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Simulation and Optimization Models for Integrated Production Planning

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ABSTRACT

The objective of this paper is to identify the integrated production planning and analyse its relationships to other production decisions. In this respect, a methodological approach has been developed for analyzing the factors involved in production management decision making . Emphasis is given to the role of modeling as part of this systematic approach. We indicate the extent to which problems in production planning can be solved by modeling techniques.

Our approach uses both simulation and optimization methodologies in a complementary manner rather than performing integrated production analysis with a large-scale model of either the simulation or optimization type. Recommendations are given for better formulation and applications of mathematical models solving given production problems.

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I. Introduction

Integrated production planning can be identified as the intermediate range matching of variable inputs to the fixed inputs of the production process with the objective of meeting demand at least cost. Integrated production planning concerns the choice of amounts of each product (product mix), manpower skill, raw materials, and inventories as well as the timing of these production decisions. In general, the time frame is one year. For various firms it ranges from a month to a 5-year horizon. Within this time period the production facilities can be considered fixed, although small increments may be made in connction with the capital budgeting process. The amounts and types of raw materials, manpower, inventories, and the product mix are variable to a large degree within this time frame.

It is the necessity of making intermediate-range commitments for raw material inventories, sales and advertising campaigns, labor negotiations, storage and transportation contracts, and new equipment orders that makes integrated production planning essential for most firms. It is usually difficult and costly to change these commitments.

II. Relationships of Integrated Production Planning and other production decisions.

Integrated production planning cannot be effective if it is separated from the other decisions of the firm. Production Planning is the major interface of production management and the marketing and financial management functions of the firm. The coordination with the marketing function must determine an intermediate-term production plan which meets fluctuations in demand.

Similarly, it is essential to plan raw material inventories and seasonal inventories, as well as work in process, with the knowledge of the firm's financial planners. Otherwise sudden layoffs or shortages may result when cash is not available. If these three parts of the firm can cooperate in an aggregate plan for the firm, profitable results are much more likely.

Figure 1 illustrates the relationships of integrated planning and other production decisions within the firm. The integrated planning function depends on the long-term capacity planning function for forecasts of future demand and for long-term capacity plans. On the basis of actual orders and inventory status, it issues production and inventory plans to the short-term scheduling and control functions. It works in parallel with capital budgeting for marginal capacity decisions. It reports on current status through the scheduling function as discrepancies between schedules and actual work in process.

It is abvious that integrated production planning should be closely coordinated with the other functions of the firm depicted in Fig.1. Information flows between functions are not adequate in themselves. Useful tools include sales forecasts, capital and operating budgets, and schedules as well as experience. Decisions in each function should be made with an overall view, as they are, in fact, highly interdependent.

In this respect, a conceptual framework has been established for analyzing the integrated production systems. For each production decision the major factors are identified, their interrelationships are described, criteria are selected, and the techniques for selection of the best alternatives are specified. This methodological approach to integrated production planning emphasizes the managerial viewpoint rather than the mathematical technique involved in solution. In so doing we have emphasized the importance of the systematic approach and the role of modeling as part of this approach. It is important to develop the models for integrated production planning from this viewpoint for two reasons:

a- Many production problems can become intractable in their full development, but the information requirements are usually not sufficient to support a model at that level of detail and much effort may be wasted.

b- Even an approximate solution to the right problem is better than the exact optimum for an irrelevant statement of the problem.

III. Mathematical Models for Integrated Production Planning.

3.1. Methodological Approach

Simulation and optimization models for integrated production planning are helpful in organizing the data base and in providing a problem-solving or optimization approach.

Mathematical models require measurement scales for the inputs and outputs of the production system. With the form of the relationships and available data, we can predict a measured output to be achieved from the inputs. Understanding the functions and objectives of the production system, we can identify a criterion which should be optimized. Linear programming models, in which the relationship between inputs and outputs is expressed as a linear mathematical function, are widely used for production process planning, for scheduling and for capital budgeting when examining incremental additions to the productive capacity [1]. These models could be brought together to produce an integrated model which would allow many different production decisions to be made. This procedure has the advantage that all the production decisions would be based on the same set of basic assumptions and on the same data base. An example of the aggregate planning linear programming model is the decomposition model of Dzielinski [2]. However, we cannot endorse this large-scale linear programming model as a general panacea to all integrated production systems. Some systems cannot be meaningfully linearized within present ranges of compatibility. In fact it should be necessary to adapt models to particular situations and to evaluate production decisions in additional ways beyond these models.

Although simulation models are useful for integrated production planning, they would rarely be bulit for use only in aggregate planning. One reason is that the data base can be kept up to date only by constant use. Another reason is that the cost of building and maintaining the model and deta base is usually too high for a problem that is strictly planning. The result of these two considerations is that simulation models will be available for integrated production planning only if they are also used for scheduling.

The proposed methodological approach for integrated production system analysis is to first explore the problem with an optimization approach, such as linear programming, at an aggregate level. Experience with the aggregate model can help define what questions can best be answered by simulation, as well as what questions can be answered only by optimization after additional detailed information is obtained by simulation. The rationale for this approach is that most questions the analyst is trying to answer are at least partial optimizations, but it is difficult to answer anything more than feasibility questions with simulation unless an adequate experimental design is conceived and carried out. Formulation of problems for an optimization technique focuses the analyst's attention on solving the problem rather than merely on modeling it.

This approach uses both simulation and optimization methodologies in a complementary manner rather than performing an analysis with a large-scale model of either the simulation or optimization type. The optimization model gives final policy guidance on questions of resources or schedules, while the simulation model furmishes operational data such as productivities and tests the schedules in a more detailed environment. Figure 2 illustrates the complementary relationship of optimization and simulation models.

3.2. Linear and Simulation Model.

On the basis of the aforementioned concepts, a mathematical programming model for integrated production planning and transportation has been formulated. The model minimizes the total cost of inventory holding and shortages, hiring and layoffs, start-up and shutdown, as well as production and transportation costs for a large-scale production system, as follows.

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Total Cost $= \sum_{i} \Big\{ \sum_{h,j,k} C_{1hj} \left(P_{hij} + I_{hij} - X_{hijk}\right)$ inventory carrying cost.

$+ \sum_{h,j,k} C_{2,h} \left(X_{hijk} - P_{hij} - I_{hij}\right)$ shortage cost

$+ \sum_{g,j} C_{3,g,i,j} \left(L_{ij} - L_{(i-1)j}\right)$ hiring cost

$+ \sum_{g,j} C_{4,g,i,j} \left(L_{(i-1)j} - L_{ij}\right)$ layoff cost

$+ \sum_{h,j} M \left(P_{hij}\right)$ manufacturing cost

$+ \sum_{j} S_1 \left(L_{ij} - L_{(i-1)j}\right)$ Start-up cost

$+ \sum_{J} S_2 \left(L_{(i-1)j} - L_{ij}\right)$ shutdown cost

$+ \sum_{h,j,k} U_{h,i,j,k} \; X^{*}_{h,i,j,k} \Big\}$ transportation cost (1)

Subject to:

$$\sum_{h\,k} \left[P_{hij} - X_{hijk} + I_{hij}\right] \leqq W_{ij} \qquad (2)$$

where W_{ij} = Storage Capacity of the Warehouse in plant j in period i

$$\sum_{h} P_{hij} \leqq D_{ij} \quad , \quad D_{ij} \leqq 0 \qquad (3)$$

where D_{ij} is the maximum Capacity of plant J in period i

$$P_{hij} \leqq D_{hij} \qquad D_{hij} \geqq 0 \qquad (4)$$

Where D_{hij} is the maximum Capacity of plant J to make size h in period i

$$\sum_h P_{hij} \geqq D^*_{ij} \qquad (5)$$

Where D^*_{ij} is the minimum level of capacity specified by management at which plant j must operate in period i.

$$X^*_{hijk} = \begin{cases} X_{hijk} & \text{if } P_{hij} + I_{hij} \geqq X_{hijk} \\ P_{hij} + I_{hij} & \text{if } P_{hij} + I_{hij} < X_{hijk} \end{cases} \qquad (6)$$

$$\begin{aligned} L_{ij}\left(\sum_h P_{hij}\right) &= 0 \quad \text{when} \quad \sum_h P_{hij} = 0 \\ &= 1 \quad \text{when} \quad 0 < \sum_h P_{hij} \leqq \sum_h P^1_{hij} \\ &= 2 \quad \text{when} \quad \sum_h P^1_{hij} < \sum_h P_{hij} \leqq \sum_h P^2_{hij} \\ &= 3 \quad \text{when} \quad \sum_h P^2_{hij} < \sum_h P_{hij} \leqq \sum_h P^3_{hij} \\ &= 4 \quad \text{when} \quad \sum_h P^3_{hij} < \sum_h P_{hij} \leqq \sum_h P^4_{hij} \\ &= 5 \quad \text{when} \quad \sum_h P^4_{hij} < \sum_h P_{hij} \leqq \sum_h P^5_{hij} \end{aligned} \qquad (7)$$

Because of the different mix of sizes, $\sum_h P_{hij}$ is not a fixed number. It is fixed for a given period and a given configuration.

$$W_{ij},\ P_{hij},\ X_{hijk},\ I_{hij} \geqq 0 \qquad (8)$$

Where:

I_{hij} = beginning inventory of size h in plant J in period i.

X_{hijk} = demand of size h by customer k allocated to plant j in period i.

X^*_{hijk} = amount of size h that is transported in period i from plant j to customer.

U_{hijk} = transportation equalization cost function for size h from plant j to customer k in period i.

L_{ij} = number of Lines required to produce $\sum P_{hij}$ units in plant j in period i.

L_{hij} = number of Lines required to produce P_{hij} units of size h in plant j in period i.

$C_{1hj}\left(I_{h(i+1)j}\right)$ = inventory-carrying cost function for size h per period assignable to plant j in period i.

C_{2h}(amount short) = shortage cost function for size h per period.

$C_{3,g,i,j}\left(\Delta L_{ij}\right)$ = hiring cost function in plant j of skills g in period i.

$C_{4,g,i,j}\left(\nabla L_{ij}\right)$ = laying-off cost function in plant j of skills g in period i.

P_{hij} = number of units of size h to produce in plant j in period i.

$M\left(P_{hij}\right)$ = manufacturing cost function for various production levels of product size h for plant j in period i

$S_1\left(\Delta L_{ij}\right)$ = 0 when $\Delta L_{ij} = L_{ij} - L_{(i-1)j} \leq 0$, positive value, when $L_{ij} - L_{(i-1)j} > 0$

$S_2\left(\nabla L_{ij}\right)$ = 0 when $\nabla L_{ij} = L_{(i-1)j} - L_{ij} \leq 0$; +ve value, when $L_{(i-1)j} - L_{ij} > 0$

$S_1\left(\Delta L_{ij}\right)$ = Cost involved in starting a line in plant j in period i; this does not include the hiring cost.

$S_2\left(\nabla L_{ij}\right)$ = Cost involved in shutting down a line in plant j in period i, excluding the layoff cost.

where period i = 1,...., T, periods in planning horizen
plant j = 1,....,n
sizes h = 1,2,3,4,5,6,....,H
customer k = 1,...,m

The proposed model can be used to generate a large number of "close-to-optimal" production plans, which are then sent to a detailed simulation model with the detailed cost structure shown in Figure 3. The lower cost plans are sent to a transportation linear programming model to have a transportation plan generated. Then the various alternatives and costs are presented to the decision maker, who may select one or suggest revisions to be further analyzed. The steps in the procedure are shown in Figure 4.

IV- Conclusions

The integrated planning function is the key to successful production management decisions. These decisions are not independent, they are highly interrelated. We discussed the role that the integrated production planning should play in coordinating the marketing and production systems in the medium range.

The development of models and systems that solve the joint problems of marketing and production has not been well developed to date. Our approach uses both simulation and optimization methodologies in a complementary manner rather than performing integrated production analysis with a large-scale model of either the simulation or optimization type. This approach incorporates the integrated planning and inventory and scheduling production decisions along with the order-processing, purchasing, and physical distribution functions which are tied to the marketing subsystem. This centralized decision-making needs a computer-based organization which has access to required information.

Information must be reliable and available if integrated production analyses and planning are to be made with mathematical models. The detailed data base is the prerequisite for effective production planning.

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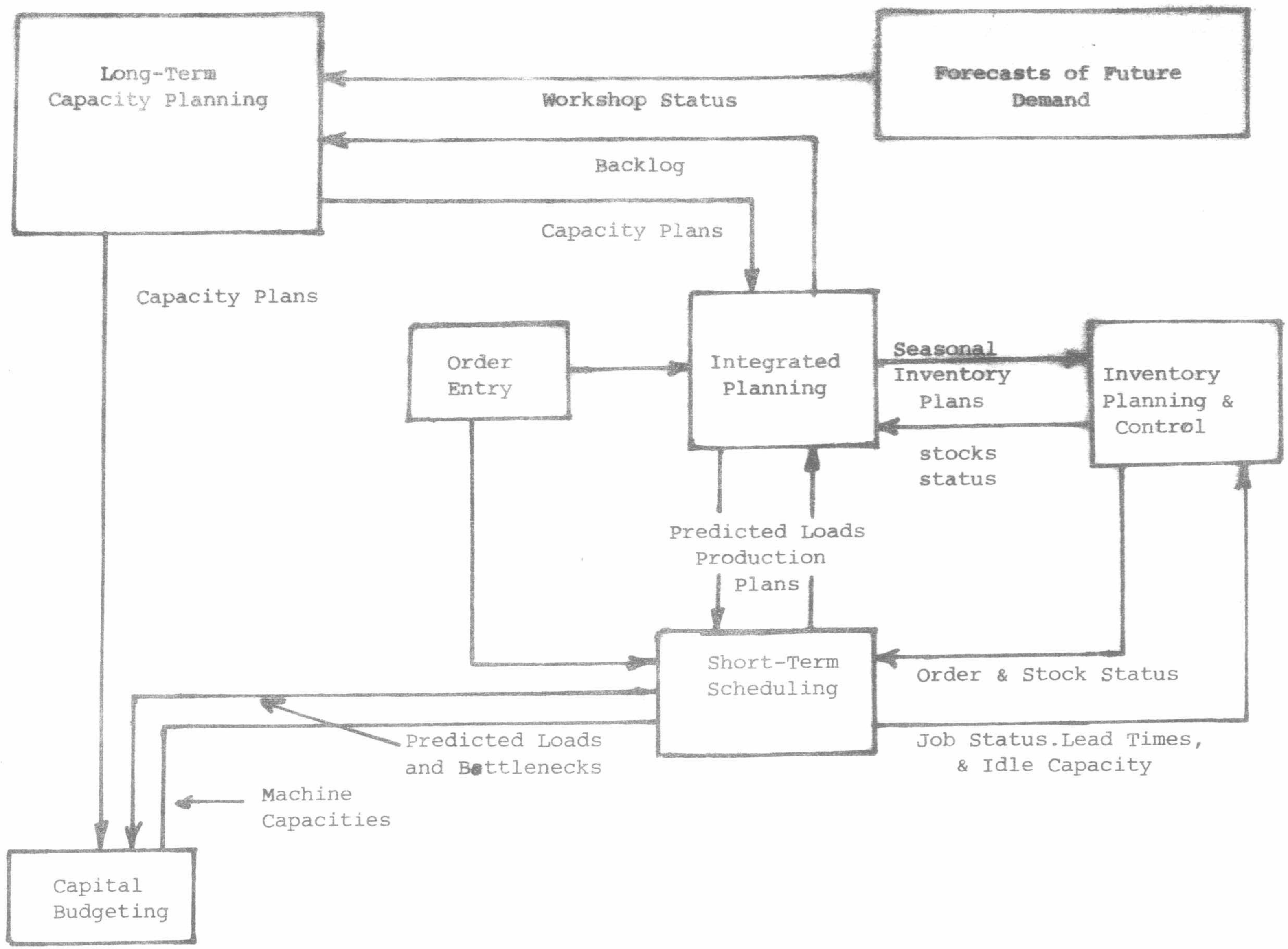

Figure.1. Relationships of Integrated Planning to other Production Decisions.

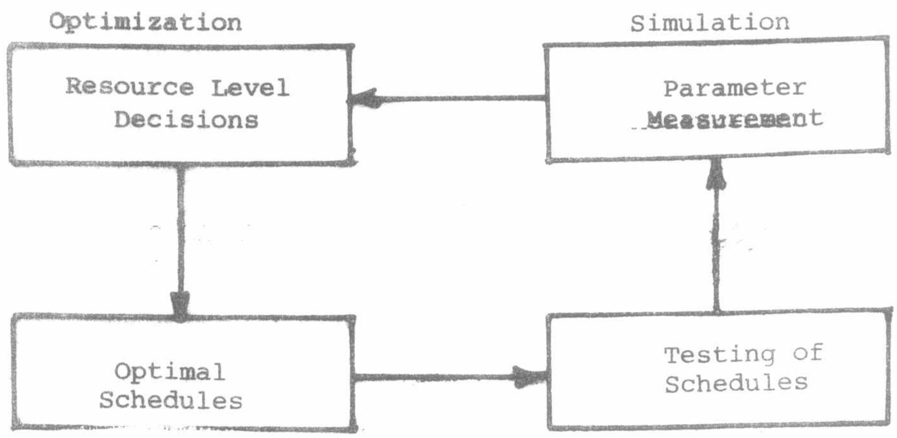

Figure 2 Complementary relationship of Optimization and simulation models.

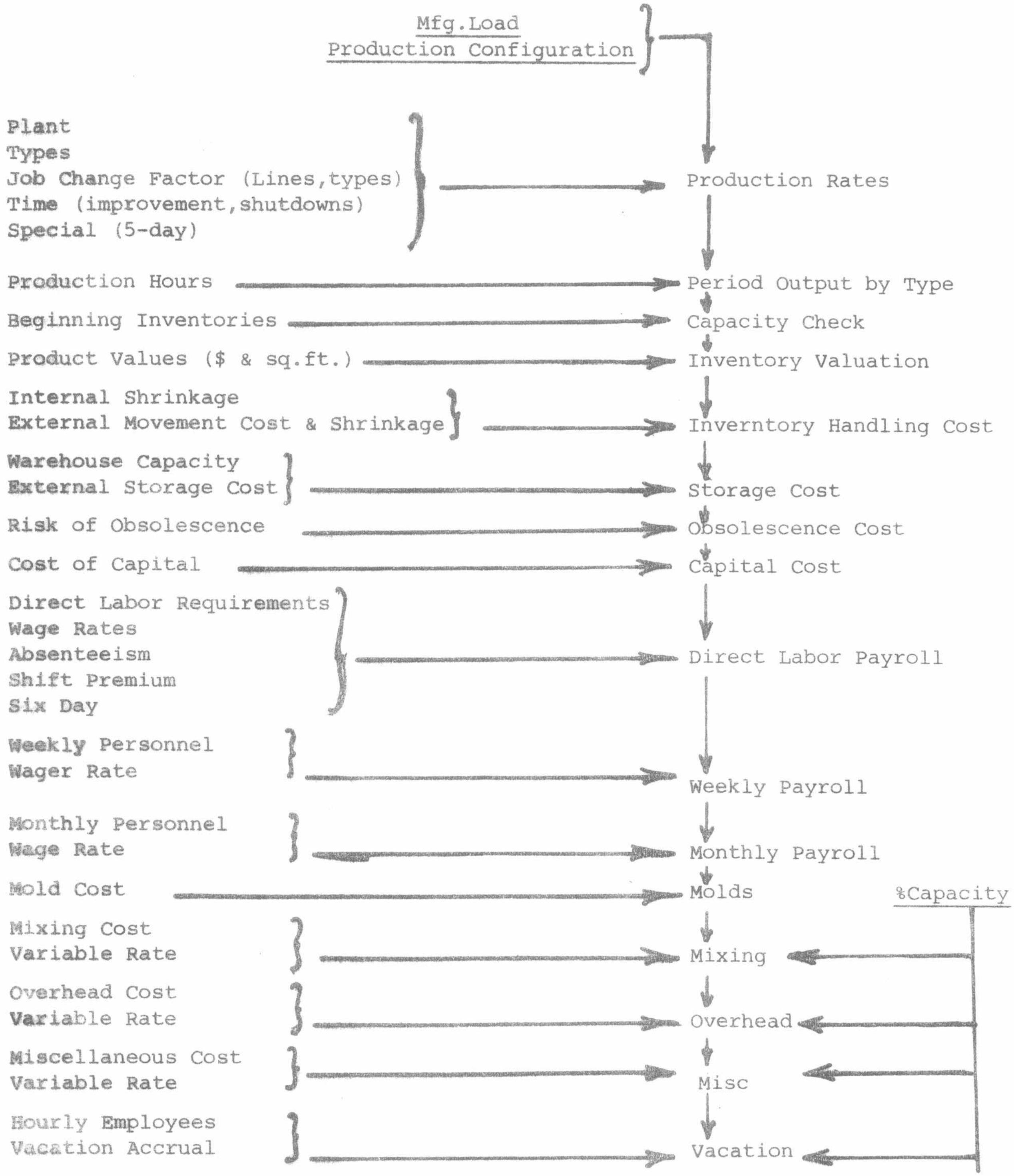

Figure 3: Production allocation model.

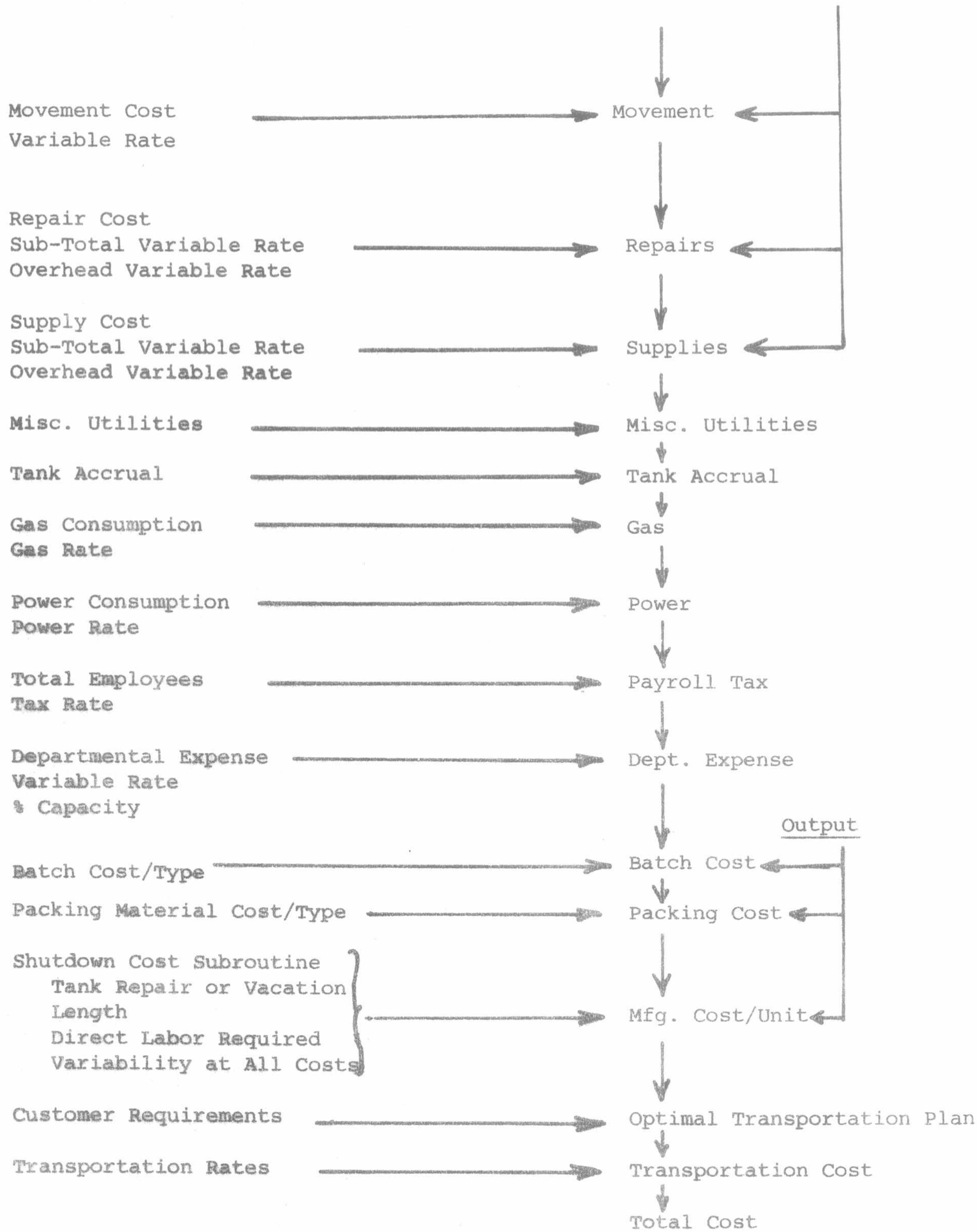

Figure 3 Continued.

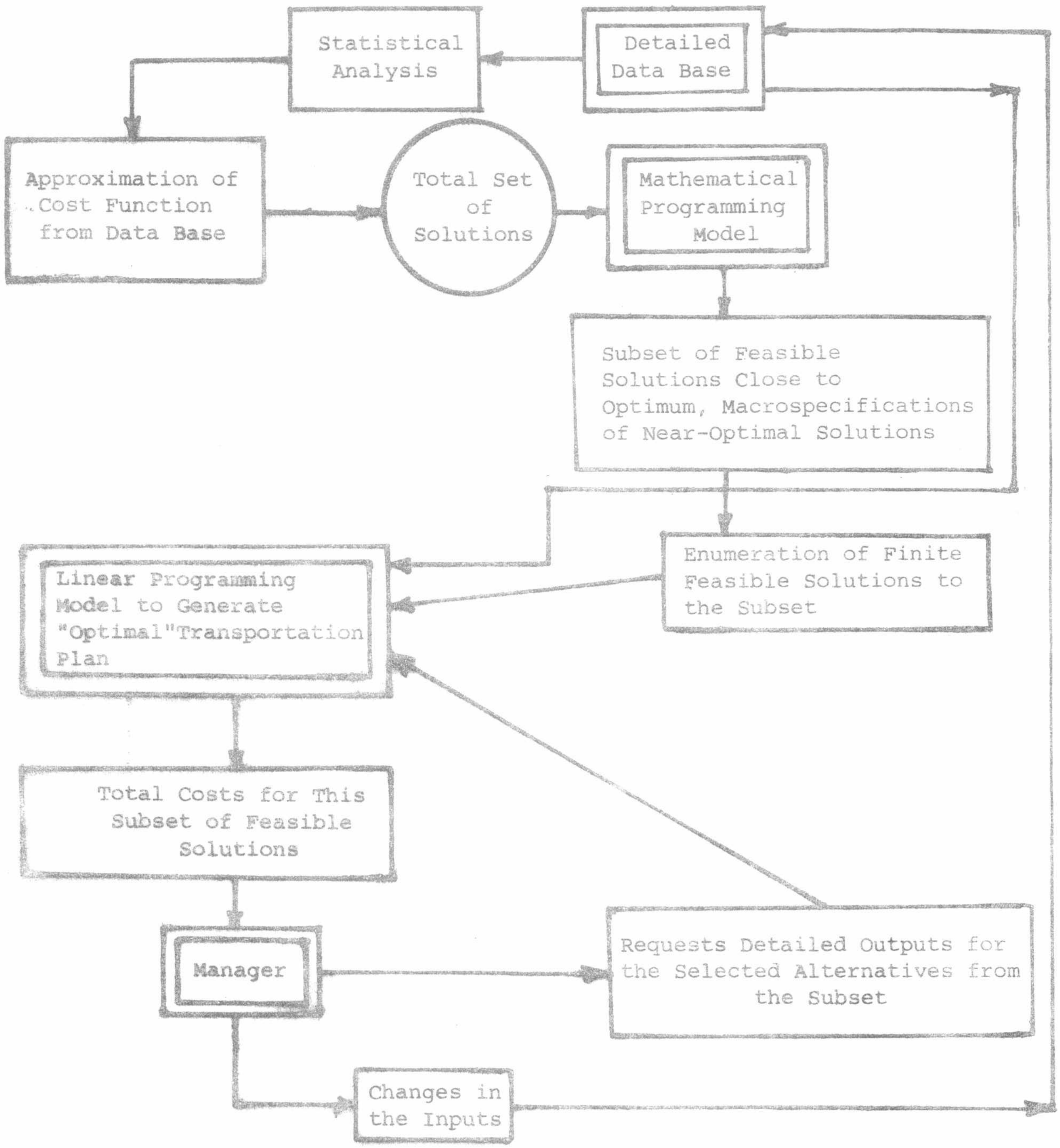

Fig. 4. Flow chart of systematic procedures. For integrated production planning.