

A Decision Framework based on Aggregate Production Planning Strategies in a Multi Product Factory: A Furniture Industry Case Study

Simon Chinguwa¹, Ignatio Madanhire², Trust Musoma³

¹University of Zimbabwe, Department of Mechanical Engineering
P O Box MP169, Mount Pleasant, Harare, Zimbabwe
chinguwa@gmail.com

²University of Zimbabwe, Department of Mechanical Engineering
P O Box MP169, Mount Pleasant, Harare, Zimbabwe
imadhanire@eng.uz.ac.zw

³University of Zimbabwe, Department of Mechanical Engineering
P O Box MP169, Mount Pleasant, Harare, Zimbabwe
tmusoma@gmail.com

Abstract: *This research study investigates the best model of aggregate planning activity in an industrial firm and uses the trial and error method on spreadsheets 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 company 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, optimize

1. Introduction

Rapid development in the globalization of markets and international trade has affected the management of operations in today's competitive marketplace thereby posing significant challenges for companies. 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. Companies are increasingly devoting themselves to international expansion and the integration of functions such as production, marketing and research and development, as well as international collaboration and networking with other firms and institutions in order to gain competitive advantages.

Aggregate planning is the process of developing, analysing, and maintaining a preliminary, approximate schedule of the overall operations of an organization. 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. Companies make decisions in various time horizons. They are classified as long term, medium term and short term decisions. The long term planning decisions affect the strategic planning while medium term affect tactical planning and short term decisions impact on the operational planning strategies. 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. 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.

2. Justification

Zimbabwean 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 optimisation tools such as spreadsheets and linear programming to achieve an optimum solution. The furniture industry is a labour intensive industry with seasonal demand in most instances.

In the local industry aggregate production planning applications are rare. The complexity of planning models is one reason why firms do not develop advanced production planning models. Zimbabwean companies generally 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 affected. Furniture manufacturing is characterized by:

1. Long production cycles;
2. Uniqueness of the products in design;
3. Products designed according to the individual requirements of the customer;
4. Complexity of the products, each comprising a large number of parts;
5. Different production operations for each product.

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. 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. Adjustments are made for monitoring and control of the industrial processes in order to respond to a changing environment to achieve optimum performance.

3. Overview of production planning

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 work force level, production lot sizes, assignment of overtime and sequencing of production runs. Optimization models are widely applicable for providing decision support in this context. Management makes decisions in varying timescales and these affect overall company objectives. There is strategic, tactical and operational planning level where at a strategic level, management deals with long term decisions such as expanding product lines and production facilities. Operational planning deals with daily allocation of resources whereas tactical planning bridges the two through planning for changes in product mix, capital assets and logistical issues such as transportation and marketing. 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.

The planning activity of an organisation is illustrated in Figure 1 below. 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.

A master production schedule is a plan for individual products to manufacture in a given time period. This plan quantifies parts, processes and other resources required in order to anticipate and eliminate bottlenecks ultimately optimising production. The accuracy of a master production schedule affects the viability and profitability of an organisation.

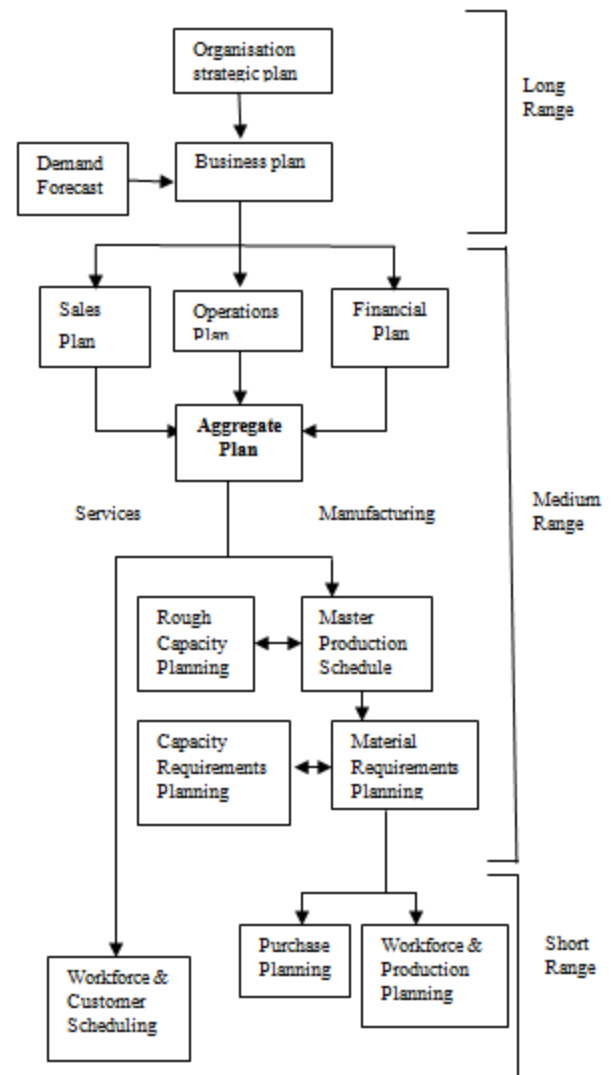


Figure 1: Operations planning hierarchy

Material requirements planning (MRP) is a derivative of master production schedule. MRP is a production planning and inventory control system used to manage manufacturing processes. Its objective is to ensure that materials are available for production and products are available for delivery to the customer. MRP achieves the lowest possible material and product in store and it plans manufacturing activities, delivery schedules and purchasing activities.

Capacity planning has always been an important issue in many industries. 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.

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

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

In many planning contexts, an important step is to construct a planning hierarchy. Namely, one structures the planning process in a hierarchical way by ordering the decisions according to their relative importance. The notion of hierarchical production planning was introduced to provide a specific framework for this, whereby there is an optimization model with each level of the hierarchy. Each optimization model imposes a constraint on the model at the next level of the hierarchy.

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. Also, there is uncertainty associated with the production function, such as uncertain yields or lead times. It is preferable to include the most critical or limiting 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. 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.

3.1 Characteristics of aggregate planning

In the broad sense of the definition, the aggregate-planning problem has the following characteristics:

1. A time horizon of about 12 months, with updating of the plan on a periodic basis (conceivably monthly);
2. An aggregate level of product demand consisting of one or a few categories of product – the demand is either fluctuating, uncertain, or seasonal;
3. The possibility of changing both supply and demand variables;

4. 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;
5. Facilities are fixed and cannot be expanded.

Aggregate planning forms an important link between facilities planning and scheduling. Facilities planning determine the physical capacity which cannot be exceeded by aggregate planning. Thus facilities' planning extends further into the future than aggregate planning and constrains the aggregate-planning decisions. Scheduling, on the other hand, refers to the short range (typically a month or less) and is constrained by aggregate-planning decisions. While aggregate planning deals with the acquisition of resources, scheduling is concerned with allocating available resources to specific jobs and orders. Thus, a marked distinction should be made between the two.

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:

1. *Hiring and laying off workers*

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

2. *Overtime.*

This involves 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.

3. *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.

4. *Inventory.*

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

5. *Subcontracting.*

Frequently firms choose to allow another manufacturer or service provider to provide the product or service to the subcontracting firm's customers.

6. *Cross-training.*

Cross/trained employees may be able to perform tasks in several operations, creating some flexibility when scheduling capacity.

7. *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. Legislation exists in many countries that have considerable restrictions on the hiring and firing of workers. In most instances companies pay generous compensations for unfair labour practice. 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.

The negative impact of hiring and firing needs to be integrated into the aggregate planning problem. The hiring process causes productive losses as new workers participate in non-productive activities such as induction training and medical checkups. The laying off process affects worker morale causing instability and confusion in their minds. This reduces employee commitment and efforts toward self improvement. The termination also results in loss of valued customers. There are high chances that the employee might not be replaced or his functions are not readily available. The greatest risk employers' face is the risk of lawsuits. The greater the difficulty in finding new employment the greater is the risks of being sued. Overtime is a source of productivity losses as it causes reduced production rates and increases the amount of defects and rework. Overtime results in fatigue, loss of sleep, inattention due to off the job concerns, increase in rework, scraps and injuries.

In periods of low demand under time can be used as a means of controlling demand. Employees that had worked overtime in periods of peak demand may be asked to work under time. This may be in the form of shorter working week or forced unpaid vacations. However this may be contentious as few workers prefer working less or receiving less pay for their effort. Part time workers are less costly than full time workers and they are more flexible but companies are likely to face scheduling challenges as the employees do not have an area of speciality. It is possible that valued employees and well qualified candidates for employment may be available on a part time basis. It is beneficial if workers who do not want to be tied to long working hours for long periods are available. A variation of part time employment is job sharing where employees share the same job either long term or temporarily. From the companies perspective the job is considered a single position. In this scenario if neither employee work for more than the recommended weekly hours then no overtime is due therefore it can be considered a way of reducing overtime obligations.

Companies can increase their effective capacity without investing in additional facilities, machines and manpower through outsourcing. Outsourcing increases a firm's competitive advantage in the areas of cost, time, quality and flexibility by selecting best sources and developing long lasting relationships with suppliers. Outsourcing is

dynamic in nature. In some instances it is necessary if the company does not possess the technological knowhow and a substantial investment is required to develop this knowledge. It also advantageous if the costs of manufacturing in-house are too high or demand for the required item is low. Break even analysis is used to justify make or buy decisions. In most instances outsourcing is preferred if the lead time of buying is substantially lower than the lead time of manufacturing.

Demand management is a tool that is used to eliminate planning problems. It 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 supply.

Options exist for situations in which demand needs to be increased in order to match capacity include:

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

Another approach for managing demand includes reducing information distortion in the supply chain. Manufacturers and their suppliers and customers form partnerships in which demand information is shared and orders are placed in a more continuous fashion. Distortion usually arises when ordering goods in batches along a supply chain. Automotive industries uses supply chain integration very effectively.

3.2 Aggregate Planning Strategies

There are two pure planning strategies available to the aggregate planner i.e. 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.

3.2.1 Level Strategy

A level strategy seeks to produce an aggregate plan that maintains a steady production rate and/or a steady employment level. In order to satisfy changes in customer demand, the company must raise or lower inventory levels in anticipation of increased or decreased levels of forecast demand. The company maintains a level workforce and a steady rate of output when demand is low. This allows the firm to establish higher inventory levels than are currently needed. As demand increases, the firm is able to continue a steady production rate/steady employment level, while allowing the inventory surplus to absorb the increased

demand. A second alternative would be to use a backlog or backorder. A backorder is a promise to deliver the product at a later date when it is more readily available, usually when capacity begins to catch up with diminishing 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. Negative results of the level strategy include the cost of excess inventory, subcontracting or overtime costs, and backorder costs, which typically are the cost of expediting orders and the loss of customer goodwill.

3.2.2 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; insecure and unhappy employees; problems with trade unions; increased inventory carrying costs and erratic utilisation of plant and equipment. It also implies a great deal of flexibility on the company's part. 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 utilise a chase strategy approach to aggregate planning.

3.2.3 Hybrid strategy

Most firms find it advantageous to utilise a combination of the level and chase strategy. A combination strategy (called a hybrid or mixed strategy) can be found to better meet organisational 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 utilising available capacity. It has been known for many years that marketing provides competitive advantage. With the advent of Information technology, major cost and efficiency gains have been made in the operations areas through inventory and production management philosophies such as Just in Time (JIT). 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.

Aggregate planning can be approached from two perspectives as it may be considered a tool to establish a plan for resource allocation or it may develop an economic strategy to meet a given demand. The first perspective aims at improving the link between production and marketing. Harmony between these departments can be improved as demand and production capacity is integrated eliminating the marketing pressure exerted on production to meet sales commitments. In addition, aggregate planning should reflect company policy such as maintaining a set customer service level and meeting strategic targets such as increasing market share as outlined in the strategic plan.

3.3 Production costs

The objective of the aggregate planning problem is to minimise the total cost of production within the planning horizon, it is imperative to investigate as to which costs effect the total cost of production. Fixed production costs

are not relevant since they cannot be changed in the planning horizon. The planning problem is designed to make decisions on aggregate production and employment levels. Therefore only those costs are relevant to the models which are associated with changing production and employment levels. Cost of raw materials, change during the planning horizon, depending on the aggregate production planning strategy chosen. The following costs are included:

1. Raw material cost
2. Direct payroll cost
This depends on the total number of workers employed during each planning period.
3. Overtime cost
4. Hiring cost, (cost of hiring new workers)
5. Firing cost,
6. Inventory cost; (cost of keeping an item in inventory, depending upon its price)
7. Shortage cost; (cost of failing to produce an item according to demand schedule)

Direct payroll costs are calculated by taking the average wage of a 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 (establishment, buildings etc.), 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.

As mentioned in previous sections, furniture industry is an industry where aggregate production planning is infrequent. The complexity of models coupled with the lack of adequate data makes firms avoids using aggregate planning models. Other studies pointed out that the use of spread-sheet modelling and trial and error approach can create useful but simple solutions to APP models. Of concern in this study is whether managers produce cost effective plans using spread-sheets as primary decision aids and the degree of variance and how managerial attributes affect decision quality. Mathematically optimal solutions are not superior to the solutions obtained by trial and error solved within spreadsheets because the cost of developing and implementing them would exceed the benefit anyway. The study suggested using the learning curve effect on the model where the user can find the least cost plan under different learning rates. In this thesis trial and error methods will be constructed and Lindo software will be used to solve a mixed integer linear programming problem.

5. Research design

Aggregate planning determines the capacity a company will need to meet its demand over a certain period of time which generally varies between two to eighteen months.

Within this time frame it is not feasible to increase capacity by building new facilities or purchasing new equipment, however it is feasible to fire and hire employees, add extra shifts, outsource, use overtime or change inventory levels. Aggregate production planning problems differ, company conditions vary a single quantitative model might not be always applicable. When all costs can be represented as linear functions then linear programming is used to determine an optimal solution. Specialised mathematical model also work well under certain conditions.

Model development

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

Minimize: Total production cost over planning horizon
 = Raw Material Cost + Payroll cost + Hiring cost + Firing cost + Overtime cost + Inventory cost + Shortage cost.

5.1 Aggregate planning techniques

There are numerous techniques which can be used to help decision makers with the task of aggregate planning. Approaches vary from simplistic, graphical methods to the highly sophisticated linear decision rule and the parametric production-planning method. The most sophisticated techniques can be classified as optimizing, search, heuristic, and dynamic methods. Within each of these categories are numerous alternative approaches, resulting in an abundance of theoretical solution procedures. The following are some of the common techniques used.

Table 1: Aggregate production models

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

5.1.1 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. Alternatives

are usually evaluated in terms of their overall costs. The chief disadvantage of such techniques is that they do not necessarily result in an optimum aggregate plan.

5.1.2 Trial and error methods

Trial and error methods are used to solve aggregate production planning since this method is easy to understand and it is used to convey planning details without getting vexed with mathematical detail. Trial and error 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:

1. Prepare an initial aggregate plan on the basis of forecasted demand and establish guidelines
2. Determine if the plan is within capacity constraints. If not revise until it is.
3. Determine the costs of the plan
4. Transform the production plan to lower costs. Perform steps 2 and 3 on it and compare the costs of the two plans.
5. Continue the process until a satisfactory plan is developed
6. 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
7. 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.

5.1.3 Mathematical techniques

A number of mathematical techniques have been proposed over the last three decades to handle aggregate planning.

5.1.4 Linear programming

Under certain assumptions the setting of production rates and workforce sizes can be viewed as a linear programming problem. A linear programming 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. One of the basic weaknesses of linear programming is the assumption of determinism; in most applications there is considerable uncertainty in the forecasts of demand. Another shortcoming is the requirement of linear cost functions. 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. There are several extensions which have been made to the basic linear programming model: the removal of convexity and/or inclusion of a set-up type cost; inclusion of many products; production at several locations; worker productivity and wages; and inclusion of effects of the detailed scheduling that will follow in the short run.

Mathematical programming (optimisation theory) is a branch of mathematics dealing with techniques for maximising and minimising an objective function subject

to linear, non linear and integer constraints on variables. Linear programming 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.

An algorithm called the simple method was developed in the first half of the 20th century to find an optimal solution to linear programming models. He proffered that the vertices of a feasible region play a special role in finding an optimal solution. The optimal solution must be a vertex of the feasible region. All that is needed is to find the vertex with the most favourable value of the objective function in order to identify all optimal solutions. Although linear programming models give an optimal solution they have some limitations i.e. the relationship among variables must be linear, the model is deterministic and only one objective is allowed.

There are also specific methods to solve linear programming models. It was suggested that if the models are too difficult to be solved directly then they can be divided into smaller sub problems that can be handled. He proposed the branch and bound methods. Branching is a way of covering the feasible region by several smaller feasible sub-regions. The procedure can be repeated recursively to each sub-region and all produced sub-regions form a tree structure called the search tree or branch and bound tree. Bounding is a way of finding upper and lower bounds for the optimal solution within a feasible sub region. If the lower bound for a sub-region A from the search tree is greater than the upper bound for any other sub-region B then A may be safely discarded from the search. This is called pruning. The efficiency of the methods depends critically on the effectiveness of the branching and bounding algorithms used.

5.1.5 Goal programming

The objective of aggregate production planning is either to maximise profit or minimise cost. In linear programming it is formulated as a single objective. However in real life there are multiple objectives to problems. Problems involving multiple objectives can be solved using linear programming where one objective is optimised and the others are considered in the constraints. This procedure generates some disadvantages such as:

1. Representing the goals by means of restrictions of linear programming leads to infeasible problem. In large problems it is difficult to find the constraint that causes the infeasibility.
2. The choice of which objective should be optimised is sometimes difficult or subjective

In goal programming the concept of optimum solution of LP problems is substituted by a satisfactory and non dominated solution. Two goal programming methods are:

1. Pre-emptive goal programming
2. Non pre-emptive goal programming

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.

In non pre-emptive goal programming the goals are assigned weights and considered simultaneously. In this case all the unwanted deviations are multiplied by weights, reflecting their relative importance and added together as a single sum to form the achievement function.

5.1.6 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. The behaviour of the rule is quite insensitive to errors in estimating the cost coefficients. However, one potential drawback of the linear decision rule is that the costs may not be really quadratic. Another drawback is that the model does not allow for costs of changing production and workforce levels which depend on the point of departure. Finally, there is no easy way of including constraints on the inventory or production levels

5.1.7 Heuristic techniques

A broad definition of this term would be methods which help the decision maker learn from his or her own experience and facilitate the development of procedures by which complicated problems can be satisfactorily solved.

5.1.8 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. A serious drawback is the essentially subjective selection of the form of the rule. 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.

5.1.9 Simulation search procedures

The philosophy 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

5.1.10 Parametric production planning

The models stated above require linear or quadratic equations. A model was developed termed parametric production planning provided another angle in production planning. Optimisation 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. The combinations are tested and used to establish the total cost. Its major limitation is that since all possible values of parameters cannot be tested there is no way to know that the result obtained is the optimal one

The selection of aggregate 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.

6. Furniture Company overview

Furniture Company is a furniture manufacturing company located in Harare. It has two factories in two 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, plasma TV stands, TV cabinets, wine racks, hall tables and mirrors among other things. Furniture Company supplies the local (93%) and export (7%) market but the bulks of their products satisfy the local market. The firm supplies individual customers, government departments, retail shops, companies among a host of its clientele.

The production performance for the plant from January 2006 to December 2011 is given in Figure 2. From the information it can be observed that maximum production was realised in February 2006.

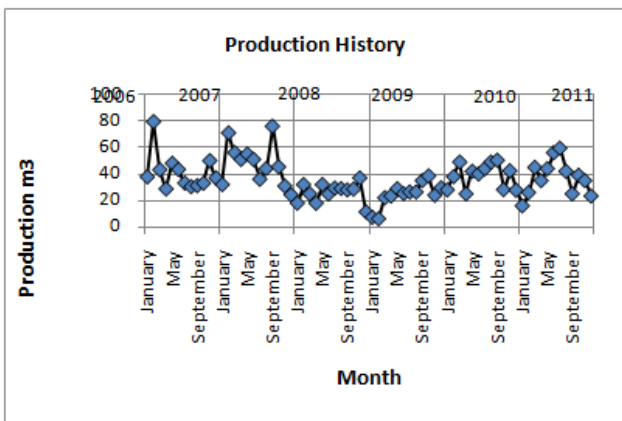


Figure 2: Production history

It can also be observed that the pre-dollarization (pre 2008) era has the highest production figures this can be attributed to increased disposable incomes, stable employment rates and sound capital equipment. The region countries proved to be the preferred export market. The post dollarization era has presented challenges in equipment capitalisation, job redundancy and cost minimisation in addition to depressed macro and micro economic environments. The low activity in December and January of every year can be attributed to the short production and selling time. The time is reserved for equipment reconditioning and the annual festive season break.

6.1 Demand forecast

The plant at its peak used to handle a capacity of 80m³ per month but this has since been reducing due to aging equipment, depressed market conditions and employee turnover. In this thesis the maximum plant capacity was estimated at 60m³ per month. The data was analysed for seasonality in a year and the monthly contribution to production was noted. The graph below shows the monthly contribution towards production from January 2006 to December 2011.

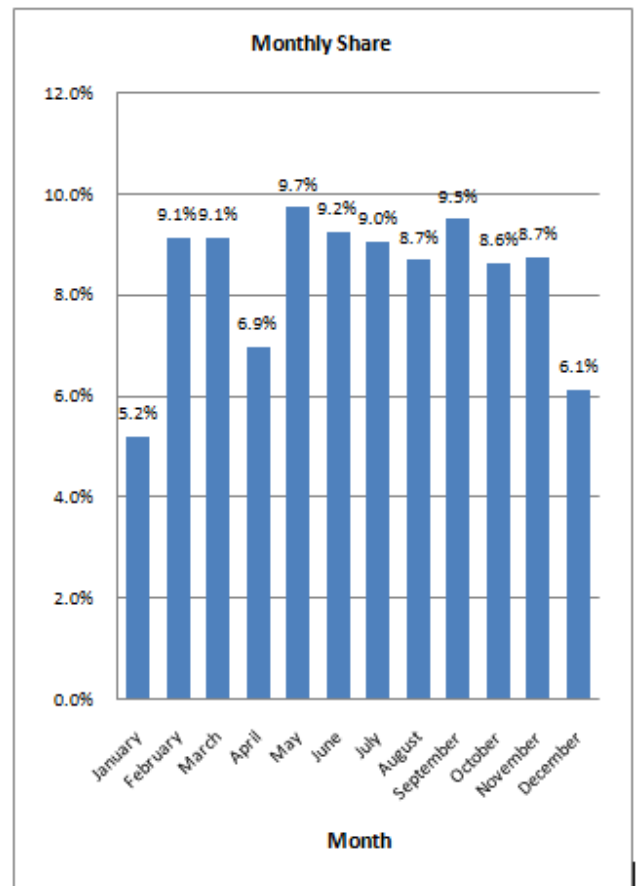


Figure 3: Average monthly contributions towards annual production

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.

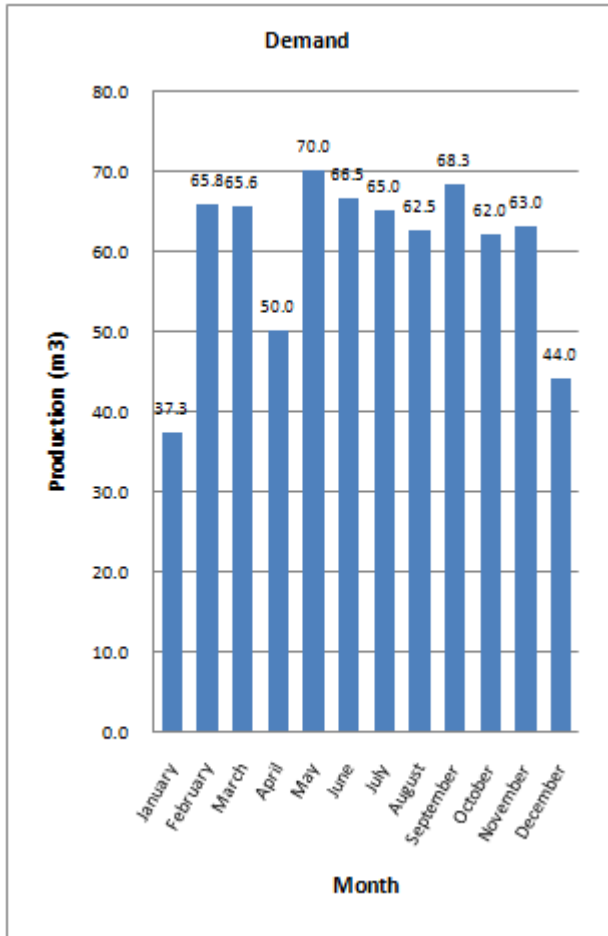


Figure 4: Demand

6.2 Aggregate production planning model

The model to be developed aims at reducing production costs. The model will 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

1. All furniture will be grouped under the five product families office, bedroom, dining, lounge and occasional
2. 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)
3. Capacity of the firm is 60m³ per month.
4. Beginning inventories are estimated to be one fourth of the capacities of the firm
5. Beginning backorder value is zero
6. Inventory level changes at the beginning of every month by the amount that is transferred from the previous month

Data

1. 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.

2. 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.
3. Working hours per day 9.5
4. Regular wage.
The minimum wage according to the National Employment Council (NEC) ruling in the furniture industry will equal \$265.
5. Overtime limitation
There is a limit of four weekends per employee for overtime which amounts to 8 days per month
6. Overtime wage.
According to the Labour 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
7. 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).
8. 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.
9. Maximum Inventory
Maximum allowable inventory 50% of the capacity of the firm
10. Minimum Inventory
Minimum inventory level One tenth of the capacity of the firm
11. Inventory Holding Cost.
The inventory holding cost is 2% of the market prices of the products per month.
12. Raw material cost are 30% of the product cost
13. Capacity utilisation of the Adam Bede factory is averaging 54% for 2011
14. 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 utilisation is hovering at 54% the company will need at least 108 workers as the company will not function at full capacity every month.
15. 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.
16. Lost sales cost.
Although it is difficult to quantify this cost can be quantified base on assumptions. This cost reflects the losses of sales revenue and goodwill when the

producer is not able to fulfil demand and it is given as 1.4 times the product cost.

17. Subcontracting cost.

Subcontracting cost should be treated as a necessity applied despite its unfavourable 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.

6.3 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 -- occasionals

5 -- office furniture

T= 1 -- January.....T = 12 for December

Parameters

D_{ij} -- demand forecasted for product j in period t

m_{ij} .. hours required to produce 1m3 of product j in period t

$OTCAP_{ij}$ – overtime production hours for product j in period t

$WRCAPMAX_{ij}$ – maximum number of workers for product j in period t

$WRCAPMIN_{ij}$ – minimum number of workers for product j in period t

w_j – raw material cost per unit of product j

i_j - inventory carrying cost per unit of product j

b_j – backorder cost per unit of product j

l_j – lost sales cost per unit of product j

$MINI_j$ – minimum quantity of inventory per product j

$MAXI_j$ -- maximum quantity of inventory per product j

$MAXBO_j$ -- upper limit for the amount of product j that can be backordered

IB_j – initial value of inventory

BB_j – 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_{ij} – units of product j to be produced in period t

IN_{ij} – quantity of product j to be kept in inventory in period t

BO_{ij} – quantity of product j to be backordered in period t

LS_{ij} – quantity of product j which the firm loses in in sales in period t

OT_{ij} – man hours of overtime labour used in period t for product j

WR_{ij} – 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

$$\text{Min TC} = \sum_{t=1}^T \sum_{j=1}^N (w_j X_{ij} + i_j IN_{ij} + b_j BO_{ij} + l_j LS_{ij} + rWH_{jt} + oOT_{ij}) + \sum_{j=1}^N (IB_{jt} + BB_{jt}) \quad (1)$$

Constraints

- $X_{ij} + BO_{i,t-1} - BO_{i,t} + CS_{i,t} + FO_{i,t} - FO_{i,t-1} = D_{i,t}$ (2)
- $\sum_{i=1}^n WR_{i,t} - \sum_{i=1}^n WR_{i,t-1} - HR_t + FR_t = 0$ (3)
- $m_{ij} X_{ij} - OT_{ij} - RH_{ij} \leq 0$ (4)
- $WR_{i,t} \leq WRCAFMAX_{i,t}$ (5)
- $WR_{i,t} \geq WRCAFMIN_{i,t}$ (6)
- $RH_{i,t} \leq WR \times WR_{i,t}$ (7)
- $OT_{i,t} \leq OTCAP_{i,t} \times WR_{i,t}$ (8)
- $IN_{i,t} \geq MINI_{i,t}$ (9)
- $IN_{i,t} \leq MAXI_{i,t}$ (10)
- $X_{i,t}, BO_{i,t}, CS_{i,t}, FO_{i,t}, RH_{i,t}, WR_{i,t}, IN_{i,t}$ are integer values (11)

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.

6.4 Application of trial and error methods

Application for different strategies will be done with a view of comparing results. The literature concerning the methods was covered in previous chapters.

6.5 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.

6.6 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.

6.7 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.

6.8 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.

6.9 Comparison of strategies

Table 2: Comparison of strategies

Cost	Hire/Fire (\$)	Overtime (\$)	Subcontract (\$)	Level (\$)	Mixed (\$)
Raw material	1 252 690	1 497 078	1252690	1 04 000	1 252 690
Labour	1 038 853	686 880	509 494	636 000	636 000
Backordering	0	0	4314	0	139 425
Lost sales	0	1245753	0	0	0
Inventory holding	10 087	10 087	10 087	65 142	21 66
Subcontracting	0	0	593 435	0	0
Total cost (\$)	2 301 630	3 439 798	2 370 021	2 095 254	2 049 681

6.10 Cost analysis

The current cost analysis at Adam Bede 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 464m³ for 2010. The cost of sales can be broken down into the following categories as depicted in the Table 3.

Table 3: Cost of sales analysis

	2011	2010	Average Percentage Contribution
Cost of sales	\$ 1 965 456	\$ 1 410 814	
Direct material cost	49.8%	49.8%	49.8%
Direct staff costs	40.4%	41.8%	41.1%
Maintenance costs	6.8%	7.0%	6.9%
Direct Operating Expenses	7.3%	8.6%	8.0%
ISO and Quality Costs	0.3%	0.2%	0.3%
Direct overheads costs	-4.7%	-7.4%	-6.0%

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.

Table 4 : Cost Comparison

	Cost (\$)	Quantity produced (m ³)	Number of employees
Current	1 786 389	446	194
Previous year (2010)	1 282 279	464	179
Trial and error	2 049 681	720	200
Linear programming	1 878 384	720	108

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 5 below

Table 5: Cost per unit

	Cost per m ³ (\$)
Current	4 005,35
Previous year (2010)	2 763,53
Trial and error	2 846,78
Linear programming	2 608,87

The cost per cubic metre is spiralling and it will balloon if left uncontrolled. It is crucial that Adam Bede ascertain a targeted cost of sales then work around it in monitoring and eliminating deviations. The analysis shows an average of \$3 384,44 per cubic metre over the past two years. Adopting aggregate production planning process yields a

cost reduction of 16% per m³ on the spreadsheet model and 23% on the use of linear programming models

6.11 Throughput

The plant currently process 1.76 cubic metres of timber product into the warehouse every day. However with each man capable of 0.3m³ 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 60m³ 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 2.73m³ of timber/furniture into warehouse. This makes an increase of 0.97m³. In the event of failure by employees to meet the daily demand it can be augmented by overtime after normal hours or during weekends.

6.12 Benchmarking

It was observed from the visits 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 minimise costs. It was also evident that the companies specialise in either hardwood or softwood products. Each company has a niche market that it capitalises on to improve revenue.

The study revealed that no furniture company utilises 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 utilise overtime, casual labour 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 campaigns 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 utilised by most companies.

7. 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.

Furniture 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.

Furniture 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. Furniture Company 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.

Furniture Company 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 Furniture Company 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. Furniture Company office furniture is well known and preferred locally. Furniture Company 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.

8. 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 thesis 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 2.27m³ per day was proffered as attainable. The Zimbabwean furniture industry lacks latest technology and these methods provide helpful production plans. Most developed softwares 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.

9. 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.

The productivity gains achievable through experience and learning should not be ignored in the models. In the event that a company proactively avoids hiring and firing it may still need to cross train its workers in different departments to meet demand.

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Author Profiles



Simon Chinguwa, in the year 2007 graduated with a, B.Eng Industrial and Manufacturing Engineering (Hons) and in 2009 he obtained an MSc in Manufacturing Systems and Operations Management from National University of Science and Technology and University of Zimbabwe respectively. He has worked concurrent with the obtaining the degrees or before, as a mechanical engineer with Load Engineering PVT (Itd), Swedish Motor Corporation and Tobacco Processors Zimbabwe. He has also taught at Harare Polytechnic and currently is employed by the University of Zimbabwe as a lecturer in Solid Mechanics, Engineering Mechanics, Thermodynamics and CAD/CAM. He doubles up his responsibilities as a Director of a Faculty of Engineering Technology Center meant to generate income and enhance innovation.



Ignatio Madanhire, graduated with a BSc Mechanical (Hons) Engineering and MSc in Manufacturing Systems and Operations Management in 1993 and 2010 respectively from the University of Zimbabwe. He has been a mechanical engineer with Department of Water – Large Dam Designs, and also worked as a Senior Lubrication Engineer with Mobil Oil Zimbabwe as well as Castrol International dealing with blending plants and lubricants end users. Currently, he is a lecturer with the University of Zimbabwe in the Mechanical Department lecturing in Engineering Drawing and Design. He has published a number of research papers on cleaner production.



Trust Musoma, graduated with a BSc Mechanical (Hons) Engineering and MSc in Manufacturing Systems and Operations Management in 2007 and 2012 respectively from the University of Zimbabwe. He has worked for BNC before joining SIRDC as a research Engineer, where he currently works in the same capacity.