Aggregate planning today

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A firm must plan its manufacturing activities at a variety of levels and operate these as a system. Aggregate planning is medium-range capacity planning which typically covers a time horizon of anywhere from three to 18 months. The goal of aggregate planning is to achieve a production plan which will effectively utilize the organization's resources to satisfy expected demand. Planners must make decisions on output rates, employment levels and changes, inventory levels and changes, back orders, and subcontracting. Aggregate planning determines not only the output levels planned but also the appropriate resource input mix to be used.

Aggregate planning might seek to influence demand as well as supply. If this is the case, variables such as price, advertising, and product mix might be used. If changes in demand are considered, then marketing, along with operations, will be intimately involved in aggregate planning.

Aggregate planning is essentially a big-picture approach to planning. Planners generally try to avoid focusing on individual products or services unless, of course, the organization has only one major product or service. Instead, they focus on overall, or aggregate, capacity. Aggregate planning is closely related to other corporate decisions involving, for example, budgeting, personnel, and marketing. The relationship to budgeting is a particularly strong one. Most budgets are based on assumptions about aggregate output, personnel levels, inventory levels, purchasing levels, etc. An aggregate plan should thus be the basis for initial budget development and for budget revisions as conditions warrant.

A majority of aggregate planning approaches incorporate continuous decision variables and require frequent adjustments to both production and workforce settings. Despite the availability and diversity of these approaches, few significant applications have been reported.

Complex models with restrictive assumptions and infeasible decisions are cited as contributing to the lack of acceptance of aggregate planning in the business environment[1].

Aggregate planning in perspective

Characteristics of aggregate planning

In the broad sense of the definition, the aggregate-planning problem[2] has the following characteristics:

- a time horizon of about 12 months, with updating of the plan on a periodic basis (perhaps monthly);
- an aggregate level of product demand consisting of one or a few categories of product – the demand is assumed to be 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 that are considered fixed and cannot be expanded.

Aggregate planning forms an important link between facilities planning on the one hand and scheduling on the other. Facilities planning determines 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 (a few months 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 basic distinction should be made between acquiring resources through aggregate planning and allocating them through scheduling.

Decision options

The aggregate-planning problem can be clarified by a discussion of the various decision options available. These will be divided into two types:

(1) those modifying demand;

(2) those modifying supply.

Demand can be modified or influenced in several ways:

- pricing;
- advertising and promotion;
- backlog or reservation;
- development of complementary products.

There are also a large number of variables available to modify supply through aggregate planning[3]. These include: hiring and layoff of employees; using overtime and undertime; using part-time or temporary labour; carrying inventory; subcontracting; and making co-operative arrangements.

In considering all these options, it is clear that an aggregate-planning problem is extremely broad and affects all parts of the firm. The decisions which are made must, therefore, be strategic and reflect all the firm's objectives. Some of the multiple trade-offs which should be considered are customer service level (through back orders or lost demand), inventory levels, stability of the workforce and costs.

Basic strategies

There are a number of strategies[4] which aggregate planners might adopt. Some of the more prominent ones are:

- maintain a level workforce;
- maintain a steady output rate;
- match demand period by period;
- use a combination of decision variables.

The first three strategies are pure strategies in that each has a single focal point; the last strategy is a mixed one. Under the level workforce strategy, variations in demand are met by using some combination of inventories, overtime, part-time workers, subcontracting, and back ordering. Maintaining a steady rate of output implies absorbing demand variations with inventories, subcontracting, or backlogging. Matching capacity to demand implies a "chase" strategy; the planned output for any period would be the expected demand for that period.

Whatever strategy an organization is considering, two important factors are company policy and costs. Company policy may set constraints on the available options or the extent to which they can be used. As a general rule, aggregate planners seek to match supply and demand within the constraints imposed on them by policies or agreements and at a minimum cost.

Aggregate-planning costs
When demand is considered given, the following costs[3] should be considered:

- hiring and layoff costs;
- overtime and undertime costs;
- inventory carrying costs;
- subcontracting costs;
- part-time labour costs;
- cost of stockout and back order.

Some or all of these costs may be present in any particular aggregate-planning problem. The applicable costs will be used to select alternative strategies.

Review of aggregate-planning models
Overview of models
Essentially, the aggregate-planning problem can be stated as follows: given a set of forecasts (Ft), determine production, inventory, and workforce levels $(Pt, It,$ and $Wt,$ respectively), $t = 1,2, ..., N$, which minimizes cost subject to appropriate constraints. Typically, the planning is done on a monthly basis over a six-to-18-month horizon, N. Most of the existing aggregate-planning models found in the literature try to minimize an objective function representing "total relevant costs".

At first, based on intuitive feasible solutions, Barter and Graphs are used as simple methods[5].

Based on explicit cost, the three classic analytic optimization methods – the linear decision rule, the transport method, and the linear programming – have traditionally assumed deterministic demand. These methods further require the estimation of several uncertain, obscure costs (hiring, firing, shortage, carrying, etc.) and impose rigid cost functions[5].

"Goal programming attempts to minimize the deviations from prioritized goals"

The cost-based simulation and heuristics models more adequately reflect specific conditions. An iterative, trial-and-error procedure is used to find minimum total variable costs. The simulation model, while more flexible than optimization models, ensures only local (rather than global) optimization. Other cost-based heuristics include parametric production planning, the search decision rule, and the more recent production-switching heuristic. All of these models tend to sacrifice mathematical optimality in favour of less rigid cost functions and more realistic models. What management actually wants is a tool to assist them in planning and decision making. To this end, firms were found to prefer a deterministic simulation model over the more elegant optimal or near-optimal solution approaches. A cost simulation with stochastic demand model called the production decision framework has been developed[5].

All models for aggregate planning discussed above depend on the estimation of a number of cost parameters. Some other approaches –

which do not require explicit cost parameter estimates – bring us closer to the model to be proposed here. Based on implicit costs, the management coefficients model focuses on making decisions consistent rather than mathematically optimal. This approach uses linear regression of historical decision variables to determine preferred sets of coefficients. To accommodate the multiple and often conflicting objectives inherent in aggregate production-planning decisions, goal programming, an extension of linear programming, attempts to minimize the deviations from prioritized goals and to get away from rigid cost formulations.

Techniques for aggregate planning
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:

- *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.

- *Mathematical techniques.* A number of mathematical techniques[6] have been proposed over the last two decades to handle aggregate planning.

- *Linear programming and extensions.* 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.

- *Linear decision rule.* When various costs can be approximated by linear and quadratic functions it turns out that the decision rules[6] 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.

- *Heuristic and simulation 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.
- *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.

- *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.

New developments in aggregate planning
A reformulation of the aggregate-planning problem
Reformulation of the aggregate-planning problem[5,7] will more closely agree with situations frequently encountered in practice. The proposed reformulation assumes that a firm's production planners want to determine the expected service and inventory levels for a given production profile in the face of uncertain seasonal demand. By using several different production profiles which are each consistent with the firm's staffing, subcontracting, and overtime policies, it is possible to pick the profile that best meets the firm's preferences for service level and inventory turns. Actually, the trade-offs between inventory and service level are examined so that an informed choice can be made by all those concerned.

While most methods rely on explicit cost estimates, this method proposes an approach which utilizes inventory/ service level trade-offs to facilitate effective aggregate planning. One of the advantages is that communications can be established among production, marketing, and finance managers who often have conflicting goals. Also, levels for inventory turns, service, and production can be set which are consistent with one another. Furthermore, several alternative production profiles can be examined in a relatively short time through the use of the simulation model.

Production decision framework – a heuristic method
The production decision framework[7] is a dynamic model proposed to assist the manager in the planning process. Emphasis was placed on developing a logical, understandable, and straightforward model.

"The planning problem is subdivided into one of nine states"

The development phase utilizes a ratio, named RPCC, which represents the relative value of the cost of changing the production level to the cost of carrying inventory. This ratio is used to determine the length of an effective planning horizon. Two indicators, the current period ratio and the planning horizon ratio, are calculated to reflect the demand to current production rate over different time periods. Based on

the joint values of these indicators, the planning problem is subdivided into one of nine mutually exclusive and exhaustive states. A set of action statements, representing logical responses to each of the subproblems, is formulated.

A discrete production-switching rule

The trend towards high-volume batch and continuous flow process within American manufacturing has resulted in increasing numbers of crew-loaded facilities. Most available aggregate-planning models contain continuous variables and require frequent adjustments to both production and workforce settings.

The production-switching rule[8] was developed to accommodate discrete production environments which rely on crew loading. Inventory costs are estimated using an interval approach rather than traditional point estimates. The model allows incorporation of overtime options and is interactive in nature. Decision variables from the model can be disaggregated and linked directly to lower-level planning activities.

Improved hierarchical production planning

The hierarchical approach, by partitioning the problem into a series of subproblems, is able to reduce the complexity of the solution process, trading off mathematical optimality for good, feasible solutions with reduced costs. Such an approach is desirable in practice.

The improved hierarchical production-planning model[9] consists of four modules:

(1) forecasting;

(2) aggregate production planning;

(3) disaggregate production planning;

(4) sequencing.

When no forecasts for individual products are provided, the improved hierarchical production-planning model overcomes this weakness by appending a front-end forecasting module. In addition to reducing direct costs, this model provides efficient tools to aid managers in their decision-making process. It is not confined to one decision level only; in fact, middle management, production-planning personnel, schedulers, etc. can all benefit from the use of the various modules within the hierarchical production-planning system.

Conclusion

Intermediate-range planning establishes general levels of employment, output, and inventories for periods of two months to one year. In the spectrum of planning, it falls between the broad design decisions of long-range planning and the very specific and detailed short-term planning decisions. It begins with an overall forecast for the planning horizon and ends with preparations for applying the plans to specific products and services.

The essence of intermediate planning is the aggregation of products or services into one product or service. This permits planners to consider overall levels of employment and inventories without having to become involved with specific details which are better left to short-range planning.

Obviously, no one aggregate-planning decision model can capture all the nuances of a complex manufacturing environment. However, to be realistic, a model must reflect the realities of the production environment in which it is to be used. It appears that the complexity and the restrictive assumptions of these techniques limit their widespread acceptance in practice. Attention must also be focused on providing managers with the tools necessary to calculate the appropriate costs that are used as inputs to these models.

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