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An Optimized Production Plan That Can Be
Implemented and Used within a
SME in the Water Filtration Manufacturing Industry
for



By

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Executive Summary

The project report creates a production schedule for a SME manufacturing company in the water purification industry. Even though it involves a specific company it could be adapted to suit any water filtration manufacturer in South Africa as well as another small manufacturing company looking to create an optimised production plan. The purpose of this project is to provide a report to OUTBAC detailing their current *as-is state* and then highlighting the benefits of a *to-be state* by implementing a production schedule and EOQ Inventory Model for better understanding of their production system. The research methodology used in this project follows traditional Industrial Engineering methodologies. The project report follows an Operations Research approach, generating a production model and thereafter discussing implementation of the model. This will enable OUTBAC to gain a better understanding of their production process and plan ahead according to expected sales demand and how they can better achieve their operational goals. The models discussed could be used to incorporate all of OUTBAC's products.

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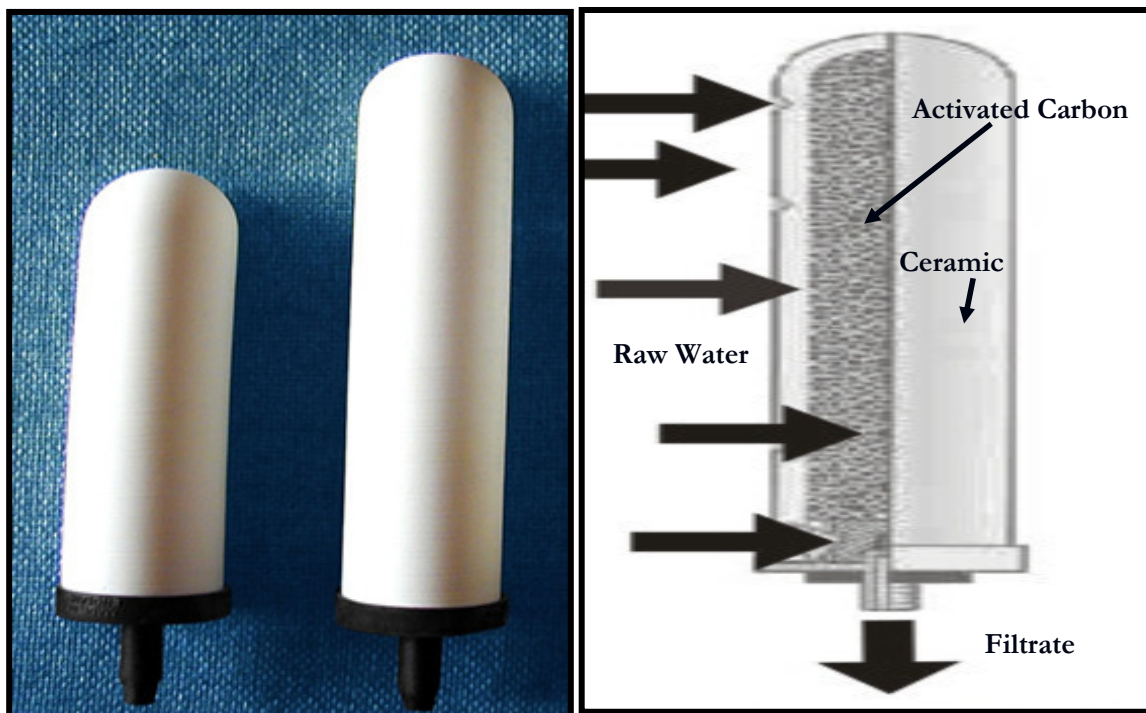
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Chapter 1

Introduction and Aim

OUTBAC Ceramic Water Filters, which is a small to medium enterprise (with only a 5 member team) in the water purification and ceramic industry, approached me for guidance on their production system with regard to their most popular product; the gravity fed household bucket filtration system.

Figure 1: Ceramic water filter candles. 2009. Photo taken by Jean Simonis.



OUTBAC originated when the founder travelled by road to Kenya in 1996. The first problem to be encountered on this overland trip was the unavailability of safe drinking water. He was forced to purchase a water filtration unit at a high cost before leaving South Africa. On his return he realized that there was a need for a low cost ceramic filter alternative and decided to form a company that would be able to manufacture these units. His background in refractory ceramics

aided him in his endeavour. OUTBACs' CEO and founder does not have a background in Industrial Engineering principles, but he is aware of the possible benefits to his company in applying these techniques. Jean Simonis (2009).

Background

South Africa is facing a severe water shortage within the next few decades according to Anthony Turton (2008) from the CSIR. In the controversial report, he mentions that South Africa lacks the Dilution Capacity which means that water will need to be treated even more in the next few years due to the fact that levels of pollutants and other effluents are increasing. Another interesting remark is that most of South Africa as well as the other SADC regions rainfall levels lie far below the world average of 860 mm/yr. Anthony Turton (2008) says, "This has led me to conclude that water scarcity is a fundamental developmental constraint, not only to South Africa, but also to the entire SADC region."

According to Anthony Turton (2008), there are three strategic water quality challenges to combat the problems that he highlighted. South Africa's negative position on Dilution Capacity leads us to believe that the water quality is rapidly decreasing and the only way to reverse this is to involve decision makers in the private sector as well as in the public sector. According to Anthony Turton (2008), South Africa's water resources have already been fully allocated and that we need to pay special attention to climate change since this will have a drastic effect on South Africa.

Thanks to the research of Dr Turton and the work of the CSIR it is now known that special attention needs to be given to companies that are trying to come up with solutions regarding water quality. Small companies can do little to mobilize government to take action with regard to water quality but they can start on their own level to combat the problem. Water filter companies like OUTBAC can make a difference to South Africans by offering a low cost product that will

eradicate water quality problems and combat water borne diseases working in partnership to combat the looming water crisis in Southern Africa.

OUTBAC's role

Many SME's in South Africa struggle to keep their businesses profitable after start-up and lack the knowledge and know-how as to getting their businesses to grow from an IE perspective. There is not enough knowledge transfer occurring between engineering professionals and those in the field and the work shop/production site. It is also important that the employees of OUTBAC be trained so that they are familiar with the new system and that the new system can be maintained by the workers.

By focusing on the outputs of the models OUTBAC will be able to realize their growth potential as well as evaluate and adjust, if necessary, their current position in their business. From the information gained from this project, OUTBAC will have the potential to facilitate company growth and could play a role in providing clean and safe water for all in South Africa.

Figure 2: Raw filter candles prior to assembly. 2009. Photo taken by author



Figure 3: Flanges that will be glued to the filter candles during the assembling process. 2009. Photo taken by author



Project Aim

The aim of this research is to analyze the current *as-is state* of OUTBAC, with specific focus on the production line, which produces the Bacster Bucket Filter. A working model will be created which will be used to further enhance the *as-is state*. By formulating a mathematical program to create a production plan and then by using an EOQ Inventory Model to control raw material levels, the *to-be state* will be realized. The *to-be state* should be beneficial to OUTBAC by providing management overall insight of the expected returns once the solution has been implemented as well as to offer OUTBAC improved control with regards to their expected unit sales and a recommendation as how to achieve their operational goals.

Project Scope

OUTBAC produces 3 filtration devices namely:

- a) traditional bucket ceramic filter (BACSTER)
- b) high pressure, in-line filtration system (BACOUT)
- c) outdoor, camping ceramic filter (OUTBAC)

This research document will concentrate on the process used for producing the bucket filter. The bucket filter consists of 1 x 5l bucket, 1 x 10l bucket, a tap and two ceramic filter candles. The bucket filter is the most popular product. The project scope can be described in the following steps:

1. analyse historical sales data for the past 36 months and forecast sales for the next 6 months so that a production plan for the next 6 months can be designed
2. use sales data that has been forecasted as inputs to create a mathematical Integer Programming model encompassing all production constraints
3. design an EOQ Model to balance the raw material inventory levels preventing the production line from stopping due to lack of stock. The purpose of inventory theory is to determine rules that management can use to minimize the costs associated with maintaining inventory and meeting customer demand according to Winston & Venkataramanan (2004)
4. production plan implementation ensuring worker and management buy-in
5. involve management and operations from step 1 to step 4 for buy-in: for model implementation and acceptance (author has the advantage of knowing the process, having worked at the company for the partial fulfilment of the bachelors degree, as well as – actually and continuously using the product)

Chapter 2

Literature Study

Project and Product Environment

The pathogens *Salmonella*, *Shigella* and *Vibrio cholerae* are associated with severe diarrheal disease world wide. It is estimated that 4.5 million deaths are caused by diarrheal diseases and that the number of diarrheal cases per year in developing countries, are more than 800 million according to Du Preez & Venter (2001). The World Health Organization, WHO (2008), specifies that of the total number of diarrheal deaths, 1.6 million diarrheal deaths are related to unsafe water, sanitation, and hygiene—the vast majority of deaths being among children under 5 years of age. The deaths are mostly as results of the more than 1.1 billion people still lacking access to improved water sources.

The recent outbreak of cholera in Zimbabwe & RSA serves as an illustration to the above facts, where inadequate water supply, contaminated water and poor sanitation are prevalent, high levels of diarrheal infections and deaths have occurred. This has impacted on the social, health and economic conditions of our Southern African society. According to the latest WHO results, WHO (2009), 3 759 people have died of cholera in Zimbabwe while 80 250 people have been infected during 2008 and 2009. About half of the patients who died from the water-borne diarrheal disease failed to reach any of the country's 365 cholera treatment centres. They state that the cholera outbreak in Zimbabwe is believed to have been caused by the nation's dilapidated infrastructure that has left sewage flowing openly in the streets while drinking water has gone untreated.

With the government only spending just over 1% in 2008 of the estimated R 180bn needed for complete overhaul of our own crumbling water purification and sewerage infrastructure according to FTE (2008), are we heading in the same catastrophic direction as Zimbabwe? Will

people have to start looking for alternative solutions for cleaning their own drinking water? The poor do not have such a luxury. They are forced to use polluted water as their only source of drinking water.

According to WHO (2009), of the 1.1 billion people without access to safe water, some 84% live in rural areas where centralised water distributions and treatment systems are too complicated or too expensive.

Filtration can be defined as the removal of a suspended particle from fluid, liquid or gas by passing the fluid through a porous or semi-permeable medium. Cartridge filtration (using ceramic candles) requires water pressure to drive the filtration process. The filter system therefore undergoes a pressure drop through the housing and the cartridge, which is affected by the fluid flow rate and density, the filtration material density and the inlet and outlet port sizes according to Dickenson (2007).

An example of the positive impact of ceramic filters in disaster situations is given in Clasen (2006). He tells the story where in late 2003; heavy rains and poor water management caused severe flooding in the Montecristi District of the Dominican Republic: “Emergency responders faced the need to provide safe drinking water to thousands of householders whose normal surface and other sources were destroyed or contaminated. Oxfam GB (an worldwide aid and relief company) implemented various interventions, including a pilot programme in February 2004 to provide 431 families with a water filter designed for household use. The filter was fabricated from two locally-procured 20L buckets with lids, three imported Brazilian CWF elements, and a plastic tap. Threaded nipples on the bottom plates of the hollow, can-shaped candles were inserted through holes made in the bottom of the top bucket and lid of the bottom bucket, sealed with the accompanying gaskets and wing nut, and a tap in the bottom bucket”. The program proved to be very successful and led to further such interventions in the area.

OUTBAC plays a pivotal role in the eradication or prevention of water borne. It is important to have OUTBAC's production process running as smoothly as possible so that the filters can reach the people that need them.

Existing Literature regarding production planning

There is no available literature regarding production planning formulation and implementation within the water filtration industry but there are numerous semi-generic models that have been implemented regarding production planning that can be adapted to a certain degree to represent the inner-workings of OUTBAC.

According to Messac (2003), a production-planning problem that looks at the continuous arrival of raw materials is solved. It is also known as a continuous-time production-planning problem. By finding the optimal production rates and the optimal stages at which production rates are to be altered the problem is solved to optimality. Production costs are lowered by incorporating into the model production rate changes at any time and not necessarily at the end of a period. Mathematical programming is used to solve the problem.

Messac (2003) discusses the analysis a manufacturing system that is subject to random breakdown and repair. The authors seek to find the optimal point for a machine-inventory model in which to develop. Examples are shown where the method is implemented and the results show that the model was effective.

Messac (2003) developed two methods to protect against uncertain demand, namely building inventory and by increasing production capacity for a period of time. The purpose of this was to find common ground between inventory, capacity and backlogged demand. Production planning can be very difficult and highly unpredictable. The use of the model as a bench mark will allow the project to be more accurate than it would without the model.

According to Messac (2003), a fluid-flow (named so due to the high volume of production) model for manufacturing systems with the aim of minimizing inventory costs is developed. They compare two models, one where the machines are reliable and the other where the machines are unreliable. The reliable machine model uses quadratic programming with linear constraints.

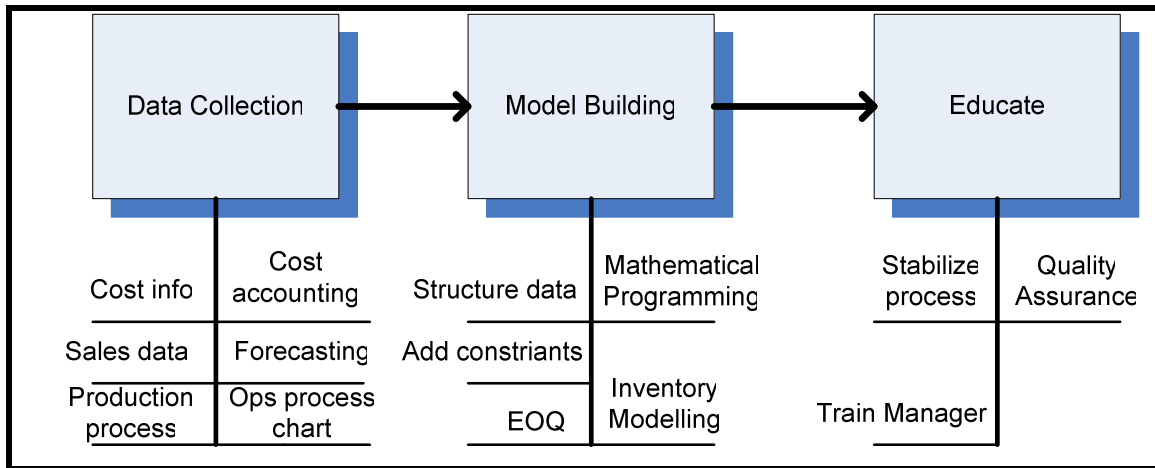
Messac (2003) describes a decision support system for production planning that also aims at maximising productive hours. An example is given where statistical data is provided. The statistical methods used in the model provide production planning variables that are more reliable than those chosen from random variables.

Integer programming (IP) for mixed product optimization was used to solve a Theory of Constraints (TOC) problem. The aim of the model is to maximize profit and to determine alternative methods of product routings so that the IP is still in optimality. The authors show that the mixed product optimization methods used result in a closer realisation of the goals associated with the TOC philosophy.

Methods, Tools and Techniques

There are 3 main sections to this project, the data collection, model building phase and the educate phase respectively. This is re-enforced in the figure. Under each section various IE methods, tools and techniques are used.

Figure 4: Literature Review Process



Data Collection

In the data collection phase various methods are used to collect the relevant data. Cost info needs to be collected for the production process. Costs need to be categorized into variable and fixed costs so that they can be incorporated into the IP model.

According to Seal (2009), variable costs are costs which vary in direct proportion to changes in the level of activity. If the production level of OUTBAC is doubled then the variable costs are also doubled but when the variable cost is expressed on a per unit basis then the variable cost remains constant. A cost is variable with respect to the activity base. The activity base is a measure of whatever causes the occurrence of variable cost. An activity base can be direct labour hours, machine hours or units produces or sold. Variable costs in OUTBAC can be categorized into cost of goods sold, manufacturing costs, manufacturing overhead and others.

According to Seal (2009), fixed costs remain the same in total Rand value within a range of activity. These costs remain constant in total but become smaller as the level of activity increases on a per unit basis. Long term fixed costs, or committed fixed costs for OUTBAC will be investment in facilities, depreciation, taxes, insurance and salaries of operating personal. Discretionary fixed costs arise from yearly decisions when there is a need to spend money in a specific area. OUTBAC might assign advertising, research, public relations to discretionary fixed costs.

Sales data needs to be studied as this will be the demand that needs to be satisfied. According to the demand for the past 3 years it will be determined which type of forecasting technique to use. The Methodology according to Wilson & Keating (2007) will be used for the forecasting of demand, will be:

1. Specify objectives
2. Determine what to forecast
3. Identify time dimensions
4. Data considerations
5. Model selection
6. Model evaluation
7. Forecast preparation
8. Forecast presentation

According to Wilson & Keating (2007) the data that is used most frequently in forecasts are time series. Time series forecast can exhibit various patterns over time and you have to choose the components relative to the specific forecast. OUTBAC's past sales data might reflect seasonality, a trend, cyclical pattern or an irregular pattern. Descriptive statistics will provide a mathematical soundness of the forecast. The accuracy of the forecast will be tested according to the mean error (ME), mean absolute error (MAE), mean percentage error (MPE), mean absolute percentage

error (MAPE), mean squared error (MSE), root mean square error (RMSE) or the Theil's U error. The accuracy of the forecast model will depend on these results to determine which forecasting technique is the better one.

According to Wilson & Keating (2007) "All the time-series smoothing methods use a form of weighted average of past observations to smooth up and down movements, that is, some statistical method of suppressing short term fluctuations. The assumption underlying these methods is that the fluctuations in past values represent random departures from some smooth curve that, once identified, can plausibly be extrapolated into the future to produce a forecast or series of forecasts."

Depending on the historic sales data the forecast method that will be used will be either Simple Moving Average if there is substantial randomness, Simple Exponential Smoothing if there is no trend or seasonality present, Holt's Exponential Smoothing if there is a trend or Winter's Exponential Smoothing if the data contains both seasonality and a trend. The error will determine which method is appropriate.

A Microsoft add-in, Forecast X, which is a family of forecasting tools capable of performing the most complex forecast methods and requires only a brief learning curve that facilitates immediate, simple and accurate operation regardless of user experience, will be used. The ProCast feature will determine the best forecasting technique for the data series. The data cleansing option can then be used to improve the accuracy of the forecast. Forecast X then tabulates the results in the form of a report and the user is able to select the properties of the report.

No formal time study will be undertaken although an operations process chart will be used to gain an understanding of the current process as well as the total time the filter units take to go through the operation. According to Niebel & Freivalds (2003) "The operations process chart shows the chronological sequence of all operations, inspections, time allowances and materials

used in a manufacturing process, from the arrival of raw material to the packaging of the finished product.” Time units can be estimates and don’t necessarily have to be exact. A completed process chart will help the manager visualize the present method.

Model Building

As can be seen from the figure the model building phase consists of structuring the data collected in the data collection phase, mathematical program model building and organizing the end product (working model) so that the inventory (EOQ) model can be constructed.

The aim of a mathematical programming model is to mimic a real world situation so that decisions can be made regarding the system that has been modelled. The aim of the model is to minimize cost or maximize profit. Depending on what we decide our decision variables are we can then begin to build constraints into the model to limit our resources like raw materials. We will use the seven-step model building process methodology as stated in Winston & Venkataramanan (2003) to construct the model.

These steps are:

1. Formulate the problem
2. Observe the system
3. Formulate a mathematical model of the system
4. Verify the model and use the model for prediction
5. Select a suitable alternative
6. Present the results and conclusion of the study to the organization
7. Implement and evaluate recommendations

According to Silver, Pyke & Peterson (1998) there are some limitations to using linear/integer programming. One of the main problems is the fact that demand is assumed to be deterministic even though demand fluctuates. Demand is determined to be deterministic since we have

developed forecasting methods to best fit the demand pattern as close as possible. Linear/integer programming also requires that cost functions be linear in nature but this can be overcome by using piecewise functions.

According to Silver, Pyke & Peterson (1998) the benefits of linear/integer programming is the ability to find the dual of the problem to find the maximum levels in inventory, parametric methods allow a simple determination of the production plan. Another benefit is to use goal programming when there are multiple objectives which must be prioritized.

A computer package, Lingo 7, will be used to represent all the OUTBAC constraints and objective functions. Lingo is an interactive computer software package that can help in solving mathematical programming problems. Lingo which is a matrix generator according to Winston & Venkataramanan (2003), “A matrix generator allows the user to input the relevant parameters that determine the LP’s objective function and constraints; it then generates the IP formulation from the information.” We would be able to enter all the relevant costs associated with each specific period only once hence the matrix generator functions. We would be able to view the results in a concise form in the form of an output analyser. Lingo will help us in building the model because of its numerous built in functions such as set looping and probability functions. Our constraints will be written in Lingo and the IP will hopefully be solved.

When demand is constant it is easy to calculate the replenishment quantity of the primary raw material, A. OUTBAC will undoubtedly experience a time varying demand. When varying demand is present according to Silver, Pyke & Peterson (1998), replenishment quantities should be filled at the beginning of a period i.e. the beginning of the month. We will look at 3 approaches and choose the one which will have the lowest cost:

1. Use of the basic economic order quantity
2. Use of the exact best solution to a particular mathematical model of the situation
3. Use of an approximate or heuristic method

When the demand rate for raw material, A, is approximated to be constant we will use the first approach. This will be calculated as

$$EOQ = \sqrt{\frac{2AD}{vr}},$$

Where D is the estimate of the average demand, A is the fixed cost element, the unit variable cost v and the carrying cost r.

According to Silver, Pyke & Peterson (1998), “To account for the discrete opportunities to replenish, at the time of replenishment the EOQ should be adjusted to exactly satisfy the requirements of an integer number of periods. A simple way to do this is to keep accumulating periods of requirements until the closest total to the EOQ is found.”

To distinguish between the next two methods it is important to introduce a variability coefficient, VC.

$$VC = \frac{\text{Variance}}{\text{avDemand}}$$

If $VC < 0.2$, then use the Simple EOQ or the Wagner-Whitin Algorithm.

If $VC \geq 0.2$, then use a heuristic.

According to Silver, Pyke & Peterson (1998), “The Wagner-Whitin algorithm guarantees an optimal selection of replenishment quantities under a set of assumptions. The algorithm is an application of dynamic programming, a mathematical procedure for solving sequential decision problems.” We can use a simple spreadsheet program, Microsoft Excel, to calculate the optimal solution. There are some draw backs to this algorithm. The method could get quite complicated confusing the user, there is a need for a well-defined ending point in inventory levels, and the fact that it is assumed that replenishments can only be made at the beginning of a period.

Because of the difficulty with using the Algorithm, heuristics have been developed to overcome this stumbling block. The Silver-Meal or the Least Cost Heuristic, according to Silver, Pyke & Peterson (1998), “Selects the replenishment quantity in order to replicate a property that the basic EOQ possesses when the demand rate is constant with time, namely, the total relevant costs per unit time for the duration of the replenishment quantity are minimized.” Since we are constrained to replenish at the beginning of the period the best strategy must involve replenishment quantities that last for an integer number. It has been proven that most heuristics outperform the EOQ approach. According to Silver, Pyke & Peterson (1998), there are situations when the heuristic will not be beneficial. These situations are when the demand pattern drops rapidly over a number of time periods and when there is no demand for some of the periods.

Education

After the data collection and the model building phases have been completed, the education phase can then take place. The educating phase serves as a way to hand over to management so that they can run the system when we leave but before this can happen it has to be determined if the production process is in statistical control. According to Gitlow, Oppenheim & Levine (2005), “A process that has been defined and documented can be stabilized and then improved. In great measure this can be accomplished through the use of statistical control charts. Without valid measurements, process improvements are difficult if not impossible, and perhaps the best means of measuring process performance is a statistical control chart.”

OUTBAC’s current production process is acceptable in terms of quality assurance but a count chart will be used to make sure this is the case. More than one filter defects are permissible without rendering the candle defective. To use c charts the area of opportunity needs to be the same and this is the case since the filter candles are all the same size. This research paper will not spend time exploring quality control issues as this has been done in another research proposal.

The advantages of a stable process according to Gitlow, Oppenheim & Levine (2005), is that management will know the process capability and can predict future performance, costs and quality levels. Productivity will be at a maximum. Management will also be able to measure the effects of change to the system.

Once the production process is stable, then the hand over to management can begin. It will entail the training of a manager and provide members of the staff with templates so that they can collect relevant data with ease.

Data Analysis

That data analysis section of this project has been fully developed and the data that will be needed vs. the data collected will be analysed and decided upon whether or not to be used or not.

The forecasting technique that is going to be used will be decided on and this process took place during a visit to OUTBAC during June/July and the sales data can now be analysed. Forecasting data will be collected by analysing existing sales records at the OUTBAC office. OUTBAC keeps sales data for a period of three years so it will be possible to retrieve this data so that the forecasting process can begin.

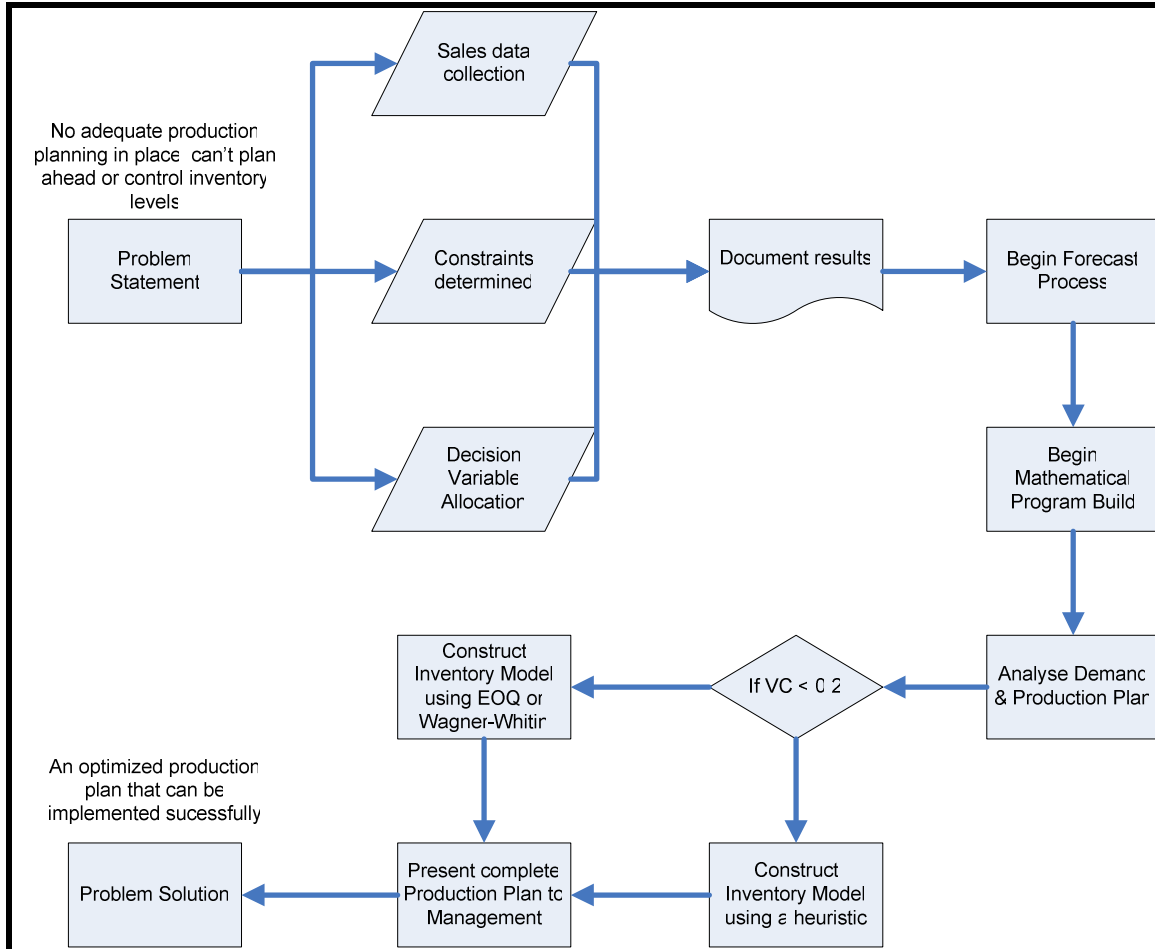
The various decision variables and production constraints have also been determined after conducting the site visit.

The quality control aspect of this project is also at its beginning stages and will be implemented at a later stage once the recommendations of this project have been approved. The quality control aspects will be used to test if the implemented project conforms to quality control standards. The inventory model follows once a production plan is in place.

It is imperative that management buy-in to the production plan idea from the start of this project. Management should be involved in each step and it will be up to them to provide the necessary data or allow access to conduct data analysis.

Development of Conceptual Design

Figure 5: Conceptual Design steps



The conceptual design phase can be organized in a flow chart. The above steps are going to be performed so that the problem statement can be solved in the appropriate way, with the help of what was said in the literature study. The conceptual design flow chart is not fixed as some of the processes may be changed as the project progresses.

Chapter 3

Final Development Plan

Forecasting

The Methodology according to Wilson & Keating (2007) will be used for the forecasting of demand so that the data is structured in an understandable manner.

Specify objectives:

The forecasting process's statement of objectives states that the sales data for the past three years will be used to as accurately as possible to determine the sales data for the 6 month period in which the Integer Program (IP) will be used. The application of the forecast process will be discussed with management of Outbac so that they are familiar with the process and realize the benefits.

Determine what to forecast:

The number of bucket filter products will be the item to forecast. The bucket filter drives the amount of variable production costs. The bucket filter consists of 2 ceramic filter candles. These filter candles contain the main raw material which will be modelled by an Inventory Model to accurately predict the re-ordering nature.

Identify time dimensions:

The forecast that will be used for OUTBAC will be in the form of monthly sales data that spans back 3 years. There is quite sufficient time before the forecast is needed so greater care can be given to choose a forecasting method that has the lowest error. OUTBAC plans to use the forecasting method for any future months that they would like to forecast and hence an ample time to determine the method would be beneficial to OUTBAC. The forecasting time horizon will be 6 months.

Data considerations:

It is important to consider the quantity as well as the type of data that is available. The sales data that has been collected for OUTBAC comes from internal sources, namely their marketing section of the company. They have organized the data according to number of units sold per month as well as Rand in sales per month.

Model selection:

OUTBAC's sales data that has been collected show an upward trend with an initial base level which translates into the Holt-Winter's method. The simple exponential smoothing method could also be selected depending on the statistics that have been collected. As for the other Industrial Engineering forecasting methods they would not be as accurate as Holt's method.

The Simple Exponential Smoothing methods as well as the Holt's method are compared side by side in the appendix as a comparative study.

Model evaluation:

The exponential smoothing forecasting method seems inadequate. The ideal alpha value for the forecast time span is:

$$\alpha = \frac{2}{N+1}$$

where N is the number of periods. Alpha would then equate to 0.054 which is very low. Values for alpha typically chosen should be less than 0.5 but 0.054 seems too low.

The formula for the next period's forecast is:

$$F_{t+1} = \alpha X_t + (1-\alpha)F_t$$

Where F_{t+1} = Forecast value for period t+1

α = smoothing constant ($0 < \alpha < 1$)

X_t = Actual sales value in period t.

F_t = Forecast (i.e. smoothed) value for period t

To further substantiate this, the data table shows that the MAD and %MAD decreases when Alpha approaches 1. This seems to suggest that there is a trend or some sort of cyclic variation suggesting that the Simple Exponential Smoothing forecasting method would not be appropriate. Appendix B shows the use of the Simple Exponential Smoothing forecasting technique.

Because of the presence of an upward trend the Holt forecasting method was used. To initialize Holt's method we need an initial estimate of the base and the trend. A 12 month warming up period was chosen to determine these values. The initial trend level was calculated by using the previous year's sales value differences between months and averaging them. The initial base level could have been chosen to be the previous month's sales but it was decided to average the past years sales data and adding 6 times the trend of the 12'Th month due to the fact that this is more accurate as well as yielding a lower MAD value.

Three equations and two smoothing constants are used in the model:

$$F_{t+1} = \alpha X_t + (1-\alpha)(F_t + T_t)$$

$$T_{t+1} = \beta(F_{t+1} - F_t) + (1-\beta)T_t$$

$$H_{t+m} = F_{t+1} + mT_{t+1}$$

Where:

F_{t+1} = Smoothed value for t+1

α = Smoothing constant for the level ($0 < \alpha < 1$)

X_t = Actual value during period t

F_t = Forecast (i.e. smoothed) value for period t

T_{t+1} = Trend estimate

β = Smoothing constant for the trend estimate ($0 < \beta < 1$)

m = Number of periods ahead to be forecast

H_{t+m} = Holt's forecast value for period t+m

To determine the most accurate values for the smoothing constants, alpha and beta a two way data table was set up. An alpha value of 0.3 was chosen and a beta value of 0.5 was chosen to represent the smoothing constraints to yield a MAD of 4.05 and a %MAD of 3.43. Refer to Appendix C for the forecast table and results.

The Mean Absolute Error (MAE) is calculated as follows:

$$\text{MAE} = \frac{\sum |A_t - F_t|}{n}$$

And the Mean Percentage Error (MAD%) is calculated as follows:

$$\text{MAD}\% = \frac{\sum [(A_t - F_t) / A_t]}{n}$$

n for both formulas is the number of periods used in the calculation.

Forecast preparation:

The forecast can now be enhanced by eliminating out of control points and by creating a worst-case scenario, best-case scenario or a most likely scenario.

Forecast presentation:

It is important that management understand what the forecast is meant to convey as well as how the sales data was used in the forecast. The success of the forecast depends on whether management understands and has confidence in the forecast. The use of the charts in the Appendix should be sufficient for management to understand.

The values that were obtained from the forecasts for the next 6 month period will be used as the input demand for the Integer Program (IP).

IP Model Building

We will use the seven-step model building process methodology as stated in Winston & Venkataramanan (2003) to construct the model.

Formulate the problem:

The problem is to determine an optimized production plan that will maximize profit for the OUTBAC Bucket Filter process. OUTBAC requires a 6 month planning horizon for adequate planning.

Observe the system:

Before a working model can be constructed it was necessary to collect a whole range of data relating to the production process. Firstly all the production related costs had to be determined specifically the fixed costs.

Depreciation for tax purposes is determined by using the modified accelerated cost recovery system (MACRS) and it determines the depreciable life of an asset. According to the MACRS

rules there are a number of recovery periods depending on the property class. OUTBAC’s main fixed production costs are for the Oven, Miller, Dryer, Moulds, Mixer, Master Mould and tools. These are categorized under the property class of 7 years which means that depreciation percentage recovery is spread out over 7 years.

Table 1: MACRS recovery periods for Manufacturing Equipment

Recovery Year	% By recovery year
1	14%
2	25%
3	18%
4	12%
5	9%
6	9%
7	9%

It has been determined that all manufacturing equipment will be sold after 5 years and then new equipment is to be purchased. This translates to 78% of the initial value recovered. The Book Value (BV) is then calculated to be:

$$BV = InstalledCost - AccumulatedDepreciation$$

Refer to figure for all the calculations to determine the Book Value of fixed assets. The Present Values (PV) of the various fixed assets is also shown. The PV represents the purchase price of the equipment. The interest rate per year is assumed to be 13% per annum. A recovery period of 5 years then translates into 60 months. The tooling equipment cannot be sold after 5 years for a significant value; therefore, there is no book value for tools and the tools can be used for 4 years.

Overhead are costs that are not easily assignable to a product but these costs do occur. These include administration, utilities and insurance costs.

The monthly payments on all the equipment is shown in table 2 respectively. These costs are always present in OUTBAC regardless of which product is manufactured and regardless of the number of units that are produced. The monthly payments are calculated by the MS Excel function PMT.

= PMT(interest rate/month, number of months, -Present Value, Book Value, 0)

Table 2: Fixed costs per month

Fixed Costs	% recovery	BV	PV	i	i(month)	n	n(months)	PMT/year R	PMT/month R
Oven (Kiln)	0.78	4400	20000	0.13	0.010833	5	60	5,007.31	R 402.61
Miller	0.78	2200	10000	0.13	0.010833	5	60	2,503.65	R 201.31
Dryer	0.78	2640	12000	0.13	0.010833	5	60	3,004.38	R 241.57
Moulds	0.78	2200	10000	0.13	0.010833	5	60	2,503.65	R 201.31
Mixer	0.78	2200	10000	0.13	0.010833	5	60	2,503.65	R 201.31
Master mould	0.78	0	2500	0.13	0.010833	5	60	R 710.79	R 56.88
Tools	1	0	5000	0.13	0.010833	4	48	1,680.97	R 134.14
Workers x2									R6000.00
Overhead									R13000.000
Total Payments/month									R 1,439.13
Total									R 20,439.13

Variable costs also play a significant role in the costing of OUTBAC as these costs increase and decrease as the production level increases and decreases respectively. Each filter candle weighs 180 grams in its raw form i.e. without the activated carbon, flanges and bearings. Of this weight 50% contains raw material A, 10% raw material B and 40% raw material B. Each of these weights has different cost structures. The other variable costs are listed in Table 3.

Table 3: Variable Costs

Variable Costs	Cost per KG	Cost per Unit
Raw Material A	R 18.00	R 3.25
Raw Material B	R 22.00	R 0.40
Raw Material C	R 25.00	R 1.80
Carbon	R 35.00	R 8.00
Plastic (Fitting)		R 6.00
Plastic (Buckets)		R 40.00
Tap		R 25.00
Primer		R 0.50
Advertising		R 3.50
Shrink Wrap		R 1.00
Bubble Wrap		R 0.50
TOTAL COST PER UNIT		R 89.95

The variable and fixed costs will form part of the maximization function of the mathematical program.

Formulate a mathematical model of the system:

Using a Integer Program a production planning model will be developed to optimize the number of bucket filters to produce. The model will determine the profit maximization method. Various constraints and decision variables will be defined to mimic the system which OUTBAC has in place.

The variables that will be used will be the following:

$\text{costf}_t \quad \underline{\underline{\Delta}}$ as the fixed costs that occur during OUTBAC’s production cycle during month t, where $t \in \mathfrak{R}, t = \{1..6\}$

$x_t \quad \underline{\underline{\Delta}}$ as the number of bucket filter units that will be produced during month t, where $t \in \mathfrak{R}, t = \{1..6\}$

$i_t \quad \underline{\underline{\Delta}}$ as the number of bucket filter units that will be stored in inventory during month t, $t \in \mathfrak{R}, t = \{1..6\}$

- \max_{tm} $\underline{\underline{\Delta}}$ as the maximum amount of raw material, m , that is on hand during month t in kilograms, where $m = \{A, B, C, Carbon, Plastic, PBucket, Tap, Ad, Wrap\}$ and where $t \in \mathfrak{R}$, $t = \{1..6\}$
- cost_t $\underline{\underline{\Delta}}$ as the amount of variable costs that OUTBAC incurs during production in month t where $t \in \mathfrak{R}$, $t = \{1..6\}$
- cap_t $\underline{\underline{\Delta}}$ as the number of units of bucket filters that can be produced during month t where $t \in \mathfrak{R}$, $t = \{1..6\}$
- d_t $\underline{\underline{\Delta}}$ as the demand that has been forecasted for bucket filter units during month t where $t \in \mathfrak{R}$ $t = \{1..6\}$
- sellingp $\underline{\underline{\Delta}}$ is the given selling price of a bucket filter
- inv_t $\underline{\underline{\Delta}}$ as the amount of bucket filters that can be kept in inventory during month t where $t \in \mathfrak{R}$, $t = \{1..6\}$

Modelling OUTBAC's production plan will require various constraints that will represent the inner working of the production process. These constraints along with explanations are listed below:

Inventory Constraints:

Inventory at OUTBAC is of vital importance due to their limited storage capacity. In some months they plan on expanding their current storage area. Construction will begin from month 2 and end in month 4. During this time a part of the storage space will not be able to be utilized. The capacity refers to the number of complete buckets that can be stored in inventory during each respective month.

$$i_{t-1} + x_t \geq d_t$$

States that the inventory in $t-1$ period as well as the number of units produced in that month has to be greater or equal to the demand that has been forecasted for that month. OUTBAC does not perform back-ordering.

$$i_1 = i_0 + x_1 - d_1$$

Is the initializing constraint for inventory on hand during each month.

$$i_0 = 72$$

Is the inventory on hand before the forecast period begins.

$$i_t \leq \text{inv}_t$$

The inventory on hand during month t has to be less or equal to the inventory capacity for each month.

Table 4: Inventory Capacity

Month	Inventory Level Capacity (Units)
1	50
2	50
3	40
4	30
5	40
6	50

Production Constraints:

The various production constraints constitute the criteria for the production part of the process. Production capacity will also fluctuate from month to month respectively due to annual leave taken by employees as well as downtime required by machines for maintenance. These capacity constraints are listed below and the production capacity is an estimated figure by OUTBAC.

Table 5: Production Capacity

Month	Production Capacity (Units)
1	150
2	150
3	150
4	120
5	120
6	150

$$x_t \leq \text{cap}_t$$

The production capacity each month has to be greater or equal to the number of units that will be produced each month.

Table 6: Raw Material Capacity

$$0.1x_t \leq \text{max}_{t,A}$$

$$0.02 x_t \leq \text{max}_{t,B}$$

$$0.08 x_t \leq \text{max}_{t,C}$$

$$0.08 x_t \leq \text{max}_{t,\text{Carbon}}$$

$$2 x_t \leq \text{max}_{t,\text{Plastic}}$$

$$2 x_t \leq \text{max}_{t,\text{PBucket}}$$

$$x_t \leq \text{max}_{t,\text{Tap}}$$

$$x_t \leq \text{max}_{t,\text{Ads}}$$

$$1.5 x_t \leq \text{max}_{t,\text{Wrap}}$$

Raw Material	Capacity per month
A	20 Kg
B	10 Kg
C	15 Kg
Carbon	20 Kg
Plastic	500 units
Pbucket	280 units
Tap	500 units
Ads	20000 Pamphlets
Wrap	250 square meters

These are the constraints that make sure that the number of units produced during each month does not exceed the raw material capacity for each month.

Objective function:

The goal of the objective function is to maximize profit for the Bucket Filter Production line. Fixed costs are evident from Table 2 and they do not depend on the number of units produced each month. Table 3 shows the various variable costs that are present. Inventory holding costs for bucket filters is R15 per month per bucket represented by $10 i_t$

$Costf_t = 22\,439$ (total expected fixed cost) and the selling price for the unit is $sellingp = 250$.

$3.25x_t + 0.4x_t + 1.8x_t + 8x_t + 6x_t + 40x_t + 25x_t + 0.5x_t + 3.5x_t + 1x_t + 0.5x_t$ represents the variable costs per unit. When combined you get $89.95x_t$ as the variable cost element.

$$\text{Max } z = \text{sellingp} - \text{fixed} - \text{variable} - \text{inventory}$$

$$\therefore z = 250x_t - Costf_t - 89.95x_t - 10i_t$$

$$\therefore z = 160.05x_t - Costf_t - 10i_t$$

Verify the model and use the model for prediction:

From the above constraints and variables it is now possible to program the model into Lingo so that the feasible production plan can be realized. The model in raw code form can be viewed in Appendix D. Each line of code is commented on to give more clarity to the model. The model is then run for de-debugging purposes and checked for validity.

Select a suitable alternative:

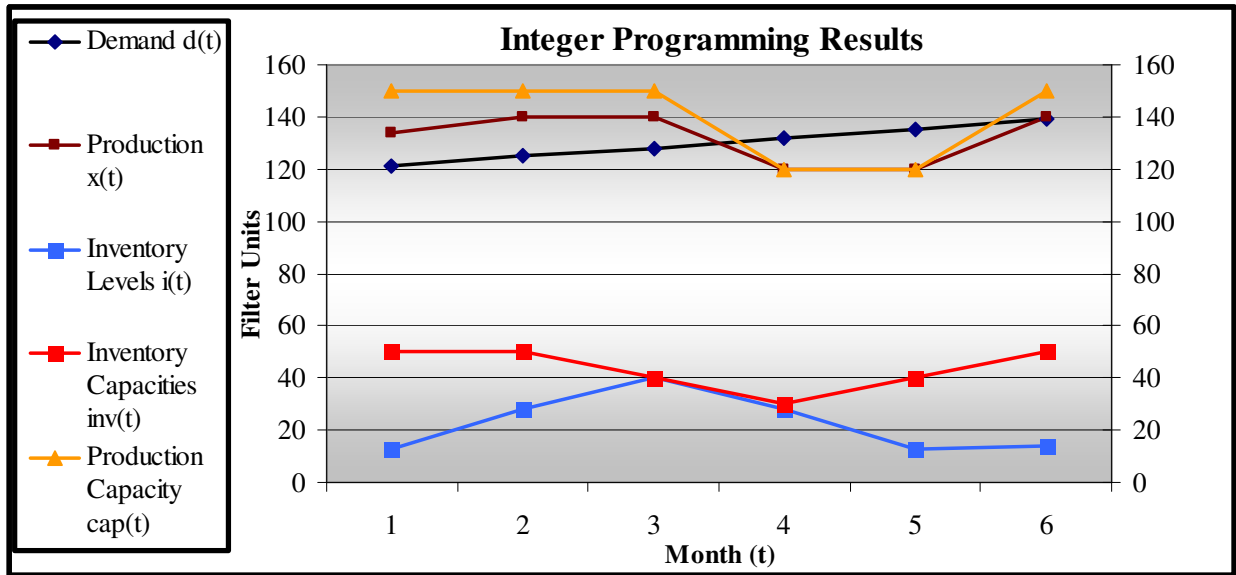
Numerous alternatives can be run to enhance the model such as the time value of money, back-ordering (if necessary), discount factoring as well as Regular and Overtime labour constraints can be implemented for even more clarity. This can be done if OUTBAC requires more detail and accuracy.

Present the results and conclusion of the study to the organization:

The results of the study will be presented to OUTBAC in a graphical and explanatory method to promote maximum understanding. The results of the Lingo Mathematical Program can be shown graphically as indicated below in Figure 6. The outputs of the model can also be viewed in raw

form in Appendix D.

Figure 6: Mathematical IP Results



Evaluation, Implementation and Recommendations:

It can be seen from the above graph that the proposed production plan (optimization part) falls well below the constraints put forth. Both the production figures as well as the inventory levels are shown on the same graph. The recommendations put forward in this project should be implemented in a timely fashion to determine its feasibility following a recommended methodology for implementation.

In addition, implementation should be conducted over the first two months namely month 1 and month 2 and the actual vs. forecasted values should be compared. Once the comparison is done additional additions to the optimization model could be performed to streamline the production process. If the current model is sufficiently accurate the models could then be modified and implemented on a month to month basis whereby the models are continuously updated. There should be room for continuous improvement and to further streamline the production plan facility planning as well as other IE tools, methods and techniques could be used to strengthen OUTBAC’s business.

EOQ Model

Various assumptions need to be made when dealing with EOQ data. According to Silver, Pyke & Peterson (1998) they are:

1. The demand rate is given in the form $d(t)$. The demand rate varies from time to time but it assumed to be known.
2. The entire requirements of each period must be available at the beginning of that period.
3. The unit variable cost does not depend on the replenishment quantity.
4. The cost factors do not change appreciably with time.
5. The item is treated entirely independently of other items.
6. The replenishment lead time is known with certainty so that the delivery time can be timed to occur right at the beginning of the period.
7. No shortages are allowed.
8. The entire order quantity is delivered at the same time.

The need exists to choose a suitable EOQ model for Raw Material A. In the table below the amount of raw material A used in production for each month is shown (0.130 grams of raw material A per filter unit * the number of expected filter sales for that month) and from there the VC equation can be calculated to determine which EOQ model is appropriate.

Table 7: VC Calculations

Month	Demand per month	Production per month
1	121	134
2	125	140
3	128	140
4	132	120
5	135	120
6	139	140
Month	Raw A used (KG)	Raw A used (KG)
1	15.73	17.42
2	16.25	18.2
3	16.64	18.2
4	17.16	15.6
5	17.55	15.6
6	18.07	18.2
Variance	0.7436	1.633666667
Average	16.9	17.20333333
VC	0.044	0.094962217

From the literature study it has been stated that If $VC < 0.2$, then the Simple EOQ or the Wagner-Whitin Algorithm should be used or else if $VC \geq 0.2$, then a heuristic should be used. It is clear that in the above Table 7 that VC is equal to 0.1 so a decision needs to be made between the simple EOQ or the Wagner-Whitin Algorithm. It needs to be made clear that the EOQ model proposed is with regards to raw materials and NOT filter units. OUTBAC needs to decide when to replenish raw material stock, specifically Raw material A.

$$v = \text{unit variable cost}$$

Assuming the variable cost to Bikita Mine (Zimbabwe), who manufactures raw material A, marks their product up 75%; it can be shown that their variable cost is R10.30 per Kg ($18/1.75$). The variable cost to OUTBAC is the cost that they pay for a 10kg bag of raw material A i.e. R180 per 10 kg.

$$r = \text{cost incurred by OUTBAC for carrying raw material A in inventory per month}$$

R will be relatively high in OUTBAC's case because of limited storage space at present. It can be seen in the text above that OUTBAC is planning on increasing their inventory holding capacity in the future. Inventory carrying cost depends on weight of the material, bulkiness as well as special storage instructions. Raw material A cannot get wet while in storage so special precautions need to be taken. Assume that $r = R15$ per 10 kg bag per month.

$a =$ ordering cost per order incurred by OUTBAC

Bikita Mine ships raw material A by special courier. OUTBAC also has to spend time ordering raw material A through email and numerous faxes have to be sent and received before the shipment is released. OUTBAC also has to pay customs before the courier releases the material. $a = R125$.

These values have not been added into the IP formulation because these values are specific to the ordering and storing of raw materials.

Substituting these values into the equation below yields:

$$EOQ = \sqrt{\frac{2AD}{vr}}$$

Where:

A = ordering cost per order incurred by OUTBAC per kg

D = the average demand over 6 months (17.2 kg)

V = unit variable cost for raw material A per kg

R = cost incurred by OUTBAC for carrying raw material A in inventory per month per kg

Thus EOQ stands at 4 kg. It can be seen from the below table that the first month requires 17.42 kg of raw material A, thus the replenish quantity of 17.42 kg is needed before month 1 begins i.e.

before production begins for the forecasted sales values. Since OUTBAC only receives shipments in 10 kg denominators this number will be rounded up to 20 kg.

Table 8: Cumulative requirements

	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
Raw Material A requirements	17.42	18.2	18.2	15.6	15.6	18.2
Cumulative requirements	17.42	35.62	53.82	69.42	85.02	103.22

For better clarity the table below will illustrate the EOQ method. The delivery time is on average 2 weeks so OUTBAC needs to re-order the appropriate replenishment quantity as listed in Table 9 for each successive month.

Table 9: Inventory stock for Raw Material A

Month	0	1	2	3	4	5	6
Starting inventory (in kg)	-	20	2.58	4.38	6.18	10.58	4.98
Replenishment quantity (in kg)	20	-	20	20	20	10	20
Requirements per month (in kg)	-	17.42	18.2	18.2	15.6	15.6	18.2
Ending inventory (in kg)	20	2.58	4.38	6.18	10.58	4.98	6.78

Chapter 4

Recommendations and Conclusion

OUTBAC's streamlined production plan for the up and coming 6 months followed an Industrial Engineered approach and aims to facilitate a better understanding to management of what will be expected of them in terms of production requirements. Numerous other tools, techniques and methods can be used in the future to further help OUTBAC gain insight into their business. Business Engineering can be used to highlight the various operating functions within OUTBAC and how they relate to each other as well as ways to further enhance the business. Quality Engineering can be used to help reduce defect variances in their production processes. Facility Planning can be used to optimize the space available to OUTBAC and to eliminate waste.

The purpose of this project to provide OUTBAC with a production plan that could be implemented with minimum effort and expect to yield a fair return. The production plan (forecasting, integer programming and EOQ) could be adapted to incorporate of all OUTBAC's product streams.

Spending time at OUTBAC and gathering the necessary data made understanding the customer need quite simple. The analysed sales data for the past 3 years was forecasted for a time span of 6 months. The results of the comparative study between two forecasting techniques showed that production quantities, utilizing the Holt's forecasting method, of 122, 125, 129, 132, 136, 139 units in each respective month was needed to satisfy the demand for those months.

More data was analysed and it was determined that an optimized integer program could be designed encompassing all the production constraints. OUTBAC would be experiencing an inventory holding problem as well as capacity limitations during the months concerned. OUTBAC needed to perform major maintenance as well as enlarging the current stock holding area during the 6 month period. The IP took into account the demand for each month, capacity constraints as well as numerous other constraints relating to production. The result was a

structured production plan with an expected profit of R 3086 for the bucket filter production stream. Once OUTBAC is able to eliminate waste, as discussed in the methods above, and understand their target market better the business can expect a greater profit margin.

It was decided that OUTBAC also needed to control their raw material inventory levels so that production would never need to be halted because of low inventory levels. The simple EOQ method was an appropriate method of determining the replenishment quantities.

OUTBAC has been informed on the findings of this project document and they would like to test the results of this project with an actual production case. OUTBAC has been worked with closely during the course of this project and has been informed of the progress continuously. A good working relationship built on trust and understanding has been developed. They believe that this project has highlighted the fact that they need to get a better handle on their production processes and be open to new ideas and improved methods in production, marketing, supply chain and management if they want to become a leader in the water filtration industry.

This project illustrates that even the most basic Industrial Engineering principals can be applied to a small company to create change within the company to promote further opportunities, to increase productivity and ultimately create a greater profit.

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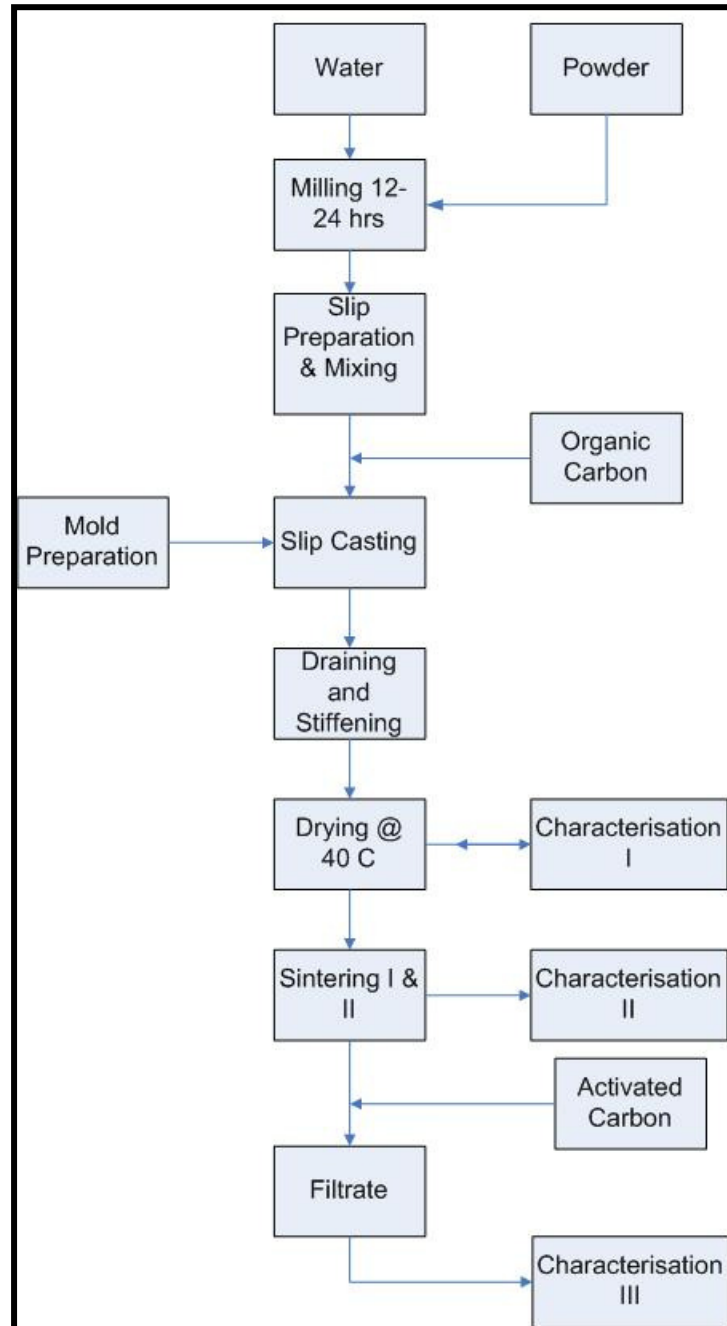
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Appendix A

Filter Production Process

Figure 7: Filter Production Process



Appendix B

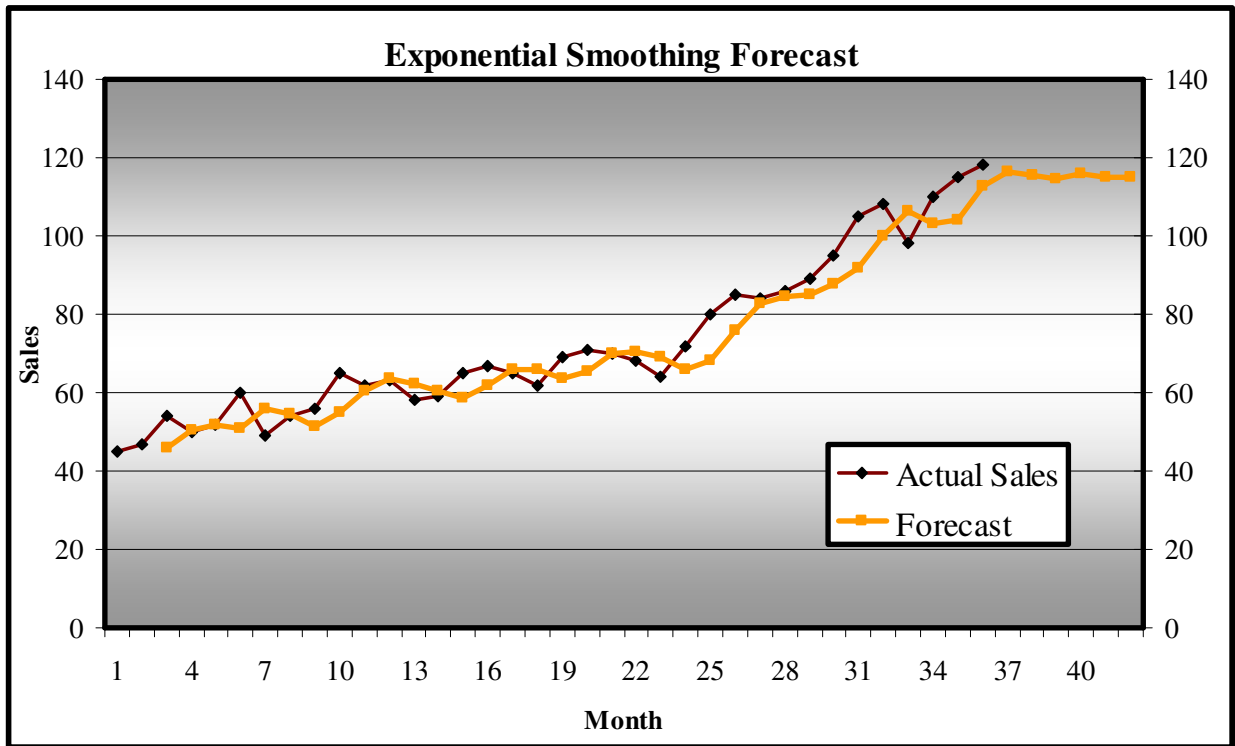
Simple Exponential Smoothing Forecasting

Table 10: Simple Exponential Smoothing Forecast

Month	Sales	Forecast	Error	Abs error
1	45			
2	47			
3	54	46	8	8
4	50	50.5	-0.5	0.5
5	52	52	0	0
6	60	51	9	9
7	49	56	-7	7
8	54	54.5	-0.5	0.5
9	56	51.5	4.5	4.5
10	65	55	10	10
11	62	60.5	1.5	1.5
12	63	63.5	-0.5	0.5
13	58	62.5	-4.5	4.5
14	59	60.5	-1.5	1.5
15	65	58.5	6.5	6.5
16	67	62	5	5
17	65	66	-1	1
18	62	66	-4	4
19	69	63.5	5.5	5.5
20	71	65.5	5.5	5.5
21	70	70	0	0
22	68	70.5	-2.5	2.5
23	64	69	-5	5
24	72	66	6	6
25	80	68	12	12
26	85	76	9	9
27	84	82.5	1.5	1.5
28	86	84.5	1.5	1.5
29	89	85	4	4
30	95	87.5	7.5	7.5
31	105	92	13	13
32	108	100	8	8
33	98	106.5	-8.5	8.5
34	110	103	7	7
35	115	104	11	11
36	118	112.5	5.5	5.5

37	112.5	116.5	-4	4
38	116.5	115.25	1.25	1.25
39	115.25	114.5	0.75	0.75
40	114.5	115.875	-1.375	1.375
41	115.875	114.875	1	1
42	114.875	115.1875	-0.3125	0.3125
Alpha	0.5			
MAD	5.205882			
MAD %	4.468569			

Figure 8: Forecast vs Actual



Appendix C

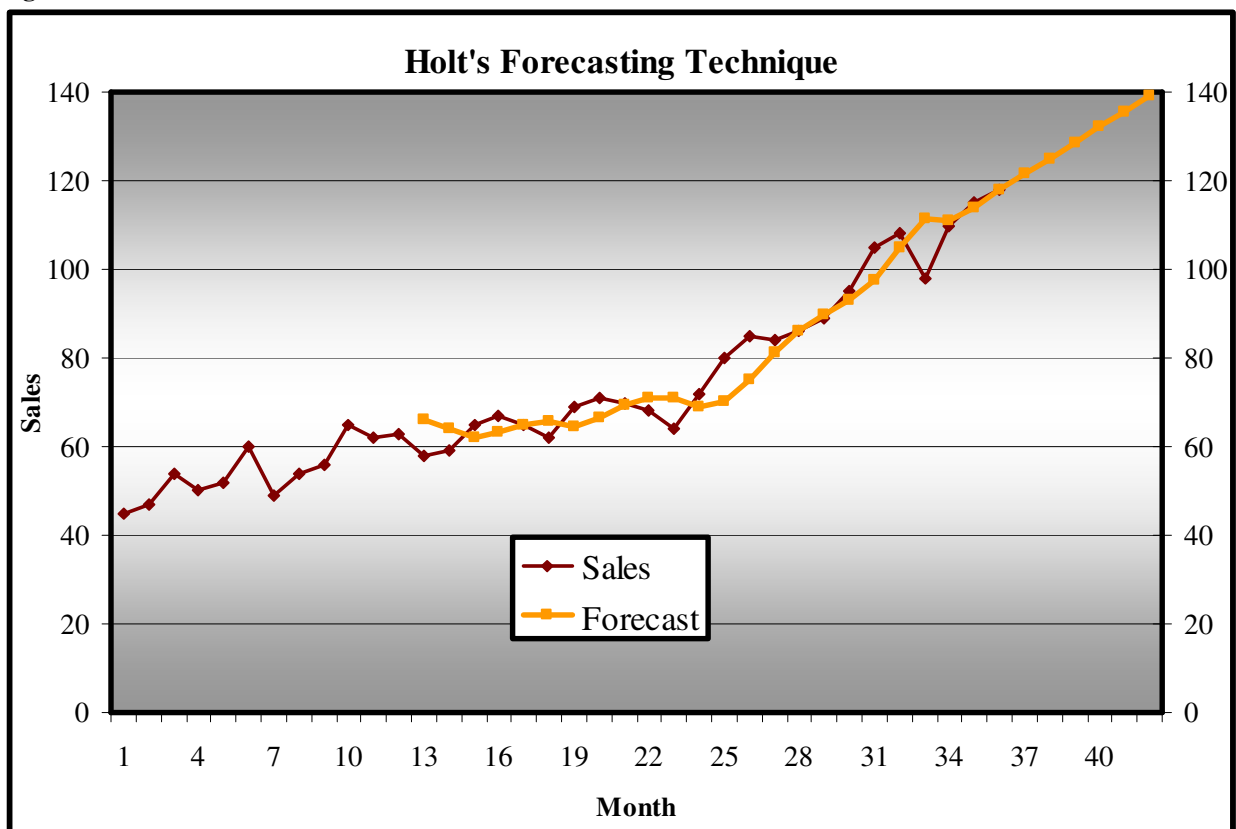
Holt's forecasting method

Table 11: Holt's Forecasting Technique

Month	Sales	Lt	dI/dt	Tt	Forecast	Error
1	45					
2	47		2			
3	54		7			
4	50		-4			
5	52		2			
6	60		8			
7	49		-11			
8	54		5			
9	56		2			
10	65		9			
11	62		-3			
12	63	64.56818	1	1.636364		
13	58	63.74318		0.405682	66.20455	8.204545
14	59	62.6042		-0.36665	64.14886	5.148864
15	65	63.06629		0.047719	62.23756	2.762443
16	67	64.27981		0.630617	63.11401	3.885991
17	65	64.9373		0.644054	64.91042	0.089577
18	62	64.50695		0.106851	65.58135	3.58135
19	69	65.92966		0.764782	64.6138	4.386203
20	71	67.98611		1.410616	66.69444	4.30556
21	70	69.57771		1.501107	69.39672	0.603276
22	68	70.15517		1.039285	71.07881	3.078814
23	64	69.03612		-0.03988	71.19446	7.194455
24	72	69.89736		0.410682	68.99624	3.003764
25	80	73.21563		1.864475	70.30805	9.691953
26	85	78.05608		3.352459	75.08011	9.919893
27	84	82.18597		3.741179	81.40853	2.591466
28	86	85.94901		3.752106	85.92715	0.072848
29	89	89.49078		3.646939	89.70111	0.701112
30	95	93.6964		3.926281	93.13772	1.862283
31	105	99.83588		5.032879	97.62268	7.377317
32	108	105.8081		5.502565	104.8688	3.131243
33	98	107.3175		3.505961	111.3107	13.3107
34	110	110.5764		3.382444	110.8234	0.823448
35	115	114.2712		3.538615	113.9589	1.041143
36	118	117.8669		3.567143	117.8098	0.190185

1	121.434	121.434	3.567143	121.434	0
2	125.0012	125.0012	3.567143	125.0012	0
3	128.5683	128.5683	3.567143	128.5683	0
4	132.1354	132.1354	3.567143	132.1354	0
5	135.7026	135.7026	3.567143	135.7026	0
6	139.2697	139.2697	3.567143	139.2697	0
Alpha	0.3				
Beta	0.5				
MAD	4.039935				
MAD%	3.4292				

Figure 9: Sales vs Forecast



Appendix D

Lingo code

sets:

month / 1..6 /: d, I, x, inv, cap ;

! The objects or sets that define the problem can be viewed as months. For each month, objects need to be determined that will aid in the finding the optimal production plan. The demand (d) that has been forecasted, the inventory (i) that is on hand, the number of units (x) to produce, the inventory capacity (inv) per month as well as the production capacity (cap) or each month are the objects. Since the sets have been defined they can be used to build the model;

endsets

data:

d = 121 ,125, 128, 132, 135, 139 ;

inv = 50, 50, 40, 30, 40, 50 ;

cap = 150, 150, 150, 120, 120, 150 ;

! The data sets are the sets that have known values for each month as can be seen. ;

enddata

Max = @SUM (month(t): 160.05 * x(t)- 20439 – 10 * i(t));

! The objective function for Outbac is to maximize profit. The model needs to sum the total sales figures minus the production costs over all month's t. ;

i(1)=0 + x(1) -d(1);

! Is the inventory constraint to define the units of inventory on hand at the end of the first month. It will calculate the inventory on hand the previous month then add the number of sales for the current month minus the demand for the first month. This constraint is in the form of an initializing constraint. ;

@FOR (month(t):

! A FOR loop is used to loop over all the month's t for each specific production constraint. ;

0.13 * x(t) <= 20;

! The amount of raw material A that is used must not exceed 20 Kg per month. Each unit requires 0.13 Kg of A. ;

$$0.02 * x(t) \leq 10;$$

! The amount of raw material B that is used must not exceed 10 Kg per month. Each unit requires 0.02 Kg of B. ;

$$0.08 * x(t) \leq 15;$$

! The amount of raw material C that is used must not exceed 15 Kg per month. Each unit requires 0.08 Kg of C. ;

$$0.08 * x(t) \leq 20;$$

! The amount of Carbon that is used must not exceed 20 Kg per month. Each unit requires 0.08 Kg of Carbon. ;

$$2 * x(t) \leq 500;$$

! The amount of plastic that is used must not exceed 500 units of plastic per month. Each unit requires 2 units of plastic in the form of flanges. ;

$$2 * x(t) \leq 280;$$

! The amount of plastic buckets that can be used must not exceed 280 bucket units per month. Each unit requires 2 plastic buckets. ;

$$x(t) \leq 500;$$

! The amount of plastic taps that can be used must not exceed 500 taps per month. Each unit requires 1 tap. ;

$$x(t) \leq 20000;$$

! The amount of advertising pamphlets that can be used must not exceed 20 000 leaflets per month. Each unit requires 1 leaflet. ;

$$1.5 * x(t) \leq 250);$$

The amount of plastic wrap that can be used must not exceed 250 square meters per month. Each unit requires 1.5 square meters of plastic wrap. ;

@FOR (month(t)lt#GE#2:

! A for loop is once again used for the inventory constraints. The constraint should loop over all months t where the condition, t must be greater or equal to 2, is true. ;

$$i(t) = i(t-1) + x(t) - d(t);$$

! The inventory constraint needed to index the inventory on hand at the end of each month. ;

$$i(t) \leq \text{inv}(t);$$

! The inventory on hand at the end of each month needs to be less than or equal to the inventory storage capacity for that month. ;

$$x(t) \leq \text{cap}(t);$$

! The number of filter units produced per month needs to be less than or equal to the capacity of Outbac for that month. ;

@FOR (month(t):

!A FOR loop is once again introduced to assign the various variables as Integers. ;

@GIN (x(t));

@GIN (i(t));

);

Lingo Solution Report

Global optimal solution found at step: 0

Objective value: 3085.700

Branch count: 0

Variable	Value	Reduced Cost
D(1)	121.0000	0.0000000
D(2)	125.0000	0.0000000
D(3)	128.0000	0.0000000
D(4)	132.0000	0.0000000
D(5)	135.0000	0.0000000
D(6)	139.0000	0.0000000
I(1)	13.00000	0.0000000
I(2)	28.00000	0.0000000
I(3)	40.00000	0.0000000
I(4)	28.00000	0.0000000
I(5)	13.00000	0.0000000
I(6)	14.00000	0.0000000
X(1)	134.0000	-160.0500
X(2)	140.0000	-160.0500
X(3)	140.0000	-160.0500
X(4)	120.0000	-160.0500
X(5)	120.0000	-160.0500
X(6)	140.0000	-160.0500
INV(1)	50.00000	0.0000000
INV(2)	50.00000	0.0000000
INV(3)	40.00000	0.0000000
INV(4)	30.00000	0.0000000
INV(5)	40.00000	0.0000000
INV(6)	50.00000	0.0000000
CAP(1)	150.0000	0.0000000
CAP(2)	150.0000	0.0000000
CAP(3)	150.0000	0.0000000
CAP(4)	120.0000	0.0000000
CAP(5)	120.0000	0.0000000
CAP(6)	150.0000	0.0000000