PLANNING AND MONITORING TOOL TO CONTROL PROFITABILITY IN A MANUFACTURING CONCERN: A CASE STUDY AT C CHEMICALS.

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ABSTRACT

The aim of this paper is to analyse the key profit drivers in a manufacturing concern, and develop a decision tool based on optimisation techniques. The aim is planning and managing these profit drivers so that the target revenue and profit are realised during an operating period. This was done through developing a forecasting tool based on Visual Basic that was used by the organisation to project the future demand of its products. This tool was linked to a database that had details on past product performance. Planning software was developed using linear programming, which identified the optimum product mix and the sales outlets locations to maximise revenue and profit.

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1. INTRODUCTION

The situation in many businesses is that the operations department is burdened as it struggles to find ways to deal with bottlenecks that hinder profitability. In a bid to improve profitability, the theory of constraints was applied. It was realized that there is a need to look at the problem from a strategic view. The paper reviews the theory of constraints at the operational level and then looks at the supply chain from a holistic viewpoint. The case study company is discussed and the challenges faced in planning and monitoring are indicated. A mathematical formulation of the product-mix was developed and results from Microsoft Excel Solver showing the quantities that the company needs to produce to achieve profitability are presented. C Chemical manufactures chemical products classified into nine market segments based on application. The segments are Dairy and Agriculture, Metal Treatment, Boiler and Water Treatment, Mining, Engineering and Heavy Industrial Manufacture, Transport & Haulage, Commercial and Industrial Laundry, Hospitality and Housekeeping, Hospital and Healthcare, Food and Beverage. The problem was how can the operations department plan and control the plant to maximise revenue. The paper set out to demonstrate the benefits achieved through planning for the optimum product mix before dealing with the constraints that hamper company achieving performance goals.

2. LITERATURE REVIEW

The basis of the paper was in the following areas:

2.1 Theory of Constraints (TOC)

Theory of constraints is a management philosophy proposed by Goldratt that deals with managing constraints of bottlenecks that prevents the company from achieving its goal of making profit, [1], [2]. Bottlenecks are the machines or processes which control the throughput of the system, thus managing them effectively and efficiently yields higher system throughput. Many production control systems have been proposed to improve throughput in the past. Among them are the Materials Requirement Planning (MRP), Just-In-Time (JIT), Kanban, Constant Work-in-Process (CONWIP), Drum-Buffer-Rope (DBR) system, [2]. The approach previously has been to deal with the problem within the company. However, there is a need to look at the entire supply chain. Salmi highlighted how supply chain speed and flexibility have become key levers for competitive differentiation and increased profitability, [3]. The faster the supply chain, the better a company can respond to changing market situations and the less it needs inventory thus resulting in higher return on capital employed. Supply Chain flexibility, on the other hand, has become an important factor because customers require increasingly customized products that satisfy their unique needs.

The goal of supply chain management is to replace some of the physical stock with intelligent information and planning, that is, with the ability to analyze what is possible in different parts of the chain and the best global plan. The challenges of supply chain management vary by industry and customer segment. Supply chains fall into three main classes depending on where the major constraints lie: material-intensive, asset-intensive and distribution-intensive industries, [2].

In material-intensive-industries, such as high-tech and machinery manufacturing, the largest costs and constraints are related to the management of procured and manufactured materials. In asset-intensive industries, such as paper and metal, planners need to concentrate on optimizing machine capacity utilization and the product mix. In distribution-intensive industries, such as the consumer packaged goods industry, the major challenge is to manage the distribution network and finished goods inventory from the factory to the end-customer. The goal of supply chain development should not be the blind standardization of processes according to someone else's "best practice templates" but to streamline and integrate the entire supply chain based on the needs of the end-customer. The development team should constantly search for improvements that will increase the customer value of supply chain delivered products and services while maximizing the total margin, [2].

Some companies have used standard tools such as Enterprise Resources Planning (ERP) software to do transactions and control systems. However such tools are limited when it comes to supply chain analysis and profit optimization. According to the Gartner Group, ERP systems accommodate only the simplest supply chain optimization requirements [4]. ERP systems cannot give optimal answers to many central planning questions, such as, what should be produced, when and where, so that the level of customer service and supply chain profitability are as high as possible. Such questions fall in the area of Product Mix decisions. There is need to support the ERP's capabilities with the virtues of an optimization tool to maximize value in the planning and controlling of the supply chain activities.

A number of tools have been used to address supply chain optimization. Mabin and Davies looked at application of theory of constraints to product-mix problem. One way to solve the Product Mix problem is to use Linear Programming, which can handle multiple planning periods and multiple product lines, [5].

2.2 Linear Programming (LP)

LP is a mathematical technique concerned with the optimal allocation of scarce resources, [6]. This is allocation amongst competing activities. It is a procedure to optimize the value of some objective (for example, maximum profit or minimum cost) when factors involved (for example, labour, or machine hours) are subject to some constraints (for example, 1000 labour hours are available in a week). Thus LP can be used to solve problems, which conform to the following:

- The problem must be capable of being stated in numeric terms.
- All factors involved in the problem must have linear relationships, e.g. a doubling of output requires a doubling of labour hours; if one unit provides $10 contribution 10 units will produces $100 and so on.
- The problem must permit a choice between alternative courses of action.
- There must be one or more restrictions on the factors involved. These may be restrictions on resources (labour hours, tons of material, etc.) but they may be on particular characteristics, for example, a fertilizer must contain a minimum of 15% phosphates and 30% nitrogen or a patent fuel must contain no more than 6% ash, 2% phosphorous and 1% sulphur.

In expressing LP Problems there are two major factors to consider:

- Objectives: The first step in LP is to decide what result is required, i.e. the objective. This may be to maximize profit or contribution, minimize cost or time or some other appropriate measure. Having decided upon the objective it is now necessary to state mathematically the elements involved in achieving this.

- Limitations or Constraints: Circumstances always exist which govern the achievement of the objectives. These factors are the limitations or constraints to the LP problem. These, in any given situation must be clearly identified, quantified, and expressed mathematically. They must be linear.

Al-Aomar, [7], highlighted linear programming application to solving Product-Mix problem but still has potential in Southern Africa region.

2.3 Synergy Between Linear Programming and Theory Of Constraints

TOC and LP approaches are complementary to each other. LP offers advantages of flexibility, universality, combined with speedy LP solution, considerable 'what-if?' information and ability to change quickly and easily. LP provides a good starting point for production planning. TOC provides a philosophy within which to use the LP to gain extra advantage; it encourages us to be more innovative in exploring the static LP. Mabin and Gibson, highlighted how TOC encourages rigour in exploiting the constraints fully before subordinating other activities to suit the constraint, and before adding new capacity, [8].

3. CASE STUDY

3.1 Operation Need

C Chemicals is a chemical processing company with nine market segments. The general process is mixing and processing of raw material for different products. Most of the raw materials are imported and products may share common raw materials. The company's top management after having set a business plan document containing both strategy and budgets ready for presentation to the Board of Directors had left a gap on implementation. The Operations Department had to deal with the constraints in the plants to meet company goal of profitability. This led to the department trying out the Theory of Constraints techniques in the plant to satisfy Sales Department demands.

3.2 Complexity of the Current System

These are some realities that constrain business's ability to supply the optimum product mix all the time:

i) Very wide and diverse product portfolio, which makes the planning task complex. The company has about 284 SKUs in total in the nine product families.
ii) The Enterprise Resources Planning (ERP) system (Sage Line 200) being used could only deliver accuracy in carrying out transactions but not recommend when and what to supply optimally. This means it has no capacity to provide advice on what to purchase, manufacture and supply in terms of type of product, its quantities and time, bearing in mind the dynamics of both the internal and external operating environment.
iii) There are many products that share the same scarce resources (raw material, people and plant). This makes planning the allocations very essential but more complex.
iv) Many of the input materials are imported and the dynamics of foreign currency exchange rates have a bearing on what to deal in.

Thus the need to develop a system that manages the product mix to maximise revenue and profitability and to set revenue and profit targets instead of volume targets.

4. MODEL DEVELOPED

The use of optimum product mix problem is enhanced by a simple cyclic flow diagram developed by the authors given in Figure 1. This model deals with product mix decision before looking at how constraints can be changed using theory of constraints.

4.1 Description of the Problem

The problem set is formulated into a simple Linear Programming problem within the following premises:

i) Product sold in all the market segments (categories) company-wide can only be as much as the total product manufactured or purchased by the organisation.
ii) The total profit made is made up of the sum total of all the 'profit per unit' for all the product sold
iii) The product manufactured and/or sold are zero or greater than zero in quantity (non-negative)
iv) The selling price of each product sold is either zero or greater (non-negative)
v) All product sold by the company put together should be at least worth the amount of money the business needs to sustain its operations
vi) The cost of materials and resources used in producing the products should be at most equivalent to the working capital plus other capital that the business has allocated for this activity
vii) The cost of the total human resource used to produce the product the business is selling should be at most equivalent to the money the business has allocated in the budget for that resource
viii) The business operations must be such that the business at least makes enough money to take care of all of it obligations
ix) The business uses full absorption costing and there is an overhead recovery rate applied to each product sold
x) The business has nine market segments and does not want to close or prejudice any of these in any of its operating months
xi) The business has three operating branches and does not want any of these to be closed, deprived or short-supplied with products at any one given time

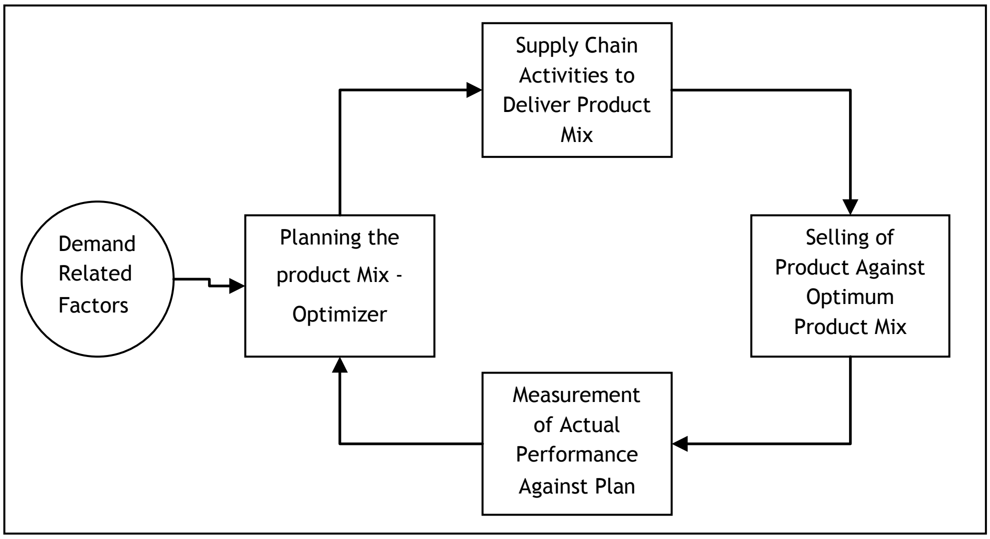

Figure 1: Process Flow for the Supply of the Optimum Product Mix

4.2 Problem Formulation

The following equation summarizes the model for the product mix which is to maximize profit:

$$Z = \sum_{i=1}^{N} (s_i - Cmat_i - Cman_i - Cover_i) * x_i \qquad \text{Equation 4}$$

Subject to:

$$\sum_{i=1}^{N} x_i * Cmat_i \leq B_{mat} \qquad \text{Equation 5}$$

$$\sum_{i=1}^{N} x_i * Cman_i \leq B_{man} \qquad \text{Equation 6}$$

$$\sum_{i=1}^{N} x_i * Cover_i \leq B_{over} \qquad \text{Equation 7}$$

$$\sum_{i=1}^{N} x_i \leq P_{cap} \qquad \text{Equation 8}$$

$$x_i, Cmat, Cman, B_{over}, B_{man}, B_{mat} \geq 0 \qquad \text{Equation 9}$$

Where,

Z	=	objective function, profit to be optimized
s_i	=	selling price per unit of product *i*
C_{mati}	=	cost of material in producing one unit of product *i*
C_{mani}	=	manpower cost in producing product one unit of product *i*
C_{overi}	=	cost of factory overheads in producing one unit of product *i*
x_i	=	quantity of product for i = 1 to $i = N$
B_{mat}	=	budget allocated for all production materials
B_{man}	=	budget allocated for production manpower
B_{over}	=	budget allocated for production overheads
P_{cap}	=	maximum plant capacity

Equation 4: gives the computation of the profit contributions for all products ranging from $i = 1$ to N. The equation means that the sum of revenue from product x_i to product x_N less the manpower, materials and overhead costs incurred in producing these products gives the objective function value, which is the profit target.

This model is constrained by the following factors:

Equation 5: The cost of all the materials used to produce all the x_i products ranging from $i = 1$ to N is less than or equal to the amount of money allocated in the materials budget for the period under review.

Equation 6: The cost of all the direct and indirect manpower attributed to the production of all the x_i products ranging from $i = 1$ to N is less than or equal to the amount of money allocated in the manpower budget for the period under review.

Equation 7: All the costs incurred in manufacturing overheads that are associated with the production of products x_i for $i = 1$ to N are to be less than or equal to the amount of money the business has budgeted for this purpose. Otherwise the production operation has to be within budget.

Equation 8: The total volume of product produced within the time in question is not more than the plant's maximum capacity. The maximum capacity is the sum of all capacities for different product portfolios.

Equation 9: The number of products for *i* = 1 to *N*, the cost of materials, the cost of manpower, the cost of overheads, the budget for materials, the budget for manpower and the budget for overheads are not less than zero. We cannot have negative products, material, manpower and overhead costs and budgets within the planning period. This is the non-zero constraint equation.

4.3 Assumptions in Applying the Model to a Real Life Situation

The following assumptions were considered in applying the model:

i) The supply chain lead times are assumed to be zero or immaterial for the purposes of this research. These are the purchasing lead times; the production and delivery lead times. This assumption implies that the demanded deliverables become available as and when required. These are deliberately handled this way because they are properly and adequately afforded the due attention by the MRP in the ERP application.

ii) The foreign currency is assumed to be available at the time it is required and in the exact amounts needed for the purchase of materials.

iii) The product cost and selling price are assumed to remain constant throughout the material flow, between the solver's recommendation through till the product is sold and the money is realized. This is far from reality, but essentially, the reality in the real world is that some products are purchased on cash-on-delivery (COD) basis; some paid within 15 days while some go for the long 60 to 90 days. This is more biased towards *finance where* the focus is debtor days and cash flow.

iv) Manufacturing is expected to convert the materials into finished products in the timeframe allocated. This assumes no window of product unavailability due to plant downtime. This assumption's validity is based on the huge capacity that the business has. This does not mean that there are no breakdowns but using theory of constraints one can breakdown effects are reduced by buffering.

v) The fundamental premise is that the model's solver is based on the sales performance data of the previous period. The width of the product portfolio/base is such that the seasonality of products is smoothed out, as when one product within one family begins to display slowness in movement owing to a season change, one within the same family would display a rise in demand. Examples are on water treatment chemicals, where in the wet season, the demand for one product goes high and the other product's demand goes very low. Essentially, averaging the demand for such products within their family does not compromise significantly the essence of the solver's recommendation tool.

vi) The sales volume of the three factories' product mix shall be handled from the central office.

5. RESULTS

The Product Mix Finder system was developed using Visual Basic within Microsoft Excel. The access page that gives the user entry into the system is shown in Figure 2. It is from this page that the user can choose to see the table of contents or launch the mixer or close the application.

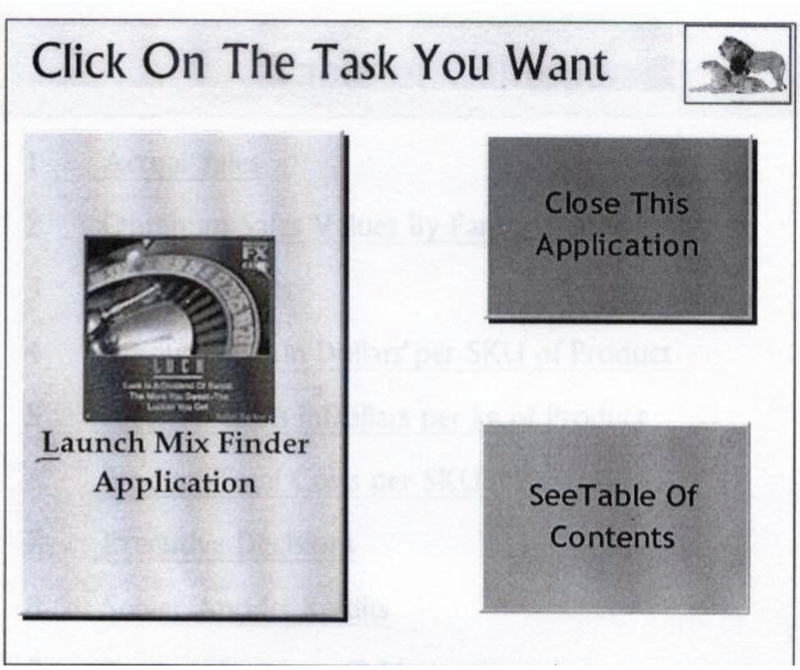

Figure 2: The Access Page to the Mix Finder Application

Figure 3 shows the snippet of the table of contents which gives user access to the different spreadsheets that provide information such as sales forecast, labour cost and material cost. These spreadsheets are used to update information on a daily basis. For the sake of maintaining anonymity of company the spreadsheets were not shown.

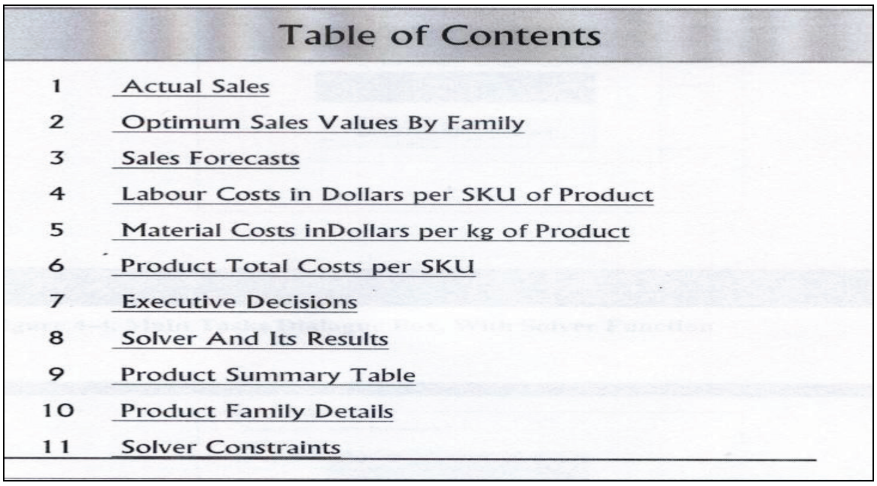

Figure 3: Table of Contents snippet

From access page shown in Figure 2 one can proceed to launching of the application which would lead to Figure 4 shows the solver functions. The User can run the solver, view solver results or exit the program.

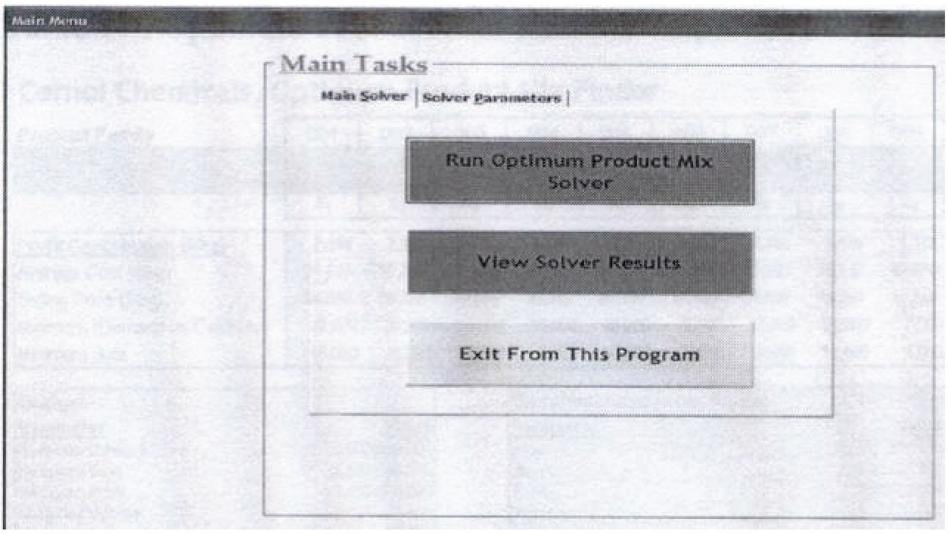

Figure 4: Solver Functions

Figure 5 gives access to data updates such as foreign currency rates, factory capacities, financial and sales detail. These contribute to the calculations of the profit and the constraints used in the solver.

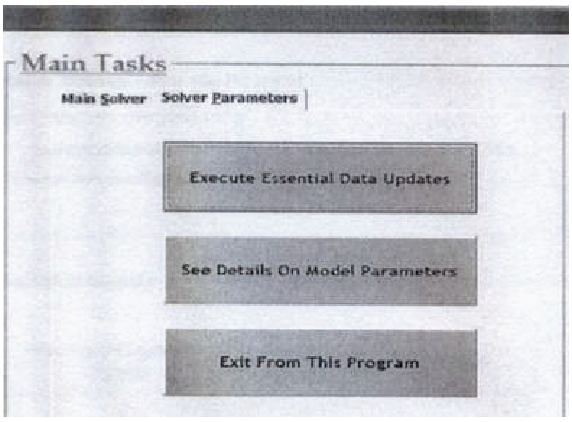

Figure 5: Data Updates or Model updates Dialogue Box

The detail of financial updates and sales updates are shown in Figure 6 and Figure 7 respectively.

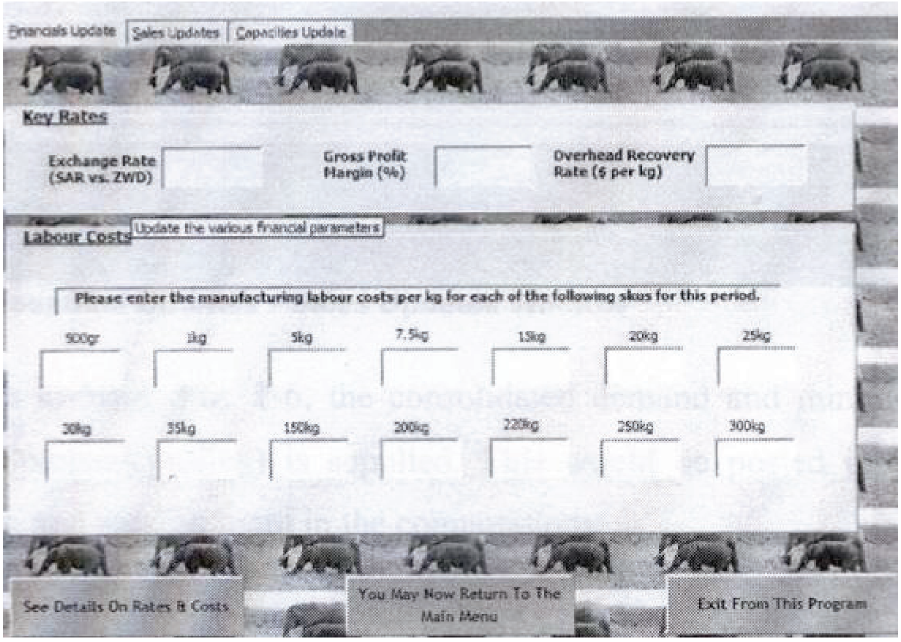

Figure 6: Financial updates

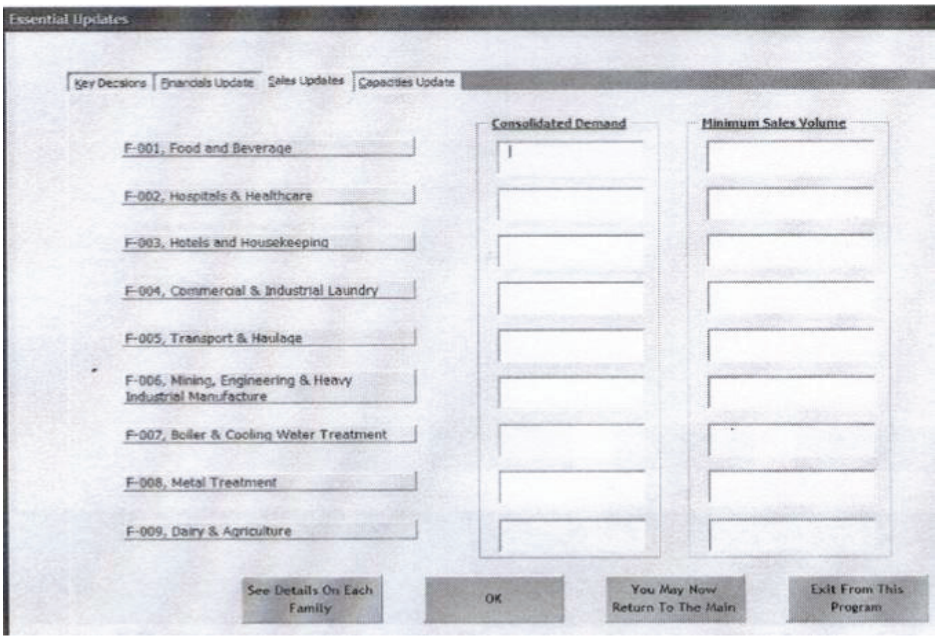

Figure 7: Sales Updates

Since the business serves nine market segments nine product families were used. Figure 8 shows the results after running the Product Mix Solver. The product families are labelled 001 to 009. The parameters input to the solver such as profit contribution, average cost, selling price, capacity of the plants and minimum sales expected are calculated through links of spreadsheet to the raw data. The Product Mix Solver gave output of expected volumes for each product family to maximise profit.

Product Family	001	002	003	004	005	006	007	008	009
Optimum Qty To Be Sold	26000	27000	15000	18000	11000	40000	13000	16000	10000
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
Profit Contribution/kg	11,197	6,598	9,573	13,310	19,588	8,503	10,118	7,194	3,353
Average Cost/kg	16,795	27,526	14,360	19,965	29,382	12,754	15,314	10,791	8,276
Selling Price/kg	27,992	34,123	23,933	33,276	48,970	21,257	25,432	17,985	11,628
Min (Demand vs Capacity)	260,000	30,000	15,000	30,000	200,000	65,000	20,000	15,000	10,000
Min Sale	26,000	22,000	15,000	14,000	8,000	15,000	13,000	8,000	9,000

Budget	
Revenue	7,313,689,000
Cost	3,100,000,000
Profit	4,213,689,000
Minimum Volume	130,000
Maximum Capacity	855,000

Solver's Output	
Volume	176,000
Cost	3,042,489,610
Revenue	4,730,664,402

Figure 8: Results of the model

The results shown in Figure 8 are a profit of Z$4 million from revenue of about Z$7 million. Product Family 005 (Transport and Haulage) contributed the highest profit of Z$19 558/kg while Product Family 001 (Food and Beverage) contributed to the second highest profit of Z$11 197/kg while the optimum quantities were 11 000kg and 26 000kg respectively.

From this result the Operations Department proceeded to analyse the constraints that hindered the Product Family 005 and Product Family 001 from even contributing more to the profitability of the company. Thus the iterative method is maintained which is a better planning and monitoring tool for C Chemicals to concentrate on machines or systems that contribute the most to the survival of the company. This tool helped the company survive in the turbulent environment during the economy melt down in Zimbabwe.

6. CONCLUSION

The paper was aimed at modelling an optimum product mix finder that can be employed in a manufacturing concern to maximise profitability thus assisting management in decision-making. Literature on theory of constraints, linear programming and product mix was reviewed to substantiate the mathematical formulation for the case study company. Microsoft Excel and VBA programming was used. Sample business scenario was simulated and results analysed. The case study company embraced the tool for implementation. The results gives the Operations Department ability to work on the constraints that most affect the profitability of the company. As the constraints used were based on the situation on the ground in formulation of the linear programme model. Dealing with the constraints without knowing their contribution to the profitability of company would lead to waste of effort thus the synergy of Theory of Constraints and Linear Programming which needs to be embraced by Operations Managers within the region to survive global competition.

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