Aggregate Production Planning Framework in a Multi-Product Factory

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Abstract—This study looks at the best model of aggregate planning activity in an industrial entity and uses the trial and error method on spread sheets to solve aggregate production planning problems. Also linear programming model is introduced to optimize the aggregate production planning problem. Application of the models in a furniture production firm is evaluated to demonstrate that practical and beneficial solutions can be obtained from the models. Finally some benchmarking of other furniture manufacturing industries was undertaken to assess relevance and level of use in other furniture firms.

Keywords—aggregate production planning, trial and error, linear programming, furniture industry

I. INTRODUCTION

RAPID changes in global markets and international trade has affected the management of operations in terms of competitive positioning in the marketplace thereby posing significant challenges for organizations. The concept of production management has evolved beyond the scope of a single manufacturing location. Increased competition, coordination and control of production activities of factories spread across regions have become more important than ever [1]. The aggregate plan generally contains targeted sales forecasts, production levels, inventory levels and customer backlogs. Aggregate planning is an attempt to balance capacity and demand in such a way that costs are minimized. Aggregate planning, being medium term in nature aims at bridging the gap between strategic planning and operational planning. Aggregate planning takes about 2 to 18 months [2]. During this period capacity can be managed by adding more machines or workers, increasing working hours, reducing workforce. Other decisions taken include changing the product mix and to some extent the layout. In this way the company is able to adapt to the dynamism of the market [3].

II. JUSTIFICATION

Local furniture industry has been facing challenges such as lack of technology, obsolete equipment, long turnover time and short product lifecycles. A solution approach to aggregate planning problem can be used using optimization tools such as spreadsheets and linear programming to achieve an optimum solution. The furniture industry is a labor intensive industry with seasonal demand in most instances.

The application of aggregate production planning in the country is limited. The complexity of planning models is one reason why firms do not develop advanced production planning models. Most companies perform demand forecast, but due to changing customer patterns, production inefficiencies and nature of products the firms do not develop strategies to meet the changing demands. Ad hoc strategies to manage supply and demand are effected.

Explicit determination of the demand in terms of products in this era is difficult therefore it fails to give the projected load on the production facilities [4]. Aggregate production planning is therefore, an important aspect that determines demand in such a way as to give a clearer picture of the actual production load. To achieve this, the products are classified according to their size and type of operation. In this study several aggregate planning models will be developed to find the minimum cost for allocating the resources [5]. Adjustments are made for monitoring and control of the industrial processes in order to respond to a changing environment to achieve optimum performance.

III. OVERVIEW OF PRODUCTION PLANNING (APP)

Manufacturing planning and control address decisions on the acquisition, utilization and allocation of production resources to satisfy customer requirements in the most efficient and effective way. Typical decisions include workforce level, production lot sizes, assignment of overtime and sequencing of production runs. Optimization models are widely applicable for providing decision support in this context [5]. Management makes decisions in varying timescales and these affect overall company objectives based on the same models.

In a highly competitive and constantly changing market environment, it is even more important to have a high degree of coordination between all the planning activities. It is widely recognised that there is a great deal of potential for reducing costs in many areas if more efficient aggregate planning methods can be found which harmonises the system in its entirety [3]. The planning activity of an organisation is illustrated in Fig 1.
The business plan which is long term in nature yields the
sales, operational and financial plan; these are key components
of a functioning aggregate plan. A business plan elucidates
management commitment and decision in the deployment of a
company’s resources. It sets the tone for a company’s
priorities and means of achieving the same. Essentially it is a
roadmap for business success. It highlights a well thought plan
company needs to take to reach, maintain and grow revenue

Capacity planning is the process of determining the
production capacity needed by a manufacturing to meet
changing demands. Capacity can be defined in two ways:
design capacity and effective capacity. Design capacity is
the capacity of a process or facility as it is calculated to be whilst
effective capacity is the useful capacity of a process after
maintenance, changeover, loading and other stoppages has
been accounted for. The ratio of the actual output from a
process or facility to its design capacity yields the utilisation
of the firm [7].

\[
\text{Utilisation} = \frac{\text{actual output}}{\text{design capacity}} \quad (1)
\]

\[
\text{Efficiency} = \frac{\text{actual output}}{\text{effective capacity}} \quad (2)
\]

The identification of the relevant costs in aggregate
production planning is an important issue. For production
planning, firms typically need to determine the variable
production costs, including setup-related costs, inventory
holding costs, and the relevant resource acquisition costs.
Costs associated with imperfect customer service, such as
when demand is backordered should be catered for.
Planning problem always exists because there are limited
production resources that cannot be stored from period to
period. Choices must be made as to which resources to include
and how to model their capacity and behaviour, and their costs
[5].

There is uncertainty associated with the production
function, which are uncertain yields or lead times. It is
preferable to include the most critical resource in the planning
problem for instance, a bottleneck. Alternatively, when there
is no dominant resource, then it becomes necessary to model
the resources that could limit production.

There are two types of production functions. The first
assumes a linear relationship between the production quantity
and the resource consumption. The second assumes that there
is a required fixed charge or setup to initiate production and
then a linear relationship between the production quantity and
resource usage. Related to these choices is the selection of the
time period and planning horizon. The planning literature
distinguishes between strategic and operational time periods
[8]. For strategic issues, the planner has to worry about how to
schedule or sequence the production runs assigned to any time
period. The choice of planning horizon is dictated by the lead
times to enact production and resource-related decisions, as
well as the quality of knowledge about future demand.

A. Characteristics of aggregate planning [4]

In the broad sense of the definition, the aggregate-planning
problem has the following characteristics:
- A time horizon of about 12 months, with updating of the
  plan on a periodic basis (conceivably monthly)
- An aggregate level of product demand consisting of
  one or a few categories of product – the demand is
  either fluctuating, uncertain, or seasonal
- The possibility of changing both supply and demand
  variables
- A variety of management objectives which might
  include low inventories, good labour relations, low
  costs, flexibility to increase future output levels and
  good customer service
- Facilities are fixed and cannot be expanded

Aggregate planning is used in a manufacturing environment
and determines not only the overall output levels planned but
the corresponding input resources for the related products.
Various alternatives exist for matching demand with capacity.
Options which can be used to increase or decrease capacity to
match current demand include:

**Hiring and laying off workers** - Hiring additional workers as
needed or by laying off workers not currently required.

**Overtime** - This entails asking or requiring workers to work
extra hours a day or an extra day per week, firms can create a
temporary increase in capacity without the added expense of
hiring additional workers.

**Part-time or casual labour** - By utilizing temporary workers
or casual labour (workers who are considered permanent but
only work when needed, on an on/call basis, and typically
without the benefits given to full/time workers) companies
reduce the salary bill significantly.

**Inventory** - Finished/goods inventory can be built up in
periods of slack demand and then used to fill demand during
periods of high demand

**Subcontracting** - Frequently firms choose to allow another
manufacturer or service provider to provide the product or
service to the subcontracting firm’s customers.
Cross-training - Cross-trained employees may be able to perform tasks in several operations, creating some flexibility when scheduling capacity.

Other methods - Among these options are sharing employees with counter/cyclical companies and attempting to find interesting and meaningful projects for employees to do during slack times.

The furniture industry is a labour intensive sector thus the workforce variable in aggregate planning needs to be approached cautiously. Earlier studies suggested that worker transfer between production lines is more beneficial than hiring and firing. Worker flexibility has more impact in aggregate planning as it enhances worker learning and reduces labour attrition due to laying-off. Heterogeneous efficiency of transferred workers reduces costs associated with labour efficiency and throughput losses. Incentives, extend of planning and the manufacturing environment which is characterised by the tooling, work piece material, measurement instruments and part complexity has an effect on worker flexibility.

Demand management tends to make demand smooth and less seasonal therefore it allows planning for constant production throughout the year. The strategy implies that demand be shifted from high or peak seasons to low seasons where most firms are operating below capacity. Aggregate Planning can be used to influence demand as well as supply. Options exist for situations in which demand needs to be increased in order to match capacity (supply) include [10]:

- **Pricing.** Vary prices to increase demand in periods when demand is less than peak.
- **Promotion.** Advertising, direct marketing, and other forms of promotion are used to shift demand.
- **Back ordering.** By postponing delivery on current orders demand is shifted to periods when capacity is not fully utilized.
- **New demand creation.** A new, but complementary demand is created for a product or service.

Also manufacturers and their suppliers and customers can form partnerships in which demand information is shared and orders are placed in a more continuous fashion.

B. Aggregate Planning Strategies

There two pure planning strategies available to the aggregate planner are level strategy and a chase strategy. Firms may choose to utilize one of the pure strategies in isolation, or they may opt for a strategy that combines the two[7].

i. **Level Strategy** - A level strategy seeks to produce an aggregate plan that maintains a steady production rate and steady employment level. As demand increases, the firm is able to continue a steady production rate, while allowing the inventory surplus to absorb the increased demand. A level strategy allows a firm to maintain a constant level of output and still meet demand. This is desirable from an employee relations standpoint.

ii. **Chase Strategy** - A chase strategy implies matching demand and capacity period by period. This could result in a considerable amount of hiring, firing or laying-off of employees, increased inventory carrying costs and erratic utilization of plant and equipment. The major advantage of a chase strategy is that it allows inventory to be held to the lowest level possible, and for some companies this is a considerable savings. Most firms embracing the just in time production concept utilize a chase strategy approach to aggregate planning [8].

iii. **Hybrid strategy** - In some instances a combination strategy can be found to better meet organizational goals and policies and achieve lower costs than either of the pure strategies used independently.

The role of aggregate planning may be described as establishing a regime of production situations that are achievable, controllable and utilizing available capacity. However capacity is more expensive than inventory. It is in capacity management that companies have the largest potential to gain competitive advantage. For this to occur companies need skill based competencies in aggregate production planning system design.

C. Production costs

The objective of the aggregate planning is to minimise the total cost of production within the planning horizon, hence need to investigate which costs affect the total cost of production on aggregate production and employment levels. The following costs are included [7]:

- Raw material cost
- Direct payroll cost
- Overtime cost
- Hiring / Firing cost
- Inventory / shortage cost

Direct payroll costs are calculated by taking the average wage of each worker and multiplying it with the number of workers employed during the period. Salaried staff and management costs are excluded, since they are considered to be relatively fixed during the planning horizon. Overtime costs are calculated by multiplying the total man-months of overtime by the regular pay and the overtime payment factor. Hiring costs include the cost of interview test, medical examination and training. Termination benefits, gratuities, and negative impact on employees’ morale all help determine the firing cost. Inventory costs are the sum of holding or storage cost, interest on tied capital and depreciation. Shortage costs are due to the potential loss of the customers and the negative effect on the reputation of the firm.

The complexity of models coupled with the lack of adequate data makes firms avoids using aggregate production planning (APP) models. Also the use of spread sheet modelling and trial and error approach can create useful but simple solutions to APP models. Studies have suggested using the learning curve effect on the model where the user can find the least cost plan under different learning rates. In this study trial and error methods will be constructed and Lindo software will be used to solve a mixed integer linear programming problem [9].
IV. RESEARCH DESIGN

Aggregate production planning (APP) determines the capacity a company needs to meet its demand over a certain period of time varying from two to eighteen months. During this time frame it is not feasible to increase capacity by building new facilities or purchasing new equipment, however it is feasible to adjust employee level, add extra shifts, outsource, use overtime or change inventory levels.

A. Model development

The basic model to minimize the total cost is developed as shown below.

Minimize:

\[ \text{Total production cost over planning horizon} = \text{Raw Material Cost} + \text{Payroll cost} + \text{Hiring cost} + \text{Firing cost} + \text{Overtime cost} + \text{Inventory cost} + \text{Shortage cost} \]

B. Aggregate planning techniques

The techniques range from simplistic, graphical methods to the highly sophisticated linear decision rule and the parametric production-planning method. The most sophisticated techniques can be considered as optimizing, search, heuristic, and dynamic methods. Within each of these categories are numerous alternative approaches, resulting in an abundance of theoretical solution procedures. Table I gives some of the common techniques used [3].

<table>
<thead>
<tr>
<th>Classification</th>
<th>Type of Method</th>
<th>Type of Cost Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feasible Solution</td>
<td>Barter</td>
<td>General/not explicit</td>
</tr>
<tr>
<td>Methods</td>
<td>Graphic/tabular</td>
<td>Linear/discrete</td>
</tr>
<tr>
<td>Mathematically</td>
<td>Linear programming models</td>
<td>Linear/continuous</td>
</tr>
<tr>
<td>Optimal Methods</td>
<td>Transportation models</td>
<td>Linear/continuous</td>
</tr>
<tr>
<td></td>
<td>Linear decision rules</td>
<td>Linear/quadratic/continuous</td>
</tr>
<tr>
<td>Heuristic decision</td>
<td>Simulation search procedures</td>
<td>General/explicit</td>
</tr>
<tr>
<td>procedures</td>
<td>Management coefficients</td>
<td>Not explicit</td>
</tr>
<tr>
<td></td>
<td>Projected capacity utilisation</td>
<td>Not explicit</td>
</tr>
<tr>
<td></td>
<td>Parametric production planning</td>
<td>Quadratic/not specified</td>
</tr>
</tbody>
</table>

Informal techniques: These approaches consist of developing simple tables or graphs which enable planners to compare projected demand requirements visually with existing capacity, and this provides them with a basis for developing alternative plans for achieving intermediate-range goals.

Trial and error method[1]: It is used to solve aggregate production planning since this method is easy to understand and it is used to convey planning details without getting involved with mathematical detail. It is used to develop manufacturing plans, determine cost and feasibility of each plan and selection of the lowest cost plan among feasible alternatives. Trial and error methods follow the steps below:

- Prepare an initial aggregate plan on the basis of forecasted demand and establish guidelines
- Determine if the plan is within capacity constraints. If not revise until it is.
- Determine the costs of the plan
- Transform the production plan to lower costs.

- Continue the process until a satisfactory plan is developed
- Perform sensitivity analysis to evaluate the effect of changes in such parameters as the carrying cost rate, the costs of hiring and firing and demand
- Track the plan (compare actual results to the planned results)

Two extreme plans i.e. the level production and the chase strategy are developed first. Compromises within these extremes are then developed and evaluated.

Linear programming (LP): It is concerned with maximisation and minimisation of a field of a linear objective function in many variables subject to equality and inequality constraints for instance the function may seek to minimise the cost of hiring/firing workers, holding inventory. The problem consists of selecting the values for several non-negative variables so as to minimize a linear function (the total relevant costs) of these variables subject to several linear constraints on the variables. An important benefit of a linear programming model is the potential use of the dual solution to obtain the implicit costs of constraints such as the maximum allowable inventory level. An algorithm called the simplex method was developed to find an optimal solution to linear programming models [5]. The optimal solution must be a vertex of the feasible region. All that is needed is to find the vertices with the most favourable value of the objective function in order to identify all optimal solutions.

Goal programming [4]: The objective of aggregate production planning is either to maximise profit or minimise cost. In linear programming it is formulated as a single objective. Whereas, in real life there are multiple objectives to a problem. Problems involving multiple objectives can be solved using linear programming where one objective is optimised and the others are considered in the constraints. In goal programming the concept of optimum solution of LP problems is substituted by a satisfactory and non-dominated solution. In pre-emptive goal programming the levels of achievement are provided, priorities to goals are determined. More important goals are optimised before low level goals are considered. Several solutions can be obtained and the best solution will depend on the priority assigned to each goal.

Linear decision rule: When various costs can be approximated by linear and quadratic functions it turns out that the decision rules for setting the workforce sizes and production rates are of simple linear form. The objective of this method is to derive linear equations or decision rules which can be used to specify the optimal production rate and workforce level over some prescribed production planning horizon. The linear decision rule has been shown to lead to costs significantly lower than those encountered under the existing management procedure. There is no easy way of including constraints on the inventory or production levels.

Management coefficients approach: It assumes that managers behave in a rational fashion. Past behaviour of managers is used to estimate the unknown coefficients in plausible decision rules. The strong point of this method is that it has intuitive appeal to management. This makes implementation
considerably easier than in the case of a sophisticated mathematical decision model. The assumption that the past is a good description of the future may prevent the manager from quickly adapting to new conditions in a rapidly changing competitive environment [3].

**Simulation search procedures:** The approach here is that a closed-form mathematical solution cannot be obtained when the model is made truly representative of the prototype situation. Therefore, a mathematical model is developed which represents quite accurately the actual cost functions and constraints. Then, by a trial and error procedure, the variables are varied until there results no further reduction in the total relevant costs. A computer is often used to facilitate this search procedure. These procedures include search decision rule, parametric production planning, and a manual simulation approach.

**Parametric production planning:** This model provides another angle in production planning. Optimization guarantee is relaxed and two rules in terms of four parameters are created. The first rule gives the size of workforce and the second the production quantity. The four parameters take values between 0 and 1 [7]. The combinations are tested and used to establish the total cost.

The selection of aggregate production planning strategy depends on several factors like demand distribution, competitive position of the company, the product cost structure and the product line. In this thesis quantitative techniques will be used to aid the decision making.

**V. FURNITURE COMPANY OVERVIEW**

Spring Master Company is a wood furniture manufacturing company located in Harare with two factories in two different operating sites. The main plant deals with hardwoods like teak, oak and mahogany, while the second plant mainly manufactures pine furniture. The areas of analysis were the production departments/sections namely: the breakdown section, machine shop, sub-assemblies, carving, and upholstery section, assembly section, finishing section, final fitting section and the warehouse. The company manufactures furniture for the office, bedroom, lounge, dining and occasional. The other items include chest of drawers, TV stands, TV cabinets, wine racks, hall tables and mirrors among other things. It supplies the local (93%) and export (7%) markets but the bulk of their products satisfies the local market. The firm supplies individual customers, government departments, retail shops, companies among a host of its clientele base.

**VI. RESEARCH FINDINGS**

The production performance for the plant from January 2006 to December 2011 is given in Fig 2.
Fig 3. Average monthly contributions towards annual production

The monthly share was used to estimate the production for the month. For analysis it was not unusual to note that the January and December had the lowest figures. This can be attributed to the short operating times. It was also seen that April and August had significant drops in production (6.9% and 8.7% respectively). Possible justification for this might include significant holiday breaks and hence a decline in the output. The demand forecast for the months is shown graphically below.

Fig 4. Demand

B. Aggregate production planning model

The model to be developed aims at reducing production costs. It will also analyse chase and level demand strategies. The strategies will be used to come up with a hybrid strategy that reduces the costs even further. The results will be compared against computed results from the linear programming model. The linear programming model will be used to develop a model to enhance the decision making process for management.

Assumptions
- All furniture will be grouped under the five product families office, bedroom, dining, lounge and occasional
- Demand is in USD terms and the company aims at achieving 60m³ of production. 42% being office, 18% dining, 16% occasional, 12% lounge, 12% bedroom. (from past financial records)
- Capacity of the firm is 60m³ per month.
- Beginning inventories are estimated to be are one fourth of the capacities of the firm
- Beginning backorder value is zero
- Inventory level changes at the beginning of every month by the amount that is transferred from the previous month

Data
Demand - The demand for a given month is calculated from the annual target and multiplied by the monthly contribution towards the target based on 5 year analysis.

Working days - Working days per month vary in months with long holidays and breaks (January, April, August and December). On average they are assumed to be 22.

Working hours per day: 9.5

Regular wage: The minimum wage according to the National Employment Council (NEC) ruling in the furniture industry will equal $265.

Overtime limitation: There is a limit of four weekends per employee for overtime which amounts to 8 days per month

Overtime wage: According to the Labor law the wage payable for each hour of overtime paid by increase the amount overtime is paid increasing the amount of normal work wage per hour by fifty percent

Hiring cost: According to the World Bank Reports Doing Business the average hiring cost per worker is equal to 6% the gross salary (nationmasters.com)

Firing cost: According to the same report, the firing cost can be estimated to be 29.3 weeks of wages. However the cost actually depends on the amount of time a worker has been employed. In this study the firing cost will be calculated by multiplying the salary by 7.3.

Maximum Inventory: Maximum allowable inventory 50% of the capacity of the firm

Minimum Inventory: Minimum inventory level One tenth of the capacity of the firm

Inventory Holding Cost: The inventory holding cost is 2% of the market prices of the products per month.

Raw material cost are: 30% of the product cost

Capacity utilization of the Spring Master Company factory is averaging 54% for 2011

Maximum number of workers: Although the workers vary with the chosen strategy but based on the company capacity of 80m³ per month and the capacity of employee to be 0.3m³ per month the number of shop floor workers required is 200. However since the capacity utilization is hovering at 54% the company will need at least 108 workers as the company will not function at full capacity every month.

Backorder cost: This cost arises when the demand cannot be met in the period it is supposed to be. It can be calculated as equal to 0.75 times the product cost.
**Lost sales cost:** Although it is difficult to quantify this cost can be quantified based on assumptions. This cost reflects the losses of sales revenue and goodwill when the producer is not able to fulfill demand and it is given as 1.4 times the product cost.

**Subcontracting cost:** Subcontracting cost should be treated as a necessity applied despite its unfavorable costs otherwise all companies would opt to subcontract instead of producing themselves. For this reason subcontracting cost will be higher than the total cost/unit but will be lower than the lost sales. Subcontracting cost is assumed to be cost 1.2 times the product cost.

**B. Linear programming model**

The following model is based on the Lindo Systems optimisation. Many LP models contain hundreds of constraints and decision variables. The objective of the model is to minimise all related costs in the setting up of an aggregate plan. Such costs include raw material cost, labour costs i.e. regular, overtime, hiring and firing costs, inventory costs, backorder, subcontracting and lost sales cost.

**Model parameters**

Products j: 1…N  \( N = 5 \)

Periods t: 1…T  \( T = 12 \)

\( N = 1 \) -- dining furniture

\( 2 \) -- lounge

\( 3 \) -- bedroom furniture

\( 4 \) -- occasional

\( 5 \) -- office furniture

\( T = 1 \) -- January…………..T = 12 for December

**Parameters**

\( D_{tj} \) -- demand forecasted for product j in period t

\( m_{tj} \) -- hours required to produce 1m3 of product j in period t

\( OTCAP_{tj} \) -- overtime production hours for product j in period t

\( WRCAPMAX_{tj} \) -- maximum number of workers for product j in period t

\( WRCAPMIN_{tj} \) -- minimum number of workers for product j in period t

\( w_{tj} \) -- raw material cost per unit of product j

\( i_{tj} \) -- inventory carrying cost per unit of product j

\( b_{tj} \) -- backorder cost per unit of product j

\( l_{tj} \) -- lost sales cost per unit of product j

\( MINI_{tj} \) -- minimum quantity of inventory per product j

\( MAXI_{tj} \) -- maximum quantity of inventory per product j

\( MAXBO_{tj} \) -- upper limit for the amount of product j that can be backordered

\( IB_{tj} \) -- initial value of inventory

\( BB_{tj} \) -- initial value of backorder

\( WH \) -- number of regular per worker in period t

\( r \) - cost of man hour regular time

\( o \) - overtime cost per man hour

\( h \) - cost of hiring a worker

\( f \) - cost of firing a worker

**Decision variables**

\( X_{tj} \) – units of product j to be produced in period t

\( IN_{tj} \) – quantity of product j to be kept in inventory in period t

\( BO_{tj} \) – quantity of product j to be backordered in period t

\( LS_{tj} \) – quantity of product j which the firm loses in in sales in period t

\( OT_{tj} \) – man hours of overtime labour used in period t for product j

\( WR_{tj} \) – number of workers for product j in period t

\( RH_{t} \) -- regular man hours of product j in period t

\( HR_{t} \) -- number of workers hired in period t

\( FR_{t} \) -- number of workers fired in period t

**Model**

The objective of the company is to minimise total costs and the model can be constructed as follows

\[
\min TC = \sum_{t=1}^{T} \sum_{j=1}^{N} \left[ (w_{tj} X_{tj} + l_{tj} LS_{tj} + b_{tj} BO_{tj} + i_{tj} IN_{tj} + r RH_{t} + o OT_{tj}) + \sum_{t=1}^{T} (w_{tj} + f FR_{t}) \right]
\]

**Constraints**

\[
X_{tj} + IN_{tj} - LS_{tj} + BO_{tj} - BO_{tj+1} - D_{tj} \leq 0 \quad \forall (t,j)
\]

\[
\sum_{t=1}^{T} W_{tj} R_{tj} - \sum_{t=1}^{T} W_{tj} R_{tj+1} - HR_{t} + FR_{t} = 0 \quad \forall (t,j)
\]

\[
m_{tj} X_{tj} - OT_{tj} - RH_{t} \leq 0 \quad \forall (t,j)
\]

\[
W_{tj} \leq WRCAPMIN_{tj} \quad \forall (t,j)
\]

\[
WR_{tj} \geq WRCAPMAX_{tj} \quad \forall (t,j)
\]

\[
RH_{tj} \leq WH \times WR_{tj} \quad \forall (t,j)
\]

\[
OT_{tj} \leq OTCAP_{tj} \times WR_{tj} \quad \forall (t,j)
\]

\[
IN_{tj} \geq MINI_{tj} \quad \forall (t,j)
\]

\[
IN_{tj} \leq MAXI_{tj} \quad \forall (t,j)
\]

\[
X_{tj} \leq RH_{tj} \times OT_{tj} \times HR_{tj} \times FR_{tj} \times WR_{tj} \quad \forall (t,j)
\]

\[
X_{tj} + BO_{tj} + LS_{tj} + HR_{tj} + FR_{tj} + WR_{tj} \quad \forall (t,j)
\]

The LINGO 13.0 model was constructed and the results are given. Equation 2 is a constraint that ensures that the production quantities, backordered quantities and lost sales do not exceed the total demand quantity. Equation 3, 4 and 6 are constraints about the number of workers. Equation 4, 7 and 8 are constraints about regular and overtime working hours. Equation 9 and 10 are inventory limiting models.

**C. Application of trial and error methods**

Application for different strategies will be done with a view of comparing results. This was covered in conjunction with other evaluation methods.

**D. Chase strategy**
Chase strategies entail production at a rate in unison with demand. The strategies available include changing the workforce level. The strategy keeps the maximum workforce at 200 which is enough to meet maximum demand at the current production levels. The minimum required level of workforce is 93. The extra manpower is hired and laid off as and when necessary.

In this strategy a workforce size of 108 is needed at the current utilisation levels of around 54%. The minimum number of workers required is 93 and the cost of this strategy amounts to $3,439,798. This can be attributed to the failure of this strategy to fully meet demand as can be seen by lost sales in all the months of year except January and December. There is a limit on the amount of production achieved by overtime as this equates to 8 days per month and in most cases these are of less working time than regular days. In the analysis 8 working hours were assumed.

Subcontracting is used where the companies resources cannot meet the expected demand and in this case in the months of February up to December. Subcontracting has the benefits that the company is able to let another company produce at a price lower at or at par with the company prices and there are significant benefits that may accrue like labour savings and storage of inventory. The costs of the different strategies are shown in the Table 2.

**E. Level**

The level strategy employed 200 workers producing 60m³ of products per month. The advantage of using this strategy for Furniture Company is that the first and last months of the year can be used to build stocks that might be used during periods of peak demand. The total cost for this strategy is $2,095,254. Labour cost and inventory holding cost for this strategy are significant factors that contribute to the total product cost.

**F. Mixed**

Analysis of all strategies shows that the level strategy can be used to reduce costs even further by utilising the backordering process where delivery to customers is postponed until production can match demand yields reduced cost. The total cost for this strategy amounts to $2,049,681. There is a significant backordering cost associated with this strategy in comparison with the level strategy.

**G. Lingo solution**

The total cost computed by the LINGO 13.0 model is $1,878,384 which is a slightly better solution as compared to the trial and error methods. LP models can be practical and beneficial once models have been constructed. Constraints are easily applied to the formulated model.

According to the generated solution of the linear production model a workforce of 108 people is enough to cater for the whole year with variation in demand being met using inventory and over time. Most of the demand is met within the year so there is backordering and lost sales cost. Trial and error methods also give a good approximation of the production costs and cannot be totally ignored. However in real life situation many objectives have to be settled at once not just the cost aspect to it. For instance it might be necessary to reduce cost, reduce the hiring and firing rates and the cost limits. Linear programming can be modelled to cater for the underachievement or overachievement of certain goals like inventory levels, firing and hiring thresholds and the ceiling production cost targeted.

**VII. Data Analysis**

**A. Comparison of strategies**

**Table II**

<table>
<thead>
<tr>
<th>Cost</th>
<th>Hire/Fire ($)</th>
<th>Overtime ($)</th>
<th>Subcontract ($)</th>
<th>Level ($)</th>
<th>Mixed ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material</td>
<td>1,252,090</td>
<td>1,497,078</td>
<td>1252,090</td>
<td>1,04,000</td>
<td>1,252,090</td>
</tr>
<tr>
<td>Labour</td>
<td>1,038,633</td>
<td>680,000</td>
<td>509,944</td>
<td>0.06,000</td>
<td>0.06,000</td>
</tr>
<tr>
<td>Backordering</td>
<td>0</td>
<td>0</td>
<td>4014</td>
<td>0</td>
<td>139,462</td>
</tr>
<tr>
<td>Lost sales</td>
<td>0</td>
<td>1,248,053</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Inventory holding</td>
<td>10,087</td>
<td>10,087</td>
<td>10,087</td>
<td>65,142</td>
<td>21,66</td>
</tr>
<tr>
<td>Subcontracting</td>
<td>0</td>
<td>0</td>
<td>593,433</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total cost ($)</td>
<td>2,301,630</td>
<td>3,439,798</td>
<td>1,370,021</td>
<td>2,095,254</td>
<td>2,049,681</td>
</tr>
</tbody>
</table>

**B. Cost analysis**

The current cost analysis at Spring Master Company shows that the cost of sales for the 2011 trading year was $1,965,456 against a figure of $1,410,814 for 2010. However the total annual production for 2011 was 446 m³ against a figure of 464 m³ for 2010. The cost of sales can be broken down into the following categories as depicted in the Table III.

**Table III**

<table>
<thead>
<tr>
<th>Cost of sales analysis</th>
<th>Average Percentage Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>2010</td>
</tr>
<tr>
<td>Direct material cost</td>
<td>49.8%</td>
</tr>
<tr>
<td>Direct staff costs</td>
<td>40.4%</td>
</tr>
<tr>
<td>Maintenance costs</td>
<td>6.8%</td>
</tr>
<tr>
<td>Direct Operating Expenses</td>
<td>7.3%</td>
</tr>
<tr>
<td>ISO and Quality Costs</td>
<td>0.3%</td>
</tr>
<tr>
<td>Direct overheads costs</td>
<td>-9.7%</td>
</tr>
</tbody>
</table>

From the above analysis and the fact that the computed results from the trial and error methods and the linear programming model exclude maintenance, quality and direct operating expenses. The cost of sales in the table can then be adjusted to exclude these costs to enable a fair comparison.
the parameter presented in Table V below.

<table>
<thead>
<tr>
<th></th>
<th>Cost ($)</th>
<th>Quantity produced (m$^3$)</th>
<th>Number of employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>1,786,389</td>
<td>446</td>
<td>194</td>
</tr>
<tr>
<td>Previous year (2010)</td>
<td>1,282,279</td>
<td>464</td>
<td>179</td>
</tr>
<tr>
<td>Trial and error</td>
<td>2,049,681</td>
<td>720</td>
<td>200</td>
</tr>
<tr>
<td>Linear programming</td>
<td>1,878,384</td>
<td>720</td>
<td>108</td>
</tr>
</tbody>
</table>

From Table 4 it can be appreciated that the cost of sales has gone up since the previous year i.e. 2010 this can be attributed to the increase in cost of raw materials, overheads and direct labour costs. An accurate assessment of the cost can be based on the parameter presented in Table V below.

<table>
<thead>
<tr>
<th></th>
<th>Cost per m$^3$ ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>4.005,35</td>
</tr>
<tr>
<td>Previous year (2010)</td>
<td>2.763,53</td>
</tr>
<tr>
<td>Trial and error</td>
<td>2.845,78</td>
</tr>
<tr>
<td>Linear programming</td>
<td>2.608,87</td>
</tr>
</tbody>
</table>

C. Throughput
The plant currently process 1.76 cubic metres of timber product into the warehouse every day. However with each man capable of 0.3m$^3$ per month this falls short of expectations. This will ultimately yield much lower production as reduced speeds; minor stoppages and plant unavailability weigh in. A target of 60m$^3$ per month which the proposed model assumes is realistic and achievable judging from past targets and production figures. The aggregate production planning strategies proffered are in agreement with this production target. The daily target becomes 2.73m$^3$ of timber/furniture into warehouse. This makes an increase of 0.97m$^3$. In the event of failure by employees to meet the daily demand it can be augmented by overtime after normal hours or during weekends.

D. Benchmarking
It was observed that most furniture industries are family owned businesses where decisions are centrally made. The type of management does not allow essential components of aggregate planning like demand forecast and re-planning to be carried out effectively. Ad hoc strategies by default tend to be used in meeting demand. From interviews it was highlighted that there is an insatiable demand for furniture products such that there little use of aggregate production strategies. It was also pointed out that raw material especially timber is being sourced from non-sustainable local sources such that in the long run alternative sources of timber have to be explored. This will have adverse effects on the production cost and judging from the influx of cheap foreign furniture products mainly from Asia, it becomes imperative companies minimize costs. It was also evident that the companies specialize in either hardwood or softwood products. Each company has a niche market that it capitalizes on to improve revenue.

The study revealed that no furniture company utilizes aggregate production planning philosophy in its entirety. Market analysis is done either to position the company with competitors or exploit changing customer tastes. It was also seen that workers in most factories all factories were above 130. Obsolete infrastructure does not impede furniture manufacturing but it tends to shift production from being semi-automatic to completely manual which ultimately results in many manual activities.

Demand for furniture was viewed as fluctuating and all companies assessed produce to match demand. The companies utilize overtime, casual labor and cross training or multi skilling among the preferred options to meet demand. It was also evident that some companies use advertising mainly as a brand awareness campaign to improve revenue. Changing prices proved popular in the strategies used to match production capacity to demand. Lead times of four weeks on average was utilized by most companies.

VIII. RECOMMENDATIONS
Mathematical techniques will likely have to be balanced with managerial judgment and experience. Whilst it might prove attractive mathematically for example in cases where firing employees makes sense, managerial experience might show decreasing productivity and worker attrition which models might fail to expose in each planning horizon. Managers act in a rational manner and will tend to make decisions that reduce exposure to risk; this makes strategies like hiring and firing or subcontracting difficult to effect even though theoretically they make business sense.

There is a tendency to blur the distinction between production planning and production scheduling. Planning precedes scheduling. Aggregate planning in particular is applied to a group of products and therefore does not yield detailed planning and scheduling information. It helps bridge the gap between strategic and operational planning.

The case study company, from analysis can taper into this strategy to realize full benefits that accrue if a systematic aggregate production planning model is utilized. From the models derived the following recommendations are suggested. Spring Master Company should adopt a hybrid system preferably that harness the benefits of level and chase demand strategies. The use of a steady workforce level that keeps production at a consistent rate should yield tangible benefits to the company. The trial and error method suggested offers a cost reduction of 16% per cubic metre and the linear programming model pushes it further to 22%. In periods of slack demand or reduced production e.g. in January, April and December the company can systematically utilise these months to send employees on vacation. A system of
annualised working hours is also an attractive proposition as not all workers are needed in the first and last months of the year. Workers can also be reduced for months like April and August. In this regard workers who had worked overtime in periods of peak demand can be asked or required to work less during this period. The workers should not include skilled labour as this creates dissension and aid high employee turnover. Skilled workers tend to engage themselves in gainful activities outside the working environment; giving them periods of extended breaks might prove counterproductive. The organization should cross train its employees to handle a variety of orders and engage in more frequent re-planning during the year. In addition management should carefully analyse their decision rules for aggregate planning before the implementation.

It should also revise its corporate strategy to incorporate a manufacturing unit strategy that outlines the company’s preferred order winning criteria. The order winning criteria is based on the need for companies to turn orders into tangible business. It premises on the need to use time, cost and quality aspects to a company’s advantage. Quality has always been a mainstay of Spring Master operations but if the cost and delivery speed angle is fully utilised, the company can reap outstanding rewards. Furniture industries tend to be more specialised and orders tend to be more unique and customer specific. In every furniture firm they are products that are well known and are considered a flagship of the organisation. Spring Master office furniture is well known and preferred locally. Spring Master can shift from a make to order philosophy to a make to stock and harness the benefits that accrue due exploitation of delivery speed. This philosophy can be coupled with pro-activeness in managing the supply chain. Managing demand through promotions and advertising will ease production loading and smooth demand.

IX. Conclusion

Furniture industry is an industry where manufacturing companies do not prefer to use aggregate production planning techniques. The reasons for their poor usage in this particular sector include their complexity and time needed to develop and refine models. The use of models in some instances is synonymous with qualified engineers as it needs an extensive mathematical background. The Zimbabwean furniture industry is dominated by family owned businesses where decision making is highly centralised. The decisions from sales, production and accounting are mainly done by a few dominant figures with the rest assuming supervisory and policing roles.

In this work it was shown that trial and error methods provide a good approximate on its use and application in an industrial set-up. Cost savings of at least 16% per cubic metre were observed and throughput of $2.27 \text{m}^3$ per day was proffered as attainable. The Zimbabwean furniture industry lacks latest technology and these methods provide helpful production plans. Most developed software on the other hand provide easy to use solutions which can be more exact and accurate than trial and error methods proposed (cost savings of 22% were realised using the linear programming model). Furniture industry is a labour intensive sector, therefore not all proposed theoretical solutions such as hiring and firing and subcontracting are beneficial to the sector.

X. Further Research

The emergence of improved hierarchical production planning has proved to be popular in the field of aggregate planning. This phenomenon is providing useful insights in the production planning process. Aggregate production planning models are formulated analytically and this often results in large mathematical programming models. As computational models become excessive and large, it is impossible to develop optimal solutions. Decomposition techniques are one way of solving large scale models.

REFERENCES


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