	Average Scrap Produced	Machines Operational	Total Scrap Produced	Cost of Scrap (Lost income from Sales)	Total Cost of Scrap
Current Production	4 554	4	18 216	R 0.93	R 16 940.88
New Production	11519.34	4	46 077	R 0.93	R 42 851.96
				Cost (R)	**R 25 911.08**

Table 21. Alternative 4 – Cost

The benefit is the difference between the current production and the production from the new increased speed:

	Theoretical Capacity Per Machine	OEE	Actual Capacity Per Machine	Total
Current Production	612 000	75%	459 000	1 836 000
New Production	799 211	75%	599 408	2 397 632
			Benefit (units)	561 632
			Contribution per unit	R 0.37
			Benefit (R)	**R 207 803.99**

Table 22. Alternative 4 – Benefit

5.3.5.Analysis Details

Below is the table with the Cost-Benefit analysis done for all the alternatives, the alternative with the smallest ratio is the best ranked option:

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Capacity Reached	2 295 000	2 203 200	2 409 750	2 397 632
Benefit (Units)	459 000	367 200	573 750	561 632
Benefit (R)	R 169 830.00	R 135 864.00	R 212 287.50	R 207 803.99
Cost (R)	R 18 980.00	R 9 984.00	R 310 147.50	R 25 911.08
Cost/Benefit Ratio	0.11176	0.07349	1.46098	0.12469
Rank	2	1	4	3

Table 23. Cost-Benefit Analysis

Chapter 6 – Conclusion and Recommendations

6.1. Production Schedule

In order to decide between the two options available to make the production schedule for company, the factors that need to be considered are:

- Accuracy, and
- Price

6.1.1.LINGO 13.0

The production schedule created from this program is very accurate as it can be seen in the figures above, there are no faults in the schedule and it gives you exactly what it needs to. The schedule can easily be implemented and will enable the company to configure their schedule in the way the program suggested and the demand will be met for the production week.

The cost for this program is rather high; the cost for the program starting at $495 (R3 900), and this could be a bit too high for the company.

6.1.2.Excel Solver

The production schedule that the Excel Solver produces gives what is expected from it and delivers a schedule that the company can implement to meet the required demand for that week.

The cost for the program is very low, if the company owns a copy of Microsoft's Office then the solver add-in for excel is free and comes with the product from out the box. If they do not own a copy of Office, starting at a cost of R1 831, it also comes with additional features like Access, PowerPoint, Word, and Outlook.

6.1.3.Recommendation

It would be recommendation that the company goes with the Excel Solver option, due to the fact that they already have the Microsoft Office product installed and then it would not cost them anything to activate the solver in Excel. Then the production schedule, after a small adjustment each time, will give them what they need in order to meet the demand.

6.2. Production Capacity

Rank	Alternative	Description	Cost/Benefit Ratio	Capacity Reached
1	2	Additional Day of Labour	0.07349	2 203 200
2	1	Additional Machine	0.11176	2 295 000
3	4	Production Speed Increase	0.12469	2 397 632
4	3	Using UTP Capacity	1.46098	2 409 750

Table 24. Cost-Benefit Summary

By analysing the data from the Cost-Benefit analysis the best option can easily be identified by which ratio is the lowest. If the best alternative had to be chosen solely on the C/B Ratio the best one would be Alternative 2 – Additional Day of Labour, but it did not reach the capacity level of 2 400 000. Because the demand is expected to fluctuate between 1 600 000 and 2 400 000 this could be sufficient but in the case where the demand is 2 400 000 they will run into trouble.

The second best alternative according to the analysis is Alternative 1 – Additional Machine, this alternative also does not reach the capacity level of 2 400 000 but what makes this alternative different to the previous one is if the demand is that high the company can still increase the capacity by deciding to run the machines an additional half day or full day of production.

Alternative 4 – Production Speed Increase can also be considered, the only alternative that should not be considered is Alternative 3 – Using UTP Capacity with costs exceeding the benefits. Other alternatives can also be created by the company later on by combining the above alternatives, e.g. procuring an additional machine and increasing production speed, and these alternatives can then in turn be compared to each other again.

The final recommendation then would be to go with Alternative 1 and install the new machine. To ensure they meet the demand when it is at its highest they can either stock pile while the demand is lower, or when required run an additional day or half-day of production to make up the deficit.

Chapter 7 – Bibliography

Barkhuizen, C. (2011, June 28). Products, Processes and other details about Company.

Cloete, F. (2011). *Digishot Products Page*. Retrieved 12 May, 2011, from AEL Mining Services: http://www.explosives.co.za/component/content/article/66/197-digishot-prodcuts-page.html

Freivalds, A., & Niebel, B. (2009). Problem-Solving Tools. In *Niebel's Methods, Standards, and Work Design* (12th ed., pp. 35-38). New York: McGraw-Hill.

Freivalds, A., & Niebel, B. (2009). Proposed Method Implementation. In *Niebel's Methods, Standards, and Work Design* (p. 373). New York: McGraw-Hill.

Frontline Systems, Inc. . (2010). *Premium Solver Platform for Excel*. Retrieved September 26, 2011, from Frontline Solvers: http://solver.com/xlsplatform.htm?utm_source=adwords&utm_medium=cpc&utm_campaign=Tier+4B+-+Premium+Solver+Platform&utm_extra=dim1/Branded/dim2/Phrase&utm_term=solver&KEYWORD=solver&MATCHTYPE=Search&AD_ID_G=6925000580&gclid=CLT4l6ervqsCFcQKtAodcg8RMw

LINDO SYSTEMS INC. (2011). *LINGO 13.0 - Optimization Modeling Software for Linear, Nonlinear, and Integer Programming* . Retrieved September 26, 2011, from Lindo Systems: http://www.lindo.com/index.php?option=com_content&view=article&id=2&Itemid=10

Madison, N. (2003). *What is Plastic Extrusion?* Retrieved June 29, 2011, from wiseGEEK: http://www.wisegeek.com/what-is-plastic-extrusion.htm

Murry, M. (2011). *Measuring Capacity in Manufacturing*. Retrieved May 19, 2011, from About.com: http://logistics.about.com/od/strategicsupplychain/a/Measuring_Capacity.htm

Seal, W., Garrison, R. H., & Noreen, E. W. (2009). Contribution Margin. In *Management Accounting* (3rd ed., pp. 231-238). Berkshire: McGraw-Hill.

Sibername Internet and Software Technologies Inc. (n.d.). *Wire Drawing*. Retrieved June 29, 2011, from Wire World: http://www.wireworld.com/seminar/wiredrawing/

SOUTH AFRICA. 1997. Basic Conditions of Employment Act, No 75 of 1997. Cape Town: Government Printer. [Laws]

Vorne Industries Inc. (2002). *Calculating OEE*. Retrieved May 19, 2011, from OEE Overall Equipment Effectiveness: http://www.oee.com/calculating-oee.html

Vorne Industries Inc. (2002). *World Class OEE*. Retrieved September 5, 2011, from OEE Overall Equipment Effectiveness: http://www.oee.com/world-class-oee.html

Vorne Industries Inc. (2010). *OEE*. Retrieved September 6, 2011, from Lean Production: http://www.leanproduction.com/oee.html

Winston, W. L., & Venkataramanan, M. (2003). Introduction to Linear Programming. In *Introduction to Mathematical Programming* (4th ed., p. 49). Pacific Grove: Brooks/Cole - Thomson learning.

Chapter 8 – Appendices

8.1. Appendix A – Current Theoretical Capacity

	m/min	m/hour	% total time usage	hours/week (120 hours)	Theoretical capacity / week
AI01					
Cat5e	62.5	3 750	100%	120	450 000
AI02					
Cat06	40	2 400	50%	60	144 000
Tel	150	9 000	30%	36	324 000
Jumper	150	9 000	20%	24	216 000
AI03					
Blastwire_A - Cores	**200**	12 000	100%	120	1 440 000
AI04					
Blastwire_A	**85**	5 100	100%	120	612 000
AI05					
UTP Flex	22.5	1 350	60%	72	97 200
Blastwire_A - Cores	**180**	10 800	40%	48	518 400
AI06					
Tel	200	12 000	20%	24	288 000
Blastwire_A - Cores	**160**	9 600	80%	96	921 600
SE01					
Blastwire_A	**85**	5 100	100%	120	612 000
SE02					
UTP	65	3 900	100%	120	468 000
SE03					
UTP	65	3 900	60%	72	280 800
Tel	75	4 500	40%	48	216 000
SE04					
UTP	65	3 900	0%	0	-
Tel	75	4 500	0%	0	-
Flat cable 4 wire	80	4 800	100%	120	576 000
SE05					
UTP	65	3 900	0%	0	-
Tel	75	4 500	0%	0	-
Blastwire_A	**85**	5 100	100%	120	612 000
SE06					
Blastwire_A	**85**	5 100	100%	120	612 000

Table 25. Current Theoretical Capacity

8.2. Appendix B – Week 21 Capacity Calculations

Week 21 - 23 May 2011 to 29 May 2011

	AI03	AI05	AI06	SE01	AI04	SE05	SE06
Availability	87.50%	87.50%	87.50%	87.50%	75.00%	87.50%	58.33%
Planned Production time	120	48	96	120	120	120	120
Planned and Unplanned Downtimes	15	6	12	15	30	15	50
Operational time	105	42	84	105	90	105	70
Performance	89.60%	90.72%	90.86%	0.00%	84.73%	83.88%	85.46%
Cycle time	0.000083333	0.000092593	0.000104167	0.000196078	0.000196078	0.000196078	0.000196078
Operational time	105	42	84	105	90	105	70
Total Pieces	1 128 900	411 500	732 700	1	388 900	449 200	305 100
Quality	96.75%	91.44%	95.37%	0.00%	99.25%	99.73%	96.69%
Total Pieces	1 128 900	411 500	732 700	1	388 900	449 200	305 100
Rejects	36 726	35 229	33 920	1	2 900	1 200	10 100
Total OEE	75.85%	72.58%	75.82%	0.00%	63.07%	73.20%	48.20%
				Not operational			

Table 26. Week 21 Capacity Calculations

8.3. Appendix C – Week 25 Capacity Calculations

Week 25 - 20 June 2011 to 26 June 2011

	AI03	AI05	AI06	SE01	AI04	SE05	SE06
Availlability	87.50%	87.50%	87.50%	87.50%	87.50%	50.00%	83.33%
Planned Production time	120	48	96	120	120	120	120
Planned and Unplanned Downtimes	15	6	12	15	15	60	20
Operational time	105	42	84	105	105	60	100
Performance	91.29%	90.45%	91.87%	0.00%	94.03%	86.80%	88.41%
Cycle time	0.000083333	0.000092593	0.000104167	0.000196078	0.000196078	0.000196078	0.000196078
Operational time	105	42	84	105	105	60	100
Total Pieces	1 150 200	410 300	740 800	1	503 550	265 600	450 900
Quality	99.10%	97.87%	96.88%	0.00%	97.71%	99.40%	99.14%
Total Pieces	1 150 200	410 300	740 800	1	503 550	265 600	450 900
Rejects	10 353	8 750	23 130	1	11 550	1 600	3 900
Total OEE	**79.16%**	**77.46%**	**77.87%**	**0.00%**	**80.39%**	**43.14%**	**73.04%**
				Not operational			

Table 27. Week 25 Capacity Calculations

8.4. Appendix D – Week 29 Capacity Calculations

Week 29 - 18 July 2011 to 23 July 2011

	AI03	AI05	AI06	SE01	AI04	SE05	SE06
Availlability	87.50%	87.50%	87.50%	87.50%	73.33%	87.50%	87.50%
Planned Production time	120	48	96	120	120	120	120
Planned and Unplanned Downtimes	15	6	12	15	32	15	15
Operational time	105	42	84	105	88	105	105
Performance	90.01%	91.56%	88.16%	0.00%	85.34%	0.00%	88.14%
Cycle time	0.000083333	0.000092593	0.000104167	0.000196078	0.000196078	0.000196078	0.000196078
Operational time	105.00	42.00	84.00	105.00	88.00	105.00	105.00
Total Pieces	1 134 100	415 300	710 900	1	383 000	1	472 000
Quality	99.09%	97.89%	96.75%	0.00%	99.11%	0.00%	99.35%
Total Pieces	1 134 100	415 300	710 900	1	383 000	1	472 000
Rejects	10 353	8 750	23 130	1	3 400	1	3 090
Total OEE	**78.04%**	**78.42%**	**74.63%**	**0.00%**	**62.03%**	**0.00%**	**76.62%**
				Not operational		Not operational	

Table 28. Week 29 Capacity Calculations

8.5. Appendix E – Production Schedule: LINGO Code

```
Model:

Title: Production Schedule;

Sets:
        Workdays/Mon, Tues, Wed, Thurs, Fri, Sat/;
        Workshifts/Day, Night/;
        Machines/SE01, SE05, SE06, AI04/;
        Product/Blast_A, Blast_B/: Demand;

        BINARIES(Workdays, Workshifts, Machines): A, B;
        Prod(Product, Machines): Produce;
Endsets

Data:
        Day = 5;
        MachineOp = 4;
        Demand = 800000 800000;
        Produce = 45900  45900  45900  45900
                  45900  45900  45900  45900;
EndData

Min = Total_A + Total_B;

@For(Workdays(i) | i#LE#Day: @For(Workshifts(j): @For(Machines(k) | k#LE#MachineOp:
A(i,j,k) + B(i,j,k) <= 1)));

Total_A = @Sum(Machines(k) | k#LE#MachineOp: Produce(1,k)*@Sum(Workdays(i) |
i#LE#Day: @Sum(Workshifts(j): A(i,j,k))));
Total_B = @Sum(Machines(k) | k#LE#MachineOp: Produce(2,k)*@Sum(Workdays(i) |
i#LE#Day: @Sum(Workshifts(j): B(i,j,k))));

Total_A >= Demand(1);
Total_B >= Demand(2);

@For(Workdays(i) | i#LE#Day: @For(Workshifts(j): @For(Machines(k) | k#LE#MachineOp:
@Bin(A(i,j,k)))));
@For(Workdays(i) | i#LE#Day: @For(Workshifts(j): @For(Machines(k) | k#LE#MachineOp:
@Bin(B(i,j,k)))));

End
```

8.6. Appendix F – Excel Solver

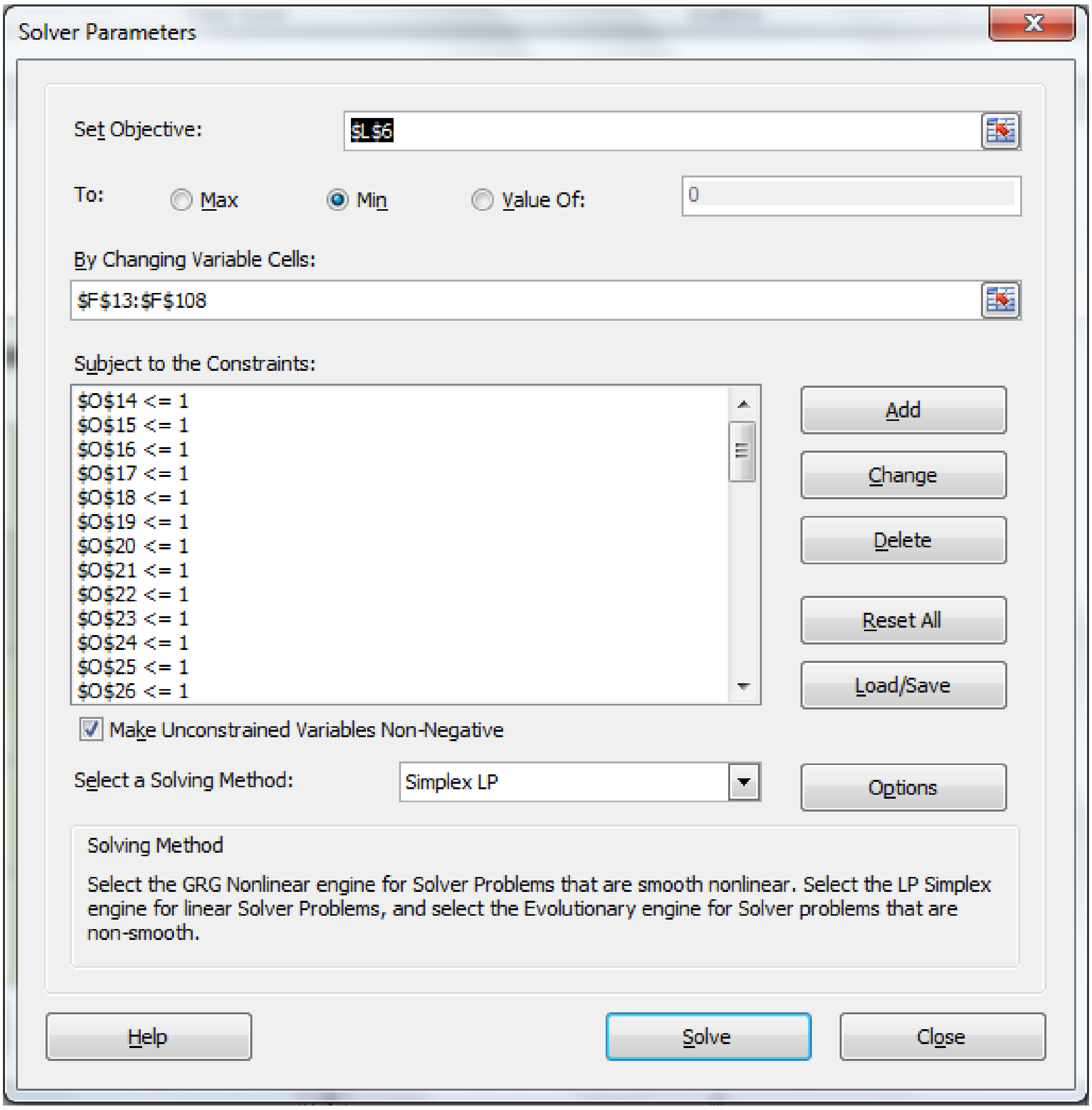

Figure 7. Excel Solver Interface

8.7. Appendix G – Excel Solver (Section of Formulas Used)

	A	E	F	G	H	I	J	K	L	M	N	O
12		Day - Shift - Machine	Decision Variable		Amount can be Produced per Shift (m)	Amount Produced that Shift (m)	Sum of Amount Produced for all Machines that Day (Depending what number of machines are operational	Sum of all possible senarious	Sum amount for each product (Depending on days operational)			
33	A	WED - NIGHT - SE01	1		45900	45900	0				1	<=1
34	A	WED - NIGHT - SE05	1		45900	45900	0				1	<=1
35	A	WED - NIGHT - SE06	1		45900	45900	0				1	<=1
36	A	WED - NIGHT - AI04	1		45900	45900	183600	321300	0		1	<=1
37	A	THU - DAY - SE01	1		45900	45900	0				1	<=1
38	A	THU - DAY - SE05	1		45900	45900	0				1	<=1
39	A	THU - DAY - SE06	1		45900	45900	0				1	<=1
40	A	THU - DAY - AI04	1		45900	45900	183600				1	<=1
41	A	THU - NIGHT - SE01	1		45900	45900	0				1	<=1
42	A	THU - NIGHT - SE05	1		45900	45900	0				1	<=1
43	A	THU - NIGHT - SE06	1		45900	45900	0				1	<=1
44	A	THU - NIGHT - AI04	1		45900	45900	183600	367200	0		1	<=1
45	A	FRI - DAY - SE01	1		45900	45900	0				1	<=1
46	A	FRI - DAY - SE05	1		45900	45900	0				1	<=1
47	A	FRI - DAY - SE06	1		45900	45900	0				1	<=1
48	A	FRI - DAY - AI04	1		45900	45900	183600				1	<=1
49	A	FRI - NIGHT - SE01	0		45900	0	0				0	<=1
50	A	FRI - NIGHT - SE05	0		45900	0	0				0	<=1
51	A	FRI - NIGHT - SE06	0		45900	0	0				0	<=1
52	A	FRI - NIGHT - AI04	0		45900	0	0	183600	872100		0	<=1
53	A	SAT - DAY - SE01	0		45900	0	0				0	<=1

Figure 8. Section of Excel Solver Sheet

Cell	Equation
J48	=IF(MachineOp=4, SUM(I45:I48), 0)
K52	=SUM(J45:J52)
L52	=IF(Days=5,SUM(K20:K52),0)

Table 29. Section of Excel Formulas Used

8.8. Appendix H – Excel Solver (Data Validation)

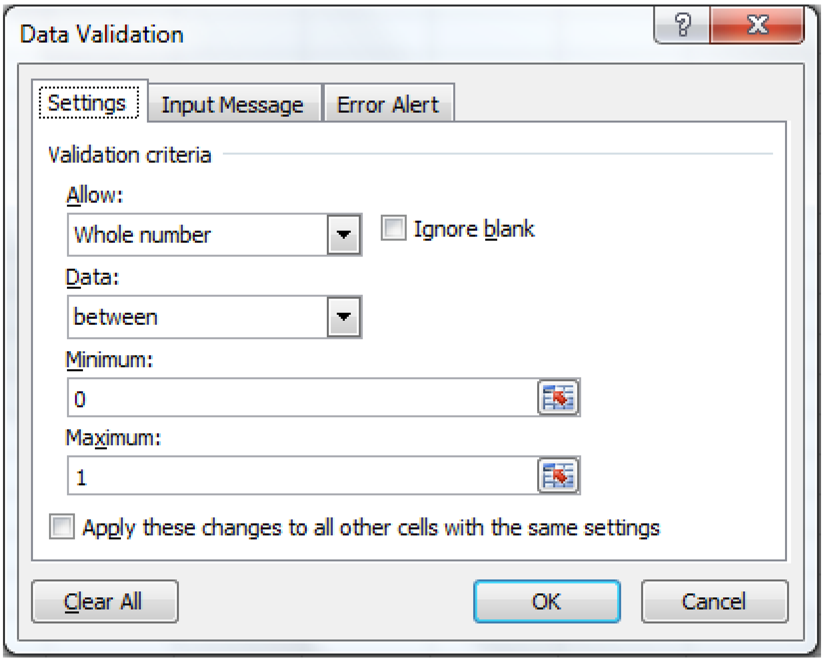

Figure 9. Excel Data Validation