CHAPTER I

INTRODUCTION

Two major interacting aspects of management of manufacturing systems are production planning and inventory control. Though intimate interaction of these two functions exist in reality, most reported research works, in past, have treated them separately tacitly ignoring the interaction. Of late, however, there is a growing trend in developing more realistic models for the integrated production-inventory systems. This trend provides the background for the work presented in this thesis.

1.1 The Production-Inventory System

A production-inventory system (hereafter referred to as PIS) is characterized by (i) flow of orders, originating as customer requisitions and (ii) concordant reverse flow of end-products from factory to customer which may accumulate at discrete points to create inventories. Though general, such macroscopic description of basic characteristics of a PIS facilitates consideration of the important activities within the PIS as related to the two flows — those of orders and of end-products. The flow of customer orders, which emanates from the enfironment, acts as an input to the system and triggers off various policy decisions within the PIS. Although the specific decisions taken are usually determined by the specific nature of the PIS, almost invariably the production order decision is the most crucial, involving harmonious interaction of various factors of production, viz. man, machine, material, money and management, and leading to the generation of the flow of end-products. Thus the exogenously generated customer orders give rise to a stream of decisions ultimately leading to the determination of production plan within a given framework of available resources.

1.1.1 Types of PIS and Problems Involved

Buffa and Taubert (1)* have grouped production-inventory systems into five classes, viz. (i) Pure inventory systems (ii) Production-inventory systems for high volume (iii) Closed job shop systems (iv) Open job shop systems and (v) Large-scale one-time projects. Pure inventory systems are irrelevant here since it devoids itself of the element of 'production' which is an essential prerequisite for a PIS. Open job shop systems and large-scale one-time projects have essentially some elements of commonality, those of heavy emphasis on scheduling and complete (or near-complete) determinism of production plans.

Eilon (2) has identified three types of production systems, viz. (i) Job production system (ii) Batch production system and (iii) Continuous production system and has discussed the types of problems encountered in each. These are summarized below in Table 1.1.

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* Figures in parenthesis refer to the bibliography at the end of the text.

Table 1.1 <u>Types of PIS and Problems Encountered</u>

Types of PIS	Number of Products		Control Concerned with	
	One	Several	Sequencing	Production Level
Job	—	✓	✓	—
Batch	—	✓	—	✓
Continuous (a	✓	—	—	✓
Continuous (b	—	✓	—	✓

Table 1.1 is only a rough guide and not a comprehensive classification system since in reality sequencing and production planning problems often occur simultaneously (Baker (3)).

Investigating the place of production planning in its correct perspective, Eilon (2) has commented as follows:

> '.... the single product case is meaningless in job production and trivial in batch production. Continuous production on the other hand may well involve only a single product, or at least a product with such minor variations from the production or inventory view point, that considering the production problem on an aggregate level is justified.'

Eilon (2) goes on to say further that

> 'The multi-product case may be regarded either as an aggregate production smoothing problem, in which the

global production level for the system as a whole is determined (with subsequent disaggregation routines), or as a variant of the batch production problem,.....'

Thus in PIS with inventoriable items (viz. continuous production systems and batch production systems or closed job shops) production planning is a very important problem, because the boundaries of the system under managerial control include a productive plant, and inventories can be used as a trade-off against the potentially heavy costs of production fluctuation. Evolution of viable production policy decisions which result in greatly attenuated, and therefore acceptable, production fluctuations is the main theme of the work presented in this thesis.

1.2 Production Planning -- Models and Strategies

The problem of production planning over time has been studied extensively in the management science literature under various technical assumptions (Silver (4)). Kleindorfer et al.(5) give an outline of the major classes of assumptions pertaining to various elements, viz. (i) Products (ii) Demand (iii) Planning horizon (iv) Cost elements (v) Cost functions and (vi) Constraints. Therefore, any production planning model can be categorized by the types of assumptions made with respect to the above elements.

A cursory survey of existing literature on production planning indicates that for almost all of them the objective function is to minimize a cost function and that considerable semantic difficulties exist.

The terminology production planning or scheduling is often employed when the cost structure of the model includes only direct production and inventory cost elements (Modigliani and Hohn (6), Johnson (7)). If the model further includes costs associated with changes in either production levels or the rate of production the analysis is referred to as production smoothing problem (Beckman (8), Klein (9)). When costs due to fluctuations of employment levels of direct labour are considered then the model is sometimes called work force balancing or employment smoothing (Holt et al.(10)). Other references have used the phrases like aggregate (production) planning (Holt et al.(10), Taubert (11)).

The solution methodologies for such production planning problems range from mathematical programming and optimal control theory to computer search techniques. Buffa and Taubert (1) and Eilon (2) have discussed important techniques available to solve aggregate production planning problems. Eilon (12) has given three common strategies underlying the solution methodologies.

(i) The first strategy is to have a static and constant production programme with an inventory large enough to absorb fluctuations in demand. Such a strategy results in low cost of planning, supervision and control with high man and machine utilization, but the average inventory level and hence cost are high.

(ii) The second strategy consists in maintaining a constant inventory level, as a safety cushion between production and customer demand, and in allowing a fluctuating production programme. This strategy naturally typifies low inventory costs but high cost of production rate fluctuations. Another drawback of this strategy is that any change in the demand pattern requires a certain time lag before production can follow suit. Strictly speaking, the inventory level does not remain constant but undergoes a small fluctuation.

(iii) The third strategy is a combination of the above two in that it allows fluctuations in both the inventory level and production programme, and seeks to achieve an optimum balance between the amount of fluctuations in both so as to minimize the total cost of fluctuations.

1.2.1 Some Comments on Production Smoothing Strategies

Certain observations can now be made with regard to the three strategies stated earlier.

(i) Almost in all cases, the criterion chosen for viable production decision is minimization of a cost function which may sometimes be too simple for purposes of computational ease to represent reality. Kleindorfer et al.(5) comments that the more operational models which often provide computational procedures for decision values also require the most restrictive assumptions. Conversely, this implies that realistic assumptions require sophisticated solution techniques which may be intractable to operating managers and also may lead to difficult-to-operate decision rules.

(ii) Although there is a general awareness of the importance of production and inventory fluctuations most studies have considered them only indirectly by quantifying the associated cost elements. Use of fluctuations of production and inventory directly as a criterion to be minimized could perhaps be used instead.

(iii) Very few studies have been reported on multistage production-inventory system. The reason may be partly due to difficulty in evolving a cost criterion while extending the conventional approach for solving these problems and partly due to increased system complexities with more complicated relationships among various system variables.

1.3 Reduced Fluctuations as a Criterion for Policy Designs

Minimization of cost as a criterion for system analysis and design has received widespread recognition. General preference of operating and middle level managers for financial figures like cost and profit are important reasons for such widespread acceptance of cost as a criterion. It also provides to the analysts an easily quantifiable objective function which is a basic requirement for applying various operations research (quantitative) techniques.

Of late, however, other alternative criteria like system reliability and system stability etc. are emerging. These criteria have been successfully used as substitutions for cost criterion specially in the analysis and design of complex systems where either a cost criterion is not easy to construct or where a single cost criterion is not a valid representation of the system's goal.

Of course, if the cost function truly characterises the system's objectives and the cost parameters have realistic significances then the policy recommended after a correct analysis may be optimal.

The manager, directly associated with the operation of a system, vividly experiences the fluctuations, which the system variables undergo, generated due to interacting effects of fluctuating input(s) and basic structure and policies followed in the system. Such fluctuation is a matter of direct concern for the manager. Hence any policy recommended to bring down these fluctuations is likely to be appreciated and accepted by him.

A study of cost structures, used by various authors, indicates that they are quantified reflections of fluctuations of major system variables. Such quantification should, therefore, bear a one-to-one correspondence with the fluctuations experienced by system variables since the latter is a cause while the cost is an effect. Unfortunately the cost structures, built for the purpose of model analysis, are affected heavily by the solution methodology and hence they fail to truly represent the real world. A criterion such as reduced fluctuations of system variables provides a viable alternative since reduced fluctuation often means reduced cost.

While the degree of fluctuating tendency of the variables can be controlled, it is usually difficult to prescribe a unique solution with such a criterion unlike when a specific optimality criterion such as cost is used. Hence, acceptability of a model with reduced fluctuations as a criterion depends largely on the qualitative judgment of both the analyst and the practitioner. In defence of such qualitative validation Forrester (13) has commented:

> 'We sometimes encounter the attitude that model validity can be treated only in a numerical and quantitative manner. This hardly seems justifiable when such a preponderant amount of human knowledge is in nonquantitative form.'

Forrester (14) further comments on a single measure of validity:

> 'Because there is always an underlying foundation at which validation criteria cannot themselves be validated and proven to be pertinent, no single measure of validity will be sufficient.'

In the context of production-inventory system while using a heuristic decision rule for aggregate production planning, Bowman (15) emphasizes that 'experienced managers are quite aware of and sensitive to the criteria of a system' and that managerial decisions are 'more erratic than biased'. He goes on to argue that managerial decisions are basically sound and that what is needed is to eliminate the 'erratic' element by making them more consistent.

In the light of the above discussions it may be said with some assertion that judging model validity and usefulness from a practitioner's point of view may make the model at least more usable. Thus reduced fluctuations of system variables, when adopted as a criterion to design better policy decisions, allows qualitative judgement of the operating managers to validate the model and hence enhances its acceptability.

The work presented in this thesis is based on the philosophy that attenuated fluctuations of system variables is a desirable system characteristic, and whenever a cost criterion can be constructed which also depicts these fluctuations, one should definitely make use of it for ease of quantitative analysis.

1.4 Object and Scope of the Present Work

The work presented in this thesis is primarily concerned with the design of viable production policy decisions in production-inventory systems so as to generate stable and acceptable system responses. To be specific, the production policy decisions are designed for a simple production-inventory system, a two-stage production-inventory system and a multistage (three-stage) production-inventory system.

For a simple PIS, two approaches have been followed. The first approach has assumed a heuristic production decision rule and proceeds to evaluate the operational parameters from stability point of view while the second approach uses modified Wiener Filter theory to obtain optimal production decision rules under uncorrelated and autocorrelated demand cases.

The two-stage PIS presents more complex relationships among system variables. Design of policy decisions in this case has been carried out under the framework of Modal Control theory to ensure stability of system responses. The resultant control policies are highly idealized but gives two very interesting indications — those of consideration of retail sales for production decisions at factory sector and of consideration of factory inventory for purchase order decisions at retail sector.

A multistage production-inventory system (MPIS) presents still more complex relationships and, hence, an Industrial Dynamics Simulation method has been used. The two above-mentioned policies are tested and found to give quite satisfactory results.

The work presented in this thesis is thus based on the philosophy that system stability is a very desirable criterion especially for complex dynamical systems. Traditional cost criteria may, however, be used when they represent such a facet of the system. Though stability, as a suitable criterion, has its genesis in engineering discipline, its use is increasingly being made in management systems (Forrester (13)). Therefore, the methodologies, developed primarily in the context of engineering systems, may be effectively used in management systems. This thesis has made use of some such techniques available in the field of engineering control systems. It is expected that in time to come system stability will prove to be a major characteristic of large and complex systems and hence suitable methodologies will either have to be adopted, if available elsewhere, or developed so as to evolve viable policy decisions.

1.5 Chapterwise Summary

Chapter I defines a PIS in general and discusses the importance of production planning problem. It also critically analyses the significance of 'attainment of reduced fluctuations of system variables' vis-a-vis 'minimization of a cost criterion' as system objectives. It also shows how the problem of production planning may be tackled when the former is accepted as the system objective.

Chapter II explains the important assumption of 'linearity' of systems and proceeds to discuss in brief the various linear system analytical techniques which are used in the study presented here, prominent among them being flow-graph analysis, stability analysis , statistical analysis (which also includes Wiener's Filtering theory) and Modal Control theory. A very short exposure is made also to Industrial Dynamics approaches highlighting its views on 'stability'.

Chapter III considers a discrete PIS with stochastic demand. A heuristic production decision rule based on sales forecast and current inventory status has been used. A flow-graph analysis gives the transfer functions in complex Z-domain between the production and sales and between inventory and sales. Ranges of smoothing parameter and decision parameter are determined for stable responses of the system from stability considerations. Time-domain relationships are then established and system oscillations are tested for various values of the above parameters for a unit step input sales vector. The exogenous sales input has been assumed to consist only of uncorrelated random noise. The variances of production and inventory for such a case are determined. A quadratic cost function, which is a pure variance criterion and which characterizes system oscillations, is suggested. The near-optimal values of the smoothing and decision parameters are found out by searching the two-dimensional space for their best combination to yield the minimum value of the cost function. It is also indicated how nonquadratic cost functions may be transformed to quadratic ones.

Chapter IV makes an attempt to provide an optimal structure of the production decision rule for a simple PIS by using a modified version of the Wiener's Filtering theory. The quadratic cost function is still retained. The analysis is then extended to the cases of autocorrelated and non-zero production lag.

Chapter V deals with the problem of designing policy decisions in a two-stage production-inventory system to result in a stable system with any desired degree of attenuation of fluctuations of system variables. A synthetic approach with the use of Modal Control theory has been followed where control policies are generated by a linear feedback of state vector. More specifically, by an appropriate selection of the generalized modal matrix the multi-input model system is decoupled in the modal domain into single-input subsystems which are then considered separately to evolve the required control policies, ensure stable system response and achieve any desired degree of stability. Although these synthetically generated control policies are difficult to implement in practice, they have two major implications viz. (i) control policies at factory sector should take direct cognizance of the state-variables of the retail sector, (ii) the ordering policy at the retail sector should associate a discouragement factor for high order backlog at the factory sector.

Chapter VI discusses important aspects and suitability of Industrial Dynamics approach to study more realistic dynamic, nonlinear and closed systems. Some generalized results have been derived for the exponential delays used generally in Industrial Dynamics models. Also the salient features of the Industrial Dynamics model of the Multistage Production-Inventory System developed by Forrester (13) are discussed. Two types of ordering policies have been tried. They are structured according to the results obtained in chapter V for a two-stage case by applying Modal Control theory. Explicitly stated, these are (i) ordering policies in distributor and factory sectors attaching more confidence to the retail sales information than to the actual requisitions received and (ii) ordering policies at retail and distributor sectors having an element of discouragement for lower than desired inventories at higher stages. It has been shown with Industrial Dynamics simulation studies that both the two policies result in more attenuated system oscillations than those obtained by Forrester (13) in his basic model.

Chapter VII sums up the results of the study, critically analyses them, and indicates scope for further work. It puts together the salient features of the study and holds that stability as a criterion is very realistic and, therefore, control system theoretic approaches provide acceptable policy decisions.

Given at the end is a bibliography on concepts and approaches by various authors relevant to this study.