MANAGEMENT CYBERNETICS:
COMPUTER SIMULATION MODELS OF OPERATIONAL MANAGEMENT ORGANIZATIONS

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TO MY FAMILY

ABSTRACT

Cybernetics is the science of effective organization, i.e. the science that describes the general principles of growth, learning and adaptation in complex, dynamical systems.

Stafford Beer regards his viable system model as a design for effective formal organization. He also declares that since his model is explicitly based upon the principles of cybernetics, it facilitates consideration of what is and is not possible within formal organizations and provides guidance in creating efficient structures.

The purpose of this research is to demonstrate and test Stafford Beer's ideas on the viable system model via the simulation of certain business activities.

A methodology for getting access to the cybernetic body of knowledge is given as well as examples of cybernetic laws relevant to managerial and business practice.

An important part of the work is devoted to the explanation and discussion of Stafford Beer's viable system model, and the importance it represents as a cybernetic method for the design of organizational structures.

Simulation models incorporating the major activities of a business firm are represented and used as case studies to investigate how basic industrial organizations based on Beer's viable system model work under operational conditions.

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CHAPTER ONE

INTRODUCTION

In the short span of the last 250-300 years the industrial world developed from simple mainly single person handicraft production systems to the large industrial machine of today.

Management used to be an easier, more intiuitive job than it is today. The vast majority of firms had a simple organization with few managers. There was specialization but the decision about allocating managers to jobs was often fluid, and jobs were tailor-made to the individuals available. Relations between managers were often informal, rules were few, and decisions were made by hunch based on past experience.

Today's firms are larger and their organizations more complex. The number of managers will have increased, the management levels will be more numerous, and more clearly defined. Specialization of jobs will have increased. Individuals will be fitted to jobs rather than vice versa.

Rules will have developed to cover many aspects of the business, such as who is authorised to spend money, how much and on what. These rules will apply to categories of people such as factory managers or manual workers; their application to individuals will depend upon which category they are in.

The fact that manufacturing systems were significant in society focused resources on the solutions of business and industrial problems. These problems attracted the attention of economists, mathematicians, sociologists, psychologists, and now cyberneticians. Most of these people's efforts were towards providing society with a relative abundance of physical goods at low cost, and available in a large range of items. The results have been a body of knowledge, experience, and techniques dealing with forcasting, organizational design, scheduling models, inventory models, computers, simulation, mathematical programming, and so on.

Any organized system (a business organization for example) must not only conserve its state of organization, but also accomplish the appropriate functions it was designed or built to carry out. Therefore, in organized systems, two types of control problems must be solved: control of the internal organization of the system, and control of its functioning which represents its interaction with its environment.

For solution of these problems the organization must have available appropriate organs responsible for controlling its functioning and maintaining the system in a state in which it is capable of working. In a business organization control is achieved via several control decision points inside the organizational structure and sub-divisions. These control decision points are strategically positioned to control the various operations of the organization, which on aggregate produce the final behaviour of the whole system.

The central role of management is to make decisions that determine the future of the organization. Decision making is complex, because the organizational systems with which we deal are complex and involve multiple criteria. This is why system concepts are so important. It is also why we will constantly attempt to maintain a systems context, even when we are discussing seemingly separate elements of production/inventory operations management.

Control decisions are taken by managers in the system. Most decision makers are people rather than machines. That is because decision making (especially in business operations) includes the making of trade-offs involving judgement between different criteria which include, in addition to economic principles, human considerations such as psychological and sociological issues.

Cybernetics was defined by Wiener as "the science of control and communication in the animal and the machine"

(Wiener 1948). This definition points out that there are general laws which govern control processes, whatever the system under control. These laws apply to every kind of controllable system large and small.

There is no doubt that the manager in a business enterprise has to handle the design and control of complex systems. That is why it is only reasonable to refer to a science like cybernetics whose aim is to recognise and analyse complex phenomena and systems, and above all find the ways of keeping them under control.

Business organizations being entities living in an environment which is constantly changing need to be self-regulating and self-organizing systems, and that is exactly what they are, and as proof we see successful business organizations (all over the world) thrive and survive for very long periods of time. Close investigation of these organizations reveals that they contain a criss-cross of information and information feedback channels. Information transmission and information feedback represent the major mechanisms, perhaps the most important of all mechanisms, in a self regulating cybernetic system.

Cybernetics has intensively studied the mechanisms which govern equilibrial and goal-seeking behaviour, and it is perfectly possible to incorporate them in business management models.

We must understand that it is inconcievable that the complexities of an organization's operations could actually be stuffed into a single big feedback mechanism. So by breaking the system into divisions and modelling those, we shall be able to devise a good complicated model of the organization which would be of practical value to our work.

We chose the science of cybernetics to be our reference point because it investigates the characteristics of complex, dynamic systems which apply to business organizations.

In management literature and especially in such literature dealing with the topic of organization we find numerous rules of action in the form of principles, guidelines or, as Beer (1979) calls them, management slogans. The advocates of scientific management stress rational, prescribed rules and procedures. In most cases, these rules represent norms which have been derived from managerial objectives, and they often are far from being operationally grounded. The classical "instructions" around which most of these procedures are modelled stress a hierarchical ordering of authority and responsibility, careful specification of tasks to be performed and of positions to be filled, formal rules and regulations to govern many decisions and actions in the organization. Hence many of the management consultants are trying to promote bureaucracy. They advise a carefully planned organization with clearly defined levels of authority, and a specified hierarchical structure with a fixed organizational chart (March 1968).

> "An organizational chart can be a valuable aid in accomplishing the organizing function" (Hicks 1978).

> "An organization chart can assist in structuring authority and accountability relationships" (Brown 1945).

> "Organization charts can be of considrable assistance to the managers" (Anderson 1977).

Haiman (1978) stresses the importance of organizational charting :

> "As people draw its structure, they can not help but analyse the organization. Through this analysis, structural faults, duplications of efforts, and other inconsistences that lead to lowered performance are revealed".

March (1968) argues that the hierarchical tradition is reinforced by the social status which attaches to the different jobs in business, by the different levels of society from which occupants for various jobs are recruited.

Stafford Beer who is a leading cybernetician and consultant in the science of management disagrees with this approach to the business enterprise. He argues that any business enterprise which exists in a rapidly changing environment cannot, if it is to survive, be very rigidly structured. As jobs change authority relationships become more flexible and many of the rules cease to be appropriate; "Organization structures are becoming increasingly short lived and unstable" (Druker 1973). A manager working in a rigid hierarchical structured organization will have his freedom of action curtailed. He will be restricted by the definition of his job's responsibility and authority. Bureaucratic specialization of work assignment reflects a felt need for certainity at top levels about the inclusion of all essential activities in the program of the firm and about the ability to affix responsibility when something goes wrong (Beer 1979).

Highly hierarchical structures are unfeeling machines which take no account of individuals and individuals' sociological and psychological needs (Checkland 1980, Stewart 1979). Charts and images of the organization are developed over long periods of time and are generally kept at a tacit level. If there is a change in policy with fundamental organizational implications, we can hardly expect that policy makers and managers will instantly develop organizational charts consistent with the implications of those policies.

For the enterprise to exist as a successful cybernetic system Beer stresses the importance of freedom and autonomy to the managers in taking their control decisions (especially managers of the basic divisions of the firm)

> "The implementation of policies should be the responsibility of organizational parts with discretion and autonomy. Autonomy, that is, the possibility to define policies, adds a huge flexibility to the system. Indeed, it permits local responses to environmental demands" (Espejo 1983).

Autonomy is a basic concept in the organizational ability to survive in constantly changing environment

> "The organism's reacting part is itself divided into sub-systems between which there is no direct connection. Each subsystem is assumed to have its own essential variables and second order feedback" (Ashby 1970).

Beer also stresses that this freedom must come within the overall harmony and synergy of the whole system "Autonomy is provided by the recursive structure of the system" (Bateson 1979) (see chap. 3).

Through his research of organizations, Stafford Beer developed what he calls a model of the viable system. A viable system is defined to be one which is able to maintain a separate existence and is survival oriented

> "The viable system is autopoietic: it produces itself. Thereby it maiantains its living identity. It preserves its own organization" (Beer 1974, 1979).

As such, Beer has charecterized all organizations (e.g. business organization) as viable systems. For the system to maintain a separate existence (viability), depends on a number of necessary conditions which, in sum, will also be sufficient (Beer 1979).

Rather than spliting the control activities into functional elements each one operating more or less autonomously (traditional management decentralization), Beer's cybernetic model divides the activities of the organization into five fundamental systems which consist in a recursive hierarchical structure "In a recursive organizational structure, any viable system contains, and is contained in a viable system" (Beer 1979) (see chap. 3). Beer's cybernetic view indicates the organization would be more effective in dealing with internal and external environments.

The approach developed by Beer was aimed at supporting the effective organization of all those levels emerging from organizational need. The criteria implicit in his design was that higher managerial commands had to be kept to a minimum consistent with the cohesion of the system as a whole

> "The metasystem...should make only that degree of intervention that is required to maintain cohesiveness in a viable system" (Beer 1979).

Besides the fact that more commands imply more dimensions of bureaucratic control, they also imply less potential autonomy for lower structural levels. The more their autonomies are constrained the less is their ability to respond to the demands of their environments, thus implying lower performance. However the other extreme, where higher levels do not command at all, would imply lack of cohesion in the system, and the inability to achieve overall policies "The presence of stability always implies some coordination of the actions between the parts" (Ashby 1970). The core of Beer's design was aiming at minimizing bureaucratic controls.

To promote his ideas about the structure of an enterprise Beer designed a special model of the enterprise based on his five system view of the viable system (see chap. 3).

Stafford Beer's theories and ideas about the organization of the enterprise come out of practical and operational experience as he has undertaken a wide variety of managerial and organizational positions for over twenty years, and has held the posts of company director, managing director, and chairman of the board. He is also a past president of the Operations Reasearch Society in Great Britain as well as past president of the Society for General System Research in the United States. He holds the Lancaster prize of the Operations Research Society of America, and the McCulloch Award of the American Society of Cybernetics.

Stafford Beer applies his model to every kind of enterprise _ from the firm to a whole industry, from the institution to a social service, from department of state to total government. Beer also applies his model to the human being and his biologiocal and social structures. He puts it plainly "the laws of viability lie at the heart of any enterprise" (Beer 1979).

Beer's model of the viable system with its organizational applications and Beer's cybernetic explanations and concepts are very appealing and find support (as shown before) from cyberneticians and organizational scientists. However, all these theories and ideas are based on mostly hypothetical situations and need to be investigated and their theoretical implications studied with reference to concrete and applied situations.

In this work we are going to apply Beer's model of the viable system (enterprise) to a business situation in order to study the way the enterprise would behave as a whole as well as studying the behaviour of its subsystems and their interactions among themselves.

In trying to apply Stafford Beer's work to real life business situations for the purposes of a research study we found that there arose a number of difficulties. These mainly centered on the reluctance of companies and firms to assist with information in any kind of work that is not of direct commercial interest to them. Also, there is a reluctance for firms to give the sort of intimate help that is required by this work unless the research is sponsored and/or inspired by themselves.

Another kind of difficulty that faced us was that real life research requires a lot of financial support for such things like transportation, mail, communications, etc. which could not be met by the budget of the university.

Faced with the above problems we decided to investigate alternative approaches. A good and first candidate was simulation. By building a simulation model with all its benefits (see chap.4), we can partially put the previous problems behind us. Besides the already mentioned benefits, computer simulation is the most commonly used of all the analytical tools of management science, and the principles are straightforward. The analyst builds a model of the system of interest, and uses the computer to simulate the system behaviour under whatever circumstances he wishes to study, and then analyses the simulation results.

As mentioned before the main purpose of our work is to investigate the theoretical implications of Stafford Beer's ideas about the nature of business viable systems, simulation offers an opportunity to do this without the incompleteness that necessarily often accompanies an empirical study.

In the process of building a simulation model, an interesting approach was to use industrial dynamics methodology, which is a methodology designed to enable quantitative studies of industrial systems (see chap.4). A simple model was built to investigate that method, and judging by the preliminary results obtained it was decided to abandon that modelling approach.

Another attractive approach was to use operations research methodology to model the different decision making points in the business enterprise since any problem that requires a positive decision to be made can be classified as an operations research type of problem. Furthermore, with this kind of modelling we would be able to study in depth the various control decisions taken by the different managers in the system, as well as being able to experiment with different variables which influence these decisions. O.R. based decision making methods help the management of any sub-division of the enterprise to practice its own freedom in optimizing its own operation, but at the same time keeping in line with the overall effectiveness of the system. This aspect is going to a be a major part of our experimentation with the model.

Our model represents a production-inventory kind of enterprise, and we chose that kind of system because it is becoming increasingly evident how the overall efficiency of a firm's operation is directly related to the production-inventory situation existing within the firm (see chap.2).

The model was designed to be as simple as possible in order to appeal to a large range of people with different backgrounds, but at the same time care was taken so as not to lose so much complexity that the model would be unrealistic and thus of little use to us as a simulation model for Beer's ideas.

The model was divided into sub-models, which represent the various activities of an inventory-production enterprise.

Probabilistic and deterministic models were used, and an attempt has been made to use only that mathematical and statistical theory which is absolutely essential.

Each sub-model was designed to be able to work independentley as a separate simulation model in order to help people who are interested in studying a particular business activity, e.g. inventory control or production scheduling.

To facilitate communication, especially for anyone who is not familiar with cybernetic notions, a linear framework is introduced for the presentation of the thesis.

The thesis is loosely divided into two parts. The first part (chapters 2,3,4) deals with the cybernetic-management backgrounds and relations, and a discussion of Stafford Beer's theories and how to apply them to a simulation study. The second part (chapters 5,6) deals with our simulation model and its sub-models and discussion of the simulation results.

Chapter 2 deals with the history of cybernetics, control in cybernetics and management, the significance of information in cybernetics and in management, and a small purpose built model showing the importance and need of information in a production system.

Chapter 3 examines Beer's definition of a viable system, and how it applies in business systems. Beer's model of the enterprise is also discussed. The chapter also includes a discussion of cybernetic concepts in management control, especially the notion of autonomy in the business organization structure.

Chapter 4 looks at some of the major activities of a business enterprise which are inventory holding and control, production planning and scheduling, and forcasting. Simulation as an approach for studying dynamic business systems is studied. The chapter also investigates the modelling aproach of industrial dynamics, and its suitability to our work through the building of a simple model.

Chapters 5 and 6 represent the modelling and simulation part of our work. Chapter 5 contains five sub-models, together with a full description of the methodology used. In chapter 6 our full model of Beer's systems one, two, three is represented and described. It incorporates all the models of chapter 5 (with some modifications). The chapter also contains a description of the results obtained from the various simulation runs.

. The final chapter contains our conclusions based on the simulation results of our model. These conclusions are mainly concerned with the validation of Beer's ideas and their applications in modern management science.

The appendixes contain the mathematics, descriptions, algorithms, flowcharts and program listings of the various simulation models.

CHAPTER TWO

CYBERNETICS AND CONTROL IN MANAGEMENT SYSTEMS

2.1 Introduction

This chapter gives an overview of cybernetics; the newly emerging descipline and its history. It also provides a view of the abiding relation between cybernetics and control and thus, the relation between cybernetics and feedback, which is an important factor in control and control mechanisms.

A definition of systems and the relation between the system control and cybernetics is also shown, which leads us to the important part cybernetics plays in the control of management systems.

Information, which is the stuff being circulated in the channels of control feedback systems is discussed, as well as its role in the whole of the control process. The part information plays in management systems is highlighted by studying examples of management information systems which are parts in important business operations such as inventory control and production control.

2.2 Cybernetics _ a short history

The term cybernetics originates from the greek word "kubernetes" meaning steersman. It is also the root of the english word to govern, or regulate, or control. It is known from history that the same term was already used many centuries back by the greek philosopher Plato to designate "the science of the steering of ships". The same term was again used in about 1843, by the french mathematician, physicist and philosopher Ampere for "the science of the control of society".

In modern times the term was first introduced in 1947 by Norbert Wiener who defined it as the science of control and communication in man, animals and machines (Wiener 1947). He used it to describe the phenomena of a system responding, rather than reacting, to its environment, and this discription includes systems such as: human beings; animals; computers; thermostats or automated factories. It should be noted that by system is meant a group of elements or parts considered as an interconnected whole with a behaviour which is not related to any particular element but to the system as a whole.

Cybernetics is a science which had started to develop by the end of World War Two. It underwent a very rapid development and it now exerts an important influence on the methods of solving certain problems in a wide range of disciplines which include engineering, medecine, biology, computing, communications and economics. Cybernetics cuts across these already established disciplines by abstracting those common features that contribute to the development of a general approach to the investigation of control and communication process in various types of systems (George 1971, Lerner 1972).

Wiener tried to give an outline of the means of developing a general control theory. He laid the foundations for the methods of considering problems of control and communication for various systems from a single and unified point of view. He and other early workers in cybernetics felt that action was needed to provide the solutions to a variety of practical problems existing at that time, during the war. For example, the production and use of computers, and in particular the use of computing devices for directing the fire of anti-aircraft guns, which among other things involved the separation of a useful signal from the accompanying noise. Other practical problems were the design of machines for reading aloud, and some problems of neurophysiology. At this time new tools appeared in the form of analog and digital computers, and it became possible to carry out cybernetic experiments which were based on modelling of control processes by means of computers.

Another important worker in cybernetics, W. R. Ashby, associates cybernetics with the science of behaviour (Ashby 1976), because it studies systems in a way which differs from orthodox ways of doing so. Ashby asserts that cybernetics treats not things but types of behaviour, as long as that behaviour has the characteristics of regularity or determinance or growth and change.

Of central interest to cybernetics is the notion of feedback, which is a vital factor contributing to adaptiveness and is important in control processes. Cybernetics is much concerned with feedback systems and their properties. It is the negative feedback of information flow from the output of a system back to modify its input, and the storage of information over long periods of time, which in controlling systems, are the basic features of cybernetic interest.

A basic characteristic of cybernetics is that it does not only consider control systems in their static state, but also during their action and development. Such an approach does reveal many relationships , phenomena and behaviours, which otherwise would remain undiscovered. For example, the study of stability as a system property would be virtually impossible without considering the dynamics of its internal organization.

Cybernetics rarely considers isolated systems, it is most often concerned with groups of systems. It considers the set of interconnections that necessarily occur between individual parts of complex systems, and it attempts to determine the properties of such systems, their behaviour, and other aspects that relate to their existence as whole systems (George 1971, Pask 1972).

2.3 Cybernetics and control

As mentioned in section 2.1, the original meaning of cybernetics is steersman. The steersman of a ship has to keep control, or his ship will wander off course, and end up on the rocks. This job needs continuous judgement, the steersman continually adjusts his tiller to keep the ship on course. He observes any variation from his course, estimates the adjustment needed to overcome it, moves the tiller, observes the results and repeats the process. Any action directed towards a goal must be controlled to achieve that goal. Progress of the action at any moment can not be known without some form of communication. The two functions of control and communication are necessary for any systematic action, voluntary or involuntary.

So being a science of control, cybernetics does not study all systems generally, but only control systems, and the range of application of cybernetics covers a large variety of systems living, mechanical and economic, in which control exists.

A characteristic feature of a controlled system is its ability to respond to changes in its environment, and to pass or progress into various states under the effect of control actions.

Feedback, as stated before, plays a central part in the process of control. There are two types of feedback _ negative and positive. Negative feedback applies to all control systems that are negative error-actuated systems, whereby the actual state of a system is compared with the desired state and the differences detected by a comparator unit in the system as positive errors. Action is then effected in the opposite direction to counteract the errors. However, in a system with time lags inherent in its feedback structure, negative feedback can lead to instability and oscillation. The oscillation will occure at precisely the frequency for which the time lags cause a phase shift of 180 degrees. Positive feedback does exactly the opposite, and it tends to amplify error until it goes out of control (Forrester 1961, George 1960, 1970, 1971, Klir and Valach 1967).

Fig.(2.1) Basic cybernetic control system

In general, we can say that a cybernetic control process of a system starts when outputs are detected and are measured by a sensor which indicates the actual state of some aspect of the system, treated as the the controlled variable. In such a case, the output signal is then communicated by the process of feedback to a comparator which compares the actual state of the system with the desired state. The difference between the two states is a measure of the variance or error. The detected error is then communicated to the effector, which may take different roles depending on the type of system it is in. Such control components can frequently be identified in human organizations. For example, often a person fulfils the role of a comparator; he may be the supervisor or manager in a business system. Or, alternatively the comparator may be an automatic device in a mechanical system (Beer 1966,1969, Pask 1972). After receiving the measured error, the effector adjusts the input to achieve the desired output and obtain a state of homeostatis, which is the process of balancing or holding steady the parameters essential for the effective control of the system despite environmental disturbances.

2.4 Systems and system definition

The system is the central theme of cybernetics, through which a problem or a set of problems is identified and subsequently solved.

It is the transfer of information from and to the system which determine the working of a cybernetic system. Stafford Beer emphasizes the importance of the system in his definition of cybernetics

> "the new science of cybernetics is the science of control and communication whenever these occur in whatever kinds of systems. The core of cybernetics research is the discovery that there is unit of natural law in the way control must operate, whether the system controlled is animate, physical or biological, social or economic" (Beer 1966).

He also defines a system as: "a group of elements dynamically related in time according to some coherent pattern" (Beer 1979). Beer emphasizes the notion that, in the final analysis, that depends on what the system is observed as actually doing.

Formulation of problems through a cybernetic approach means to define the system and then understand its mechanisms of self regulation. For example: in an inventory situation it is a problem of the implementation of a feedback of changing demand structure on the production system.

Any system is an ensemble of elements, some or all of which are interrelated. For identifiying a system, we have to know its behaviour characteristics which is represented by:

1- The manner in which various elements within the system are related.

2- The manner in which the elements react to any external influence. In cybernetics the external influence is called the environment which is the set of factors outside the system. The effects of the environment on the system are called stimuli, while the effects of the system on the environment are called responses. The response of a system to any stimulus is dictated to a great extent by the way the elements are organized within the system.

A system may comprise a number of subsets or subsystems, while the entire system might be a subset of an even larger system (Klir and Valach 1967).

Systems may be classed under any of the following three categories:

1- Closed system, which means that there is no effect of the environment on the internal elements of the system.

2- Open system,in this case the environment has an effect on the system's elements, and the system continuously exchanges materials, energies or information with its environment.

3- Partially closed system, and in this kind of system the environment has effect only on a subset of the system.

There are adaptive and non-adaptive systems. An adaptive system is one which reacts to significant environmental changes in a way that allows it to continue fullfiling its purpose. It does this through changing its own modes of behaviour accordingly, either through learning or some form of evolution.

The defining of a system boundaries with its environment is rather a difficult job. However, depending upon what the observer includes in or excludes from his definition of the particular system he has more or less defined this system within a certian boundary. The choice of variables that define the system is critical in determining what the system is, what its behaviour will be (whether or not that behaviour will be comprehensible) and what can and cannot be done about, or to,that system. Unfortunately there is no simple formula for choosing the right set. For example we may define a social system, such as a company or a department within it, as a system, but, as can be readily seen, the boundaries are not rigid, impenetrable, or closed and are rather fuzzy.

2.5 Cybernetics and management control

Cybernetics addresses the fundamental ingredients needed for all acts of organization and planning. The word cybernetics applies, as mentioned before, to any sort of closed feedback system which is adaptive; commercial enterprises and all other types of business should be of that nature. The basic metaphor of management cybernetics is that a business is like a human being. It needs a system, such as the brain and nervous system, to control it, and to carry out that control effectively requires senses and sensors, in order to pick up information about changes in the surrounding environment. Stafford Beer has stressed this in his work, and puts forward the cybernetic concept that industry or business is like an organism (Beer 1966). An entity such as a firm or an organization has the same trouble in preserving its identity and surviving in a changing environment as any organization or animal. It either evolves or decays.

As may be noted from the foregoing, control in management is the process of monitoring business operation to ensure that they attain the desired state and accomplish the planned objectives, and the taking of appropriate corrective actions when needed (Anderson 1977). This is achieved by comparing the actual results attained with the planned objectives and measuring the extent of deviations.

The deviations are reported to the manager responsible for achieving the objectives. Action is then effected to eliminate any adverse situations or effects, or take advantage of favourable conditions, and in some cases make changes to the initial objectives if they prove to be inpractical for some reason, or the circumstances on which the original plans were formulated have changed.

The controllers in a management system are those personnel in the organization responsible for planning and monitoring the activities and use of resources within specified functions of the business (Duncan 1974). In addition, controllers also have the responsibility for providing information to operating managers (who also control), in order that they have the facts on which to base the necessary corrective action which leads to the achievement of the objective for which they have planned.

Control is achieved by the dissemination of information from the control system within the adminstrative function. The administrative sections collect, record, process and provide information to the various levels of operating management who effect corrective action as seen necessary from the information provided. The administrative sections do not themselves effect action directly (Beer 1966, 1969, 1979, George 1970).

2.5.1 Control and the management hierarchical structure

In systems with a hierarchical control structure, the lower level management (controller) should decide on relatively simple local control problems which are within the capacity of his control devices. Then the control devices of the next level will be left to deal only with those control problems which have to be solved in order to co-ordinate the work of the lower level units. The same applies to the control devices of higher levels, and therefore, the volume of information which they have to process is greatly reduced and can be made to correspond to their information handling capacity. The control hierarchical structure of a modern management system is based on the successive division of the system into sub-systems between which a relationship of subordination is established. The control devices of higher order, control larger sub-divisions of the system, each of which has its own control equipment. Each sub-division is in turn broken down into smaller ones which also have their own control devices, and so on, right down to the lowest sub-division of the system where further sub-division would be impractical (Anderson 1977, O'Shaughnessy 1976).

Control of any business-like activity will not be effective unless suitable criteria are used to measure the actual results achieved. It is not sufficient just to compare current results with historical results, because this approach only indicates that the current period of time shows an improvement or a deterioration over the corresponding previous period. An effective business control should, therefore, be based on the tactical plans and targets of the corporate body.

2.5.2 Organization charts

The use of organization charts is a way of graphically portraying an organization's structure and they are relatively easy to construct. They show the skeleton of the organizational structure and depict relationships and groupings of positions and functions. The charts help to show what has been decided, they will also be useful as explanatory devices for showing to newly appointed managers and inquiring visitors. But organization charts have their dangers. Their usefulness is often exaggerated and they can rapidly get out of date and, unless they are frequently revised, they may soon give a false picture of the organization's structure (see chapt.3). Another danger is that they might give the impression that reality is as tidy as the chart _ which in many real life cases is not true (Beer 1981, Kast 1974, Stewart 1979, Young 1968).

2.5.3 Management activities to attain overall control

The main responsibility of the corporate managing director is the co-ordination, direction and control of all functions to ensure that they operate harmoniously, and follow a common path, so as to achieve the objectives of the business as a corporate entity rather than only optimizing the performance of individual departments or sections. For example: production management would like to produce the largest batches of output possible, whereas the sales management would prefer producing every item for which an order could be obtained regardless of the economic quantities which are essential for utilising the productive resources in the most effective way. Functions such as production, materials, marketing and personnel are separately structured for ease of control and administration, and each is the responsibility of a specialist functional manager. Each functional manager assists the other functional managers to enable them to operate effectively by providing them with specific information in respect to their individual area of responsibility. For example: the raw material management informs production management of material availability; production management informs marketing management of the work in progress situation as it effects orders; financial management inform all functional managers on the costs of relevant items and expenditure, and personnel management inform all functional managements about the matters that relates to personnel status. Since individual functional managers have different types of decision to make and objectives to achieve, it is an essential matter that any proposed course of action should be agreed upon by all functional managers before implementation, and it is here that the managing director plays a major role in the coherance of all the functional managers activities to achieve the results required by the corporate body. Each functional manager then interprets the agreed objectives and draws up detailed schedules, targets and time tables for the section or department under his responsibility (Beer 1966,1969, Kazmier 1974).

2.5.4 Centralization and decentralization in management control

By centralization it is meant the centralization of authority and decision making at one senior management center. Centralized authority is common in small enterprises and is often necessary if the enterprise is to survive in a competitive environment. Centralization requires that the chief executive is in close touch with or agrees all operations, makes or agrees all significant decisions, and gives or sanctions all instructions. He does not care to, or is in no position to, delegate any authority.

Decentralization is the extension of delegation. Delegation refers mainly to the granting of authority and the creation of responsibility. Decentralization is the result of systematic delegation throughout the organization. Delegation can occur without decentralization, but decentralization cannot occur without delegation. In decentralization top management initiates policies and programs, but delegates their applications in day-to-day operations and planning. Decentralization can vary in limitation from one organization to another depending on the size and operational cicumstances of the organization concerned (Stewart 1979, March 1975).

2.5.5 Hierarchical control of management systems

Hierarchies consist of decision making units arranged in a pyramid where at each level, a number of such units operate in parallel. Hierarchical structures are found primarily in socioeconomic systems and in general exist in systems which have an overall goal and the goals of all the decisions makers who constitute the hierarchy are in harmony. However, it must be noted that in real systems the individual goals of the decision makers might not be in harmony. The reason hierarchies arise was that in a large system which has a definite goal it is too complex for one decision maker to control the system alone due to the limited information processing capabilities of this decision maker. And since time flows squentially, it is possible to perform more tasks in the same time if decisions are taken in a parallel manner by the various decentralised controllers on the same level hierarchies.

Hierarchical control techniques are used for synthesising hierarchical structures for the control and optimization of large interconnected dynamical systems. A situation which has recently been analysed in the context of computational hierarchies, but which could yield insight into the behaviour of organizational hierarchies is the case where communications break down between higher management and lower level decision makers. Hassan and Singh (1980) have developed a technique which quarantees stability of systems and allows near optimal decentralized regulation.

Hierarchical control methodology offers much promise for the organizational management of integrated industrial complexes (Singh 1980).

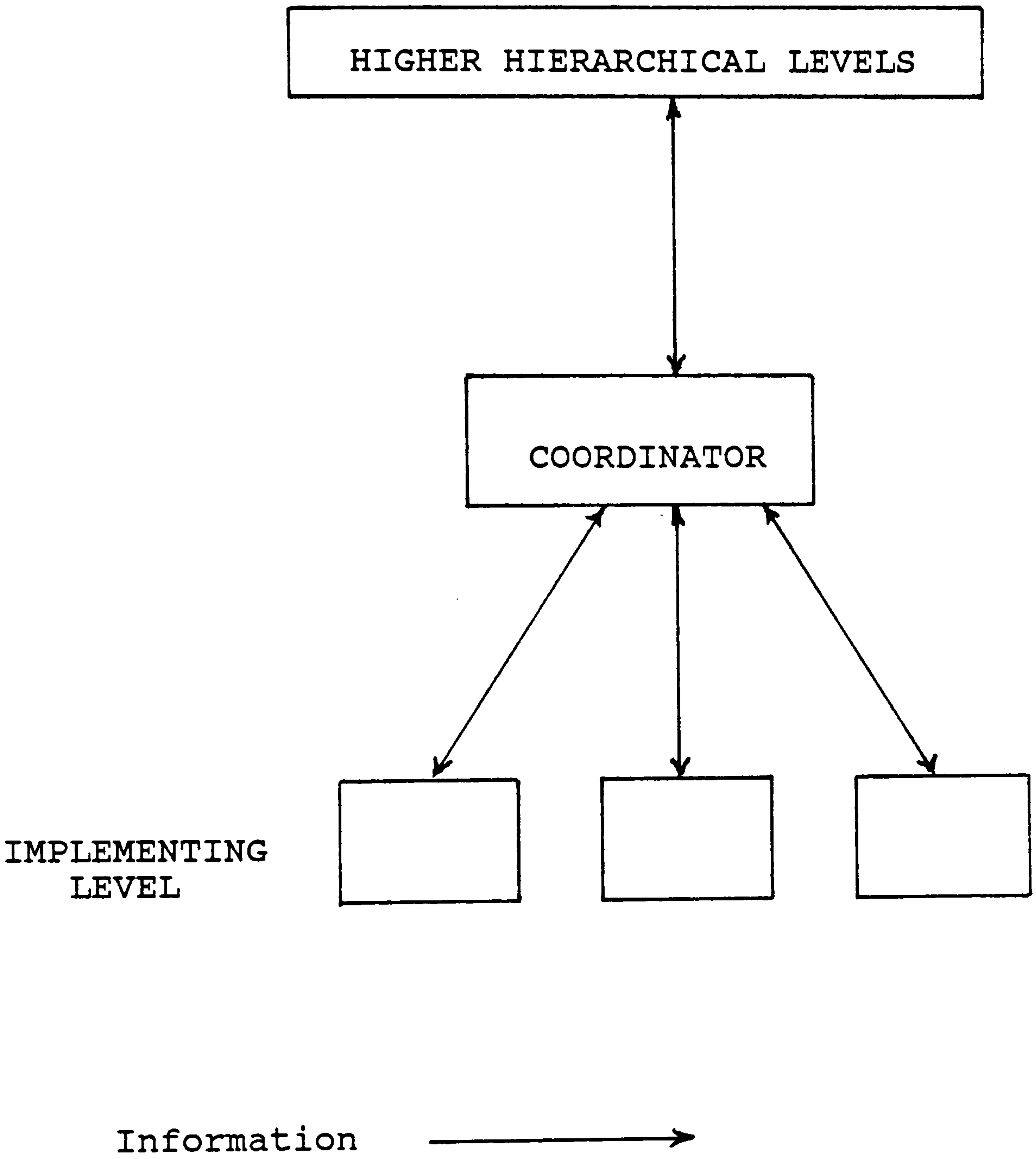


Fig.(2.2) Implementing lower level and its coordinator in a hierarchical system (from Singh 1980)

2.6 Information and management control

2.6.1 Information

The oxford dictionary (1961) defines information as: the action of informing; communication of instructive knowledge; the action of telling or the fact of being told something; knowledge communicated concerning some particular fact, subject or event.

In general information is spoken of as a term for news, reports, intelligence; anything in fact which is communicated from one person to another, one group to another, from a machine to people, from people to a machine,from machine to machine and so on.

Information should not be mistaken for data, there is a distinction between data and information. Information results from the processing of data, in other words information is derived from the assembly, analysis and grouping of data into meaningful form. In general data may be regarded as low level, unprocessed information.

Information is invaluable in the decision making process, because it reduces uncertainty about some past, current or future state or event, and it is that piece of knowledge which may be applied to a decision by a person who has the authority and responsibility to take that decision (Beer 1976, 1979).

2.6.2 Information and management control of the firm

The most fundamental purpose of management is undoubtedly the assurance of the survival of the firm. Most managements look for opportunities to lead their organizations to better performances in all directions; higher sales, higher productivity and ultimately greater profitability. In order to carry out these and other objectives that particular firms may have, it is necessary for management to be in control of the firm and all its activities. The management of a firm may consist of a large management team, with various levels and responsibilities, and this division in responsibilities will help to simplify and speed the process of overall control of the firm.

2.6.3 Information communication

The simple model of a basic information communication system in fig (2.3) shows the basic elements of an information communication system and brings out the concept of a communication channel, and the conversion of a message (piece of information) from one form to another, which is called coding. In the context of management information systems, information is constantly coded and decoded at various levels. For example: a personnel director will explain a senior management decision to the shop floor in different terms from those used at the senior management level.

The capacity of the communication channel determines the rate at which the information can flow down the channel (Ashby 1976). If the information is distorted as it passes through the channel (Ashby 1976), that is called a noise effect in the channel or a noisy channel; thus noise introduces errors into the transmitted information. Because of noise, information communication systems usually employ special error detection and correction codes which involve the transmission of more information than the that associated with the basic message and they often involve more than one channel in case the normal channel suffers too much noise or a breakdown (McCosh,Rahman and Earl 1981, Li 1972).

In information theory, information is regarded as an entity which changes the uncertainty of the receiver about a certain matter. Uncertainty in turn, is associated with the concept of entropy which can be described as being associated with the degree of disorder or uncertainty in a system. When useful information is transmitted, the uncertainty of the receiver, and hence the entropy, is reduced. In information theory the amount of information is equal to the change in entropy (Ashby 1976).

2.6.4 Management information systems

Information systems of various types exist in all organizations and range in complexity and level along various dimensions; technical, managerial, formal and informal. A management information system can be defined as a system which provides each manager in the organization with the information he needs in order to take decisions, plan and control within his particular area of responsibility (Davis 1974, Espejo 1978, Mac 1974).

Every business exists in a dynamic environment to which it is continually adjusting under the control of decisions by its management associated with the feedback mechanisms that comprise its information system. Without an adequate information system, passing knowledge about the conditions of its constituent parts and about its environment, the firm can hardly survive (Beer 1976,1979).

The manager needs information of a relevance and timeliness appropriate to the nature of his decisions, planning and control requirements. So in designing an information system, the designer should take into account the manager's desires for particular information, and he should also try to get a good feel for the manager's job responsibilities in order that the manager would only get the information he needs and not be flooded by irrelevant information (Espejo 1983).

To summarize, in a business, an information system is an auxiliary for another system, the object system or managed system. By the object system we mean the organization or firm. The information system has to provide the information needed at any point at any time in an object system in order to maintain control and stability.

2.6.5 Information and management decision making

Management is the process of converting information into action. The conversion process is called decision making. Decision making is in turn controlled by various policies of behaviour. A policy is a rule that states how the day by day operating decisions are made (Simon 1977).

Decisions are the actions taken by managers at any particular time, and are the result of applying policy rules to the particular conditions that predominate at the moment.

If management is the process of converting information into action, then it is clear that management success depends primarily on what information is chosen, and how the conversion is excuted. Every manager has available to him a large source of information. He selects and uses only a small fraction of this available information (Beer 1979, Li 1972). The manager's accomplishments are dictated by his choice and priority assignment to certain classes of information and sources of information.

Each manager is an information converter at his own particular control point in the organization, and this highlights the great interest shown in decision making and information flow in the system. An industrial organization is an interlocking complex network of information channels. These channels emerge at different points to control physical processes, such as inventory control and production scheduling. Every activity point in the system is backed up by a local decision point whose information sources reach out into other parts of the system, or organization, and into the surronding environment (Argayris 1977, Beer 1966, 1975, 1979).

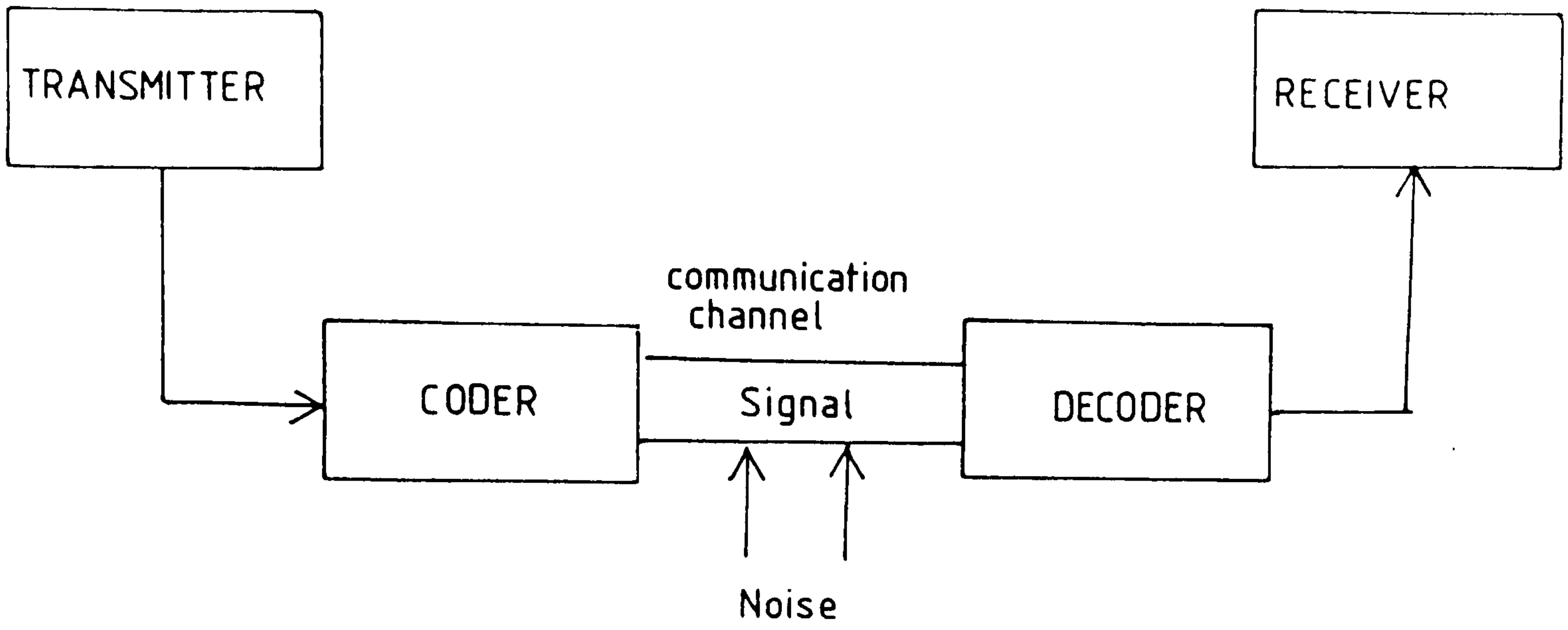


Fig.(2.3) Basic information communication system

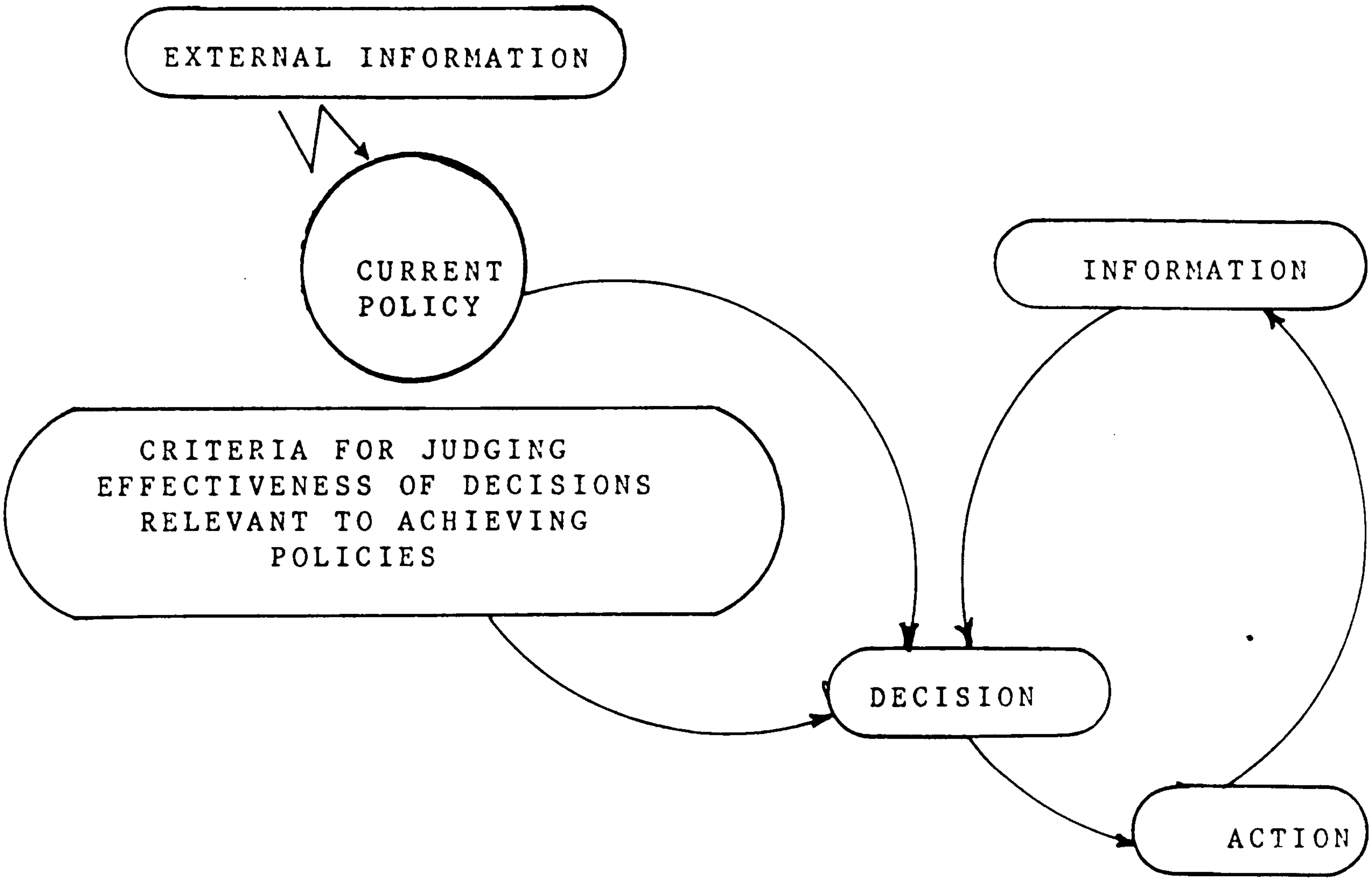


Fig.(2.4) Decision loop

Fig (2.4) above shows a decision loop in the simplified shape of an information-feedback system. Information (internal and external) is the input to a decision making point that controls action yielding new information. This decision is taken according to an existing policy which is based on a certain criteria according to the situation being controlled. In each structural circle there are delays, decisions do not respond immediatly to available information. Information about actions is not instantaneously available. The excution of activity called for by a decision requires time. Information may amplify, or decrease the decision output. Action may amplify, or alter information or decision. Disturbances (outside and inside) create noise in the whole cycle of information-decision-action.

The decision making process consists of three parts, the information defining a set of concepts indicating desired conditions, the observation of the actual conditions, and the generation of corrective action to achieve the desired conditions. Decision making is a continuous process (Haimann,Scott and Connor 1978), and it consists of a conversion mechanism for continuously changing varying flows of information into control signals that determine the rate of action in a system. The decision point is continually yielding to pressures and disturbances from the environment, and it is always attempting to adjust towards the desired goals. The amount of control action is some function of the difference between goals and the observed actual system status.

Decisions that are repetitive and routine are called programmed decisions. To an extent a defined procedure has been worked out for handling them, so that they do not have to be treated as new decisions each time they occur. If a particular problem recurs often enough, a routine procedure will usually be worked out for solving it. An appropriate algorithm will yield a programmed decision, and if fed to a computer as a program, the computer can be used as a 'programmed decision making tool'. This can be implemented in such business operations as inventory control and production scheduling (Beer 1966, 1975, 1976, 1979, Hicks and Gullett 1976, Simon 1977).

2.7 The role of information in controlling the firm's major activities

The following section is designed to highlight the important role that information plays in controlling and regulating the firm's activities. Two simple models of the firm's major activities; inventory holding and production, are studied to illustrate this role.

2.7.1 Information requirement in a simple inventory model

To show how information is a necessity for controlling a management system, let us study a simple example of an inventory control system (which represents a major component of most industrial firms and organizations).

The system to be controlled consists of an inventory and an inflow of goods from the manufacturer, and an outflow of goods sent to customers.

We study the requirements for keeping the material system running operationally. The basic operations of this inventory system besides maintaining and holding the goods in store (full description of inventory systems chap.5) are:

a- Shipping goods to customers.

b- Receiving goods from manufacturer.

It is easy to see that each of these operation needs information to initiate it. To initiate a shipment to a customer, a shipping order has to be sent to the inventory (the shipping order is an information precedent of the inventory function). This order has to give information about the customer, such as the time the goods are required, kind and quantity of goods and other information. To initiate an inventory replenishment reorder from the manufacturer, information about the status of the inventory is required, together with some decision rule which determines how much and when to reorder (again this is an information precedent of the inventory function). We thus obtain a system as in fig (2.6) where a small information system has been added to the basic system of fig (2.5), to handle the information requirement for the operational control.

It should be noticed that the information systems contain not only information but also decision rules and processes for implementing the rules. In fig(2.6) we have added two square shapes to represent the information system. The arrow from the square 'order to ship to customers' is directed towards the inventory to indicate that the information is sent in that direction to initiate an operational action of the kind 'shipping'. There is also an arrow directed towards the same square indicating that information has to reach the system from outside, to tell about a need for goods on the customers' part. Finally an arrow is drawn from square 'order to ship' towards square 'replenishment' to indicate that the function generating reorders needs information that a shipping has been initiated, in order for it to know that it should check if a status calling for inventory replenishment has been reached. The replenishment part of the information system needs information from the inventory about its status and this is indicated by an arrow. Also an arrow pointing away from the square 'replenishment' is introduced to indicate the need to send away a reorder, at the appropriate time, to the manufacturer. The arrow from 'inventory' to 'replenishment' corresponds to performing a physical inventory taking (counting). This is an operation which is much more expensive than the decision process. It is therefore an economic measure, to reduce the frequency for physical inventory status taking, to introduce an inventory status file, which stores information about the status of the inventory each time a status change is initiated. The inventory file is a mathematical model of the inventory storage, and the replenishment function of the information system may fetch or gain information about the inventory status from the inventory file, in a much less expensive way than by physical observation in the inventory itself. The need for inventory physical checking is not completley removed by this method for it is necessary to check, at certain intervals, that the inventory file satisfactorily represents the actual status of the inventory. This has been indicated by the corresponding dotted arrow in fig (2.7). This device introduces a new decision function into the system for it has to be decided when to initiate a physical inventory taking. This also is indicated in fig (2.7). In the same figure an arrow from the double-arrow representing delivery of goods from manufacturer to inventory, and directed into the square 'inventory status', this arrow represents information messages about receipt of goods at the inventory storage (Forrester 1961, Vollman 1973).

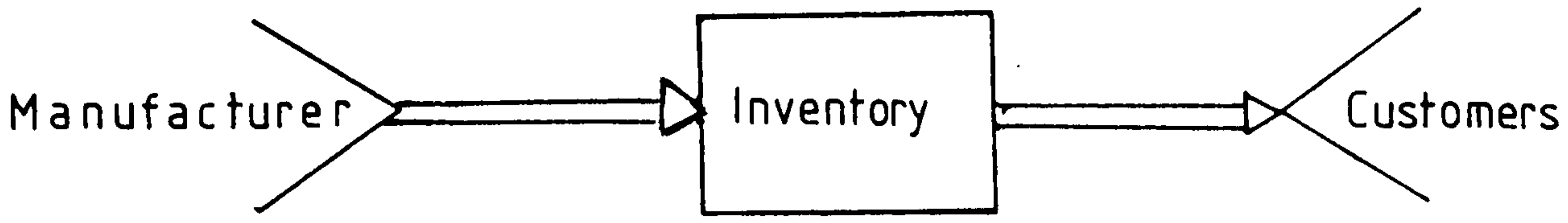


Fig.(2.5) Basic system

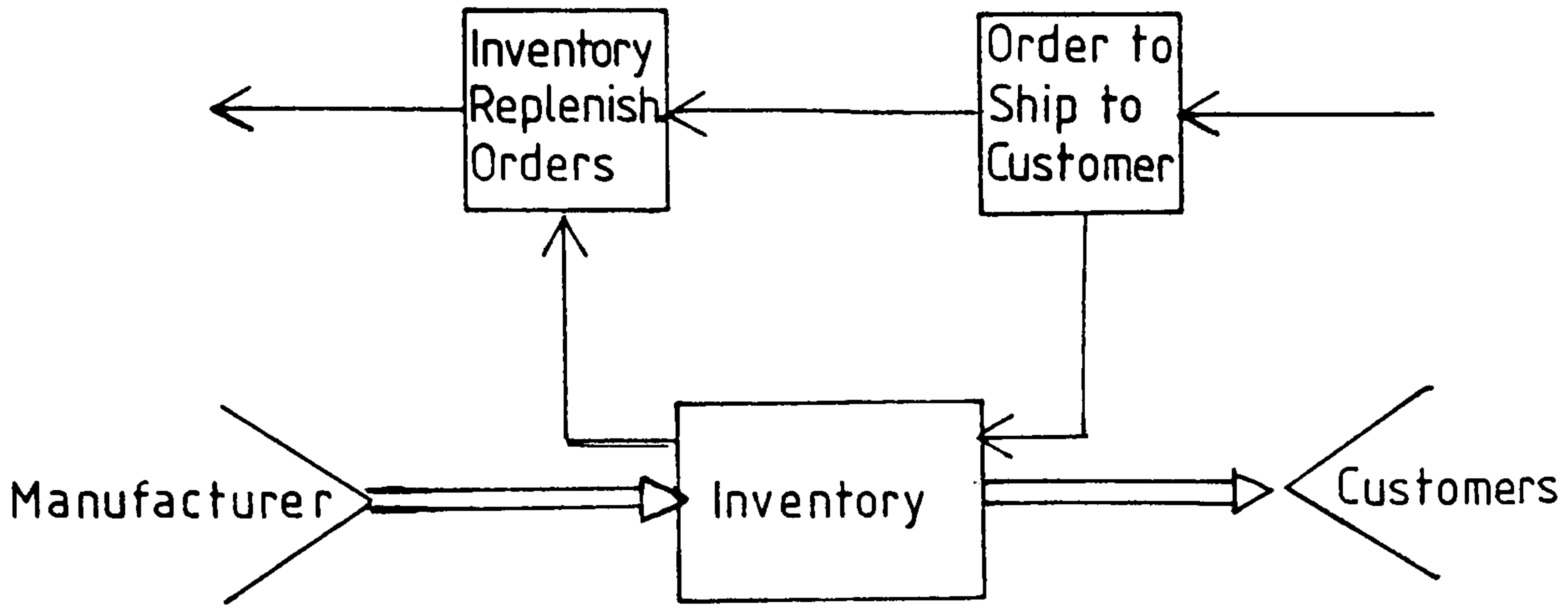


Fig.(2.6) System with basic information system

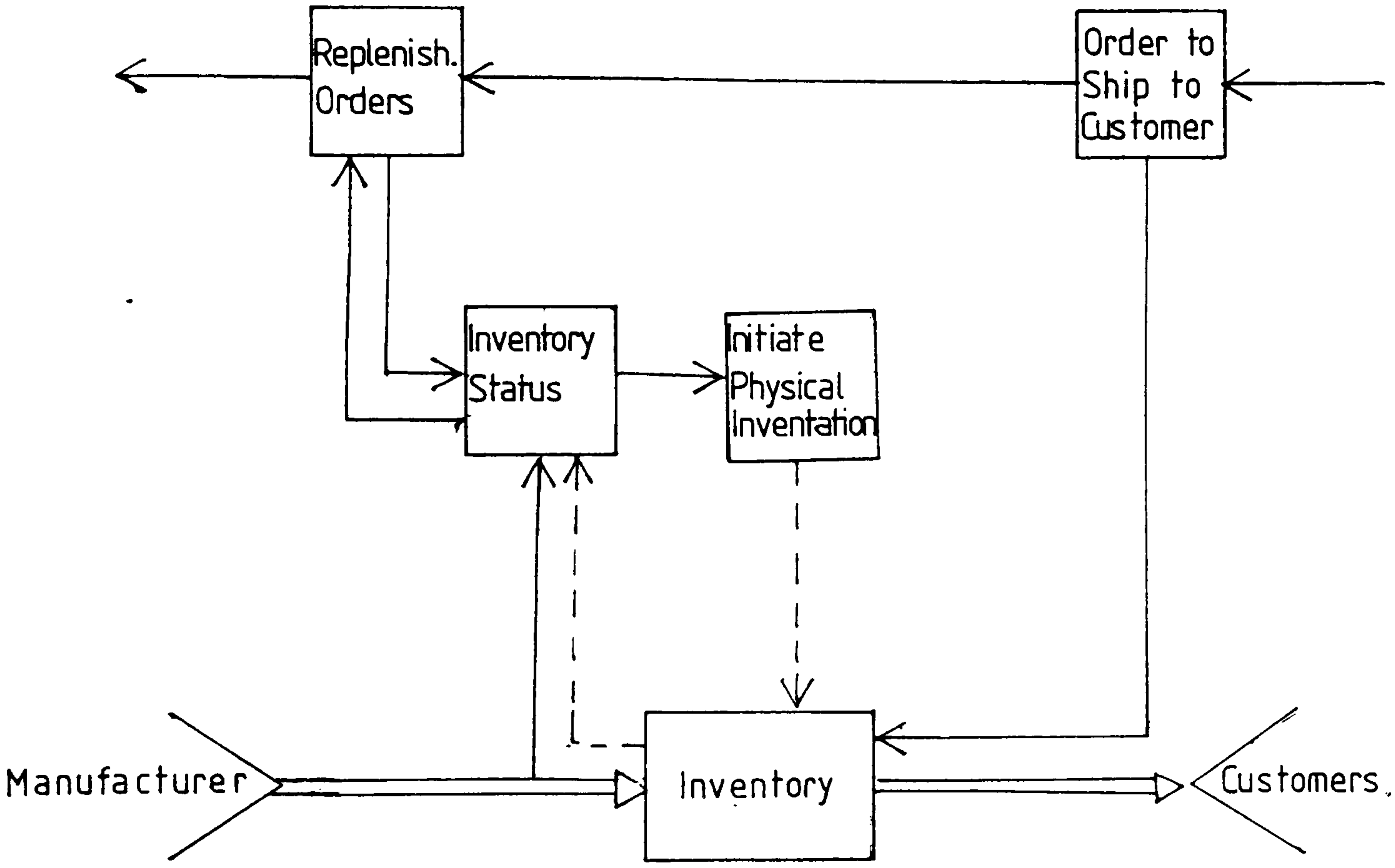


Fig.(2.7) System with added decision rule

2.7.2 Operational and directive information

To maintain operational control, there must be units for fetching information, communication, making decisions, storing information, updating stored information and displaying information. We are going to call all the information at the operational level operational information. From the previous simple model, it can be seen how important the operational information is, and if it is not provided the operative functioning of the management system breaks down.

To improve the efficiency of the system, such as making it more cost effective or more economical, a new kind of directive information is introduced. Directive information is not very necessary in the sense that the system could function without it, but it is desirable however, to the extent that it improves control. Directive information is associated with the total system goals, and the total system overview of information. To illustrate this better take as an example the local operational level of the previous model. Better operational control may reduce the inventory level without causing any stock-outs, and such a reduction is obviously an improvement, likewise a speed up of the information processing may save money by making it possible to keep a lower average inventory level. This has to be balanced against the increased information cost necessary to achieve it. To evaluate this balance may still be fairly simple, because both factors have obvious monetary measures. Things change when we come to a situation where an improvement in one subsystem is done for a price, for a cost, in another system, and where different scales of measure are involved. In our example we have the problem of whether or not it pays to reduce the inventory level even when this increases the number of times a year that we may run out of stock. This brings up the question of how to compare inventory holding costs with running out of stock costs. The important fact here is that such comparisons can only be made after it has been stated which goals are set for the system control, and how the factors studied are affecting the goals. So when looking from the total system economy point of view the above example shows that control decisions at the operational control level may fail to be of guidance, because of the simple fact that operational information at that level is simply not enough to provide knowledge of relevance to these decisions.

To show the role of directive information in system control we take a similar model as that used in the last example, but we add a production unit between two inventories. We can see how the operational information can be extended accordingly, as shown in figure (2.8) between the horizontal lines A-A and C-C, and the operational information system shown between A-A and B-B. The directive information system is introduced in the following way: we take any of the decision functions in the operational information system and ask what additional information would be relevant to it and might therefore be used to improve it. The improvement from any quantity of information will then have to be compared to the cost of processing and using that information.

In figure (2.8), take the decision function of the replenishment reorder for inventory (1) as an example. For operational functioning it may be designed using a reorder level rule, such that when the level of inventory on hand falls below a certain value (the reorder level), then a certain quantity (the economic order quantity) is ordered to replenish the inventory. This decision will work for any pair of values of reorder level and order quantity, which are high enough to ensure that the system will not run out of stock too often. When we add to the requirements of operational functioning, a requirement of best overall economy, this can raise the question of which is the optimum pair of reorder level and order quantity. In order to determine these optimum values information is needed from different parts of the system, as well as information about the goals set by the higher management of the system. In general, the information of relevance to the inventory replenishment decision are: out of stock costs and inventory holding costs.These costs have opposite effects, so that they must be balanced against each other. As the risk of running out of stock is dependent on expected delivery time and expected demand, information about these is also of importance. Thus we have added four kinds of desirable information to the two kinds required already by the operational functioning (inventory level and order to ship to customers).

We can see that whereas the operational information needed for the inventory replenishment decision is available at the inventory control subsystem level itself, this is not the case for the added directive information. For example the costs of running out of stock are not determined by information that occurs at the inventory itself. Instead this cost depends on the situation at the market, it may also depend on the goals set for the firm. This is indicated in figure (2.8) by arrows drawn from sales, customers and top management towards 'out of stock'.

Directive information not only has to be communicated from local and non-local sources, but sometimes it is not available at all, and has to be computed from other information, which in turn itself might be aquired or computed from yet further information. Eventually we need information from all over the system and its environment. It should be noticed that the list of potentially relevant information for the replenishment decision for inventory (1) in figure (2.8), is for illustrative purpose and is by no means complete, due to the fact that in reality, even for a single operational decision function for inventory replenishment, a very large amount of potentially useful information exists (Beer 1976,1979, Haimann,Scott and Connor 1978, Hicks and Gullett 1976, McCosh,Rahman and Earl 1981).

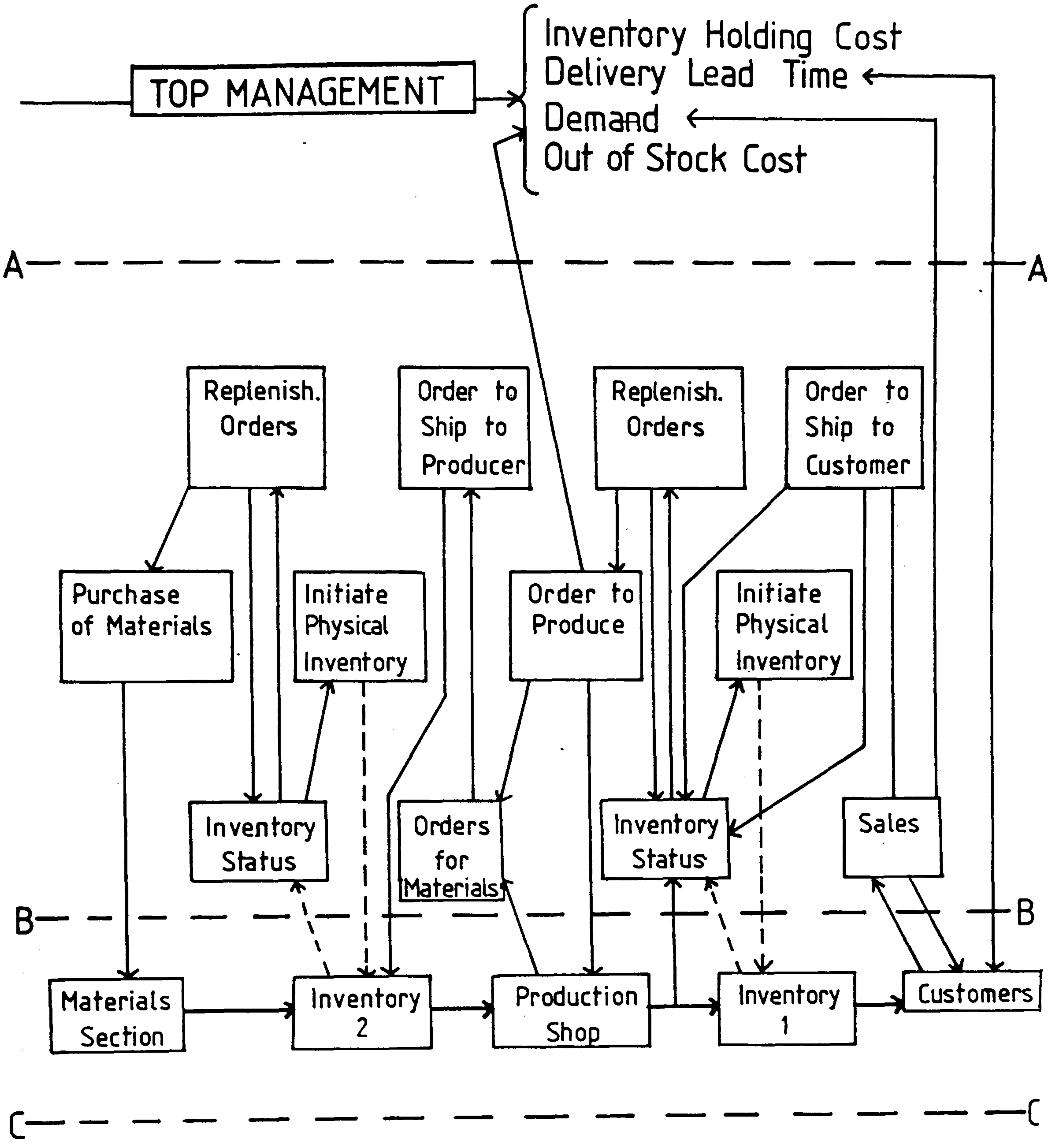


Fig.(2.8) Directive and operational information in a production inventory system

2.7.3 The need for information in a simplified model of a production shop

We assume the production unit produces appliance A, which is assembled from sub-parts B and C, which are manufactured at separate production stations. Parts B and C are manufactured using materials coming from the materials inventory storage (M.I.), and ordered when needed for the production runs. Each production station has an inventory, which it feeds.

In the model of figure (2.9) we have a simplified version of an inventory controlled production. Each production station produces only to orders from its succedent inventory, that is the inventory it is feeding. It is assumed that each inventory is provided with a constant replenishment rule, which tells when to order from its preceding production station, it is also assumed that each production station is in direct contact with its succedent inventory so that it is always known when production of a specified amount is required.

In order for the model to adapt to a changing environment, it needs some directive information, by which its way of behaving is directed from some senior guiding authority or management who has access to other wider sources of information, such as environmental information. But, regarding the need of our simple model for directive information, we shall assume that the need is infrequent insofar as the inventory replenishment rule, once given, is supposed to be valid for some time (such as a planning period of for example six months). we regard each replenishment order from an inventory to its preceding production station, to be an act of transmitting information. This means that we need a system of information channels connecting each pair of production stations and succedent inventory. These channels will be busy for an interval each time a replenishment order is issued. Thus we have found that the figure (2.9) model and its rather simple structure and operating rules, needs a fairly extensive information system. This information system is required to handle three different kinds of information:

a- Operational information of local character, frequently calling for a message, i.e. each time a replenishment order is required at one of the four inventories. Figure (2.9) shows this clearly.

b- Directive information, being transmitted from a central authority (management unit) outside the model, but which has a close contact with it. This part of the information is shown in figure (2.10), which is a modified version of figure (2.9), indicating the full information system network for our model.

c- Information to the management unit, about the overall system status sent from all points of the system.

The information system in figure (2.10) is an economical one. It limits the busy communication actions to the very local areas, while putting small demand on the longer channels communicating between the system served and the management unit (Beer 1966,1976,1979, Haiman,Scott and Connor 1978, Vollman 1973).

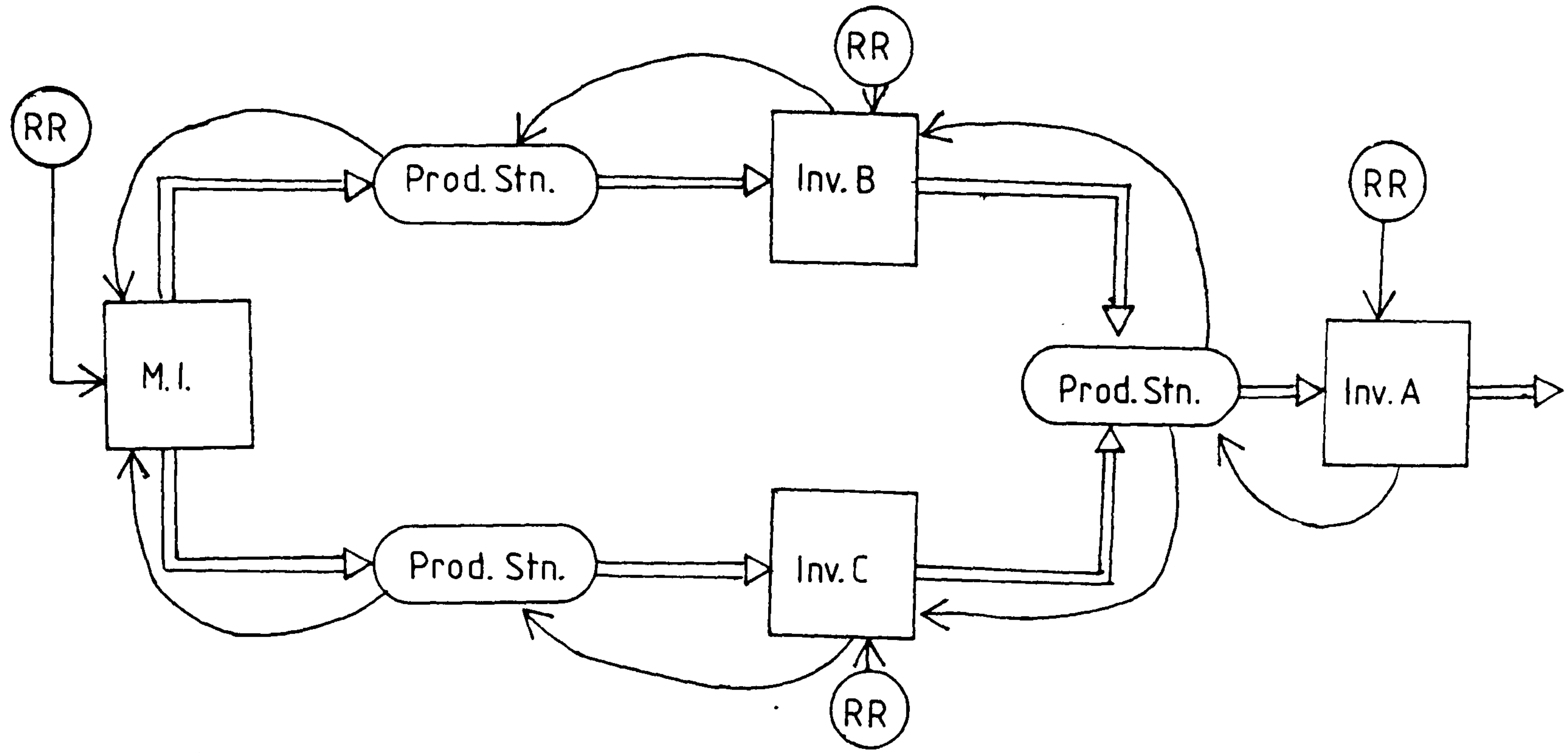


Fig.(2.9) Production system with operational information

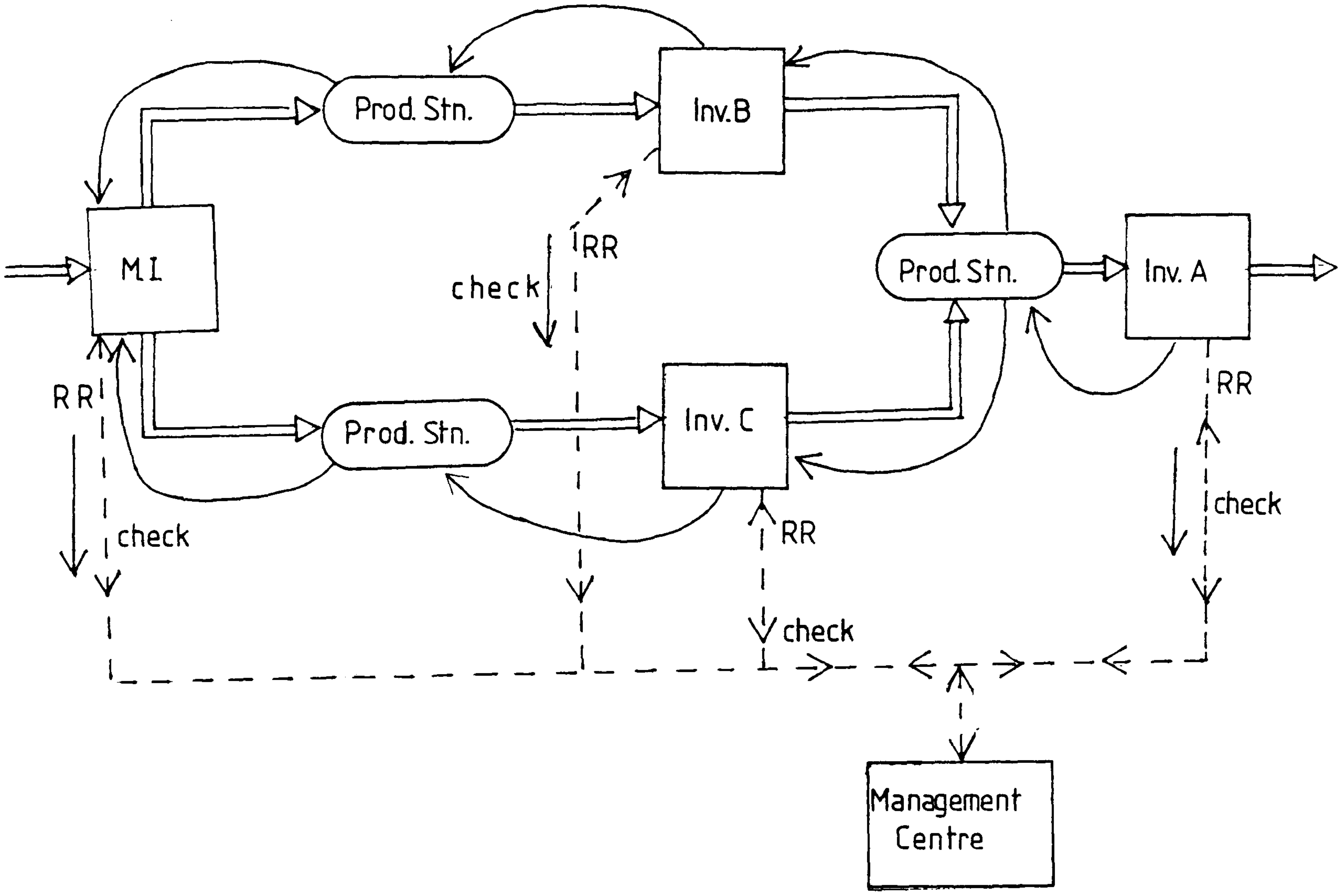


Fig.(2.10) Production system with directive and operational information system

CHAPTER THREE

CYBERNETICS AND THE BUSINESS ORGANIZATIONAL STRUCTURE

3.1 Introduction

In this chapter we are going to study the cybernetics view of how a business organization might be structured. The importance of the concept of autonomy for the lower levels of the organization will be highlighted and discussed.

The chapter also discusses Stafford Beer's ideas about the organizational structure together with the concept of the viable system and Beer's model of the viable system with its five system recursive hierarchical structure.

A description of variety as a cybernetic concept is given and its importance in management control is highlighted and discussed.

3.2 Structure of the business organization; the cybernetic view

It is very common that in a growing economy a small or moderately sized business enterprise suddenly enters a phase of rapid growth. However, with growing size, there are growing management problems as well. The existing structures do not fit the environmental demands and changes. And in that case the company cannot be managed with one management at the top who controls the business with a few subordinant managements who are responsible for functional areas within the company. This situation obviously demands a change in the organizational structure.

In order to cope with these problems of growing companies, management practice has developed the organizational concept of decentralization (see chapt.2) which implies "autonomy" for the various parts of the organization.

Cybernetics looks at the business organization as a dynamic system in a highly complex environment which is subject to cybernetic laws and rules that enable it to survive and grow in such an environment.

Cybernetics considers autonomy of the organization's parts as a major concept in the survivability and adaptability of the business organization. Autonomy refers to a system that is able to act as an independent or free agent without constraint from a higher level system. Autonomy, literally control of the self, from the Greek autos (self) and nomos (a law). As mentioned before, in management terms this corresponds to decentralization and the reduction of dependence on rigid organizational charts.

> "Adaptation demands not only the integration of related activities but the idependence of unrelated activities" (Ashby 1970).

> "Adaptation depends upon the composition of the environment into subsystems which are stable over time" (Steinbruner 1974).

Cybernetics argues that the system must be structured in a way which is hierarchical in shape but recursive in nature. This kind of structure guarantees that the subsystems have autonomy and at the same time have a kind of compliance between them that guarantees adaptability.

> "Autonomy is provided by the recursive structure of the system" (Bateson 1979).

> "In a recursive organizational structure, any viable system contains, and is contained in, a viable system" (Beer 1979).

> "A system lives through its subsystems which dispose of the power of veto" (Roepke 1978).

> "That the whole dynamic system should be in equilibrium at a particular state, it is necessary and sufficient that each part should be in equilibrium at that state, in the conditions given to it by the other parts" (Ashby 1970).

> "for the accumulation of adptations to be possible, the system must not be fully joined" (Ashby 1970).

> "There is,..., no reason why a polycentric order in which each element is guided only by the rules and receives no orders from a center should not be capable of bringing about as complex and apparently purposive an adaptation to cicumstances as could be produced in a system where a part is set aside to perform such an order on an analogue or a model before it is put into excution by the larger structure"(Hayek 1967).

The organization's recursive structure must be designed in a way that not only assures autonomy to the subsystems, but be flexible enough to allow for change to be able to cope with environmental dynamics.

> "If a system regulates itself by subtracting at all times horizontal variety as is necessary to maintain the cohesion of the total system, then the condition of autonomy prevails" (Beer 1974).

> "Flexibility and survival will be favoured by any change tending to keep variables floating in the middle of their range... what is required is a genetic change that will alter the levels of tolerance for upper and/or lower values of the variables" (Bateson 1979).

The formation of autonomous subsystems can also improve the processing of information inside the system to a great degree.

> "Strains, errors, and distortions increase in a system as the number of channels over which information is blocked increases" (Miller 1978).

> "The probability of break-down of adjustment processes among subsystems of a system decreases as the number

> of parallel information channels serving it increases" (Miller 1978).

> "A minimum rate of information input to a system must be maintained for it to function normally" (Miller 1978).

Decisions in an organization should always be made at the lowest possible level, where the necessary information is available and the fastest possible reaction to disturbances is guaranteed. But fast reaction does not necessarily mean trying to cope with any kind of minor disturbance; the process has to be carefully designed in order to provide a smooth running business.

> "A decision should always be made at the lowest possible level and as close to the scene of action as possible" (Drucker 1973).

3.2.1 Conclusion

From autonomy we get initiative, responsibility, development of personal decisions close to the facts, flexibility _ in short, all the qualities necessary for an organization to survive and adapt to new conditions.

The division of labor between autonomous business units and the management of central co-ordination must not be determined once and for all in the process of designing an organization. Depending on the development of the environment responsibilities should be subject to change in order to adapt to new environmental conditions and to guarantee the cohesion and survival of the enterprise.

A similar view is taken by the so called contingency theories in management (Lawrence/Lorsch 1970, Burns/Stalker 1961, Child 1977). According to these theories, organizations have to be adaptable to changes in technology and environmental demands as well as to the needs of the organizational members.

3.3 Stafford Beer and the organization's structure

3.3.1 The viable system

Beer characterizes the business enterprise as a viable system. He defines a viable system as one which maintains a separate existence. To maintain that existence a viable system has to have certain characteristics and qualities. The basic characteristics of a viable system are:

1- Stability as a whole.

2- The ability to learn, adapt, and evolve.

3- Have the qualities of self-repairing, self-healing, and general robustness.

4- Works according to a specified policy and a strategy.

5- Able to keep its significant output under control.

By significant output is meant what the system was designed or made (artificially or naturally) to do. This ability entails the capability of internal manipulation by the system to produce these results.

Complex viable systems such as a human being or an enterprise are seen to survive through time because of the coherance of their identity within some form of varied and potentially disruptive experience. To achieve that, viable systems make themselves certain rules of equilibrial activity which contribute to their continued existence.

This implies that every viable system contains within itself a regulator which would act upon the internal structure of the system to make the system more adaptable or more tolerable to a certain change or disturbance in its environment. It is then possible to say that all viable systems are aware systems. They are aware because they respond (not arbitrarily) to their environmental stimuli but by changing their internal state in a way that tends to ensure their continued existence. A stimuli is an outside interference which affects the system behaviour in some way.

As said before one of the main characteristics of a viable system is maintaining stability. To achieve this, the system needs a way of measuring its own internal tendency to depart from stability, and a set of rules for exprimenting with responses which will help the system to get back to a status of internal equilibrium.

Beer states that all viable systems are subject to the theory of recursiveness:

> "In a recursive organization structure, any viable system contains, and is contained, in a viable system" (Beer, 1979).

All the viable systems that constitute an organization (a larger viable system) work as an integral whole to produce the total behaviour of the organization.

To summarize, a viable system is a system that survives. It coheres, it is integral, it is homeostatically ballanced both internally and externally

> "cohesiveness is...a function of the purpose of the system. Viable systems of concentrated purpose will be closley-knit, highly cohesive. Viable sysytems of general purpose will be more loosly coherent" (Beer 1979).

A viable system has the ability to grow and learn, evolve and adapt and become stronger in its environment. However, it may fail to do that as well as it may succeed, or it may simply just muddle on.

If we look around us we can see examples of viable systems everywhere; we ourselves are viable systems, and so are all living organisms. Most goal seeking organizations are viable systems such as goverments, universities, football clubs, societies and ultimatly the whole universe.

An enterprise is an organization, it is something organic, which intends to survive, and that is why Beer characterizes the enterprise as a viable system. Beer disagrees with and deplores the idea of modelling an enterprise using the traditional organizational charts (see chapt.2). He argues that these charts only specify responsibilities and the chain of command in the firm. He calls them devices made to put the blame on someone when something goes wrong, and insists they do not show the exact "machinery that makes the firm tick".

The firm is the entity a manager controls, it is a good example of a system of high complexity in which the input and the output environments are themselves subsytems. What connects the input to the output is the domestic firm itself. That is the men, material, machinery, and capital. The previously mentioned traditional organization charts only show how each part relates to each other, with the main intention of determining where responsibilities lie. But these charts do not show all that is done, they show who does what, but not how this thing (the organization) is working together. In his bid to control his organization, the manager usually tries to intervene in the equilibrial processes of the self-regulating system (viable system) thereby, perhaps, making it unstable. The best course for the manager is often not to try to change the system's internal behaviour, which typically results in internal oscillation, but to change its structure so that its natural systematic behaviour becomes different.

Beer divides the enterprise into two parts, the first one is the operational part, which consists of the operational elements and their support systems. Each operational element undertakes one of the enterprise's basic activities, and it consists of an operation, a management unit that takes care of and controls that operation and an environment of that operation and its managenent unit. The collection of all the operational elements in the whole system is the part that does the basic activities of the enterprise. Every operational element is a viable system itself, and following the recursion theory, is itself embedded in a larger viable system which is the enterprise. Examples of operational elements are (like all viable systems) everywhere; human beings taking part in a society are operational elements so are the players of a football team, the departments of a university, the ministries of a government, etc. The second part of the enterprise is the metasystem which is the collection of all the other sub-systems in the enterprise that look after the operational elements' part.

3.4 Beer's model of the enterprise

Beer's model of the enterprise is based on his five system logical recursive hierarchy model of the viable system. These systems are called system one, two, three, four, and five. Information and control commands flow in that structure in two axis; horizontally and vertically. The vertical flow transmits information between the different levels of the hierarchy up and down, whilst the horizontal flow transmits information along the operational elements level back and forth.

Through the five systems of the model, the enterprise is able to maintain its viability, and if any of these systems is missing at any level, the enterprise's hierarchy can no longer be maintained. These systems are sufficient in maintaining the system's viability, in other words, no more than these systems are necessary to understand the ways in which the enterprise achieves an equilibrial state in its environment.

3.4.1 The systems of the model

3.4.1.1 System one:

System one is the basic system in Beer's model, it consists of those operations which produce the organization's output, and it is in fact the enterprise's "doing" system, because this level of the hierarchy is responsible for the implementation of the enterprise's actions and decisions, and includes the interactions with the enterprise's immediate surrounding environment, which result in achievement of the enterprise's main goals, and the continuity of its viability in a changing environment.

System one consists of the operational elements, each of which, as said before, represents a small autonomy in the whole system and has its own management unit which enjoys a good amount of freedom in doing its own planning to achieve its element's objectives in dealing with its own environment. As said before, each operational element is a viable system by its own, and it has autonomy and "does what it likes to maintain its viability". However, it should not be forgotten that the operational element exercises its freedom within the context of the whole enterprise, and according to its internal and external (environmental) status and constraints. The operational element's management has to control the element in response to the policy of the higher level systems in the hierarchy (systems three and five) and their over-riding instructions. It also has to react to its own environment as well as taking care of other elements' needs.

In a real business enterprise, the operational elements would represent the various divisions of the firm, and the operational level is the divisional level.

The operational elements usually interact among themselves, but this iteraction does not interfere with their individual freedom. The elements' managements usually agree on policies between themselves only within the context of operational day-to-day activities. Besides interacting among themselves, the operational elements are also linked to other systems in the firm such as systems two on the horizontal information axis (for co-ordinating actions), and to higher systems on the vertical command axis (for controlling actions).

The remaining systems of the model (systems two through five) comprise management activities designed to regulate and control the systematic interactions of the system one operational activities.

3.4.1.2 System two:

The next system in Beer's logical hierarchy of the enterprise model is system two, which can be regarded as the co-ordinating system, because its main job is the co-ordination of the activities of the operational elements which comprise system one. The operational elements are in general not completely independent, though their particular objectives may be different. It is very likely that the particular way in which one operational element chooses to achieve its objectives will have effects on the ways that the other operational elements might choose (since they share the same level of operations). One operational element's action may make it easier for another, or it may make it more difficult. Logically, the operational elements are part of the same system and they are not completely independent from each other. Their interdependence is made apparent by the fact that they do inform the other elements of their operational objectives even though these objectives have been determined individually. Higher controlling management (system three) will then ensure that these interfaces are maintained. However, the handling of the interactions is more difficult when it comes to real life implementation, since the operational elements percieve their own environment in greater detail than the higher management can percieve, and hence, new interactions are taking place, and in most situations the operational elements would usually try (sometimes strive) to maximize their individual objective functions (according to their individual own plans) first, and care about other operational elements' requirements second. Furthermore, the management units in system one are sometimes too proud, or too optimistic that nothing could go wrong, or simply too forgetful to inform other managements about important work facts. It is also a common situation, and often one of the most disruptive, when communications are cut as a result of competition between the operational elements on a variety of matters, particularly when resources such as materials and capital are concerned. There also might be some competition between the managers of different elements for desired personal achievements such as promotions, good reputation etc. Beer describes the situation dramatically "it is like the different managers are playing poker with the situation"; trust is lost and informal rules are adopted at the operational level which are intended to satisfy local operational requirements. That is why oscillation often results. Moreover, even if the operational managers operate in good will, due to their autonomic freedom, every manager treats other elements' plans only as constraints to his own freedom in achieving his goals. So the operational elements' plans will criss-cross along the information channels between the elements again and again. And each operational element will be changing its own plans according to the new constraints (other operational elements plans), and this process will continue indefinitly causing the system to go into uncontrollable oscillation and fluctuation. What is needed is a "support" system to system one with the job of damping the oscillations and providing a convergence of system one to a stable state.

The anti-oscillatory system two presents only a service to system one, and does not take any of the controlling activities of the higher management (system three). It's job is a co-ordination job only. It does not intervene in the operational elements freedom of planning, it just tries to make them cohere and co-ordinate their activities to reduce the oscillation in their system one. System two interactions with system one is on the horizontal axis of information transmision. For example, system two can re-write time tables, or re-schedule deliveries between the operational divisions in order to make different production-inventory functions run more smoothly. Besides trying to co-ordinate the operational elements' operations, system two passes information about the overall view at the operational level (system one) to the higher management in the metasystem (system three).

Sometimes preventing oscillation is not enough to insure the internal homeostasis of the enterprise, and we need fundamental changes at the operations level to rectify the situation. for example, some operational element may need to be sacrificed if synergy in the enterprise is to be achieved. System two cannot take such decisions because it is only a service system to system one. So what is needed is a system with the ability and managerial authority to take control actions, and that is system three. Talking about the closing down of an operational element's activity leads the operational managers to be in constant fear from this dissolution process, and causes them to act in a an aggressive and non-cooperative manner towards fellow operational managers. So system three must act very quikly in such cases, and even (if the situation necessiates) invoke and over-ride the even higher management (system five) authority and decisions.

The mechanics of system two are actually found and based in the interlinking of the operational elements, and also in the metasystem part of system three. So it is possible to think of system two as an elaborate interface between systems one and three, it is a part of both of them, thus emphasising the model's recursiveness.

The systems two-one interface has to do with each operational element recognizing (regardless of its motives and requirements), that there are other automonous operational elements (divisions) in the enterprise, and they have rights and requirements too, and they are not to be undermined. The systems two-one interface is about interoperational collaboration and co-ordination.

To summarize the role of system two, it monitors the activities of system one, detecting significant deviations from expectations, taking action to dampen any oscillations developing between the various system one activities, and informing system three. The goal of this sytem is communication of necessary and sufficient information to maintain internal stability.

3.4.1.3 System three:

System three is the highest level in the operational management, and the lowest of the corporate (enterprise) management. It stands as a middle link in the model's hierarchy, and is situated between the higher management system five and four, and the operational level of systems one and two.

System three's function is mainly to govern the stability of the internal environment (operational level) of the enterprise. It's main concern is the domain of system one and two. System three receives information from three parts of the enterprise. First, as a part of the vertical command axis, it receives the higher management's policy decisions, and transmits them to the operational level in a form so that they provide meaningful objectives to the operational level. That is, strategic policy decisions are translated into more operational terms which take into account the particular circumstances of each of the operational elements. The second place system three receives information from is the operational level, where it directly receives information from the operational elements' managerial units about their activities. Thirdly, system three receives information regarding the co-ordination action in the operational level from system two, which by recursion, is part of system three and one.

System three reviews the performance of the different operational elements, and resources are allocated to them as they need according to the information provided by them, and according to the strategic policy decisions. System three does, therefore, have a decision capacity, and its guidelines for the use of this decision making is higher management policy and the circumstances of the operational level. So the information from system three down the the vertical axis to the operational level is genuinely about the synergy of the operational elements. In a business enterprise system three takes the job of the operations directorate of the corporation.

System three is ideally placed to use every kind of optimizing tool in its direction of current operations, from inventory control techniques to mathematical programming. A dynamic, current model of the firm's internal working must in fact emerge at this level, and offers the ideal management tool for the control of internal stability. System three undertakes the implementation of major changes at the operational level such (as mentioned before) closing down a whole division, creating divisions, and interfering with other divisions' plans in order to maintain operational level synergy. Synergy means behaviour of integral, aggregate, whole systems, unpredicted by the behaviour of any of their components or sub-assemblies of their components taken separately from the whole. In other words, synergy is the act of working together so that the combination of the separate parts is more effective than if each acted alone; with synergy the whole is greater than the sum of its parts. Examples of senergy include the combined interaction of muscles in the body and the effects of certain drugs taken together.

The system three-one interface is all about the operational element manager recognizing that his own autonomous operational element (division) is part of a corporation, and that it has the right and power to curtail his automony if that is to the corporation's benefit. The whole three-one interface is about corporate synergy.

To summarize system's three role, it orchestrates the system ones to accomplish the organization's short term goals by issuing instructions and reallocating resources. The goal of this system is survival and internal stability for the short term (here and now operations).

3.4.1.4 System four:

Systems one-two-three are necessary components of a viable system, whom between them account for the stabilization of the internal situation. But that cannot be sufficient to maintain the viability of the system. It is a precondition of viability to have internal stability, but it takes no account of progress or change of internal structure which is important if the system is to remain viable within a changing environment.

System three cannot take the responsibility of watching and checking the external environment, since it is already preoccupied with the responsibility of controlling the internal situation. Thus we need a new system four to do this job.

System four is specifically concerned with the external environment of the enterprise. It constantly monitors the changes in that environment, and considers the alternative ways in which the enterprise can adapt to and achieve a ballanced state in that environment. System four deals not only with the immediate environment of the enterprise (one which the enterprise is actually dealing with through system one) but also with the wider environment which is of general interest to the enterprise. System four is also concerned with the furture environment of the enterprise. So system four is involved in monitoring and studying an environment which is much more than the mere sum of the operational elements environments.

In a real enterprise system four takes the form of the development directorate of the firm and undertakes the tasks of research and development, market research, corporate planning, economic forcasting and management development.

System four contains a model of the enterprise total environment which includes the internal environment as well.

System four houses the enterprise's whole apparatus for adaption, hence the retainment of a model of the enterprise (viable system) of which it is a sub-system following the cybernetic principle "every regulator must contain a model of that which is regulated" (Ashby, 1976, Conant 1969).

System four's decisions are directly associated with the nature of the objectives which the higher system five chooses for the enterprise. Hence, there is a dynamic loop between systems four and five. The types of alternatives considered by system four both influence and are influenced by the requirements of system five. So although system four can only be regarded as an "intelligence" system of the enterprise and is not concieved of as a decision section, its inevitable influence on system five's decisions (and hence the rest of the enterprise) cannot be ignored.

If system four fails to communicate with system five, or fails to monitor the complex changes in the enterprise's environment, then opportunities may be missed by the firm, or strategic policy decisions may have to be taken with an inadquate account of their consequences, and ultimately, through the insufficient response to the environment's change, would lead to the enterprise's viability not being maintained, and ceasation of its survival.

To summarize system four's role, it is responsible for interacting with the external environment and assesing the probable future consequences of plans and decisions. The focus of system four is on long term effects. The goal of this system is adaptability.

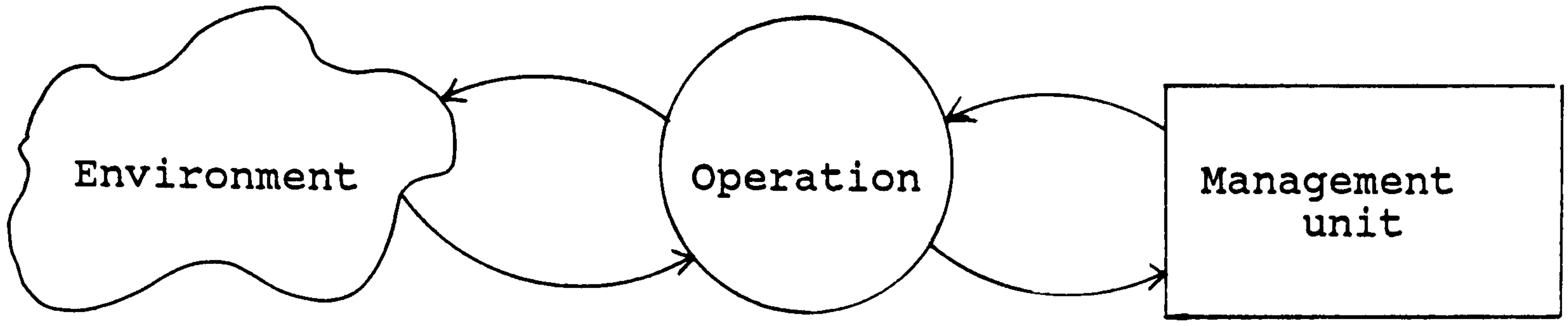
3.4.1.5 System five:

The highest system in the hierarchy of Beer's model of the enterprise, is system five, and represents the part where the enterprise's strategic decisions are taken. The function of this system is to choose between alternative strategic directions to achieve the strategic goals of the enterprise. All the strategic decisions are made with reference to the enterprise's own objectives, the state of the environment outside the enterprise (received from system four), and the internal state of the enterprise (received from system three).

In a real enterprise system five can include the board of directors, representatives of management, shareholders, workers, and investors.

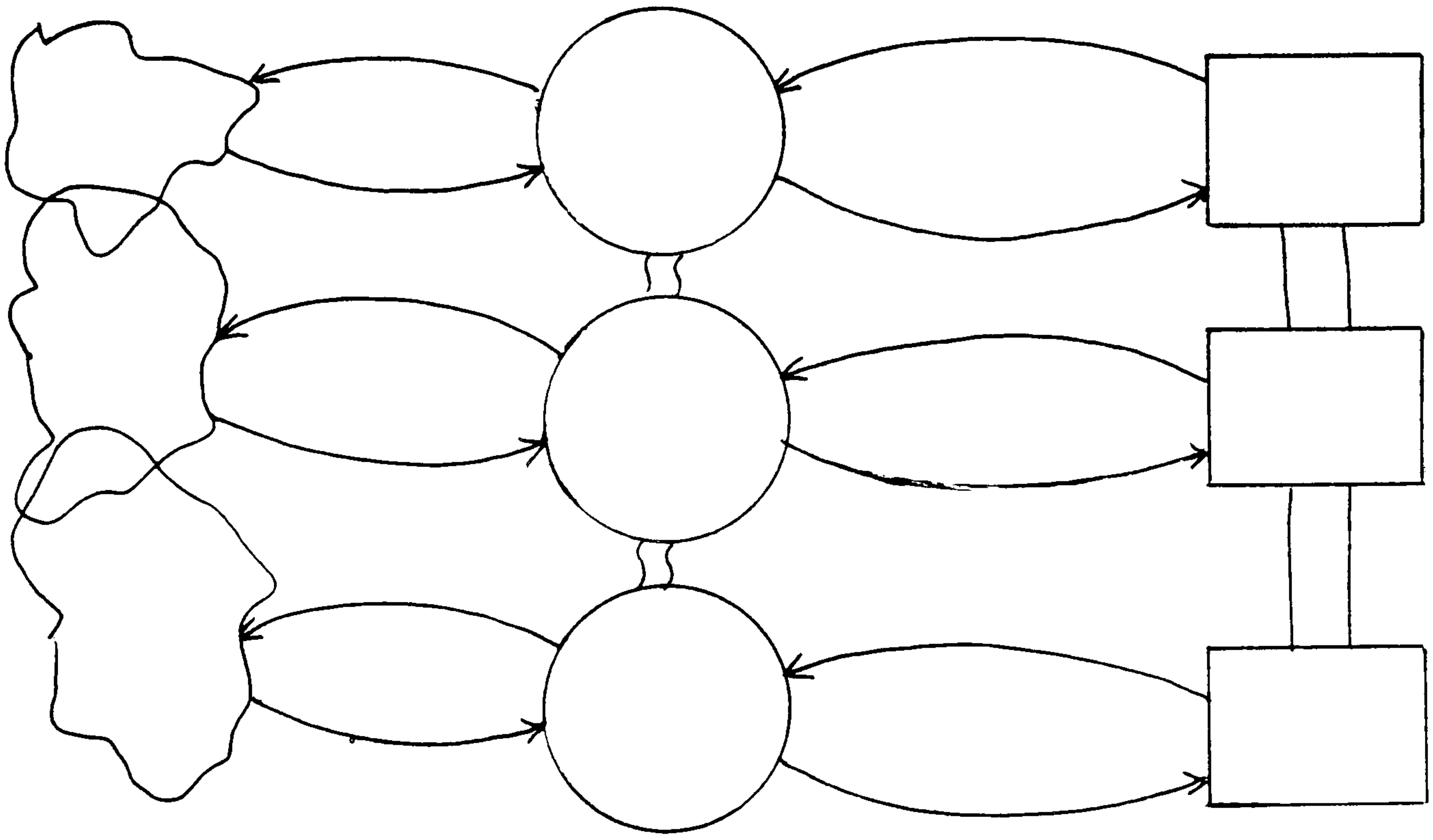
So the role of system five is the responsibility for observing the interactions between system three and four and to resolve all issues which could lead to instability. System five's goals are growth and development. It achieves these goals by using its executive authority to allocate resources between the short term interests of system three and the long term interests of system four.

Beer's primary application for his model of the viable system was to develop a total management control system for a national economy (Beer 1979). He has also made other applications to public and private organizations.



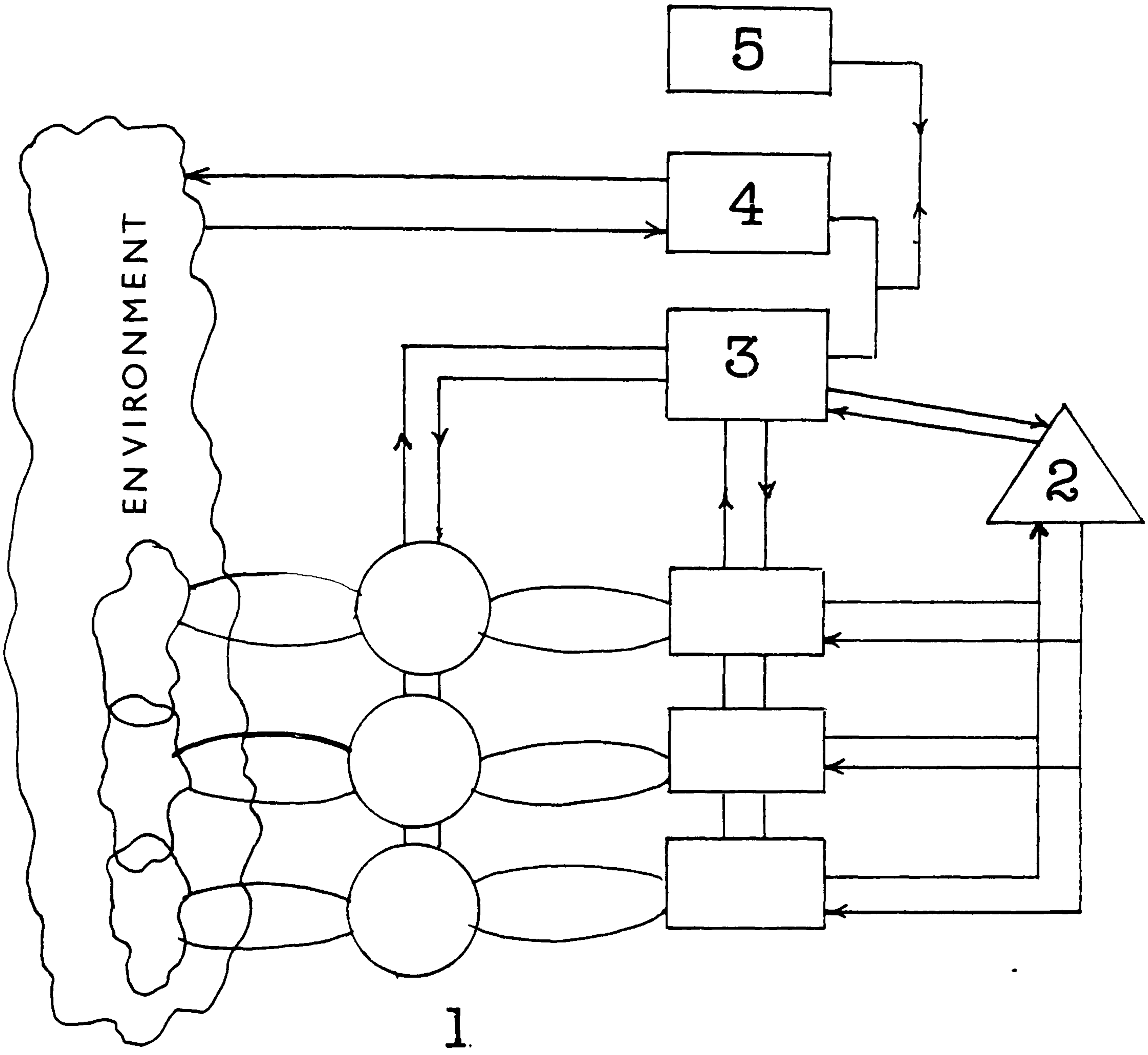
⟶ Information

Fig.(3.1) Operational element



⟶ Information

Fig.(3.2) A set of oprational elements (system one)



⟶ Information

1 System one

2 System two

3 System three

4 System four

5 System five

Fig.(3.3) Beer's viable system model

3.4.2 Communication in the viable system model

The five systems are connected by three types of two-way communication channels each serving a particular purpose: command, regulation, and verification. The central communication channel, indicated by the middle vertical axis of the diagram (fig. 3.3), is the direct command channel through which command authority flows downward and accountability upward. The second channel (right side of the model) is the routine information channel used to report, monitor, and regulate the day-to-day activities of the operational elements of system one. The third communication channel (left side of the model) facilitates direct interaction with the operating activities for the purpose of verifying (e.g. audits) operating procedures, practices and achievements.

All the above mentioned channels need to be functional, balanced relative to each other, and adequately large to handle the variety present at each point in the network.

3.5 Variety and management

In cybernetics the measure of complexity is variety (Ashby, 1976). Variety is defined as the number of possible states a system (any system) can take at any given time.

Variety proliferates in complex situations. For example, a situation with eight inputs and one output, each of them having only two possible states, has a variety of 2 behaviours which is a very large figure indeed.

Cyberneticians call any situation which can contain a large number of states a variety generator. There are many ways of stopping the generation (prolifiration) of variety. For instance, if the above situation is divided into two parts with four inputs each, the result is a large reduction in the number of possible states of that system. Divisionalization and functionalization are some of the mechanisms used by management to cope with variety prolifiration.

From the cybernetics point of view, the problem of management is precisely the control of complexity, "the management problem is a problem of handling variety" (Beer, 1979). If management wants to control a situation of its concern, it has to respond to relevant states of that situation. In other words, it has to respond to the variety being generated by the situation. If we examine any managerial action of control, we shall find that it is a variety reducer.

Managers destroy variety (Beer, 1979). They stop variety from prolifirating. They do that basically by preventing interactions through divsionalization and functionalization (especially in large systems). Managers also achieve their aim of stopping variety prolifiration by using a number of devices such as good planning, good accounting practice, good behavioural science studies, and even consideration for others (operational elements' co-ordination to stabilize the operational level).

It is natural that the managerial variety is lower than the variety of the managed operation, since the operation contains more activities of every kind, and certainly more people generating variety, than the manager for himself. Every manager is confronted with a situation of great complexity. Even if the total number of people supervised is one, the manager confronts a situation more complex than him/herself. This is so because the manager is part of the situation, so that any addition to the situation beyond the manager's own person immediatly makes the situation more complex than the manager. So managers are almost always responsible for regulation of situations more complex than they themselves are, and they therefore can only be partialy successful. That is why the manager has to design for himself techniques directed towards reducing operational variety.

An important concept in controlling variety generation and prolifiration, is the law of requisite variety: "only variety can absorb variety" (Ashby, 1976). The law points out the fact that the nature of our response to external situatons is a function of our internal complexity. If we develop more complexity we can cope with a more complex situation, and therefore, fulfil more complex tasks. In general, Ashby's law is: The variety of the controller must always match the variety of the controlled.

The manager in his bid to control a situation, must be able to deploy as much variety as that situation can possibly offer. That is, by producing a precise match between his variety (complexity) and the variety of the controlled situation. He must find ways of increasing (amplifiying) his own variety, and/or ways of reducing the situation variety. The same applies to the organisation, which in order to maintain a stable existence in its environment, has to adjust its complexity to match the complexity of its environment. This could be achieved by careful design of the organisation's internal structure.

Beer calls variety "the stuff of control", and he emphasizes its role in keeping his model of the enterprise under control.

If we take an operational element from system one in Beer's model, we find that it consists of an operation embedded in its environment and a management unit with the task of controlling that operation and regulating the whole of the operational element as a single stabilized viable system. The variety of the operation is usually more than the variety of the manager, due to the interactions of the many parts that comprise the operation. Certainly the environment deploys more variety than the operation (also due to more complexity), and according to the law of requisite variety, the management, in order to control the operational element must be able to increase (amplify) its own variety to match that being generated in the operation and its environment, or simply to reduce (attenuate) the operation and the environment varieties to the level where they will equate with the management's variety. The management's main job is to design the necessary amplifiers and attenuators that would help it achieve control. To do that the management has to interchange relevant information with the operation and the environment on the horizontal axis.

System two which is the anti-oscillatory service to system one, also produces (through its committees and methods for sharing understanding) high variety in its job of damping (controlling) the oscillation in system one, since it represents a high variety situation.

System three which is situated on the vertical axis, and is the controller of system one, applies variety amplifiers and attenuators on the vertical axis links between it and each management unit at the operational level. It's intervention in system one's activities constrains horizontal variety for the sake of cohesiveness at the operational level and the whole system's synergy. According to Ashby's law:

The sum of the variety deployed by system three in the vertical axis equals the sum of the variety deployed by the operational elements in the horizontal axis.

System four is involved in containing environmental variety; it is also concerned in generating a matching variety, and is responsible for the design of attenuating filters that convey the environmental variety to the system (organisation). System four also designs its own variety amplifiers for investigating the environment. There is a variety balance between system four and the internal environment of the enterprise (since it always keeps a model of the enterprise inside itself).

System five (which is the highest in the model's hierarchy) must develop sufficient variety to balance the variety of both systems three and four, which requires enormous attenuating effort since systems three and four generate multiplicative variety due to the complexity of their jobs.That may prove too much for system five. What system five really does is to supervise an interaction between systems three and four, in which they absorbe each other's variety. For instance, in the problem of relative investment, there will be alot of variety absorbtion between system three and system four, but that also might lead to confrontation between the two systems, which would lead to oscillation in the whole system. To avoid this kind of oscillation, system five imposes itself as a supervisor of the interactions between systems three and four, and it only has to generate enough variety to keep the interactions under control.

CHAPTER FOUR

INVENTORY CONTROL AND PRODUCTION SCHEDULING AND SIMULATION MODELLING OF BUSINESS SYSTEMS

4.1 Introduction

Chapter four is concerned with the task of giving a general idea to the reader about the basic business activities which constitute the model of the firm which we are going to build. These major activities are inventory control and production planning and scheduling. A separate model of each operation and its associated control decisions is going to be built (different models for different inventory situations) and described in the next chapter. These models would together constitute the larger model of the firm (based on Beer's ideas).

Since the model we are building is a simulation model, we give a short description of simulation and its techniques, and also its importance for successful management operations. A review of simulation's advantages and disadvantages is also given. The approach of industrial dynamics as a simulation technique for dynamic business systems is studied.

Also presented in the chapter are two simulation models. The first model is an industrial dynamics model of a hypothetical firm, and its purpose is to study industrial dynamics as a business simulation technique and its suitability to our work application (simulation of the viable system model). The second model is also a simulation model of a simplified firm and serves to show the effect of changes in decisions and lead time durations on the firm's behaviour.

4.2 Inventory control

the following sections deal with the major aspects and characteristics of the general inventory control problem. It highlights the importance of inventory holding and control in any business as well as analysing the parameters of the inventory problem such as cost, demand and lead time. It also provide a description of the main policies used in inventory control to a depth which is proportionate to the complexity of the inventory model studied in our work (chapter 5).

4.2.1 The inventory problem

An inventory problem exists when it is necessary to stock physical goods or commodities for the purpose of satisfying demand over a specified time horizon (Lowe 1974). Almost every business must carry stocks of goods in order to ensure smooth and efficient running of its operations.

Management is becoming increasingly aware that in many instances the efficiency of a business operation is directly related to the inventory situation existing within the business (Lowe 1974). It has always been realized that one of the most pressing problems in the manufacture and sale of goods is the control of inventory, and many companies fail due to the lack of adquate control of their inventory(s), whether it be raw materials used in manufacturing a product, or finished products waiting to be sold. Thus, there has been an increasing requirement for a knowledge of the mathematical theory which can be used to·analyse and control inventories (Axsater 1974).

Inventory control is the science-based art of controlling the amount of stocks held, in various forms within a business, to meet economically the demand placed upon that business (Niland 1970).

Inventory control is usually associated with industry, but many inventory control problems do occur in other organizations such as the armed forces, transport systems, hospitals, etc.

As said before, stocks held by a firm can occur in many forms. Most known forms are finished product stocks and raw material stocks held in stores. However, in between these two types are all the in-process stocks which occur naturally as part of the production process.

4.2.2 Reasons for holding an inventory

In an ideal world, where the demand upon a business is known exactly and well in advance, and where supplies arrive on time, there would be little need to hold any form of inventory other than a limited amount of in-process stocks, which would only create a completely deterministic problem, because all the problem's parameters would be exactly defined.

In practice however, demand is not always known in advance, and supplies will often be late or sometimes even early in delivery. In this kind of environment, stock holding acts as a buffer against the strange and sometimes unpredictable behaviour of demand and supply (Makower and Williamson 1975).

The main reasons for holding stocks are:

1- To act as a safeguard against longer-than-average supplies delivery times (lead times).

2- To act as a safeguard against larger-than-average demand.

3- To minimize the delay in production caused by a lack of parts. With products comprising many components and sub-assemblies, stocks of components and sub-assemblies at assembly points act as a buffer within the production system to absorb the demand that the system exerts on itself.

Other reasons for holding stock may include purchasing more supplies than immediatly required to take advantage of quantity discounts, and also to take advantage of seasonal and other price fluctuations e.g. British householders buy coal during the summer season, because the consequent saving in material cost outweigh the increased storage investment cost (Heers 1972, Hillier and Lieberman 1980, Lowe 1979).

4.2.3 The disadvantages of holding a too high or a too low inventory

Management should take care not to hold an inventory of too high or too low a level, and should maintain some kind of a balance in that respect.

Disadvantages of holding a low inventory level:

a- Customers' demand can sometimes not be satisfied, and this can lead to an immediate loss of business, and there may also be a further loss of business due to customers' dissatisfaction and/or loss of faith because of unfilled demand.

b- High demand would lead to costly emergency procedures, such as special production runs, in an attempt to maintain customers' satisfaction.

c- Low inventory level would cause the placing of replenishment orders more frequently than in the situation where higher stock levels are kept, thus incurring higher replenishment ordering costs.

d- Stoppages may happen in the production plant because of the lack of raw materials.

Disadvantages of holding a high inventory level:

a- Usually storage costs incurred are very high. These costs not only cover buildings, labour, cleaning, etc., but must also allow for deterioration and spoilage of the stored good.

b- A high capital investment in stocks means that there is less money available within the business for other requirements in the firm. Besides the fact that money is tied up in what may be unnecessary inventory.

c- Where the stored product becomes obsolete, large stock holding of that item could, in the worst situation, represent a large investment in an unusable product whose value is only that of scrap.

d- When a high stock of raw materials is held, a sudden drop in the market price of that material (a common occurrence) represents a cash loss to the business for having bought at the higher price that previously existed (Eiselt and Frager 1977, Heers 1972, Lowe 1979).

4.2.4 Inventory cost parameters

These parameters usually describe the following factors:

1- Holding cost: this represents the cost of carrying inventory in storage. It includes the interest on invested capital, storage costs, handling costs, depreciation costs, etc. Holding costs are usually assumed to vary directly with the level of inventory as well as the length of time the item is held in store.

2- Order cost (or set up cost): This involves the fixed charge associated with the placement of a replenishment order for the inventory or ordering the initializing of a production run for inventory replenishment (set up cost in this case). This cost is usually assumed independent of the quantity ordered or produced.

3- Shortage cost (stock-out cost): These are the penalty costs that are incurred as a result of running out of stock when there is demand on the item stocked. They generally include the costs due to loss in customers goodwill and due to potential loss in income. These costs are assumed to vary directly with both the shortage quantity and the delay time in fulfiling the orders. On the other hand, if the unfilled demand is lost, shortage costs become proportional to the shortage quantity only (Heers 1972, Nilland 1970).

The three kinds of inventory costs are generally closly related. When one cost is decreased, one of the other two costs, and sometimes even both increase. The total cost (the sum of the three costs) may thus be minimized by suitable decisions. It is only in this sense that we mean that the costs are controllable. Any one cost may be decreased (or increased), but this will usually tend to increase (or decrease) the other costs. An inventory control problem is concerned with the making of decisions that minimize the total cost of an inventory system. The core of the whole operation lies in controlling the three above mentioned costs, so that the total cost will be at the lowest. The inventory problem is thus defined in terms of making optimal decisions with respect to costs (Lowe 1979, Niland 1970).

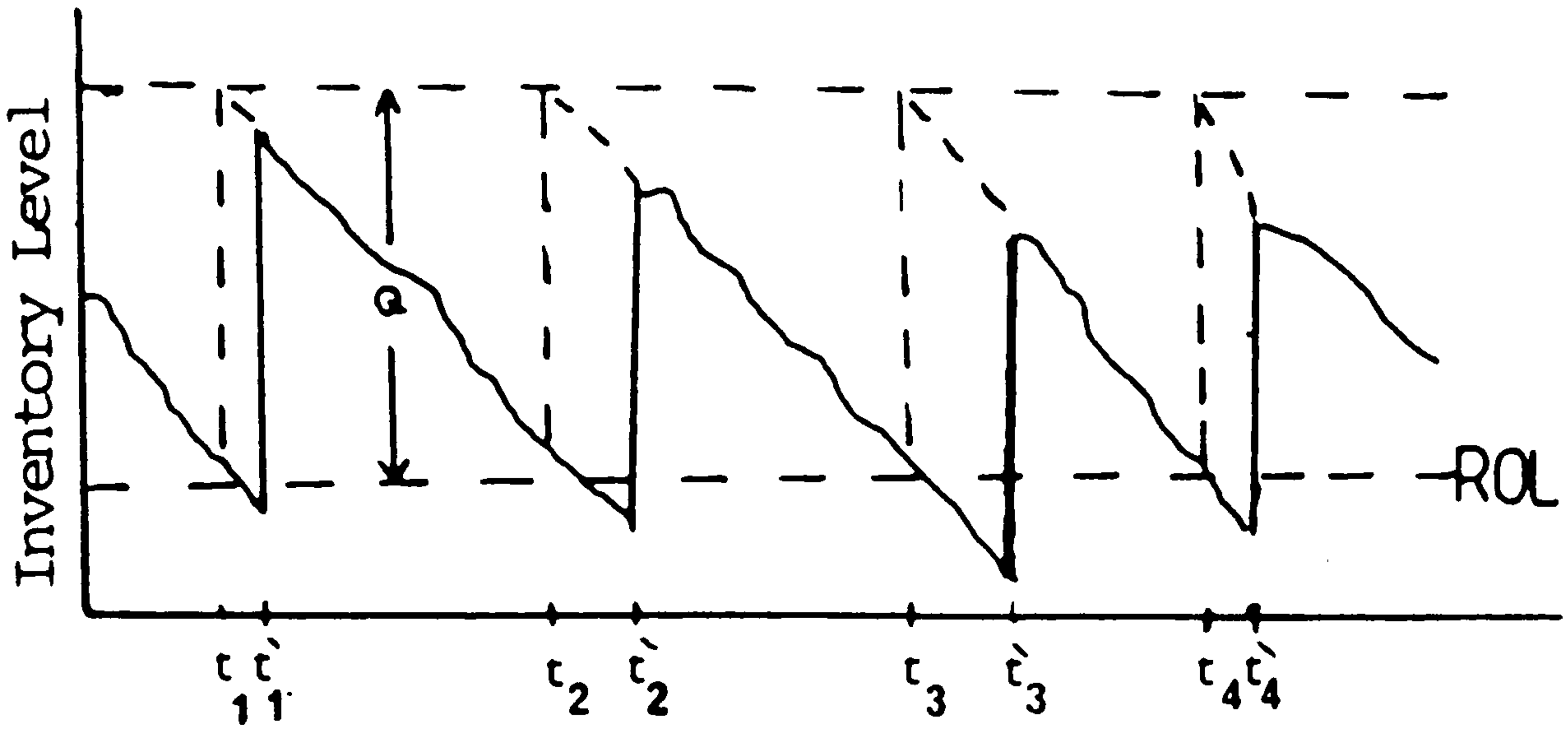
Decisions that are made always affect the costs, but such decisions can rarely be made directly in terms of costs. These decisions are usually made directly in terms of time and quantity, and are based on how much to order for inventory replenishment, and when to make that order. The time element and the quantity are the variables that are subject to control in an inventory system. They affect the holding cost, the stockout cost, the order cost and subsequently the total cost. The inventory controller's problem lies in finding the specific values of these variables that minimize the total cost.

4.2.5 Lead time

when an inventory replenishment order is placed, it may be delivered instantaneously or it may require some time before delivery is effected. The time between the placement of an order and its receipt is called lead time. Lead times like customers' demand, may be deterministic or probabilistic, and their pattern may also take the shape of a particular probability distribution.

4.2.6 Inventory policy

The firm's inventory holding practice is implemented by a series of rules which determine how and when certain decisions concerning the holding of stocks should be made. This series of rules is known as an inventory policy. There are many different kinds of inventory policies depending on the sircumstances and conditions under which an inventory is operated. The inventory policy that will be implemented in our inventory models is called the fixed order quantity and reorder level policy fig(4.1). The inventory in this policy is examined continuously. A fixed order quantity, Q, is placed when the stock level declines to a reorder point or level, ROL, regardless of the time between orders.



t_i = The time when the i^{th} order is placed

t'_i = The time when the i^{th} order is received

Q = Fixed order quantity

Fig.(4.1) Fixed reorder quantity, reorder level policy

4.3 Forcasting

A forcast is an evaluation of what is expected to happen in the future, in the light of various already known facts.

Individuals whilst living in the present, must prepare for the future. In order to prepare for the future, they must examine the past and identify repeating elements, their time cycle and their trends.

Any system with fluctuating variables must rely on forcasting to obtain an assesment of the future values of variables for decision making and control.

Forcasts are unavoidable in business decision making and planning. Effective planning for production and inventory control requires some means for resolving the uncertainty of the future. Here the term forcast is used to chracterize the mechanism of arriving at measures for planning the future. However, it should be realized that trying to solve all the uncertainty in the future is a very difficult task if not impossible, and that one can only attempt to reduce some of it. It should also be realized that there is no forcasting mechanism which will be suitable for all situations. So the simple answer to the question; why forecast, is: to plan the future. And the answer to the question; what forecast, is: every thing we need to know to plan the future. In business this covers such things as product demand and supply, costs, and delivery lead times (Anderson 1981, Nilland 1970).

4.4 Production planning and scheduling

The ultimate objective of production planning and inventory control usually takes one of two forms _ either maximum return on investment, or minimum operational costs.

Management of production and inventories is basically a question of striking a balance among production flexibility and capacity, inventory levels, and customer_service needs. All production planning procedures may be regarded as attempts to place orders on a production facility for delivery at some time in the future.

Production planning and scheduling is the process of deciding on the resources the firm will require for its future manufacturing operations and of allocating these resources to produce the desired product in the required amounts at the least total cost. The objective of production planning is to arrive at decisions about the general framework of the manufacturing operations during the period planned (planning horizon). This framework should be designed to. meet the firm's recognized goals, such as filling customers requirements, and minimizing total cost.

In a manufacturing business, inventories exist as a result of, or to support production. Total inventories can be controlled to increase only when total production exceeds demand and decrease only when demand exceeds production. The production plan shows planned totals of demand and production and the inventory resulting. Actual totals are then compared to the plan so that necessary replanning or corrective action can be taken to meet changing conditions in time to be effective. Without a production plan, it is typical for management to become alarmed, for instance, by the inventory buildup ahead of a peak season because they lack the specific information as to the level of inventory needed. Too frequently, the reaction is to cut back production rates just before the peak season, and then to react at considerable expense to increase production again when sales pick up and the inventory disappears. With a production plan, the inventory buildup can be compared regularly to the planned levels, and the question of too high or too low can be decided in time for corrective action to be effective (Anderson 1981, Heers 1972, Nilland 1970).

4.4.1 Production scheduling

The priciple function of production scheduling is to obtain a smooth timely flow of product through manufacturing steps.

Scheduling involves the sequencing of jobs to be processed by a given set of machines and the assignment of actual starting times to each individual job. As such, scheduling deals with decision making on the lowest management level of the production planning hierarchy. The set of scheduling decisions over a time horizon is vital to the firm's performance. Poor scheduling can lead to total capacity underutilization, failure to meet delivery dates, excessive work-in-process and severely upsets higher level plans (Gelders and Ludo 1981, Nilland 1970).

A production scheduling simulation model is described in chapter 5.

4.5 Simulation

Simulation is a technique of growing importance in many fields, both theoretical and applied. Naylor has suggested that the purpose of simulation is "to attain the essense without the reality" (Naylor 1979). Such a definition is obviously too broad. A more operational definition of simulation in business is given by Maisel:

> "simulation is a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models that describe the behaviour of a business or economic system (or some component thereof) over extended periods of time" (Maisel 1976).

In a computer simulation, the uncertainties, dynamic interactions and complex interdependencies of a system are all characterized by formulas stored in the memory of a high speed digital computer. The system simulation begins at a specified starting state. The combined effect of decisions, and of controllable and uncontrollable events, some of which may be random, cause the system to move to another state at a future instant of time. The evolutionary process continues in this fashion until the end of the time (simulation) horizon. Frequently, the time intervals are finely divided and extend over a fairly long horizon. As a consequence, simulation experiments often involve a vast number of calculations, rapidly performed by the digital computer. This feature of a long time of events being evolved in a few minutes (or less) on a computer, is termed time compression (Emshoff and Sisson 1976, Forrester 1961).

The increased speed and decreased cost of electronic computers, have resulted in a dramatic increase in the number of computer simulations in recent years. The growth in simulation activity is reflected in literature of fields such as engineering, computer science, operations research, statistics, economics and business. A series of annual conferences on the applications of computer simulation are established under the joint sponsorship of several professional societies. Papers on simulation are regularly published in simulation-related journals and periodicals in different countries around the world, these journals also are often organized by societies.

4.5.1 Simulation and management

In the past, firms have taken their business decisions (in a world of rapid change and extensive interaction) by depending on the experience and skill of their managers. To some extent, this is still true today; the individual skills of a manager plays an essential part in the success of a company. Simulation, however, may enable the forward-looking manager to have available more and better organized information before making his decisions. Simulation models are designed and run to provide insight to decision making problems and to help in selecting appropriate courses of action. Such analysis facilitates an investigation of both the direct and indirect consequences of random variation within a system. Since the model can be run under many different settings for the parameters and the probabilistic elements, the analyst can identify the prime sources of system fluctuations. Frequently, as a result of computer simulation, management can isolate the principal causes of trouble and trouble spots in the system, and can thereby subsequently improve the system's behaviour. So, although the modern manager is faced with a more complex world than were his predecessors, by using simulation he (or she) can at least have a clearer picture of the possible future outcomes and would need less time in which to make decisions and therefore, is often able to discard conventional time-consuming, manpower-consuming, and costly decision aids and methods of analysis (Forrester 1961, Jones 1972, Naylor 1979, Schultz and sullivan 1972).

4.5.2 Advantages of simulation

As said before, simulation is a particular kind of model of a real system. The major advantage of a simulation is that it permits study of the real system without actual physical change or modification of that system in any way. For many real systems such as military, political, social and business, major expermentation obviously involves very high risks. Such modifications may lead to very desirable results, or they may lead to catastrophe. In the case of a system being simulated on a computer, the results of various modifications can be observed in the simulation, and without physically modifying or altering the real system in any way. Besides that, in simulation alternative changes and modifications (which include policies) can be tried and their consequences observed and studied in a systematic and controllable manner (Sanders 1975).

Simulation has other advantages. As a process or system is studied in preparation for a simulation, previously hidden faults and deficiences are often revealed. These discoveries may lead to immediate alterations and improvement in the process. Simulations also have many uses as training tools, and a number of simulations have been developed for this specific purpose.

Summary of simulation advantages:

1- Permits controlled experimentation with:
  a- Consideration of many factors.
  b- Ability to consider alternative policies.
  c- No change or disturbance of actual system.

2- Effective training tool.

3- Makes management more effective through promoting more effective decision making.

4- Reveals dificiency in simulated system.

5- Lower cost, compared with real-life experimentation.

6- Reduces risk of real-life experimentation.

4.5.3 Disadvantages of simulation

The powerful advantages of computer simulation are sometimes offset to some extent by certain disadvantages. These sometimes include a high cost, the use of scarce and expensive resources and the long wait before an operational simulation is developed to tackle a certain problem. Simulations of large-scale systems are expensive, and development of a simulation requires many high-priced specialists, time on large and expensive computers and extensive studies of operating elements.

4.5.4 Conclusion

Simulation had and will have a major impact on the way people manage systems. It is being used increasingly by decision makers to provide both insight into complex problems and quantitative estimates of specific actions. The result is improved decision making.

4.6 Industrial dynamics

Industrial dynamics is the study of top management problems from a feedback control system point of view.

Industrial dynamics finds its origins in four related developments, each mainly a product of the U.S.A. military effort during and after WWII. These are:

1- The development of analytical technique for studying the dynamic behaviour of complex systems.

2- The invention and refinement of digital computers starting a decade later.

3- The translation of tactical military policies into mathematical form.

4- The use of simulation techniques during the same period for studying amd improving complex nonlinear military systems.

Professor J. W. Forrester had pioneered in important ways in each of the above four engineering related progress areas. His move in 1958 from head of the computer division at the M.I.T. Lincoln laboratory to a professorship in the M.I.T. signalled the begining of the industrial dynamics program.

The most important part of Forrster's thinking is that he treats the business enterprise in terms of its time-varying behaviour. He offers his industrial dynamics approach as: "a way of studying the behaviour of industrial systems to show how policies, decisions, structure and delays are interrelated to influence growth and stability" (Forrester 1961).

Industrial dynamics depends on the information network that integrates management functions. And it is, in fact, as described in chapter 2, how information flows through the organization that gives rise to the dynamics of industrial enterprises (Gates 1970, Weil 1971).

Forrester describes business processes by six major network variables: materials, orders, capital, personnel, capital equipment and, connecting them all, information.

In constructing network diagrams, Forrester uses 'valve' symbols to represent decision functions that control the rates of flow within the network. Signals to a valve is always information, and the regulated flows carry contents from various accumulated levels to others. The levels themselves then give further information for decision functions. The system's performance depends on relationships between the different system variables. The dynamic behaviour of each variable in the system (firm) is determined by all of its relationships with other variables, whether direct or indirect; and can only be understood by taking into account all such relationships. Sometimes these relationships extend to the external environment of the system.

In an industrial dynamics study, each variable of interest is defined as a mathematical function of other variables of interest. The entire set of such relations comprises the industrial dynamics model of the system under investigation.

In industrial dynamics, simulation is applied as a technique for observing the dynamic behaviour of a model given a specified set of environmental or input conditions, The simulation process is usually carried out on a digital computer, with data concerning the behaviour of any variable of interest returned (in printed or plotted form) to be analysed by the model builder.

The major aspects of industrial dynamics can be summarized as:

1- The emphasis on information feedback characteristics of business systems.

2- The description of business policies and its environment in precise mathematical form.

3- the use of digital computer simulation techniques, and the use of the simulation results to provide the manager with additional insight into the dynamic behaviour of his firm, so that he can more effectively design the policies which control that behaviour.

4.7 An industrial dynamics model of a business enterprise

In conducting the work represented in this thesis an initial attempt was made to use industrial dynamics to represent Stafford Beer's ideas in modelling the business enterprise. A model was constructed which is described in appendix A, but it was not considered adequate for reasons dicussed later.

The model which represents a hypothetical firm will be built in an industrial dynamics manner, and structured to give a total system behaviour pattern, by incorporating some of the enterprise's major activities (since trying to build a model that incorporates all the firm's activities is beyond the scope of our work).

A full discription of the model, the equations used and computer program listing are in appendix A.

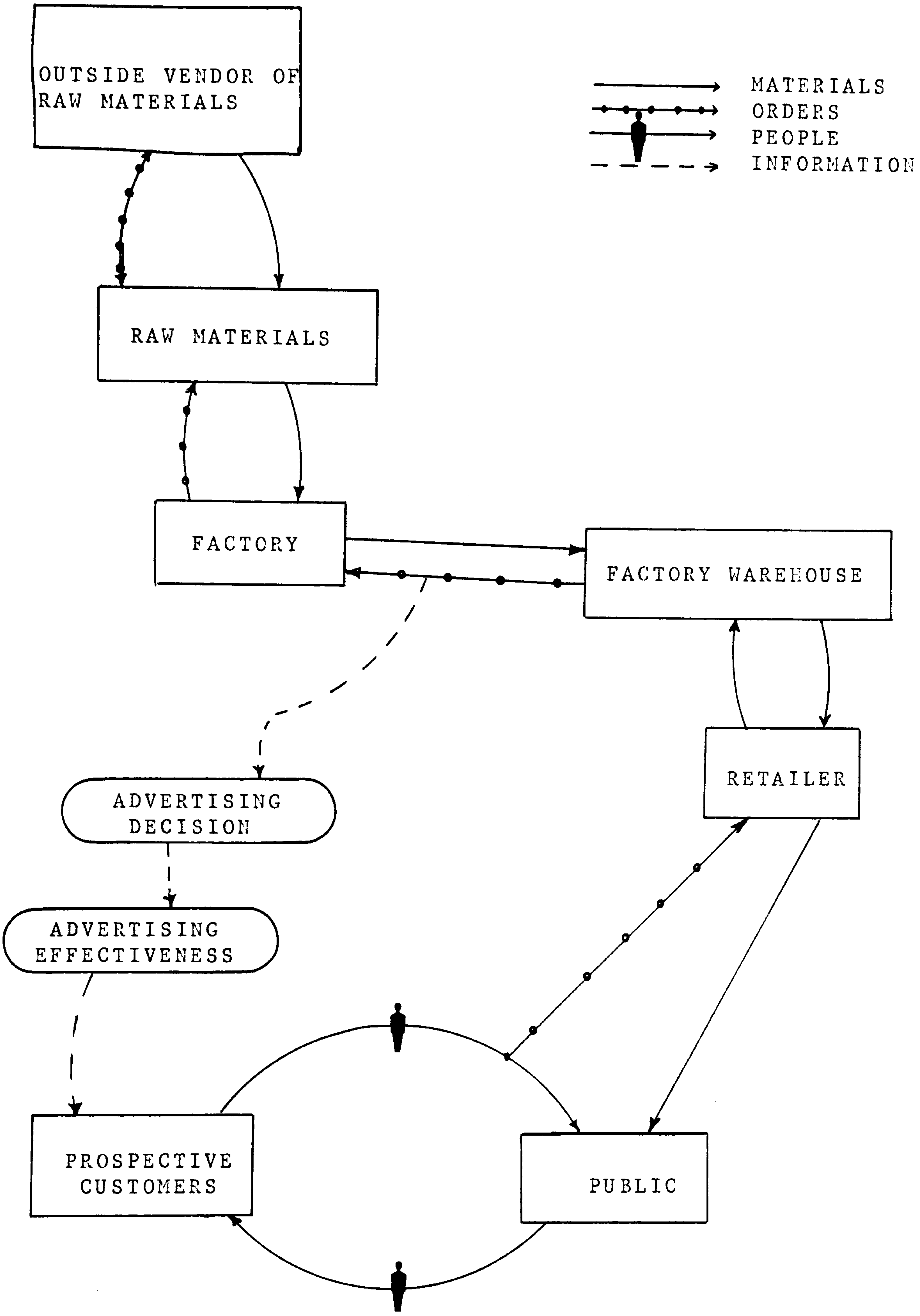


Fig.(4.2) Diagram of Industrial Dynamics model

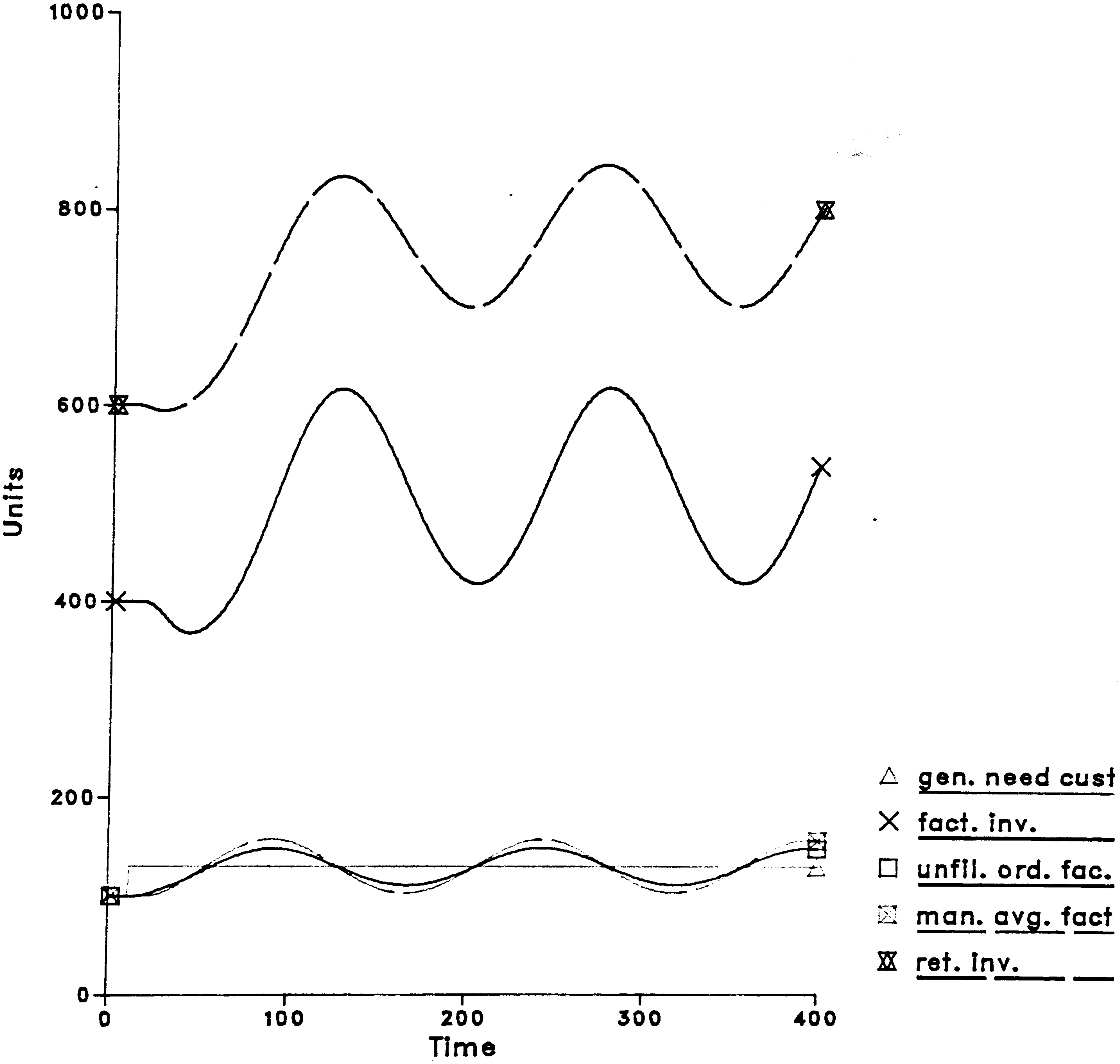


Fig.(4.3) Effects of 30% increase in customers'need on system's major levels

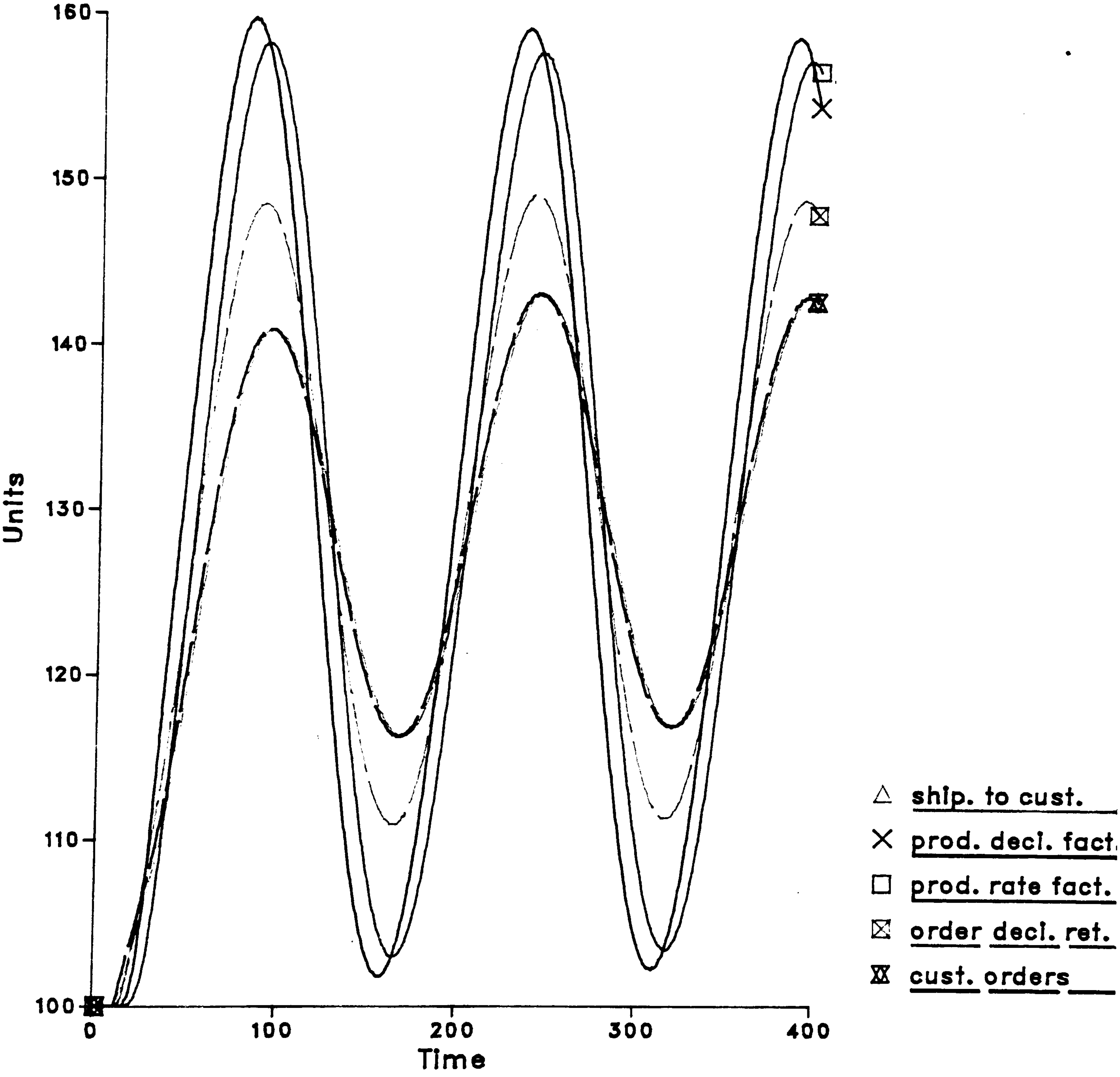


Fig.(4.4) Effects of 30% increase in customers' need on system's major rates

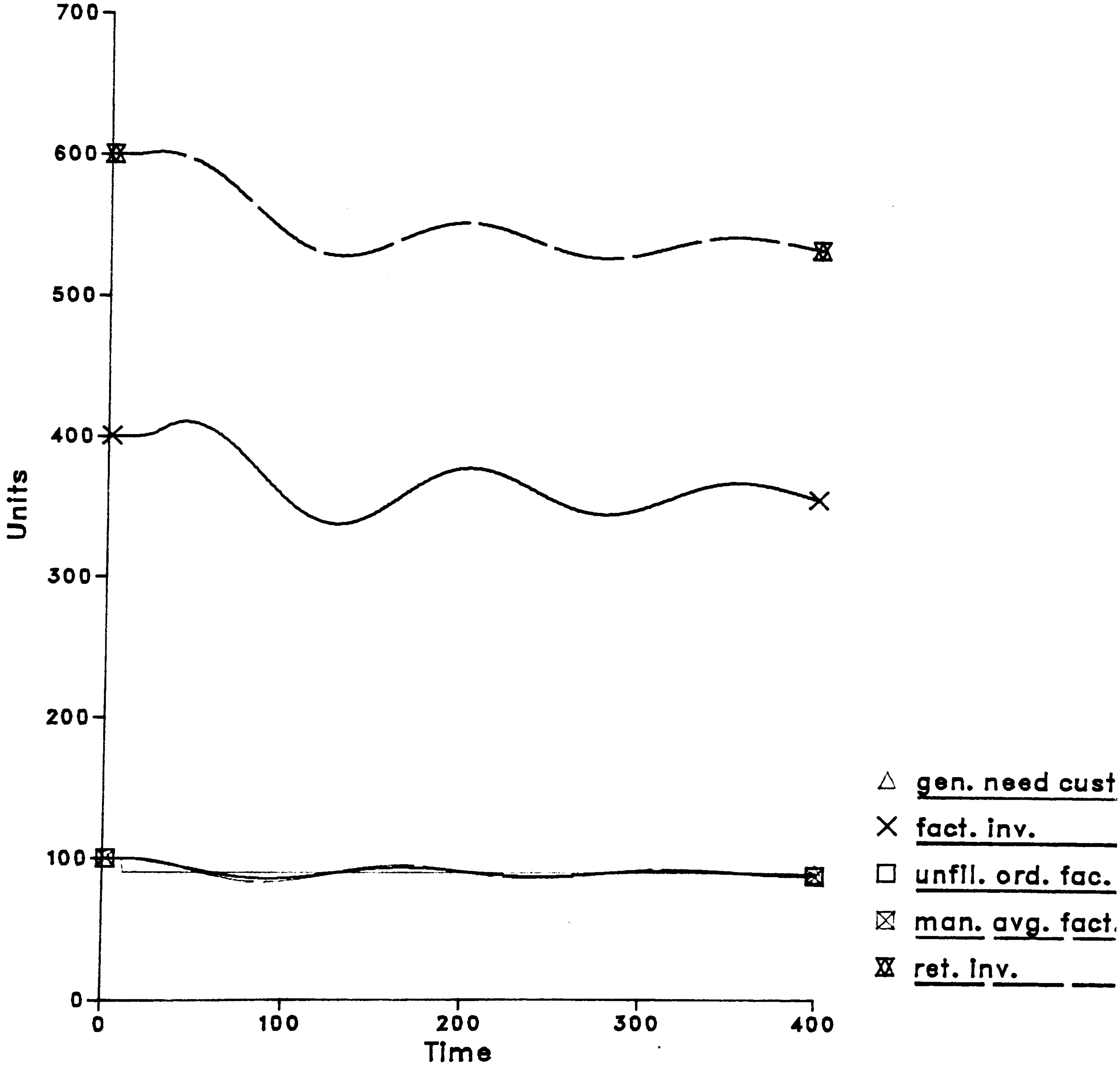


Fig.(4.5) Effects of 10% decrease in customers' need on system's major levels

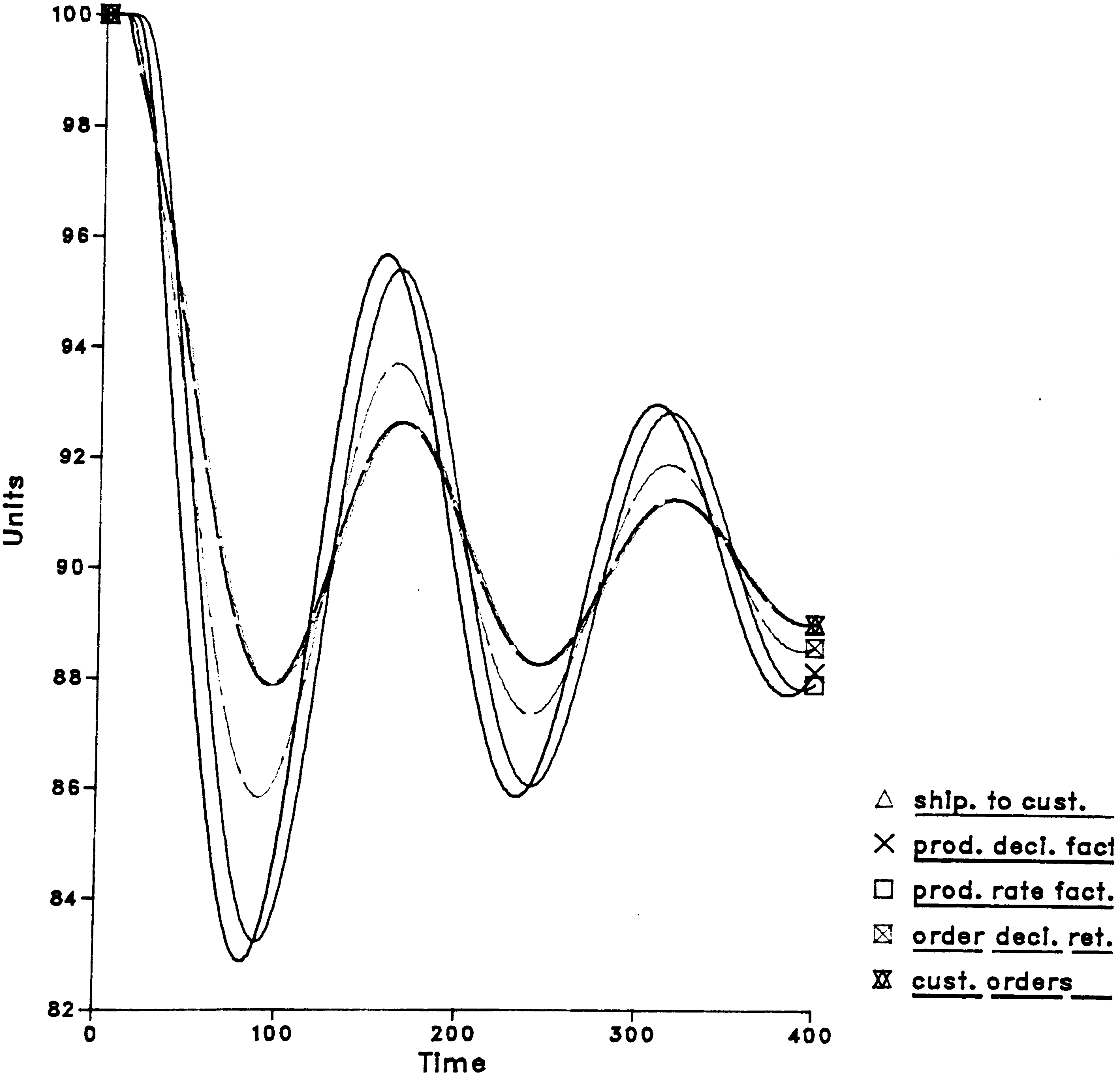


Fig.(4.6) Effects of 10% decrease in customers' need on system's major rates

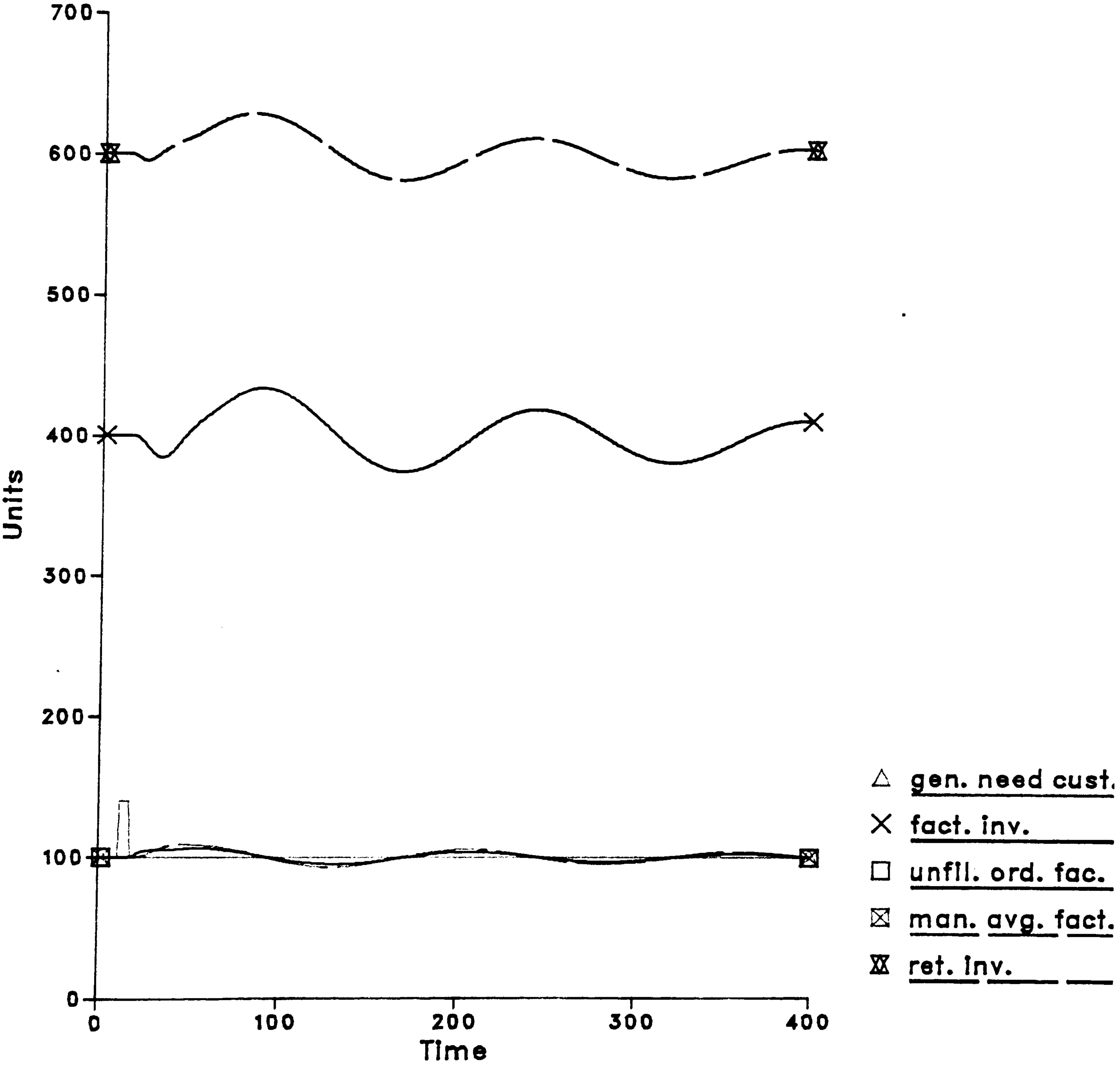


Fig.(4.7) Effects of 40% shock increase in customers' need on system's major levels

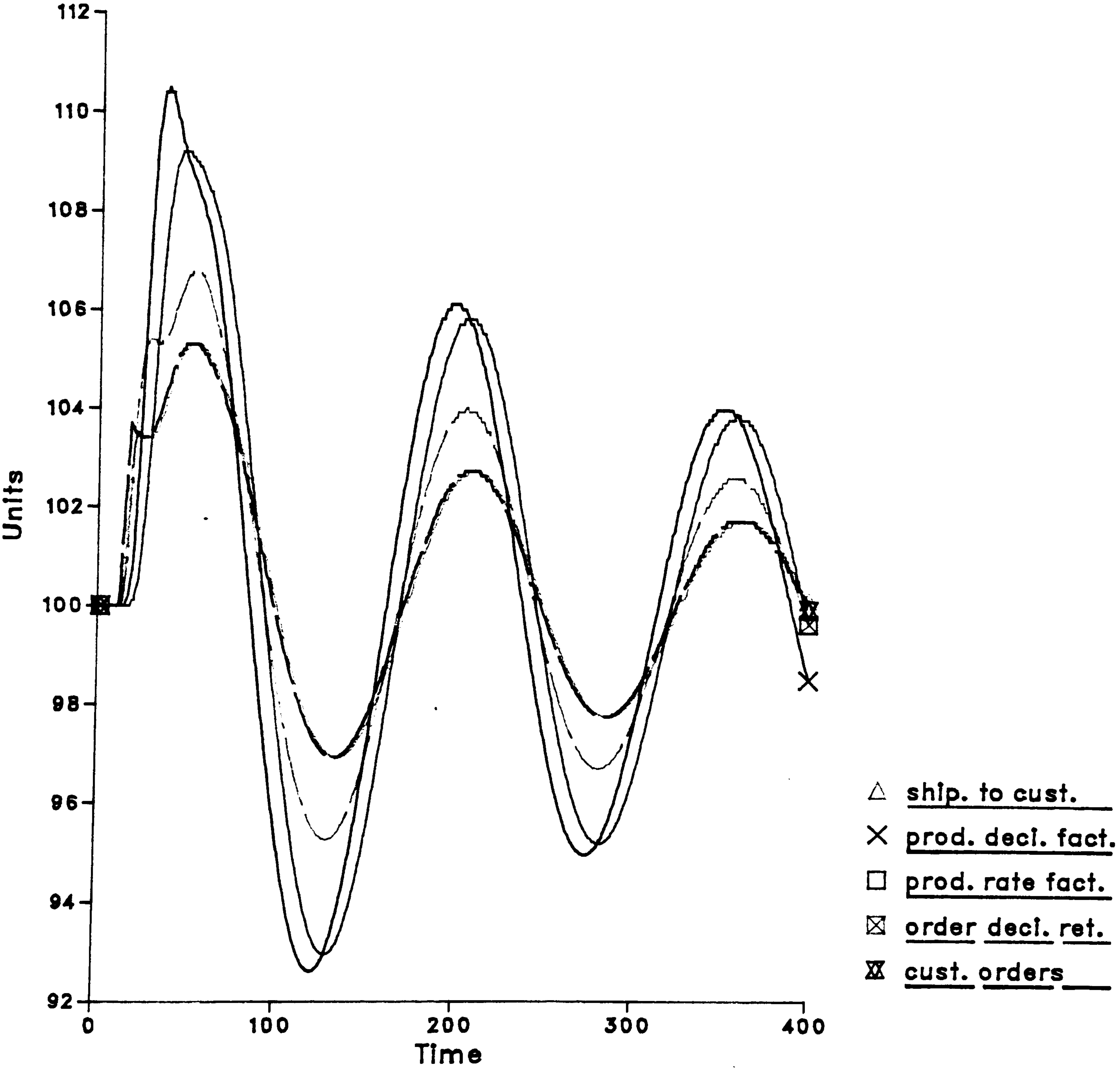


Fig.(4.8) Effects of 40% increase in customers' need on system's major rates

4.7.1 Discussion of the I.D. approach

A very distinctive feature of Forrester's simulation approach is an insistance that the simulation be completely quantitative. There is no allowance for any form of human participation in the simulation, nor is there any allowance for alternatives in policies and decisions.

As mentioned before, our aim in building a simulation model of the enterprise is to study the total system behaviour through its internal and external interactions. Internal control of the enterprise is of crucial importance; any realistic approach to the control inside the firm cannot be content with mere "amplification" effects as Forrester suggests, but should include psychological, behavioural and social factors, since it is people who run the enterprise and make the crucial control decisions at every level of its structure. As an example, Forrester takes for granted the policies that different managers declare they are going to follow. But what usually happens in real life is that managers due to different reasons and pressures (both internal and external), do not follow the originaly declared policies precisely. They either overact or underact or sometimes follow an alltogether different policy.

This shortcoming in Forrester's approach makes it unsuitable for application to Stafford Beer's ideas of the enterprise, since Beer does emphasize the human factor in his model, especially the managers' reactions to the changing situations in the firm.

Forrester's approach studies the enterprise through changes in demand,levels, and so on, but he does not emphasize the importance in basic changes in decision processes, which means that not only quantitative changes in decisions are to be taken, but also basic and organic changes. For instance, instead of changing the order quantity following a certain situation, we change the ordering policy all together. We are going to study the effects of that in the next section using a special model built for that purpose.

The quantitative-only changes in the decision points in Forrester's modelling approach, forces the amplifications in the model to be more mechanistic, as we can see from the results of our model. Amplifications in an industrial dynamics model are manifested by actions being more forceful than might at first seem to be implied by the information inputs to the governing decision. The results show that a change in the information input (increase generation of customers' demand) caused a lot of oscillation in the system. These oscillations are due to the tendency among managers for underestimating the severity of the amplification in this kind of system design. This leads to the conclusion that this industrial system is poorly designed, and it reacts slowly to input variations, and that the response or behaviour of this system is erratic and not efficient. This gives another reason why the industrial dynamics approach is unsuitable to simulate Beer's model of the enterprise as decision changes represent a basic part of the control systems in Beer's model.

The above comments are not to be interpreted as a criticism of industrial dynamics. They were made merely to show why industrial dynamics as a simulation method is not appropriate for our particular needs in this work.

4.8 A model for the evaluation of the effects of policy changes and lead time changes on system behaviour

the most common inventory system in most economies is the factory-distributor-retailer system. The distributor provides a time decoupling service between the factory and the retailer, in that he holds the factory output until ordered by the retailer. Similarly, the retailer provides a decoupling service between the distributor and the customers, in that he maintains an inventory of goods on display for sale to the customers.

4.8.1 Description of the model

This simplified model of a manufacturing firm can be used (for our purposes) as a base for preliminary implementation of Stafford Beer's theory of system one and system two of his multi-system model of the enterprise. The model will also enable us to see how basic changes (not quantitative-only changes) in decisions taken by major operations' managers can improve the overall system behaviour. To achieve this, we are going to designate the factory, the distributor, and the retailer sections as three operational elements that comprise system one. Each of these operational elements has its own manager who looks after controlling the element's operation. For example, the retailer section manager's main concern is satisfying the customer's demand, and maintaining an inventory that will maximize his operational element's effeciency.

A computer model is used to calculate week by week how the retailer inventory, the distributor inventory, and the factory output rate change in response to retail sales.

The model user will be able to observe the change in the model's behaviour resulting from changes in ordering policies, and from adding co-ordinating or cohesion actions to the controlling actions already taken by the managers of each of the operational elements.

The main functions of the retailer in the system are:

1- Take (receive) orders from customers.

2- Deliver goods to customers from his own inventory.

3- Reorder goods from distributor.

4- Receive shipments from distributor.

The function of the distributor is similar to that of the retailer except that the distributor's customer is the retailer and there is a time lag between the ordering and delivery of goods. So the distributor's main functions in the system are:

1- Receive orders from retailer.

2- Ship goods from his own inventory to retailer.

3- Reorder goods from factory to replenish his own inventory.

4- Receive shipments of finished goods from factory.

At the top end of the system we have the factory which produces the goods that end up being sold to the customers. In this model we assume the factory does not have an inventory of any kind. We also exclude the factory's raw material supply system from the model. The factory's functions are limited to:

1- Produce goods at a certain rate.

2- Change the production rate depending on orders received from the distributor.

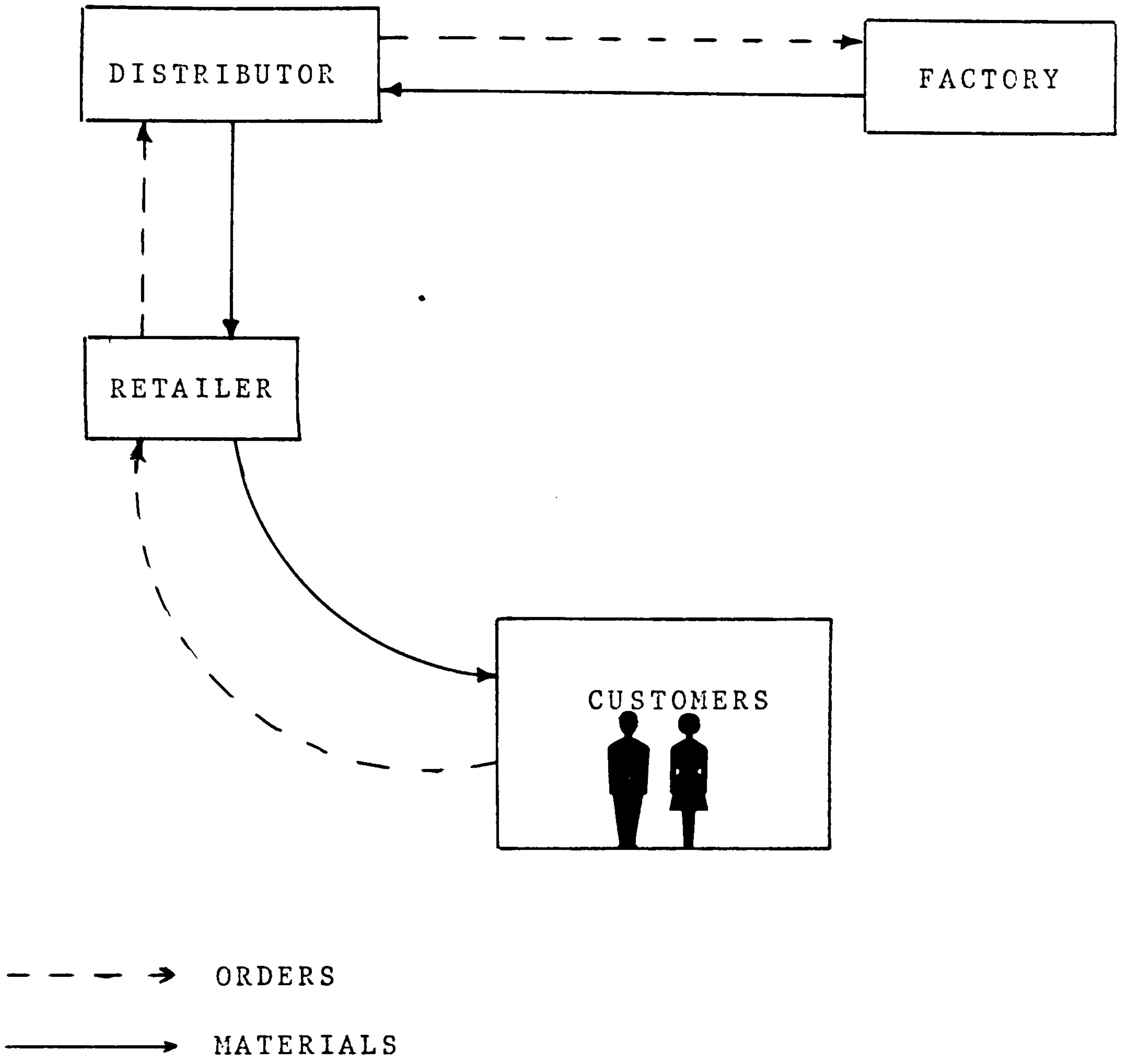


Fig.(4.9) Diagram of factory-distributor-retailer system

4.8.2 The model with the basic policy

The above model represents a simple abstraction of that which is found in any industrial system. Durable goods manufacture and distribution, more or less follow this kind of system.

The formulas for the actual computer model of the retailer are a mathematical representation of the retailer section in the model described above. We also present an example calculation using these formulas to highlight the methodology used.

Retail sales are controlled by the customers. They are part of the input to the program by the user. We assume that the retail sales in the past have been about 100 units per week.

The retailer receives goods ordered on Friday from the distributor, on a Monday one week (10 days) later. The retailer's inventory is the number of units on hand on a Friday afternoon.

The retailer inventory determining formula is:

$$\text{inventory level} = \text{prior inventory level} + (\text{goods received} - \text{goods sold})$$

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The retailer receives goods ordered on Friday from the distributor, on a Monday one week (10 days) later. The retailer's inventory is the number of units on hand on a Friday afternoon.

The retailer inventory determining formula is:

inventory level = prior inventory level + (goods received
- goods sold)

As just stated, retail orders are placed with the distributor each Friday afternoon after determining the inventory level at that time. The retail manager policy is to order the quantity that have been sold to customers during the week plus (or minus) enough units to return the base stock level back to 100 units.

retail order = retail sales to customers + (100 - inventory level)

The distributor section manager policies for maintaining his inventory are similar to those adopted by the retailer section manager (which follow a natural "selfish" path to maximize their profitability and optimize their objective functions without caring for other operational elements' requirements in the whole system).

The distributor shipments to retailer are dispatched each Wednesday from orders submitted by the retailer on the prior Friday. As mentioned before, these orders arrive at the retailer's inventory on the following Monday.

distributor shipments = retailer orders (prior week)

The distributor inventory receipts are the factory production of the previous week which is received each Monday morning.

distributor receipts from factory = factory production
(prior week)

The distributor inventory level is the number of units on hand Friday afternoon at the close of business. The inventory level actually varies during the week.

distributor inventory level = prior inventory level + (goods
received from factory - goods
shipped to retailer)

The distributor orders are placed with the factory each Friday afternoon after taking inventory. However, it takes the factory a week to change the production rate, so two weeks pass before the distributor actually receives the order. The manager's policy is to order the current week's shipment plus enough units to return the base stock back to a normal level of 200 units.

distributor orders from factory = distributor shipments to
retailer
+ (200 - inventory level)

As mentioned before, in this system's model the factory section maintains no inventory. The factory produces at the rate specified by the distributor order. There is, however, a one-week delay for shipping. The net effect is that the distributor receives the actual order two weeks after it is placed with the factory.

All the above mentioned policies which are practiced by the managers of the operational elements, are based on what is called the "normal" inventory policy which includes the significant reorder rule of order the current week's sales plus or minus enough to bring the base stock back to its normal level.

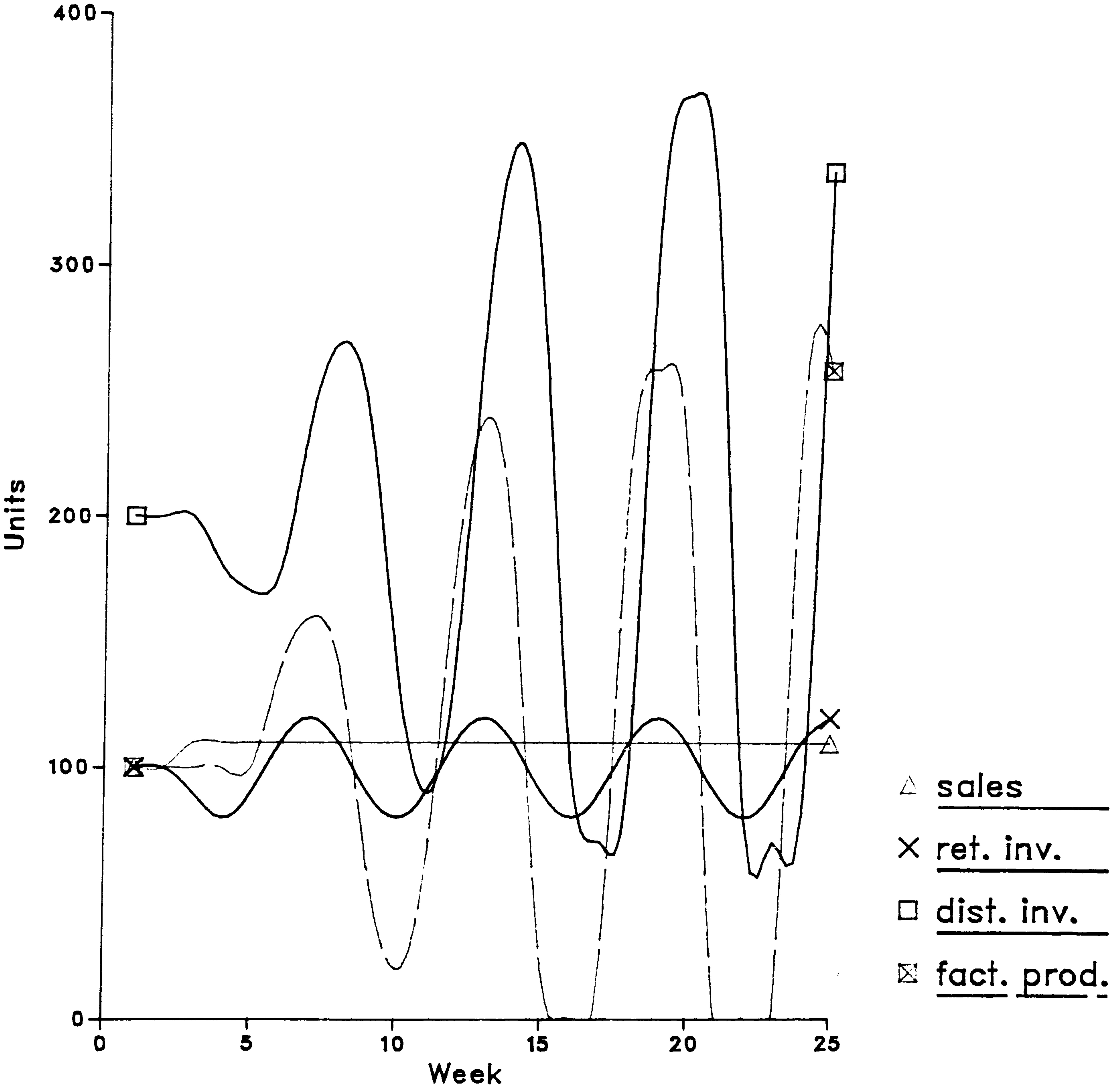


Fig.(4.10) Response of basic policy model to 10% increase in sales

Looking at the results of the experiment fig(4.10) with the so called normal inventory policy, it is quite evident that it is not a very smart policy. For although the retailer manager managed to keep his inventory "relatively" controlled and satisfied the customers, a simple ten percent increase in retail sales has set off uncontrollable fluctuations in the distributor's inventory and in the factory production rate. Even though the factory services only one distributor and one retailer, these uncontrollable swings cause the factory to completely shut down by week sixteen. Negative inventories, orders, or factory rates are not allowed.

By week twenty five the situation is still out of control. The retailer has not completely stabilized his inventory back to 100 units, the distributor inventory has not stabilized at all, and the factory is in a chaotic situation. This cyclic behaviour (oscillatory leading to explosion) of the system is the result of the neglected lead times in the system and the "blind" and "selfish" quantitative ordering policies of the retail and distributor managers.

4.8.3 The model with improved policy

This section considers the problem of controlling the fluctuations and oscillations in the system. This could be achieved through introducing change in the distributor and retailer managers' reordering policies. The basic concept applied is that of dampening the amplitude of change. This concept is implemented by changing the reorder policy to decrease the rate of replenishment of the base stock.

According to the old policy, the retailer order on Friday, the goods are shipped on the next Wednesday, and received on the following Monday. Each Friday, the retailer orders enough "to bring the base stock back to normal" even though the goods he ordered the prior Friday to bring the base stock back to normal still have not arrived. When the order does arrive the retailer over-reacts (normally) by ordering too little the next time. The net result is that this policy caused large oscillation through the system. One way to dampen the oscillations in the system is to change the replenishment policy to specify that only a percentage of the base stock difference is to be ordered. The new formula is:

retail order = retail sales + (100 - inventory level) (X%)

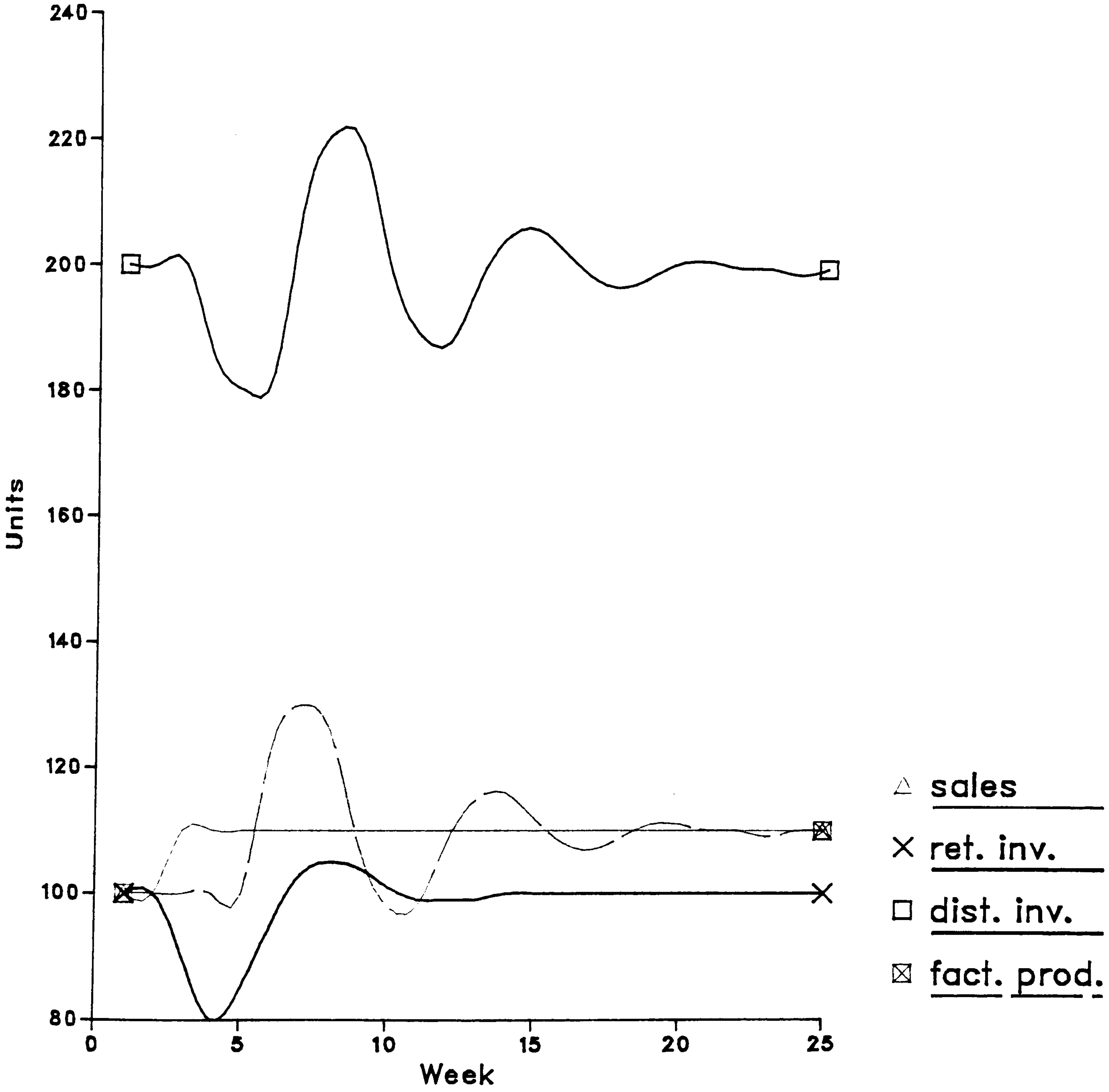


Fig.(4.11) Response of improved policy model to 10% increase in sales

From fig(4.11) we can see that the overall effect of the change in the policy is that the retailer section manager only partly reacts to increases or decreases in the base stock and allows some time for inventories to return to normal.

The distributor can follow a similar policy in ordering from the factory by including a Y% in the order formula from the factory.

The overall result of the new change in reordering policies is a dramatic improvement in the performance of the whole inventory system.

Retail reorders match the new sales level within eleven weeks, distributor reorders match the new sales level within eleven weeks, and the factory rate although is not yet stable, appears to be dampening out.

Most significantly, the system is no longer in an uncontrollable oscillation. The fluctuations have been dampened out, and the system stabilizes towards the new sales level.

4.8.4 The model with new policies and reduced lead times

Although the previous changes (introduced by system two through its different co-ordination activities) in the reorder policies of the managers in the different sections (operational elements) caused a lot of improvement in the system's behaviour, the system still suffers from some oscillations and is not perfect. There is still a long time lag before the factory catches on to the new rate. Moreover, a simple 10 percent increase in retail sales still causes a 20 percent change in the distributor shipments to retailer, and a 42 percent change in the factory production rate. In this section we are going to show how "system two" will try to control (dampen) the oscillation in the system through a decrease in the lead time between the order and its receipt at the factory.

From the previous sections under the old normal policy, the lead times were:

retail lead times:

order on	delivered on
Fridy week 1	Monday week 3

distributor lead times:

order on	change rate	deliver goods
Friday week 1	week 3	Monday week 4

The effect of these lead times were clearly seen when the retailer reorders every Friday to make up goods that have previously been ordered but not yet delivered. In effect, he makes a double reorder for the same goods. In addition, the factory takes seven weeks to begin to respond to a change in the retail sales.

The new decreased lead times, brought about, by system two introducing new working schedules, would be achieved by working the distributor section on Saturdays in order to deliver the Friday afternoon orders the very next Monday. Thus:

retailer decreased lead time:

order on	deliver on
Friday week 1	Monday week 2

Similarly the lead time for the distributor may be changed if the factory can shift to a new production rate without a week lag, and if the factory ships goods over the weekend.

distributor decreased lead time:

order on	change rate	delivered
Friday week 1	week 2	week 3

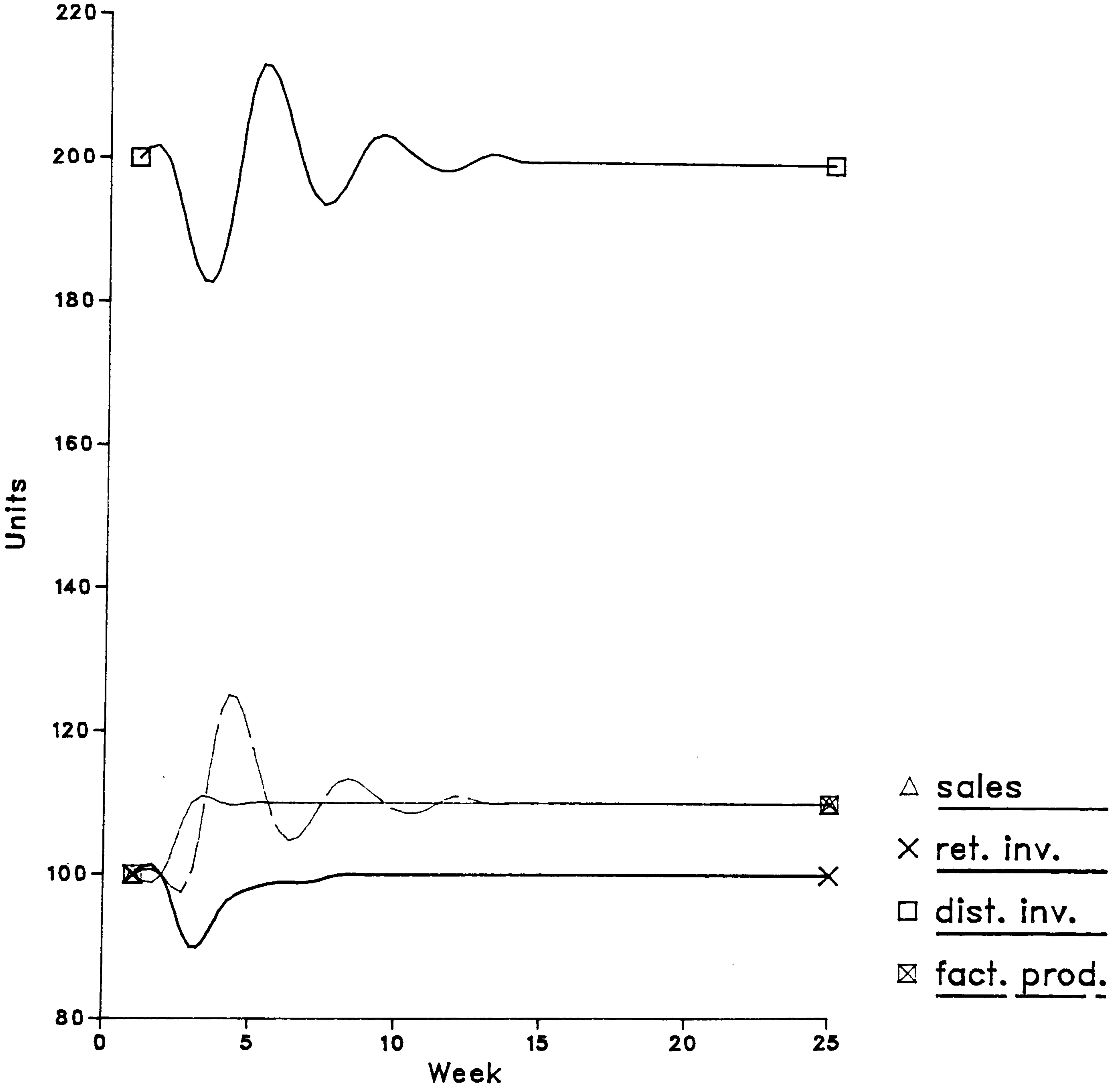


Fig.(4.12) Response of improved policy and reduced lead times model to 10% increase in sales

The result of the new lead time policy fig(4.12) is a further improvement in the overall performance of the inventory system (system one). Retail orders match the new sales rate within seven weeks. Distributer orders match the new sales rate within seven weeks, and factory rate is set to the new sales level in ten weeks. In addition to cutting response lags down, there is less fluctuation in the inventory levels.

A simple icrease of 10 percent causes a 5 percent change in the distributor shipments to retailer, down from the prior 20 percent change. Also, the factory rate changes 22 percent, down from the prior 42 percent. Thus, in general it can be said that the inventory system is now in a better shape, due to the changes in the reordering decisions and the reduction in lead times.

CHAPTER FIVE

OPERATIONAL MANAGEMENT COMPUTER MODELS
INVENTORY AND PRODUCTION PLANNING SIMULATION MODELS

5.1 Introduction

In this chapter models that represent the major activities of the firm are going to be constructed and described.

The chapter contains four simulation models of:

1- A simple inventory situation.

2- Decision making in a probabilistic inventory situation.

3- Decision making in a deterministic inventory situation with price discounts.

4- A production planning situation.

All the models were built in a way that enables them to serve the job of being parts of the viable system model to be discussed in chapter 6.

5.2 Simulation of inventory replenishment model

To evaluate the charachteristics of the inventory replenishment decision taken by the manager, we use a dynamic system simulation method, in which we utilize a random number generator to generate demand and lead time (with assumed known probability distributions) throughout the simulation run _ which cosists of 50 periods, representing the duration of one year, or 50 weeks. The demand represents the number of units of the product desired by customers per unit of time, whereas the lead time represents the number of units of time from the time a replenishment order from the manufacturer is placed until it is received.

In our work we are going to use the power resdue method (Ley 1970) and the random number generating facilities of the multics system on a Honeywell computer.

5.2.1 Description of the model

As mentioned before, we assume that the probability distribution of both demand and lead time is known (and fixed) throughout the simulation run. If demand exceeds the amount of inventory on hand, the difference represents lost sales (which incurres a stock out cost).

The sequence of events in a simulation time period of one week is: first, any replenishment order due in arrives; then demand occurs (generated by random sampling from the demand distribution); and finally, the inventory situation is reviewed and a reorder is placed of a fixed quantity Q if the replenishment rule indicates it should be. An order placed at the end of period t arrives at the start of period t+l (l is lead time, randomly generated and > or = 1).

To keep the model simple, we assume that the replenishment rule is to order Q units whenever the amount of inventory on hand plus inventory due in is less than or equal to ROL (reorder level), where Q > ROL. The inequality Q > ROL insures that there is never more than one replenishment order outstanding.

The simulation progresses by stepping time forward in fixed increments of one time period (week), beginning with period t=1.

At the start of the simulation, initial conditions are specified. The initial conditions are the level of inventory on hand, the amount due in, and the associated time due in.

A description of the algorithm and flow chart of the simulation program as well as the program listing are in appendix C.

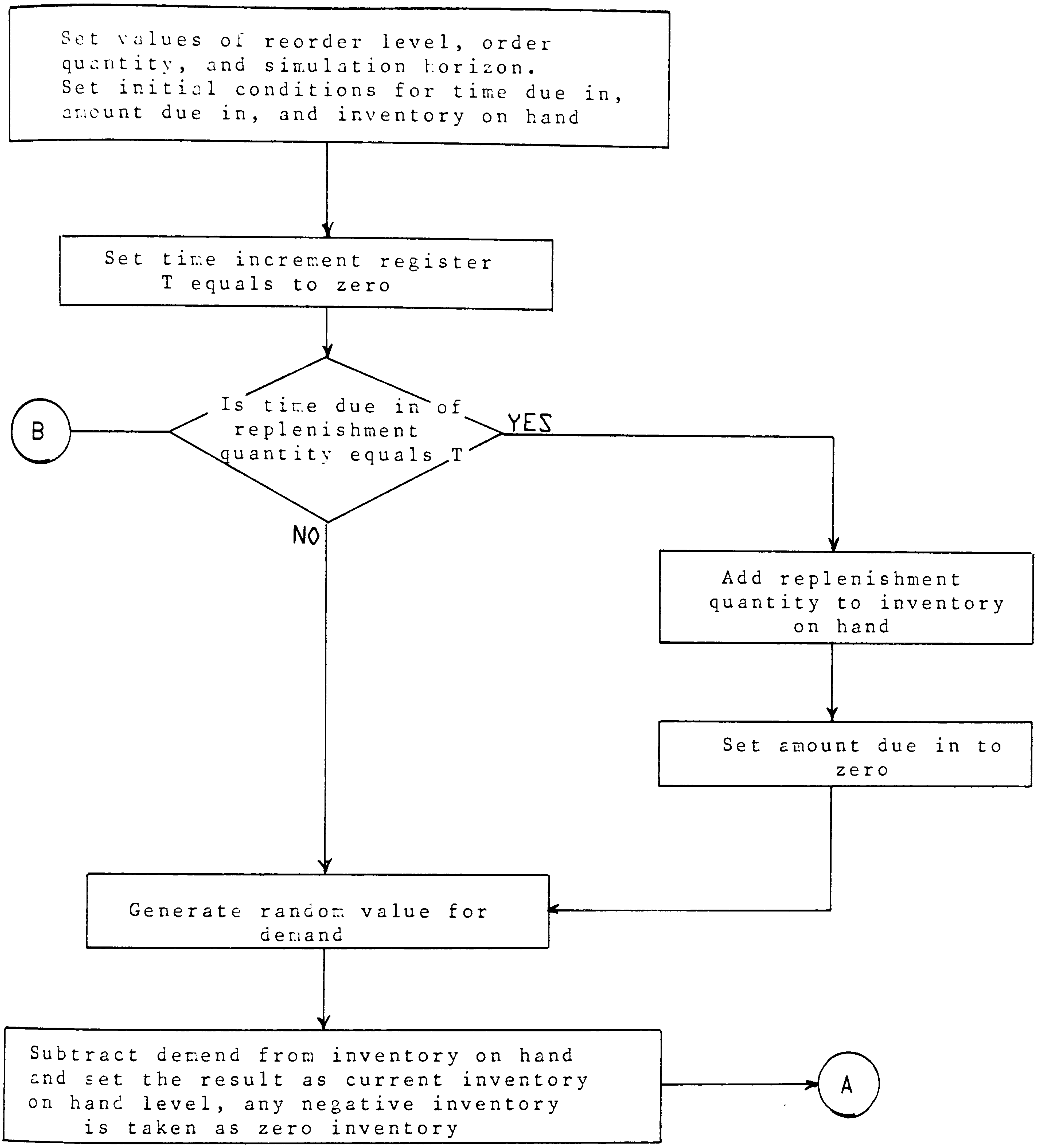


Fig.(5.1) Flow diagram of inventory system

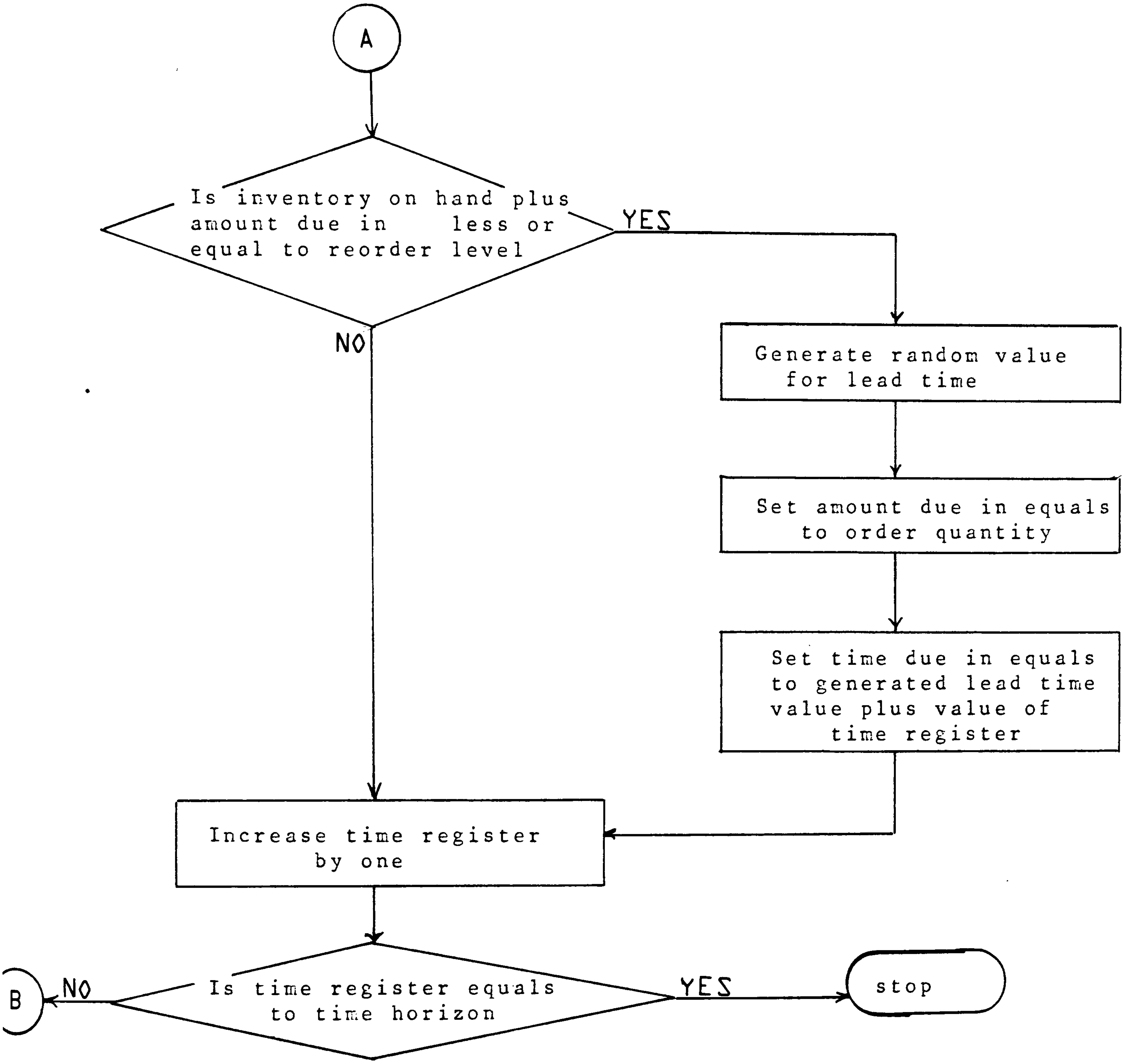

A
Is inventory on hand plus amount due in less or equal to reorder level
YES
NO
Generate random value for lead time
Set amount due in equals to order quantity
Set time due in equals to generated lead time value plus value of time register
Increase time register by one
Is time register equals to time horizon
NO
B
YES
stop

Fig.(5.1) cont.

5.3 Inventory control decision model

The model represents inventory manager decision making for the optimal economic order quantity and the optimal reorder level in fixed reorder level, and fixed reorder quantity inventory situations.

5.3.1 description of the model

The model represents an inventory system in which the demand for a single product, and the lead time are both discrete random variables with known probability distribution functions. In order to discuss the distribution of demand and lead time, a unit of time must be established (one week). A cycle is the number of units of time between the receipt of two consecutive replenishment orders. It is assumed that the distribution of both demand and lead time would remain the same from cycle to cycle, and since cycle time is a function of demand and lead time, it will also be a random variable.

In a fixed reorder level, reorder quantity inventory model the decision of "when and how much to order" is the most important decision that the inventory controller has to take (which is going to be represented in a computer simulation program based on the currently discussed model). We are going to assume a planning period of one year, during which the manager bases his decision on controlling the inventory using the minimum of spending, or put another way, maintaining the minimum cost in that operation.

Other assumptions in the model are:

a- Infinite delivery rate from the manufacturer (a complete order is received at one time).

b- An annual expected demand is given or forcasted.

c- There are three major costs associated with the inventory problem:

1- Ordering cost (ORC)
2- Holding cost (HC)
3- Stockout cost (SOC)

Total cost is the result of adding all three above mentioned costs.

The calculation of the minimum total cost and the calculation of the optimal order quantity and reorder level which yield the least expected total cost are in appendix D. Also in appendix D are the algorithm, flow chart, and program listing of the simulation model.

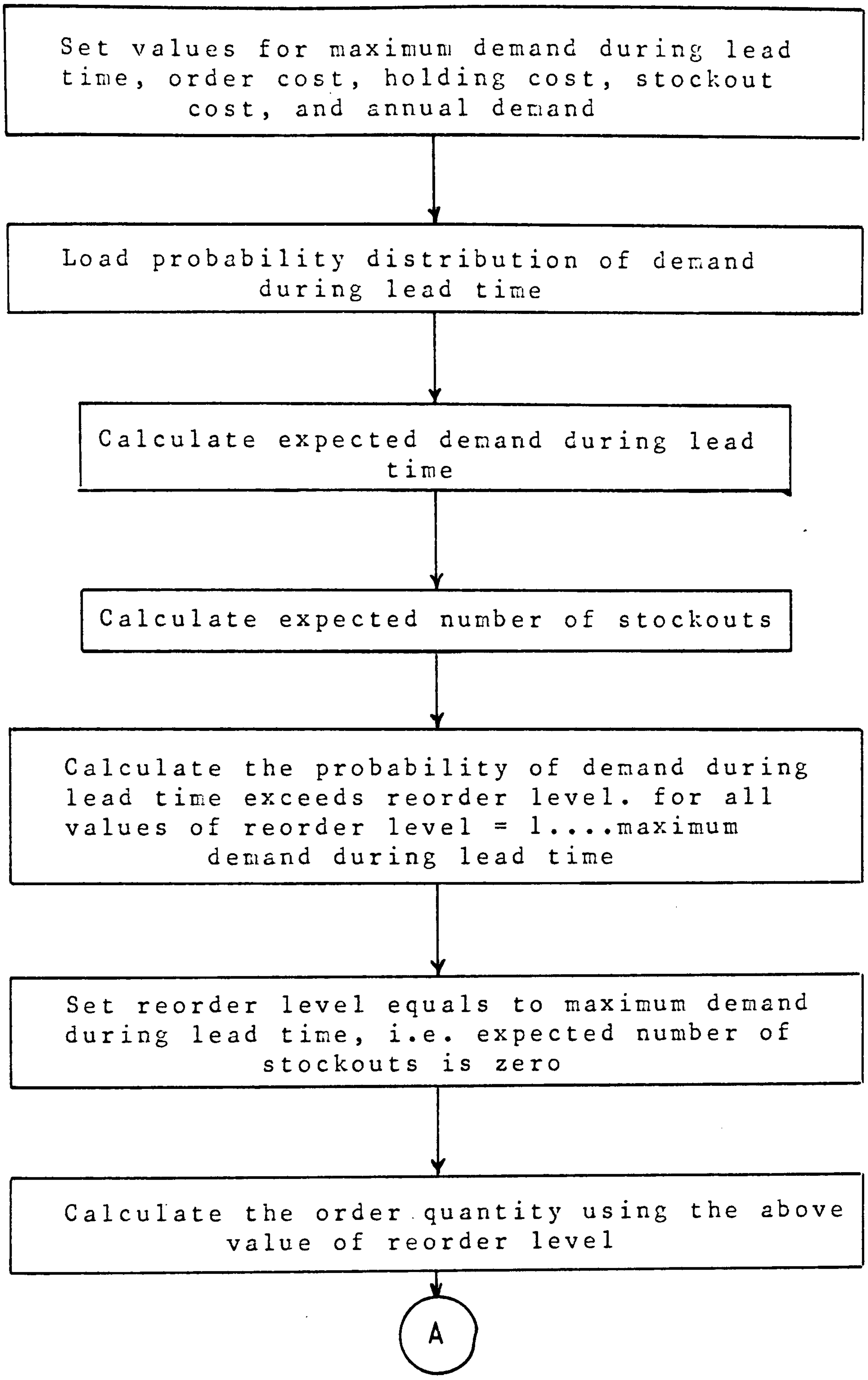


Fig.(5.2) Flow diagram Of inventory decision model

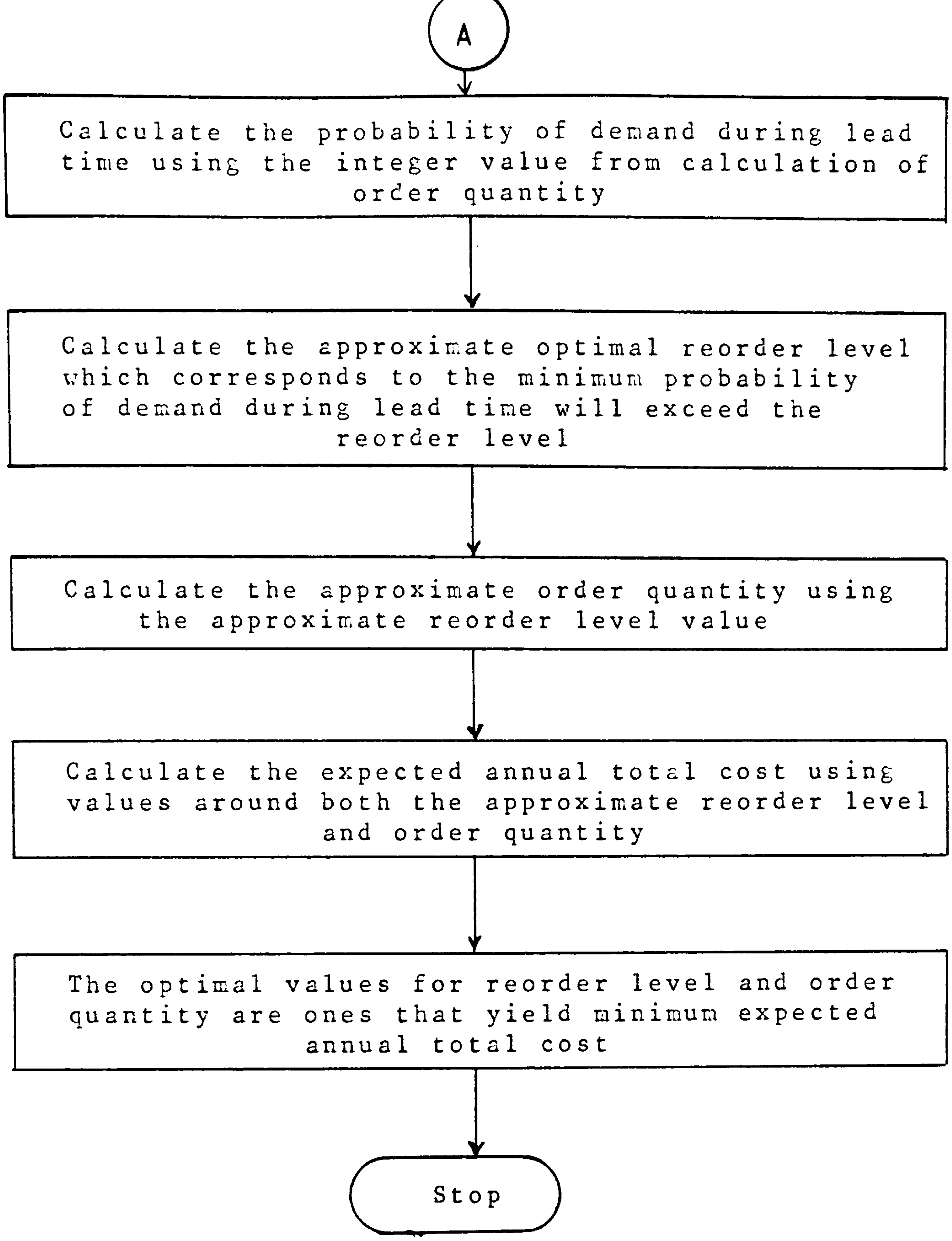

A
Calculate the probability of demand during lead time using the integer value from calculation of order quantity
Calculate the approximate optimal reorder level which corresponds to the minimum probability of demand during lead time will exceed the reorder level
Calculate the approximate order quantity using the approximate reorder level value
Calculate the expected annual total cost using values around both the approximate reorder level and order quantity
The optimal values for reorder level and order quantity are ones that yield minimum expected annual total cost
Stop

Fig.(5.2) cont.

5.4 Production planning and scheduling model

In this model we are going to consider an inventory/production problem of determining the production schedule for a certain item during the next N time periods, where there is a specified demand for the item during each period.

5.4.1 Description of the model

To simplify the model we are going to assume that there is a fixed maximum production capacity for any time period in the planning horizon , however, manufacturing costs go down as the production at the start of any period goes up. Any more than required production at one time must be held in inventory, which of course will cost money as a result of the cost associated with holding items in an inventory (holding cost).

The manager's object is to determine a production schedule that will minimize the total production cost and inventory holding cost. There are N periods of production, and the manager has to make a plan for scheduling the quantities produced and stocked that will yield minimum cost; subject to the constraints:

1- All demands are met on time.

2- The inventory level at the end of the planning horizon (at the end of period N) is zero.

There are two significant assumptions in our production planning model:

1- The amount of ending inventory at the end of period I-1 plus the amount produced in period I is available for use during the Ith period, and delivery to inventory from production is instantaneous.

2- The inventory holding cost for the Ith period is based on the amount of ending inventory for period I.

A description of the dynamic programing method used to calculate the optimal amount to produce during each time period is in appendix E. Also in appendix E is the algorithm, flow chart, and listing of the simulation program for the production scheduling model.

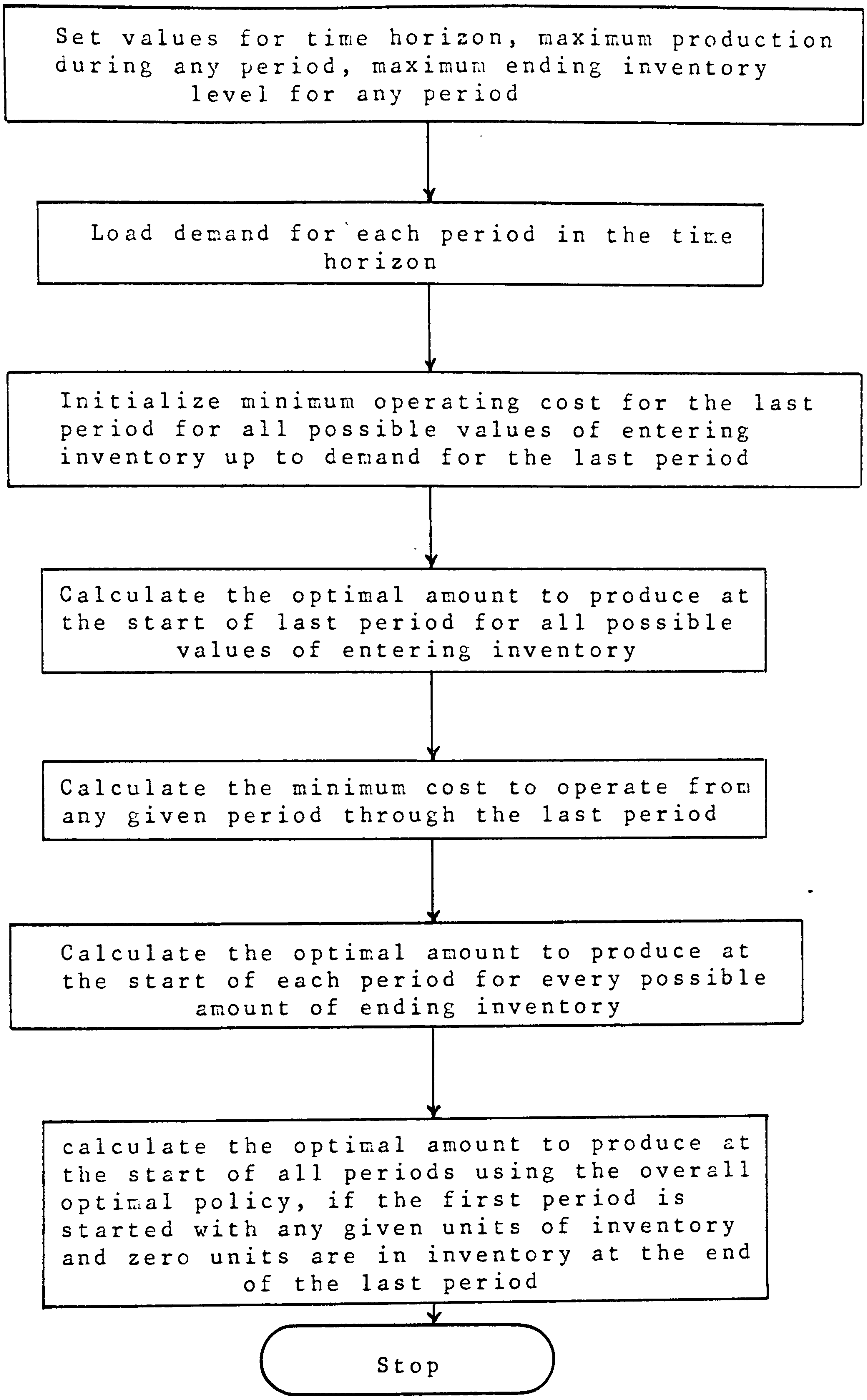


Fig.(5.3) Flow diagram of production scheduling model

5.5 Model of deterministic inventory system

In section 5.2 we discused a probabilistic inventory model with changing demand and lead time patterns which represented a realistic model of a retailer or distributor kind of inventory system. However, for a raw material section a deterministic inventory model would represent a more appropriate approach since demand and delivery lead time can be more or less constant for long periods of time.

As said before, basically, the problem in inventory control is to minimize the sum of the costs associated with maintaining an inventory, i.e. minimizing the total inventory operating cost. The key to minimize the inventory costs is the manager's decision of when and how much to order.

5.5.1 Major assumptions of the model

For this deterministic inventory model we assume the following:

1- A planning period of one year.

2- Demand pattern is known and predicted. The assumption that the demand for the the items in inventory is known is only valid in the case of raw material items needed in a manufacturing process, because usually the capacity of a production line is known, and the average need for raw materials can be easily predicted from past data. In contrast, the demand for items held in inventory to be sold is not constant throughout the planning horizon (see section 5.2).

3- the lead time to receive an order from outside vendor is known and constant for the planning period.

4- Complete orders are delivered at one time (infinite delivery time).

5- Unfilled orders are lost (no back ordering allowed).

6- There are two costs associated with this kind of inventory system: the ordering cost, and the inventory holding cost.

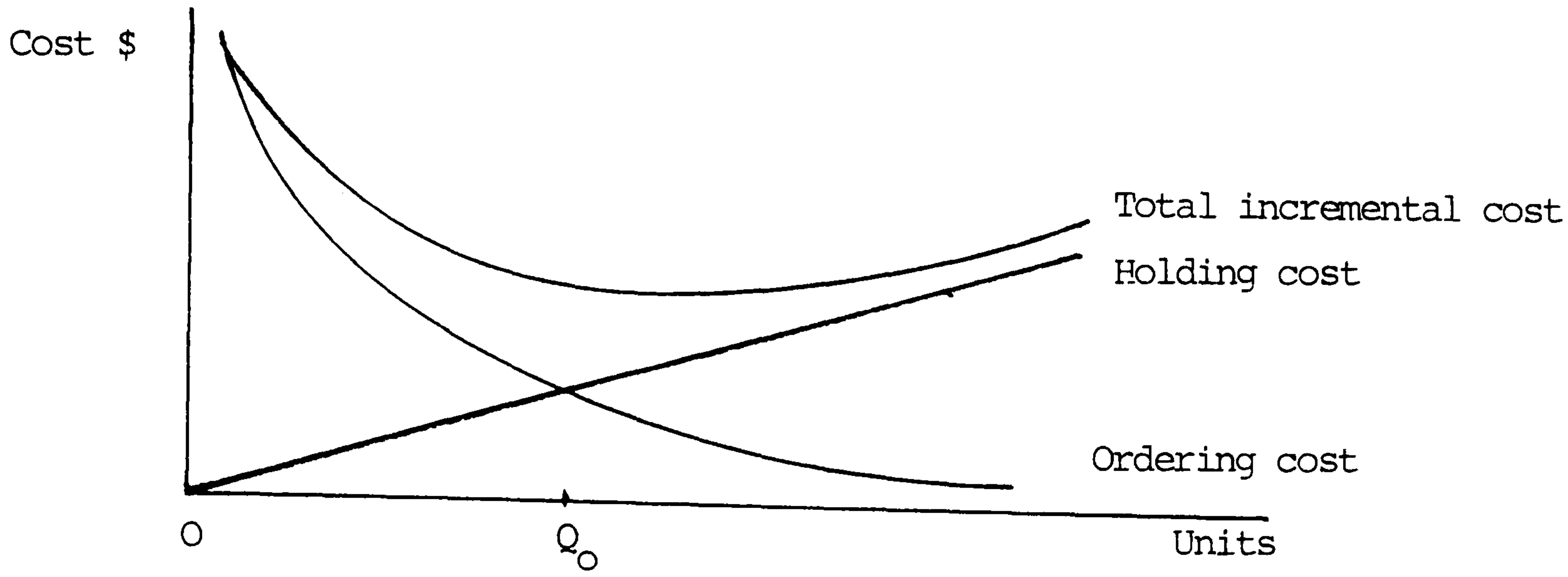
5.5.2 Introducing quantity price discounts

suppliers of raw materials often offer price reductions if customers are prepared to order larger quantities. So in this section we are going to extend the basic eoq model to include this real life phenomenon which is usually a common practice in raw materials purchasing.

Refering to section (5.3), it should be noted that in the derivation of the basic EOQ the price per unit affects the holding cost, but not the ordering cost. Nevertheless, if price discounts are introduced as variables, they will influence the total inventory operating cost TAIC. The effect of price discounts is graphically illustrated in fig (5.4).

The introduction of the quantity discount to the economic order quantity model makes it more difficult to obtain a solution. It is not possible to find directly the lowest point on the total cost curve. The general approach is to investigate the total cost curve at each price break. In addition, the curve must be analysed at different points near the price break giving the lowest total cost to see if an even better solution can be obtained.

A description of the procedure used to calculate the optimal order quantity in an inventory system with price discounts is in appendix F. Also in appendix F are the algorithm, flow chart, and program listing of the price discount model.



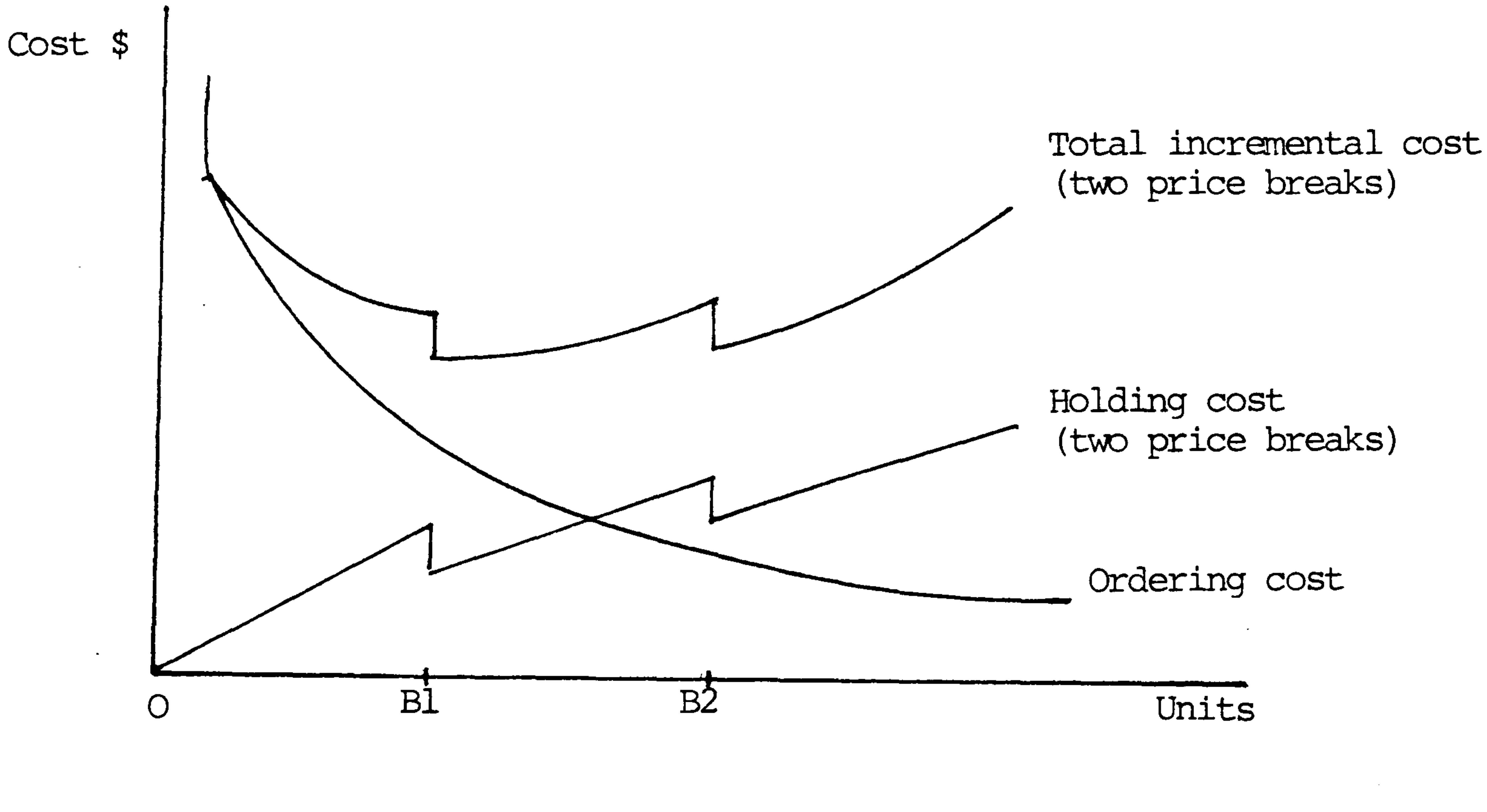


Fig.(5.4) The effects of price discounts on the order quantity

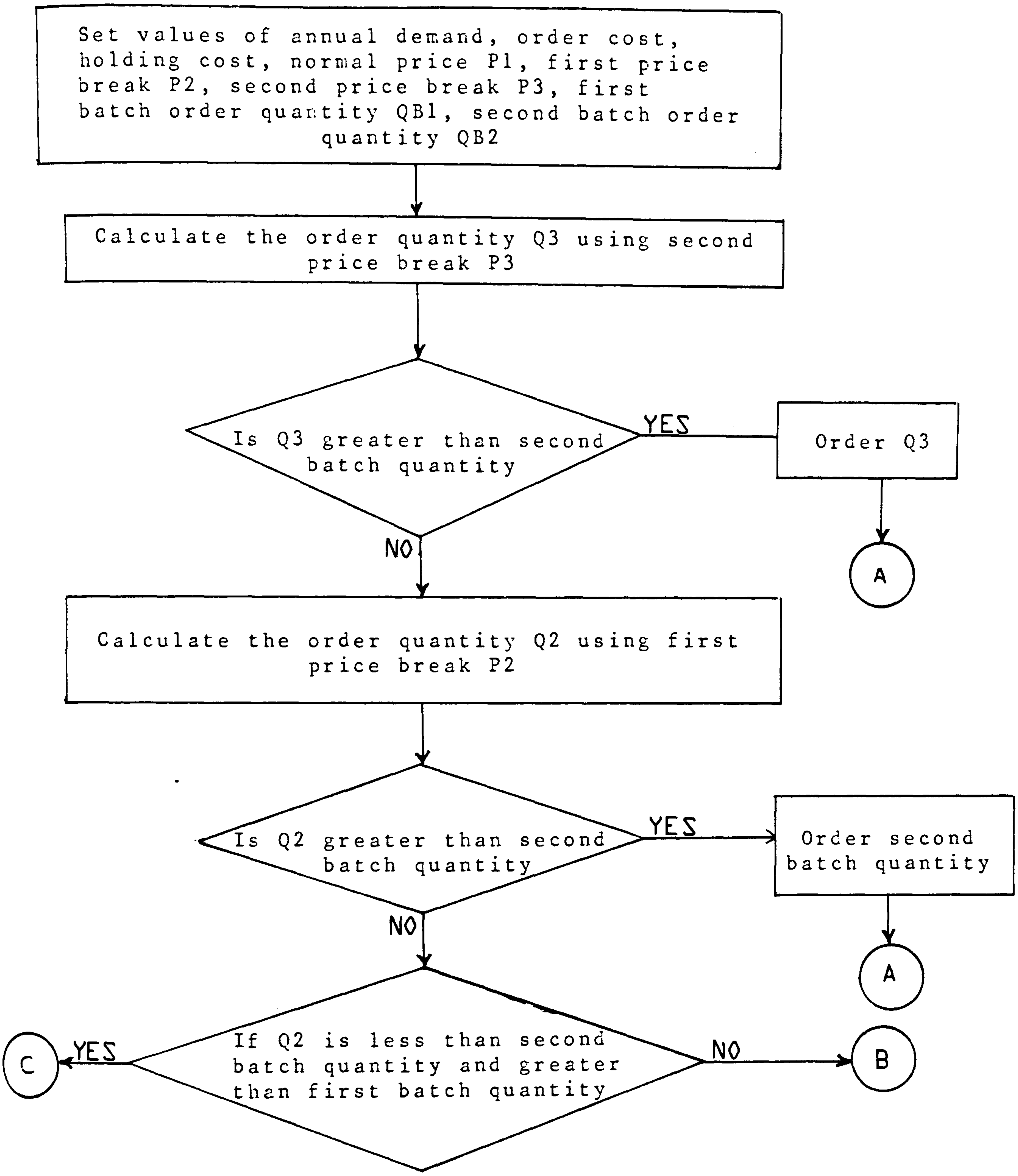


Fig.(5.5) Flow diagram of inventory decision with quantity price discounts

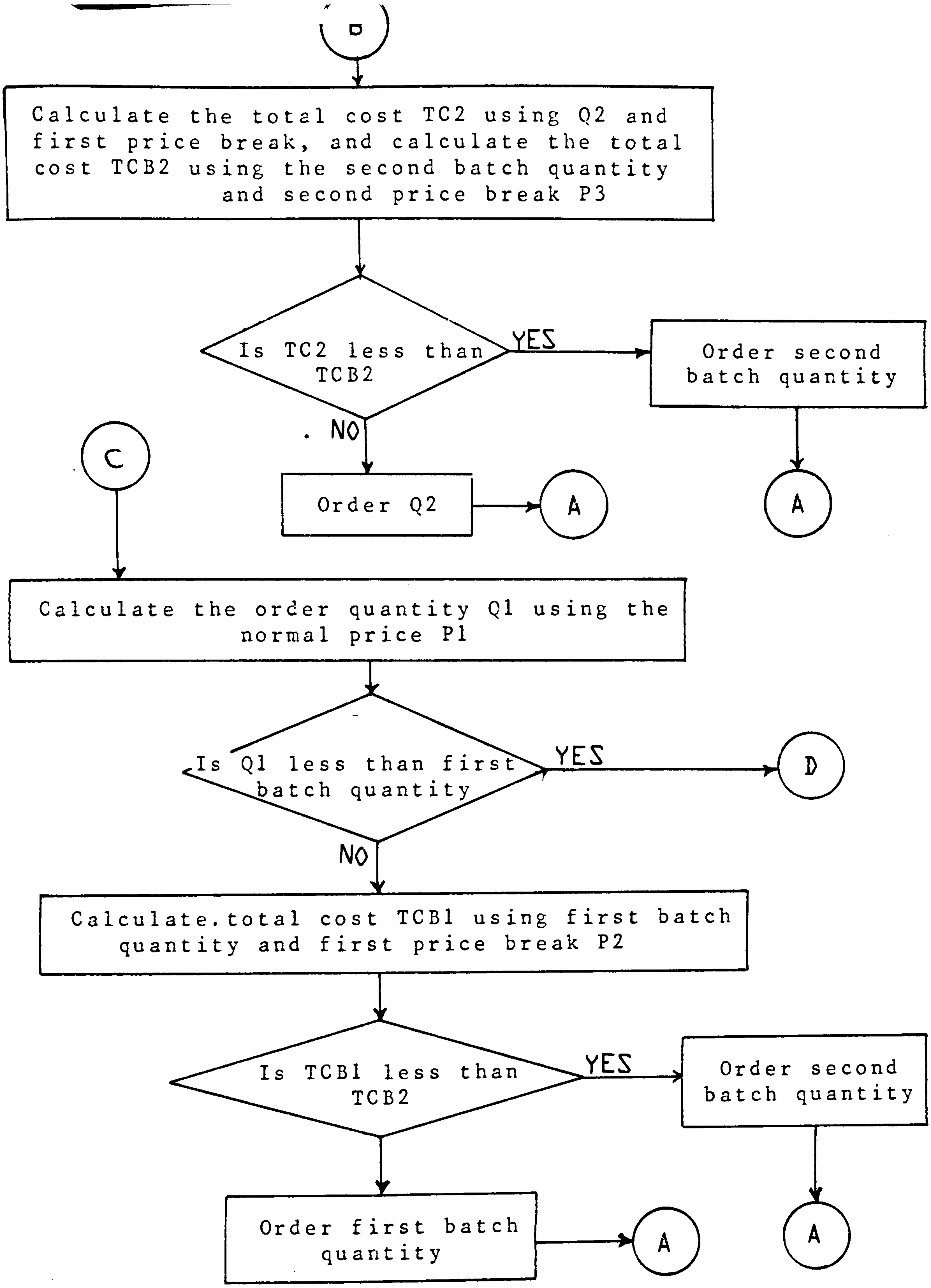

B
Calculate the total cost TC2 using Q2 and first price break, and calculate the total cost TCB2 using the second batch quantity and second price break P3
Is TC2 less than TCB2
YES
Order second batch quantity
A
NO
Order Q2
A
C
Calculate the order quantity Q1 using the normal price P1
Is Q1 less than first batch quantity
YES
D
NO
Calculate.total cost TCB1 using first batch quantity and first price break P2
Is TCB1 less than TCB2
YES
Order second batch quantity
A
Order first batch quantity
A

Fig.(5.5) cont.

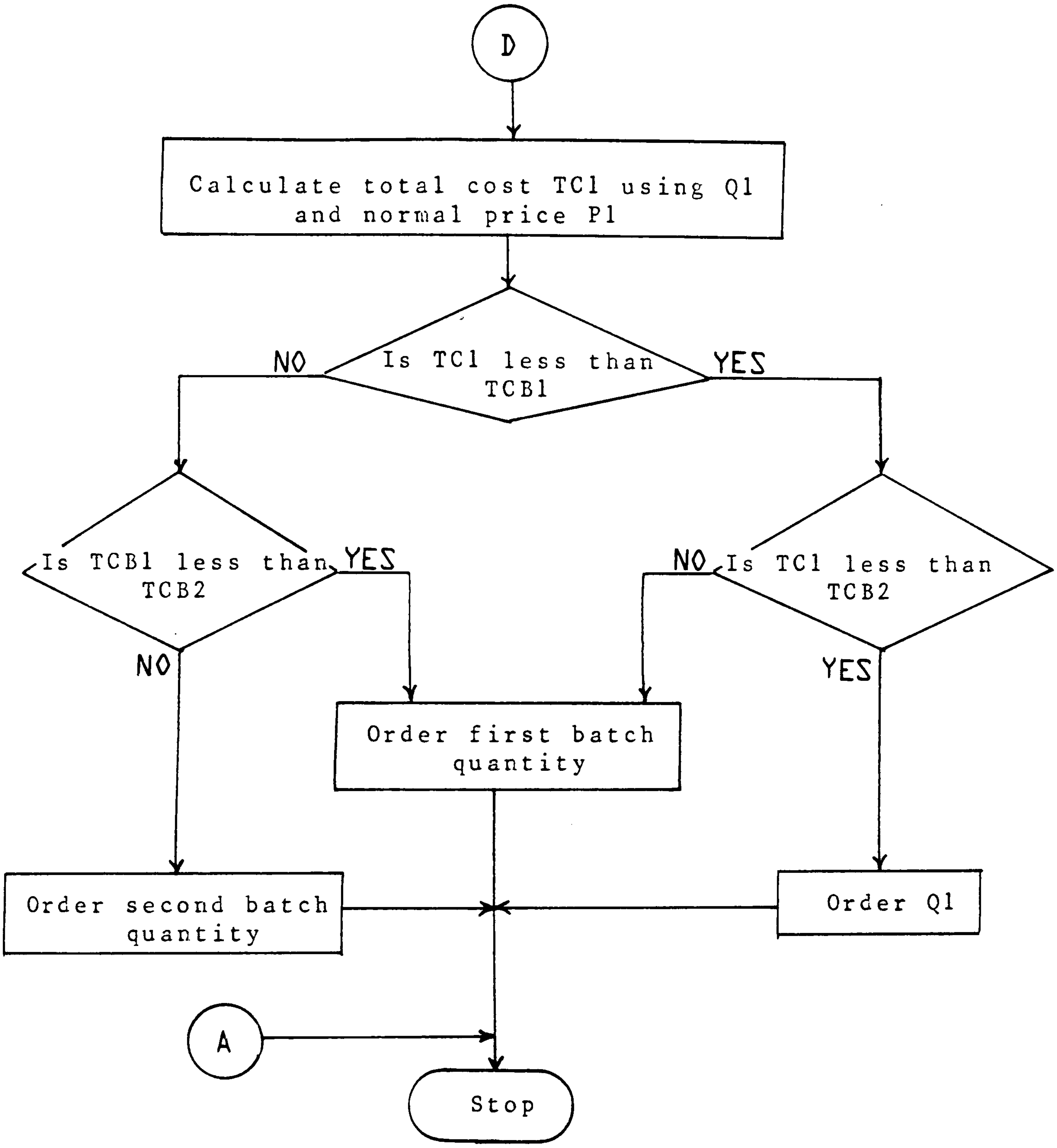

D
Calculate total cost TC1 using Q1 and normal price P1
Is TC1 less than TCB1
NO
YES
Is TCB1 less than TCB2
YES
NO
Is TC1 less than TCB2
NO
YES
Order first batch quantity
Order second batch quantity
Order Q1
A
Stop

Fig.(5.5) cont.

CHAPTER SIX

ORGANIZATIONAL SIMULATION MODEL BASED ON STAFFORD BEER'S VIABLE SYSTEM MODEL

6.1 Introduction

This chapter deals with the simulation model built specifically to simulate a Stafford Beer system one-two-three under working conditions.

The chapter shows how the model is built, and also discusses the reasons behind building it according to such a design. It also provides a detailed description of the different parts of the model and how they work together. A detailed flow chart of the model and its computer program is also in appendix G.

The chapter also includes the description of the results of several simulation experiments in which system one, two, three of the viable system model will be introduced in incremental stages , and it focuses on comparing them with Stafford Beer's ideas of system behaviour. The experiments also include experimentation with external and internal kinds of disturbances in order to observe their effects on the system's behaviour.

6.2 The purpose of the model

The main purpose of the model is to investigate how parts of an organization built following Stafford Beer's model of the enterprise, behave when linked together in that kind of structure and subjected to various operational conditions. Through this model the investigation is also going to cover Beer's systems one, two, and three, their structure, relations and most important, the roles Beer has designated to them in maintaining overall system stability.

A second purpose of the model is to serve as a simulation aid for people interested in understanding how an inventory-production system works as a complete structure. The model particularly shows the various feedback channels of information which play a vital part in the various control decisions taken by managers at different control points in the system.

For both the above purposes the model is going to show how changes in the above mentioned control decisions would affect the overall behaviour of the system. By being a system existing in an environment, its responses to that environment would decide its fate; either to survive as a stabilized cybernetics system or to decline and die due to insufficient response to the environmental disturbances.

6.3 Description of the model

The model represents an important part of an industrial enterprise; the production-distribution part. The model consists of three major sections, which together represent the production-distribution part. The three major sections are going to be designated as the operational elements comprising Beer's system one of an enterprise structure. These operational elements represent three main divisions in an industrial enterprise, and each is headed by a divisional manager (head of the management unit in an operational element) who controls the operation of that division (see chapter 3).

The three operational elements of the model are:

1- The raw materials division.

2- The production division.

3- The distribution division.

The major parts of the model are based on the specifically designed models of chapter 5. Nevertheless, there need to be some changes from the original models in certain areas such as quantities, policies,and extra variables, since the previous models were designed and built to work individually, and our model here represents a complete system of many models working together.

As mentioned before, Beer argues that the operational elements' managers in system one enjoy a certain amount of freedom in making their own operational policies and plans. But, usualy these managers go somewhat too far in practicing that freedom by adopting plans and policies that tend to maximize their profits or cost functions, but at the same time make life very difficult for other operational elements' managers. To implement this phenomena in our model, we are going to assume that every divisional manager is going to make his plans according to his own interpretation of reducing his own operational costs to a minimum, and without considering the other managers' requirements. The interactions between the different operational elements' managers would be minimal and only include simple imformation transfer which only covers giving ideas (usually vague) about such items as expected demand, need for raw materials, and annual production demands.

Also implemented in the model is provision for experimenting with different environmental disturbances both internal and external such as bad information communication channels, delays and changes in customers' demand.

The total behaviour of the system would be shown as the output of the model which would show how the system is responding to the environmental and internal disturbances as a whole structure resembling Beer's model of the enterprise.

6.4 How the major parts of the model work

In this section we are going to describe how each of the different operational elements works and what it does as part of the working system (system one).

At the top of the production-distribution system is the raw materials division, which supplies the system with the raw materials needed for producing the goods. As mentioned in the previous chapter the manager of this division has to control an inventory system of the deterministic type in which we assume that the average lead time for delivery of raw materials from the outside supplier is known and constant for the whole duration of the planning horizon.

The raw materials division manager also has the good fortune of controlling an inventory where demand is more or less constant over long periods of time (which are usualy longer than his planning horizon). This occurs because the demand comes from the production division which through information iteraction between its manager and the raw materials manager, provides the latter with an idea of the production capacity and the potential expected demand. We must emphasize here that the manager does not have a full idea about the production manager's plans and policies because of the reasons and conditions that prevail in system one (see chapter 3).

For his part the raw materials manager has to make his independent policies for the controlling of his inventory system, and these include the two most important decisions of when and how much to order as inventory replenishment from the outside supplier. His decision is governed by the notion of achieving minimum total annual cost, and thus achieving maximum profitability. His decisions are also influenced by the external environment cost parameters such as quantity price discounts. The raw materials inventory system then follows a reorder level inventory policy subject to quantity price discounts.

The manager orders a fixed (precalculated) amount of raw materials when his inventory reaches a certain (precalculated) level, or he orders a large quantity if it proves to be a more economic measure following price discounts by the outside supplier.

The raw materials divisions receives orders for raw materials from the "production division raw materials in process part", which we are going to call the raw materials at factory part. These orders come through the information channels (horizontal) in system one. At this point we make an important assumption which is that an order from the production division arrives in the same week (time period) in which it had been issued and the materials are also dispatched within the same period. If there were not enough materials, whatever quantity available is dispatched. The consignment will be subjected to a time delay before reaching the production division.

Next in the system is the production division. This division is comprised of three sections. The main section is the manufacturing section, and the other two sections are the raw materials at factory and finished goods inventory.

The raw materials at factory inventory system is an integrated part of the production division (though it has its own manager) and guards against possible delays and shortages in raw materials arriving from the raw materials division. Deliveries to the production line from this inventory have no delay at all, since both sections are situated at the same division. In this inventory system the manager is also faced with an almost deterministic type of inventory problem, since materials delivery lead time from the raw materials division is constant and known, and the demand from the production line is also predicted through the meetings between this manager and the production manager because they belong to the same division, and hence the information they exchange about their respective operations is quite precise. With all this to his credit the raw material factory manager can easily calculate the optimal inventory replenishment order quantity and reorder level values which are also based on trying to achieve a minimum total cost subject to the inventory costs existing in his system. In this section we are going to assume that when an order for raw materials is received from the production line it is dispatched in the same time period without a time lag factor. If the order quantity is larger than the inventory on hand at that period whatever available quantity is despatched to the production line floor.

The production line section manager is responsible for the production of items to satisfy demand from the distributor who in turn is receiving demand for the produced items from the outside customers.

The production manager has a production line with a certain capacity of production in each time period, and he formulates his production plans for each period based on trying to achieve a minimum total cost throughout his planning horizon. The manager makes his production plans using information available from the distributor which as said before gives only a simple idea about the pattern of demand, so the production manager is forced to use his own forcasting techniques to get a better picture of the shape of demand for the forthcoming planning horizon. After obtaining the information he needs he makes his production plans for each forthcoming period in his planning horizon, and here we assume that he can not exceed a certain production capacity for any given period. We also assume that the periods during which he does not produce are allocated for the production of another kind of product, so he can not utilize them in an emergency. We also assume that in any period, if the amount of raw materials he needs is more than the inventory on hand at raw materials factory, he can only produce the amount of items limited to the amount of raw materials available, based on one produced item for every item of raw materials.

The finished items inventory section does not need any inventory policy because it is designed as a side inventory to the production line, and in the production plan it was designed to be empty by the end of the planning horizon and thus does not carry the danger of stocking unwanted inventory.

The last major division in the system is the distribution division. In this division the manager probably faces what is the most complicated inventory problem of all the other inventory managers in the system. The inventory he controls represents a probabilistic situation where the demand from customers and lead time for dilivery of finished goods from production are both random variables.

To make his plans for the future the distribution manager has to calculate the optimum ordering quantity and reorder level that would lead to minimum total inventory operating cost. To make his calculations and because of the probabilistic nature of his inventory system, he has to utilise statistical theory in such calculations as calculating the expected demand during lead time.

In this section we assume that orders which can not be fulfilled are lost. We also assume that if orders from the production division during a certain period exceed the finished product inventory there, the distributor receives nothing, because the production policy is to send full orders or nothing, and the distributor has to wait until a full order is manufactured.

The above represents a description of the operational elements of system one and the interactions (day to day) between their management units (divisional directorates).

System two's job in the model is in the shape of the corporate regulatory center, and will be represented in the simulation model by its various regulatory actions (which will be described in the next section).

System three has the job of the operations directorate of the organization, and like system two will be represented in the simulation model by its control actions and orders to the different operational elements of system one.

The flow chart and listing of the simulation program for the model are in appendix G.

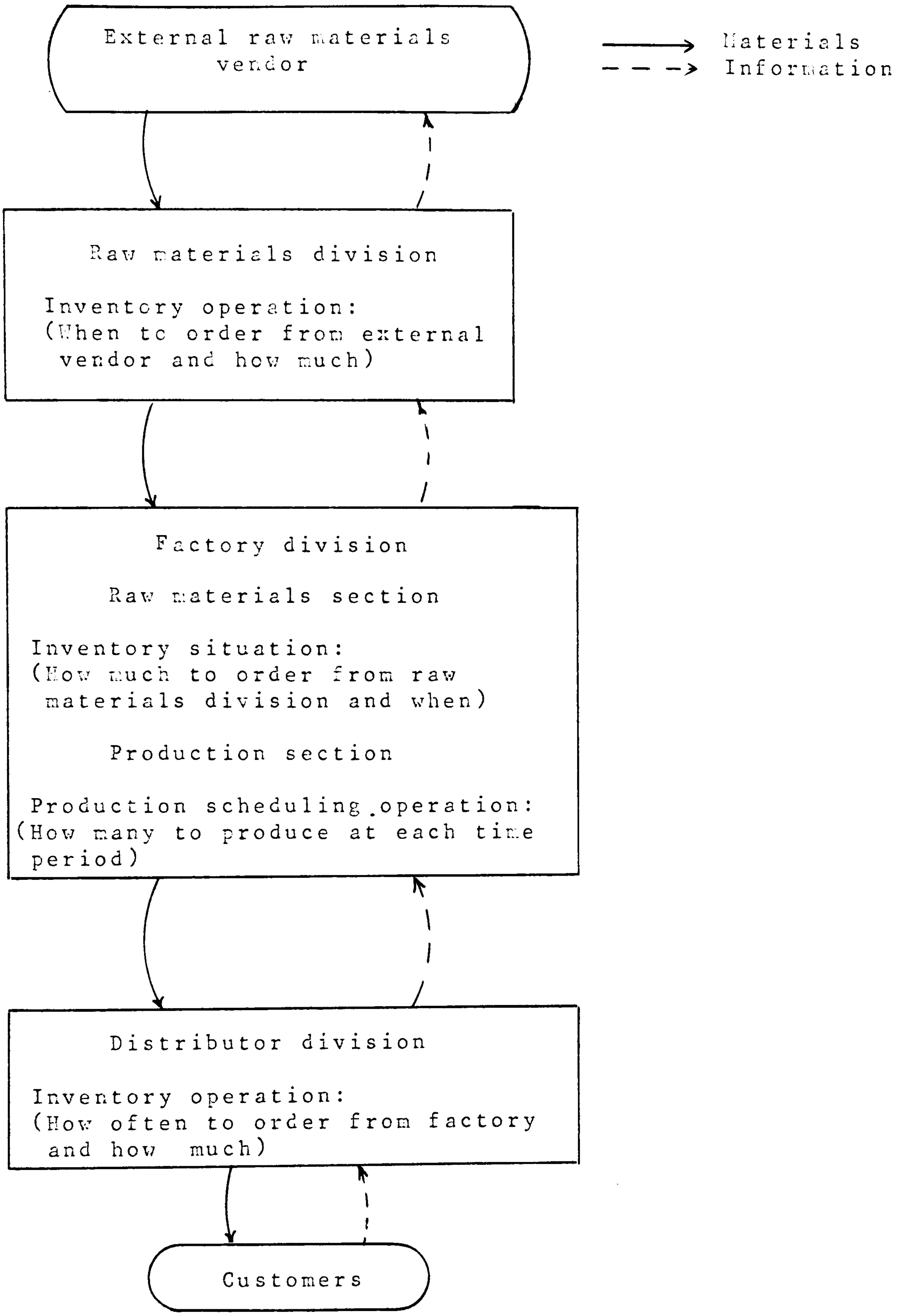


Fig.(6.1) Diagram of the basic system

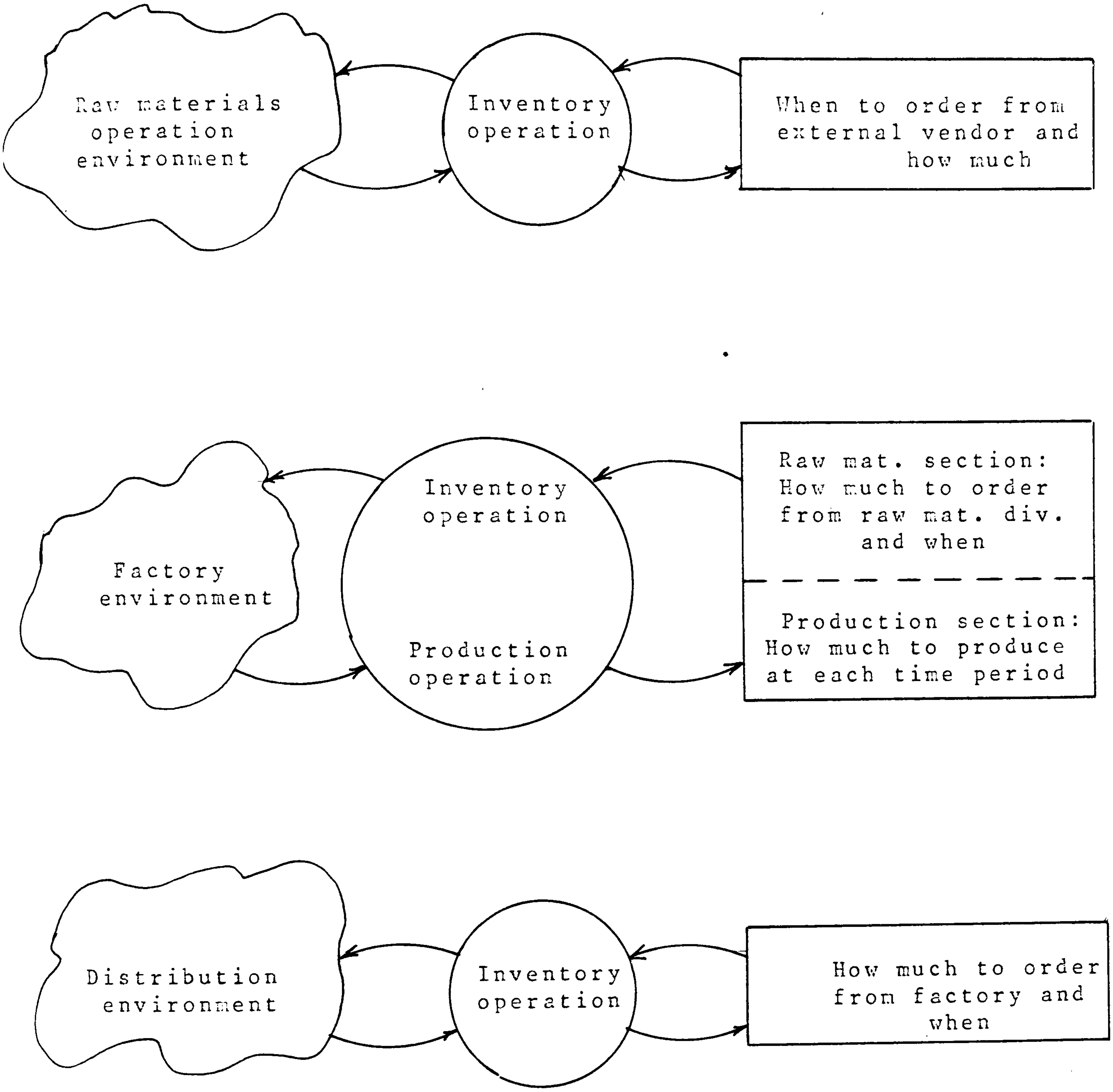


Fig.(6.2) Basic system as a system one

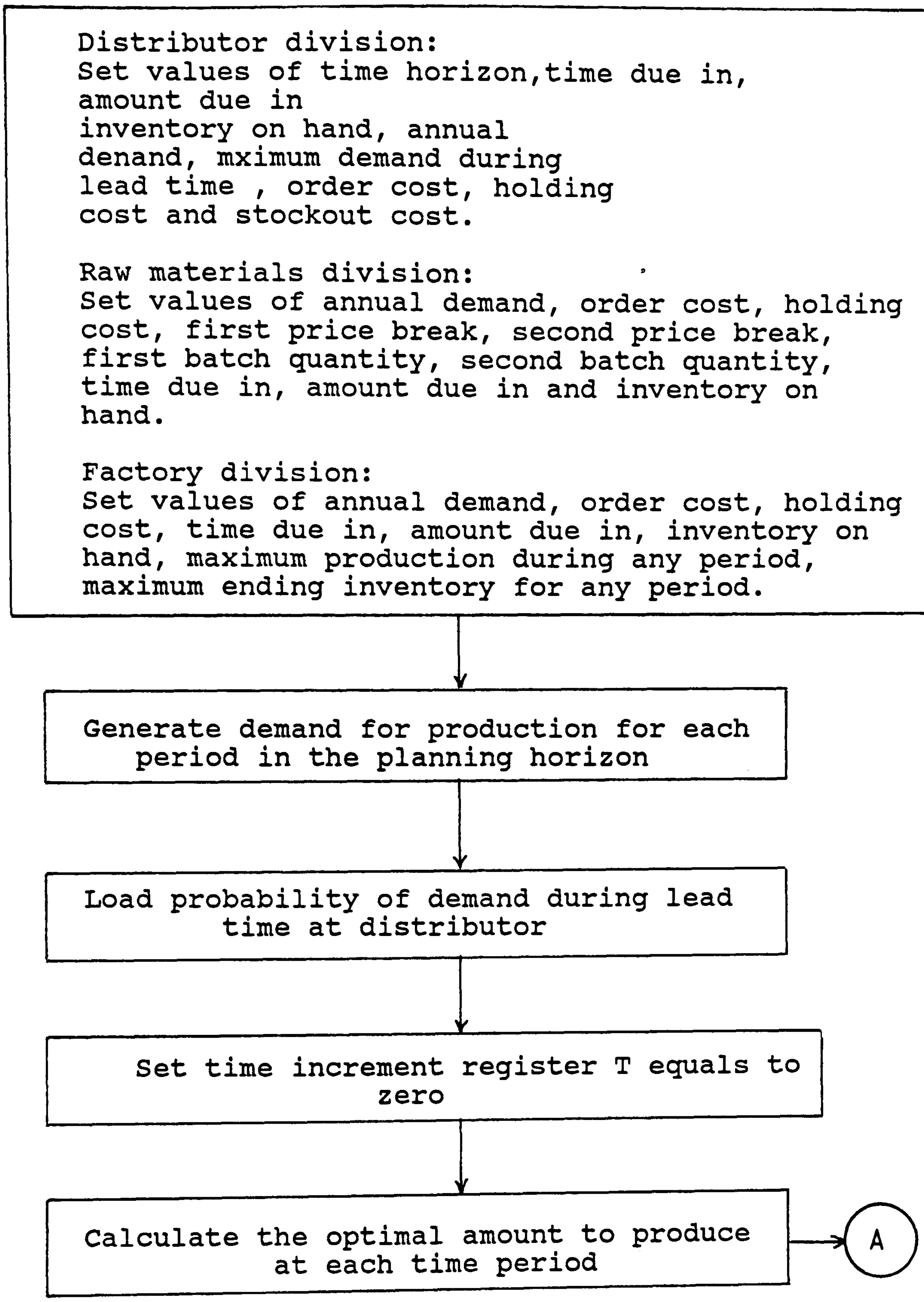


Fig.(6.3) Flow diagram of system's model

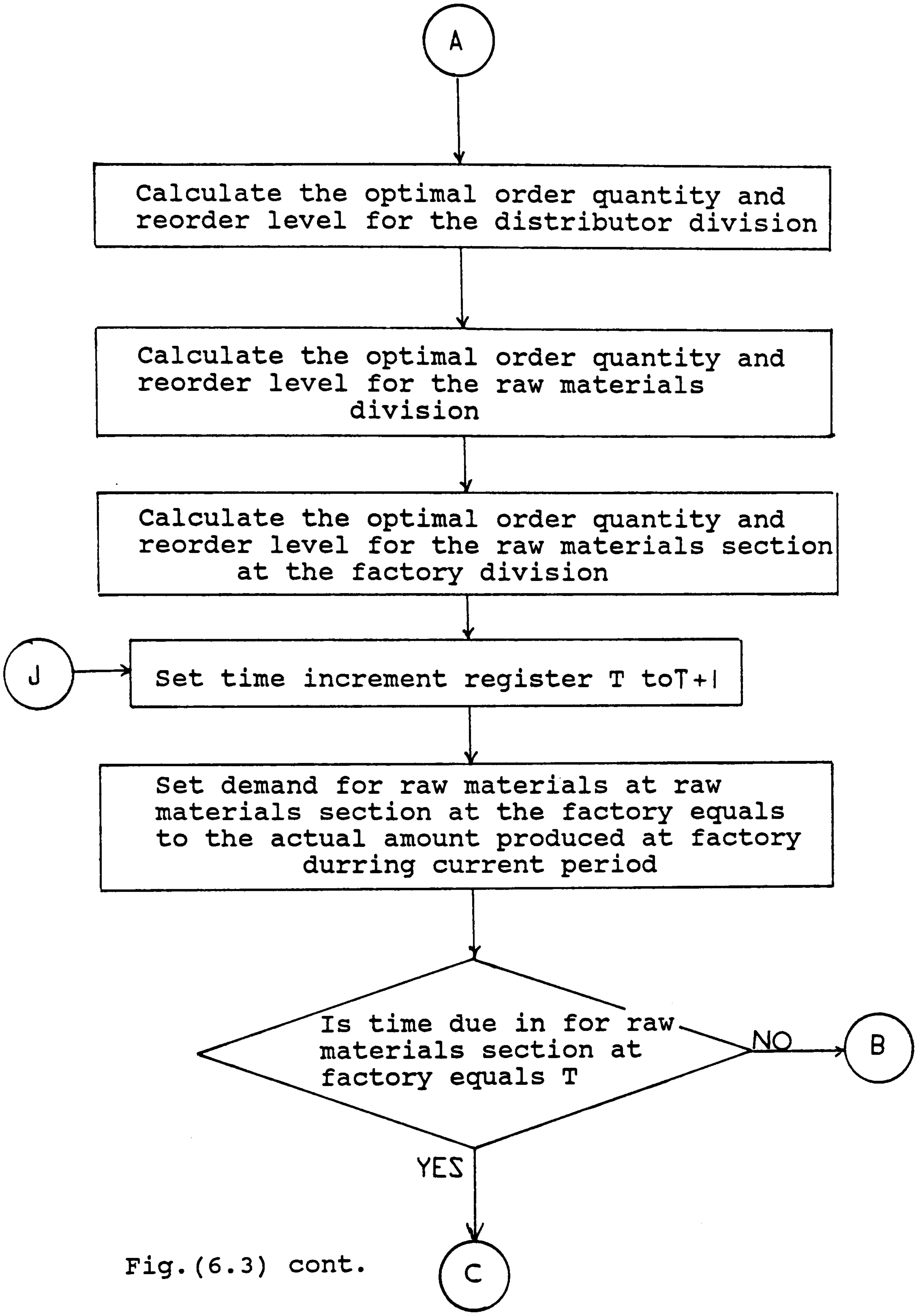

A
Calculate the optimal order quantity and reorder level for the distributor division
Calculate the optimal order quantity and reorder level for the raw materials division
Calculate the optimal order quantity and reorder level for the raw materials section at the factory division
J
Set time increment register T toT+1
Set demand for raw materials at raw materials section at the factory equals to the actual amount produced at factory durring current period
Is time due in for raw materials section at factory equals T
NO
B
YES
C

Fig.(6.3) cont.

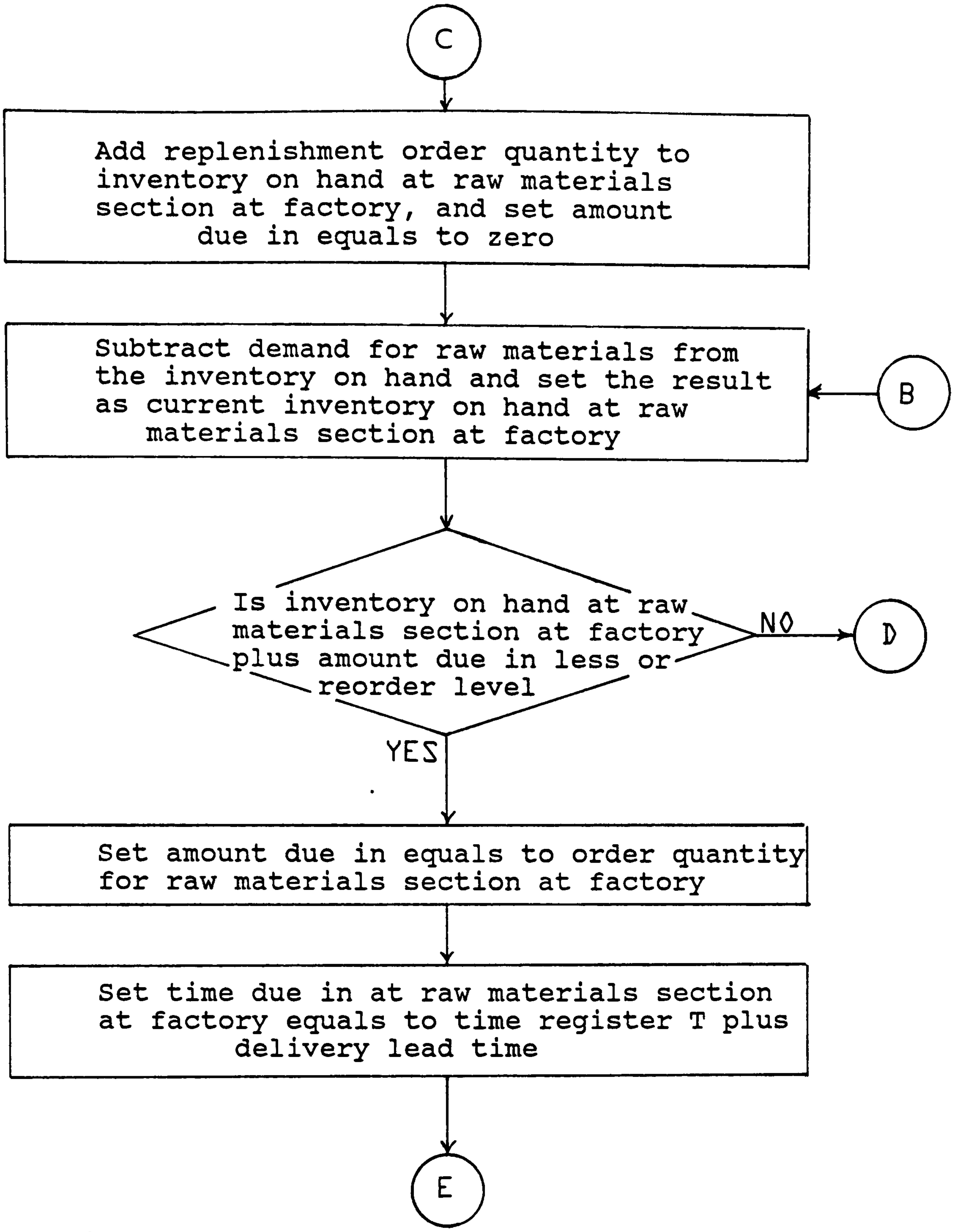

C
Add replenishment order quantity to inventory on hand at raw materials section at factory, and set amount due in equals to zero
Subtract demand for raw materials from the inventory on hand and set the result as current inventory on hand at raw materials section at factory
B
Is inventory on hand at raw materials section at factory plus amount due in less or reorder level
NO
D
YES
Set amount due in equals to order quantity for raw materials section at factory
Set time due in at raw materials section at factory equals to time register T plus delivery lead time
E

Fig.(6.3) cont.

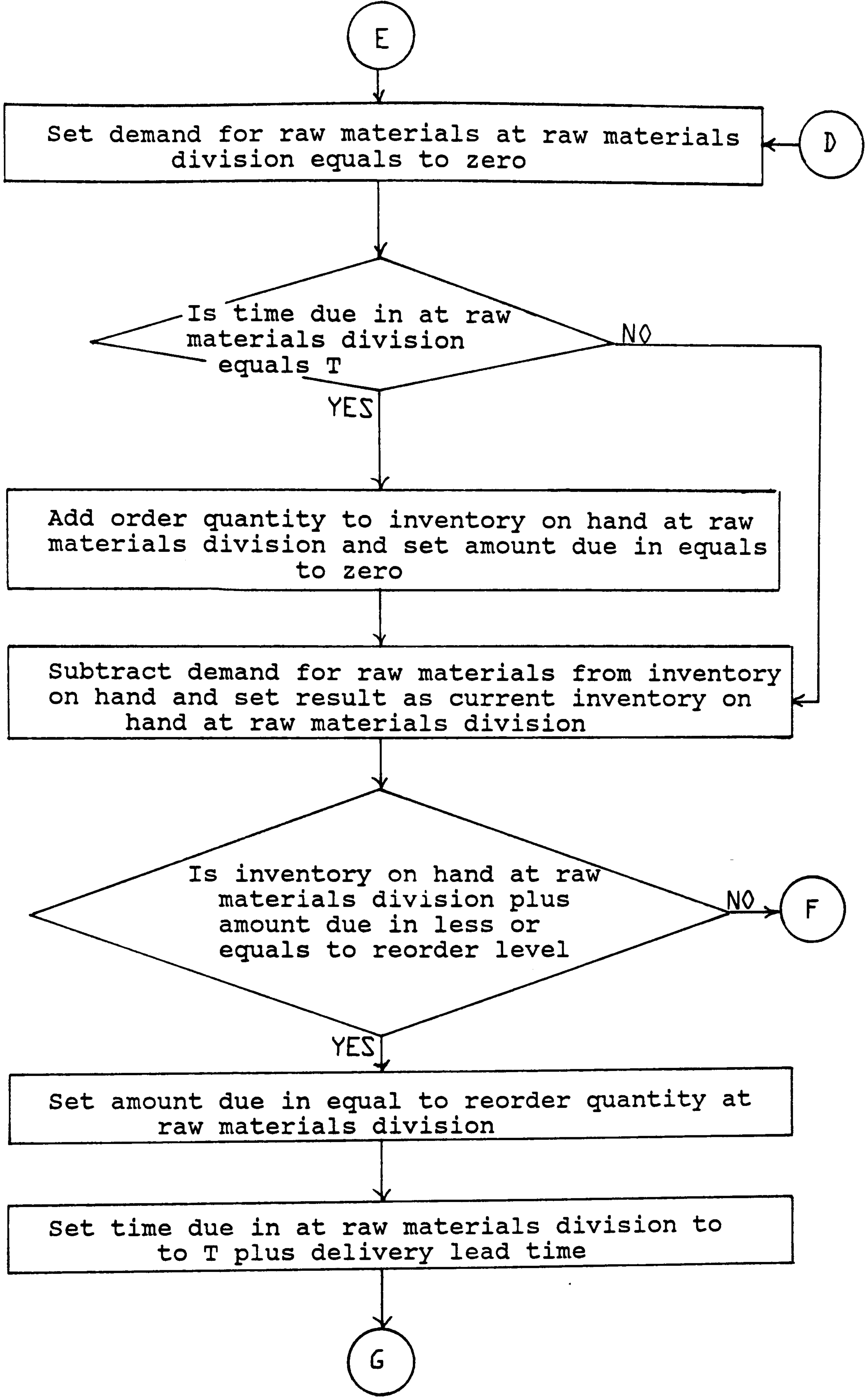

E
D
Set demand for raw materials at raw materials division equals to zero
Is time due in at raw materials division equals T
NO
YES
Add order quantity to inventory on hand at raw materials division and set amount due in equals to zero
Subtract demand for raw materials from inventory on hand and set result as current inventory on hand at raw materials division
Is inventory on hand at raw materials division plus amount due in less or equals to reorder level
NO
F
YES
Set amount due in equal to reorder quantity at raw materials division
Set time due in at raw materials division to to T plus delivery lead time
G

Fig.(6.3) cont.

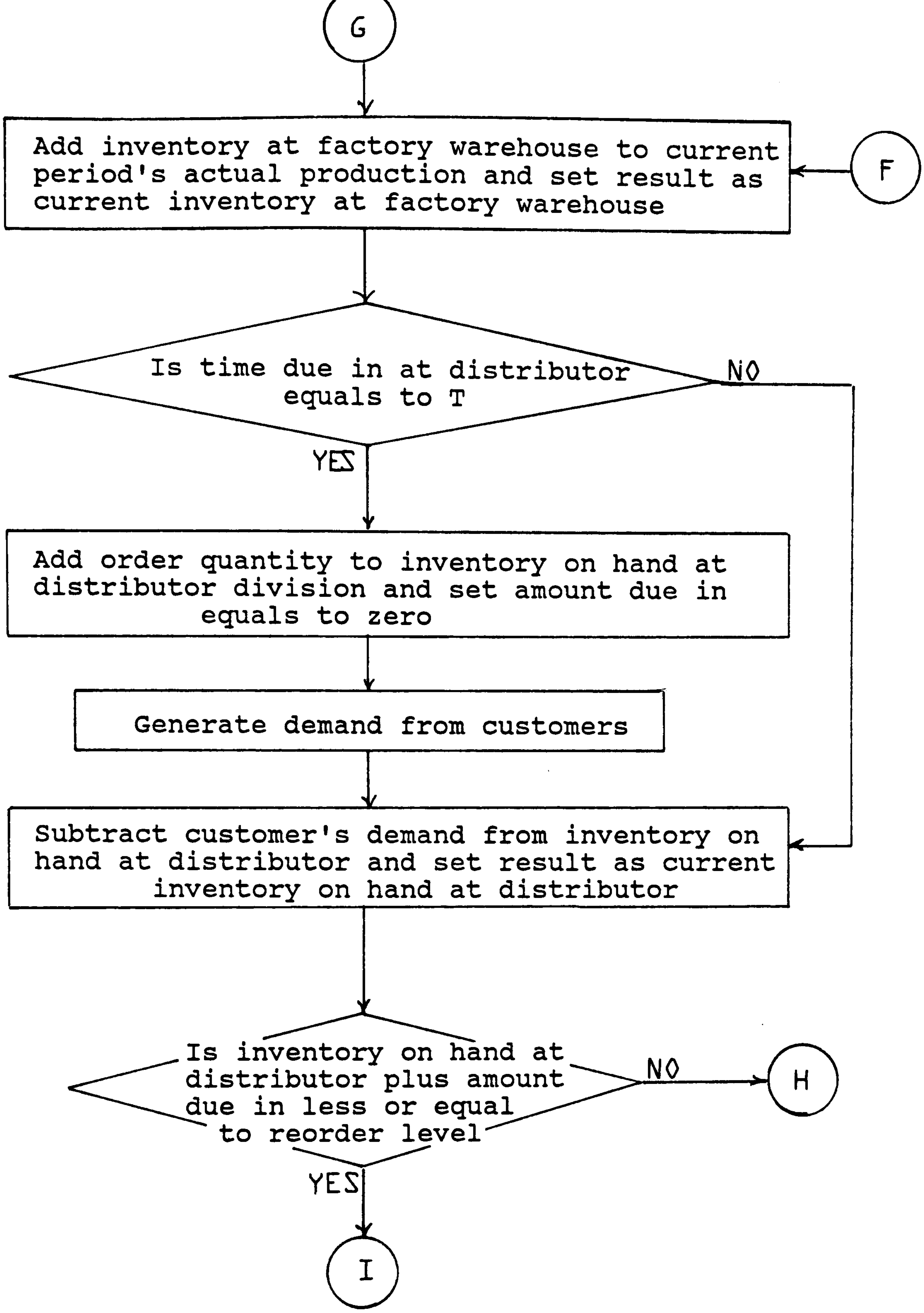

G
Add inventory at factory warehouse to current period's actual production and set result as current inventory at factory warehouse
F
Is time due in at distributor equals to T
NO
YES
Add order quantity to inventory on hand at distributor division and set amount due in equals to zero
Generate demand from customers
Subtract customer's demand from inventory on hand at distributor and set result as current inventory on hand at distributor
Is inventory on hand at distributor plus amount due in less or equal to reorder level
NO
H
YES
I

Fig.(6.3) cont.

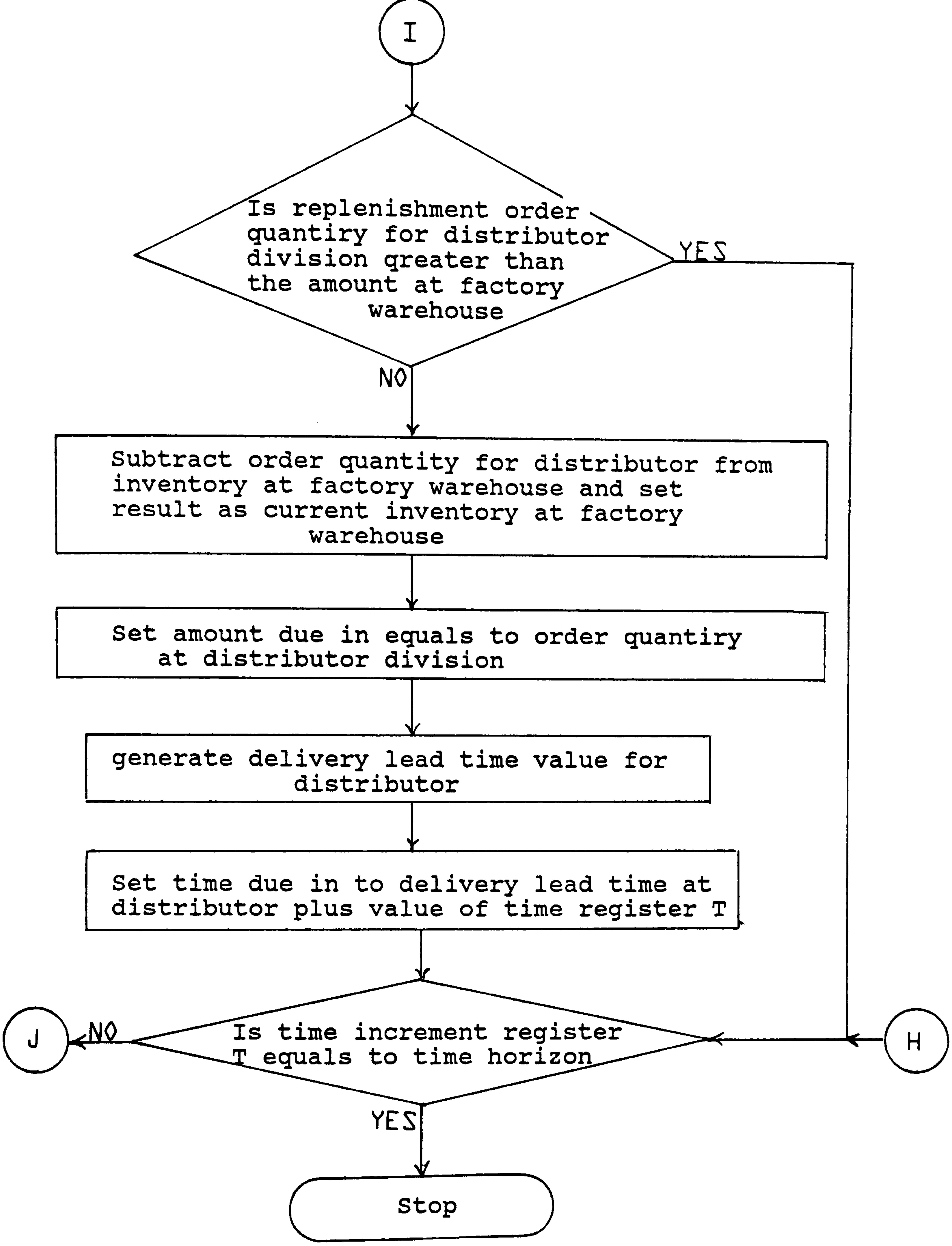

I
Is replenishment order quantiry for distributor division qreater than the amount at factory warehouse
YES
NO
Subtract order quantity for distributor from inventory at factory warehouse and set result as current inventory at factory warehouse
Set amount due in equals to order quantiry at distributor division
generate delivery lead time value for distributor
Set time due in to delivery lead time at distributor plus value of time register T
J
NO
Is time increment register T equals to time horizon
H
YES
Stop

Fig.(6.3) cont.

6.6 Experiments with the viable system model

The experimental work with our model will be in three main stages, and will be in a bottom up fashion, that is, the first of the experiments will be with the model of the basic system one which comprises of the basic operational divisions; raw materials division, the production division comprising the factory and raw materials at factory sections, and the distributor division. There will be no system two (corporate regulatory center) or system three (operational directorate). The second set of experiments will include the introduction of system two. This involves the introduction of various regulatory actions to the system, and the behaviour produced will be of the operational level working together with a corporate regulatory centre. The experiments will include the introduction of system two under two kinds of assumed operational conditions, perfect and imperfect. These conditions will be described in the experiments concerned. The third experiment will see the introduction of system three, and that will involve the implementation of all the command and control actions usualy taken by the operational directorate. As with system two, system three will be introduced under perfect and imperfect operational conditions which will be described in the experiments. The results of the third set of experiments will be of the model with the three systems working together as a complete operational system.

The first, second,and third experiments are merely designed to investigate the effects that systems two and three exert on the operational level's (system one) structure and behaviour.

In all of our experiments (except for the fourth experiment) we will assume that the demand from customers (external disturbance) will be randomly changing within certain limits that simulate normal or near normal conditions with no severe oscillations since in the case of our experiments we are interested in observing the effect of the introduction of the various systems on the behaviour of the organization.

The fourth experiment will be devoted for the investigation of the effects of severe operational disturbances on the system. These disturbances will be represented by one external (extremely high demand from customers) and one internal (very bad planning by the production section).

Initial conditions will be fixed for each experiment, and they will be changed according to the changes applied to the model as we proceed through the experiments.

If required the model has the provision for experimentation with various extra forms of external and internal disturbances to the system.

6.6.1 Description of experiments

6.6.1.1 The first experiment

The first experiment is based on the assumption that at this stage the complete system consists only of the lowest level in the system hierarchical structure i.e. the operational level, with no coordination and control activity from the higher levels of the corporate regulatory center (system two) and operational directorate (system three).

The first experiment will show the running of the basic operational level (system one) with every manager (divisional director) chasing his own goals and trying to maximize his operational element's payoff function without giving much care to the other operational elements' needs. The idea each manager has about the operations of other operational elements is minimal and the information exchange between the elements is no more than the basic information needed for day-to-day business. This represents a typical Stafford Beer model of system one with its inherent non-cooperative atmosphere among the different managers in the system. Each operational division has in its hands modern facilities such as computers and modern methodology such as operational research to help it to perform its role at its best. As said before in this experiment we assume there are no actions taken by other higher levels in the system. In real life situations this may occur when the higher level management has delegated too much of its control authority and consequently the operational elements at the operational level enjoy too much autonomy which results in them ignoring not only other operational elements' needs but any coordination instructions from the regulatory center (system two). Moreover, usually bad communication and information channels contribute to the bad effects of the operational elements lack of knowledge of other elements' needs and increase the difficulties in implementing coordination actions.

Also since communications between the operational level and the regulatory center are bad, any uncontrollable oscillations (which are bound to happen) at the operational level will not be properly relayed to the operations directorate because the regulatory center is responsible for monitoring these oscillations and trying to dampen them, and if that is not possible it reports them to the operations directorate which has the power and authority to take the necessary actions in order to improve the situation. So at this stage the model purely shows the behaviour of the operational level only without the coordination and control functions of higher levels.

Lead times durations are of two kinds, fixed and variable, and each lead time duration consists of two parts

one part covers the transportation of goods and materials and the other covers for the processing of orders and other associated activities such as packing, paperwork etc.
The values of the lead times at the raw materials section at factory and the raw materials division are of the fixed type and represent the time between any of the two sections ordering a replenishment order for his inventory and receiving it at his inventory. The lead time between the distributor division placing an order and receiving it is of the variable type.

At the start of the simulation run the initial conditions for the distributor division are: an initial inventory level of 100 units, annual demand = 900, number of demand during lead time = 60, holding cost = 3, ordering cost = 40,stockout cost = 50,. The lead time between making a replenishment order from factory and receiving it varies between 6 and 11 weeks.
The initial conditions for the factory division are: an initial inventory level of 100 units at the raw materials section, holding cost = 3, order cost = 40, and standard deviation of two which is used to calculate the reorder level and represents a required level of service of 95%, annual demand = 900. The lead time between placing a replenishment order from the raw materials division and receiving it is 7 weeks.
For the production section we have a maximum ending

inventory for each period (except last period) of 50 units and a maximum production capacity for each period of 50 units.

The initial conditions for the raw materials division are: an initial inventory level of 100 units, holding cost = 2, order cost = 40, normal price = 1, first price break = 0.90, second price break = 0.10, first lot size = 400, second lot size = 600, annual demand = 800. The lead time between making a replenishment order from external vendor and receiving it is 7 weeks.

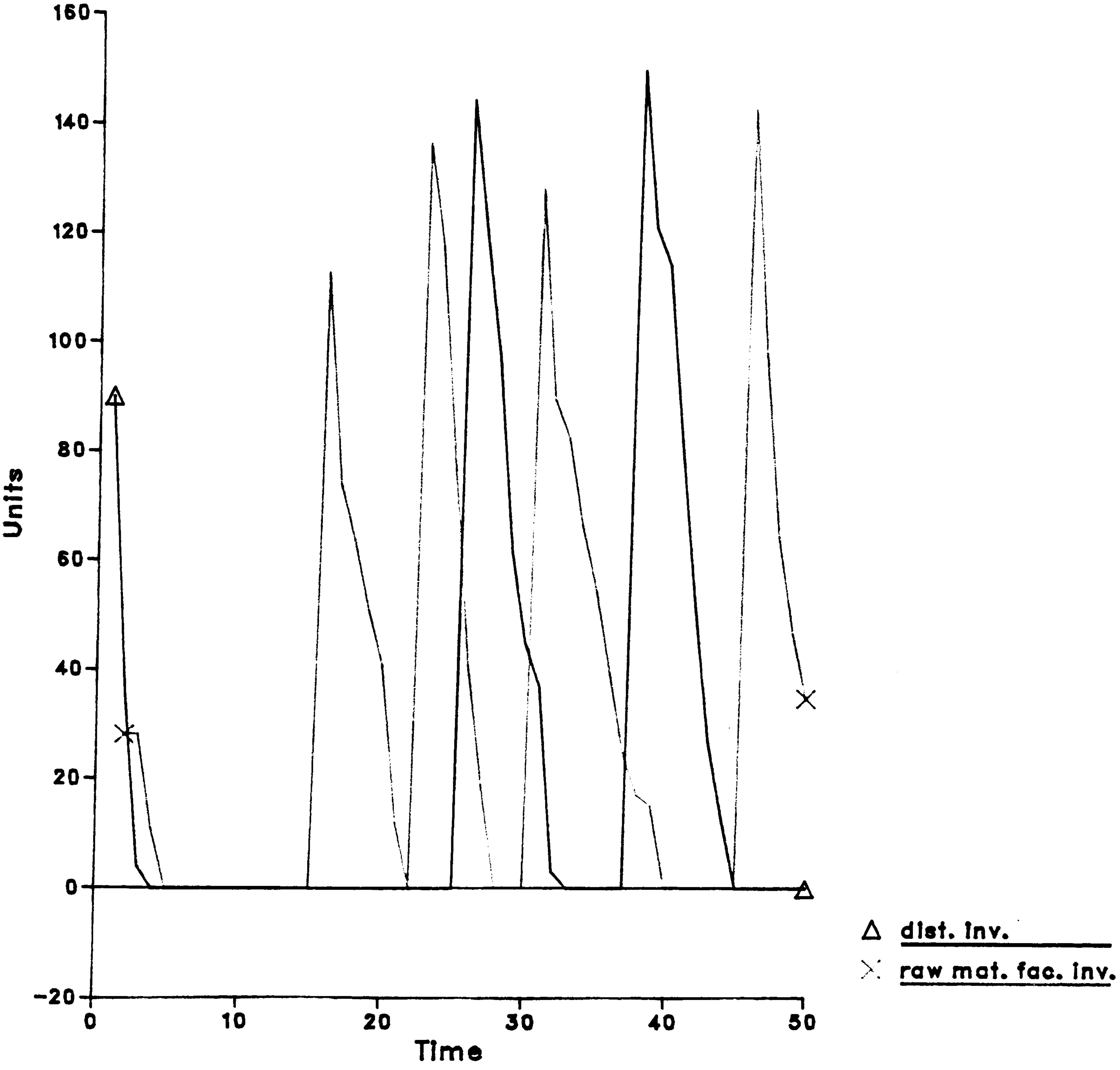


Fig.(6.4) Disrtibutor and raw materials section at factory inventories - basic system

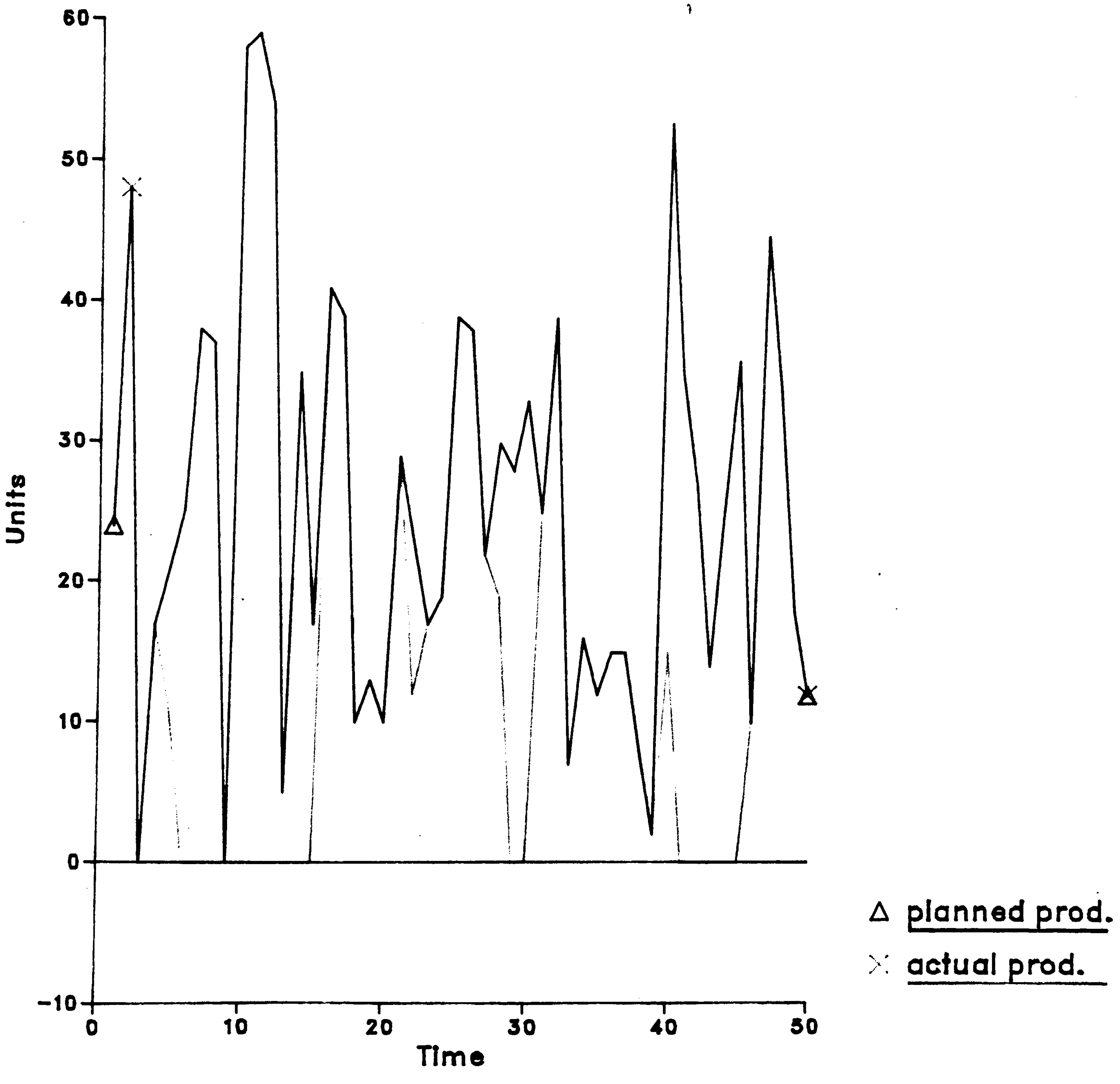


Fig.(6.5) Actual and planned production - basic system

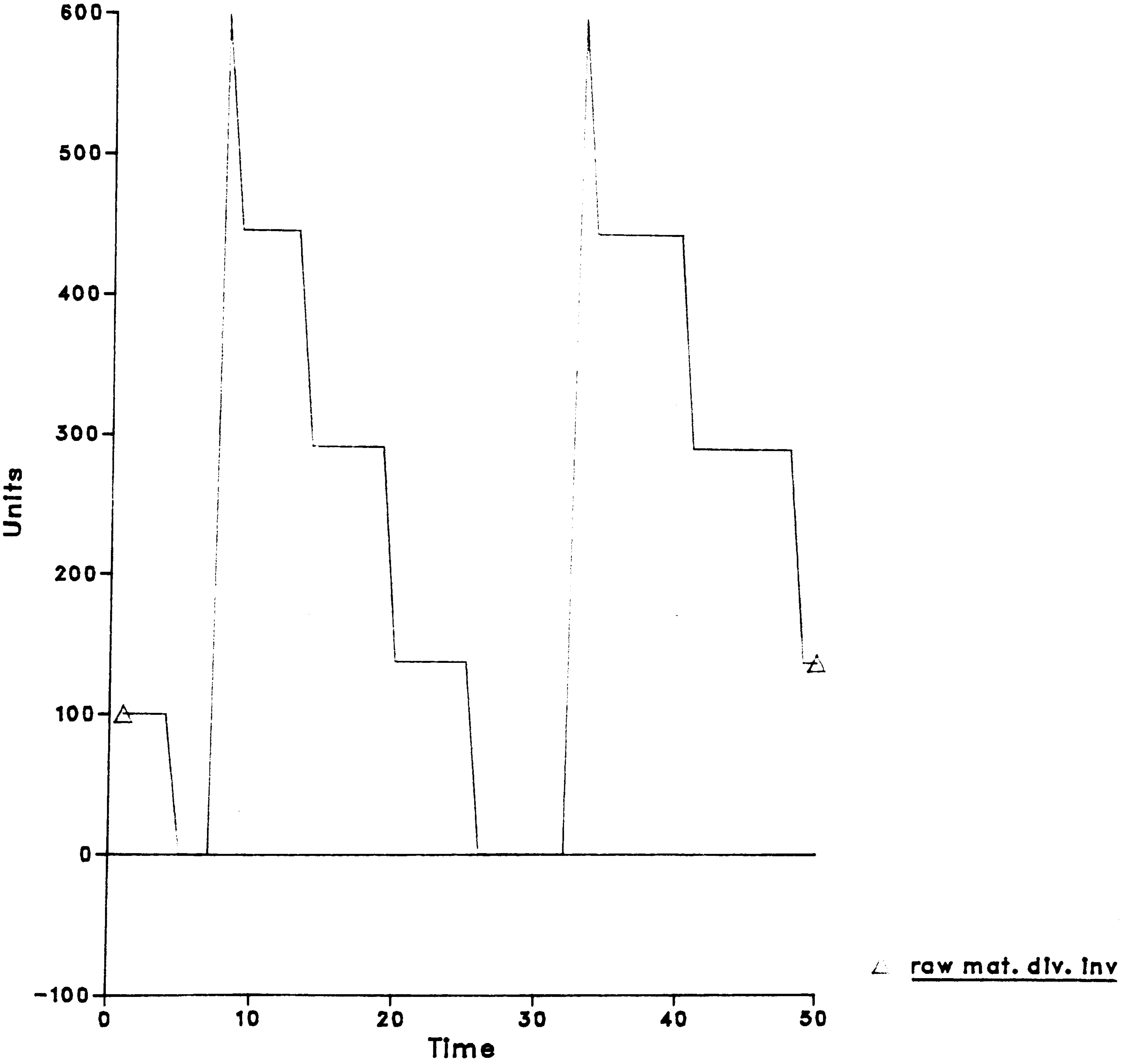


Fig.(6.6) Raw materials division inventory - basic system

Fig (6.4) above show the curves that represent the inventory situations at the distributor division and the raw materials section at factory. The quantities shown represent the quantities present at each inventory at the end of each period i.e. after the demand from the different inventories has been subtracted from them. The two above mentioned inventory situations can give a good indication of how the system is behaving according to the external demand (the distributor inventory siuation represents the ability of the organization for attaining a certain level of service to the customers).

By observing the curve that represents the distributor's inventory we can see that the situation there is disastrous. The inventory situation during fifty periods of operation has experienced stockouts for over half of the periods. This represents an inability to satisfy customers' demand during the stockouts periods and show a very poor standard of service by the system if not a total crash as an industrial organization.

Although the distributor started operations with a stock of 100 units we can see that by the fourth week he started to suffer from stockouts and did not receive any of the material he has ordered on the third week until the 26th week of operations. This is attributed mainly to the long lead times in the various points in the overall system which started this kind of situation. The distributor also suffered stockouts for eleven more periods in the second half of the simulation horizon. The distributor as an operational element could not survive as a viable system despite that from his own point of view his plans were not faulty niether there was any extreme external demand on his system. What affected his system severely were the oscillations present in the larger system which he is part of.

The other curve in fig(6.4) represents the inventory situation at the raw materials section at factory. This inventory is responsible for supplying raw materials needed in the production section. Looking at this inventory situation we can see that it is in no better shape than the inventory situation at the distributor division. Here the inventory suffered stockouts for almost half of its operating periods which ment that it could not satisfy the orders for raw materials from the production section which severely disrupted the production plan which in turn would not be able to supply finished products to the distributor as requested. This shows how the oscillations travel and magnify throughout the system disrupting operations in every single part of it. The main reasons for the stockouts in this inventory system are the long order processing and transportation lead times in both the raw materials section at factory and the raw materials division. Again here we can see that the system's failure was not because of bad suffered stockouts for eleven more periods in the second half of the simulation horizon. The distributor as an operational element could not survive as a viable system despite that from his own point of view his plans were not faulty niether was there any extreme external demand on his system. What affected his system severely were the oscillations present in the larger system which he is part of.

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Fig(6.5) contains two curves which represent the production section planned production quantities for each period in the simulation horizon and the other show the actual quantities produced during each period.
comparision between the two curves show that the production section could not meet the planned production for over twenty of the operational periods and as a matter of fact over one third of these periods it has virtually produced nothing at all. This caused the subsequent crash in the distributor system. The inability to produce the required quantity aggrevated the oscillations situation in the system, and this explains why now it takes a longer time for the factory warehouse to build up enough stocks to send a complete order quantity for the distributor (since he only sends complete orders at any time) and this will be added to the already long variable lead time at the distributor division.

The raw materials division fig(6.6) also suffered stockouts in fifteen of its operational periods despite the fact that it should suffer least of all of the other operational elements and the only cause for its stockouts was the delay in receiving orders from the outside materials vendor. The stockout situation in the materials division has a very significant nature in that it is where the oscillation in the system had started and then was magnified as it travelled throughout the system.

The observer can see that the the system as it is, suffers from uncontrollable and severe oscillations which render it incompetent as a working production inventory system.

The important conclusion we can draw from this simulation is that combining the three divisions to work as a single system leads to a very poor overall performance even though, as the models discussed in chapter five fully demonstrate, the individual divisions are following policies and using techniques which lead to optimal performance when they are treated as independent entities. Furthermore, at the time that the plans of the three divisions were made each division was happy because it had discharged its individual responsibility, and it seemed to be behaving co-operatively with the other divisions by accepting their requirements as operational constraints in its plans in order to discharge its corporate responsibility.

The above results and discussion confirms Stafford Beer's idea of oscillation happening at the operational level due to the over independence of the operational divisions, and the lack of a co-ordination or an oscillation damping system. We can see that what Stafford Beer is saying more generally is that in a business system it is not sufficient to optimize the separate and independent performances of the operational units (elements) since this will certainly not guarantee an optimal performance for the combined system.

6.6.1.2 The second experiment

The second experiment will introduce system two (corporate regulatory center) to the operational level and will be run in two steps. Step one will see the introduction of system two with an assumed perfect coordination operational environment i.e. perfect communication and information transmission between system two and the individual operational elements and complete cooperation between the two. This implies the introduction of the full "powers" of system two.

As seen from the results of the first experiment, the operational divisions themselves, while working together as a whole system, cannot avoid oscillation, because it is a result of their interactions among themselves at the operational level. System two will be represented by the oscillation damping actions taken by the corporate regulatory centre through its various interactions with the operational elements and their regulatory centres, and also through its interactions with system three (the operations directorate). The subsequent actions taken by system three as a result of that interaction will be incorporated in the third experiment.

We assume the actions taken by system two are:

a- The aim of system two is to take action to avoid, remove or change features of the total system that lead to oscillations and other undesirable system effects. One reason for oscillation in the combined system is due to the excessive time lags and lead times. So an obvious action for a system two committee to take is to rearrange existing schedules to try and reduce these time delays. Let us assume then that through a system two committee, contacts between the raw material division and raw material at factory section resulted in changes in the order procedures and transportation of materials schedules at both locations which lead to the decrease of lead time between the sending and receiving of material from raw materials division to raw material at factory section.

b- For the purpose of our model of a developed system two we may assume that similar actions resulted in decreasing lead time of goods reaching the distributor from factory.

c- The distributor division, the raw materials section at factory, and the raw materials division all suffered from severe stockouts during the early weeks of operations. The introduction of system two has provided the divisions' managers with better information and suggestions about other operational element's way of operations. This led to the managers of the different operational elements realizing that the early stockouts were because of early stockouts in other parts of the system. So to avoid that, they are advised by system two to increase their initial inventory levels by the amounts that would safeguard them from such early stockout situations.

The initial conditions for the distributor division are: an initial inventory level of 180 units and the value of the lead time before the inventory at the distributor receives any replenishment order from factory varies between 2 and 9. All the rest of the initial conditions will be the same as those in the first experiment.

The initial values for the raw material section at factory are: an initial inventory level of 180 and the lead time between ordering and receiving a replenishment order from the raw materials division is 3 weeks. All other initial conditions are the same as in the first experiment.

The initial inventory level for the raw material division is 180 units, and the lead time before receiving a replenishment order fron outside vendor is 7 weeks. All the other initial conditions values are the same as in the first experiment.

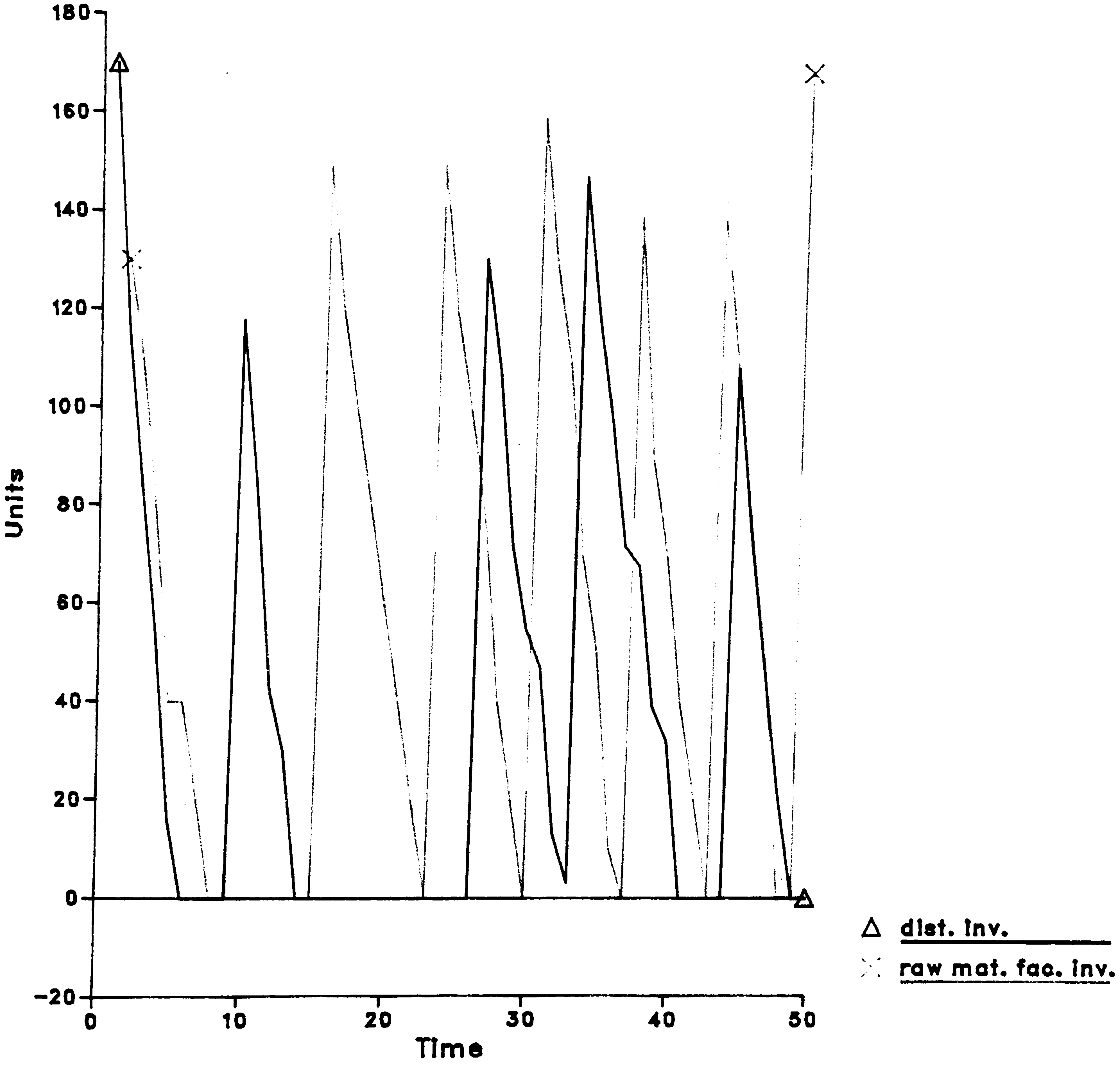

Fig.(6.7) Distributor and raw materials section at factory inventories - after adding system two (perfect)

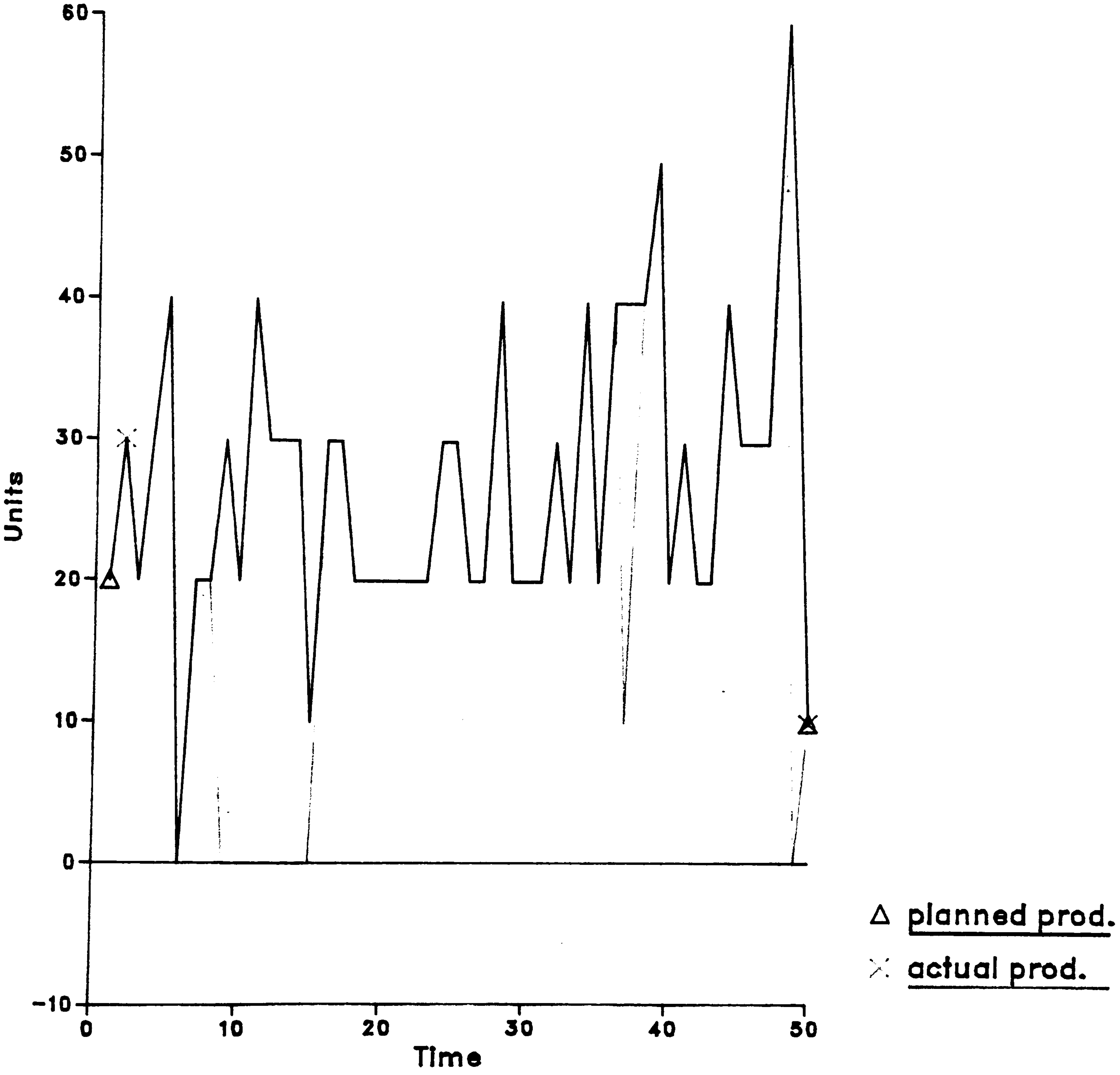

Fig.(6.8) Actual and planned production - after adding system two (perfect)

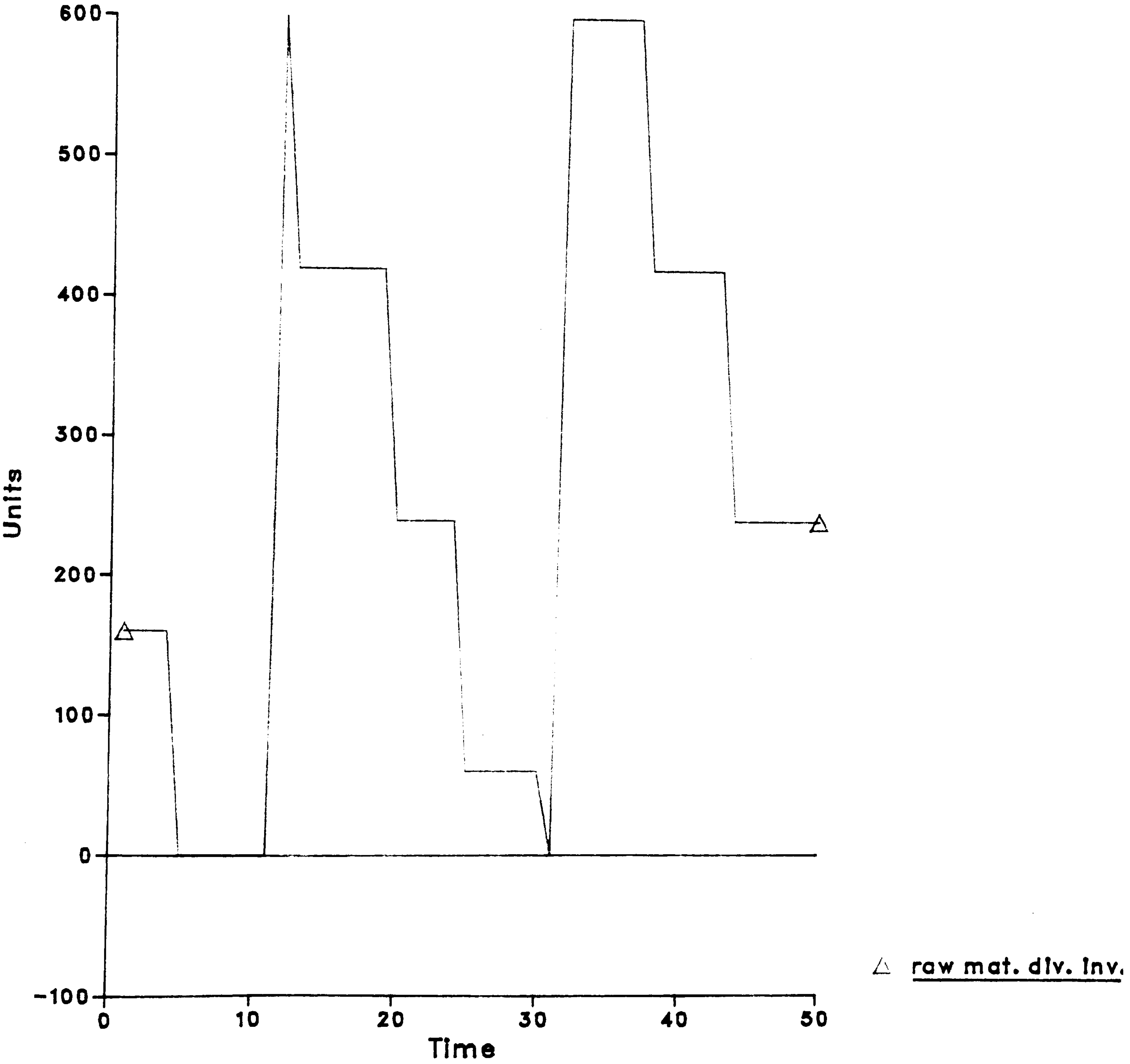

Fig.(6.9) Raw materials division inventory - after adding system two (perfect)

Fig(6.7) shows the inventory situation at the distributor division and the raw materials section at factory after the introduction of system two (corporate regulatory center) with assumed perfect conditions.

The distributor inventory curve shows that the stockout occurence has droped almost 50% which is a marked improvement on the situation under the previous experimental conditions (first expt.). This improvement is attributed to the reduction of lead time (processing) before the distributer inventory receives any replenishment order from factory warehouse. Another important factor in reducing the early stockouts in the system was the increased initial inventory level.

Although the distributor division has gained a lot of benefit due to the introduction of system two, the system still suffers from serious shortcommings in its service level to the customers which is of great importance to the organization. The reason for the stockouts is the presence of oscillations in the whole system (though much dampened compared to the previous situation) despite the activities of system two. We must also notice here that the distributor division receives the full force of the magnified oscillations in the overall system.

The second curve in fig (6.7) which shows the situation of the raw materials section at factory indicates that by starting the initial inventory by a higher level the section manager has reduced the number of stockouts at the early periods by more than 50%, and also show that the number of stockouts in the whole simulation horizon is reduced by more than two thirds of the number in the previous experiment. Another contributor to the system's better situation is the reduction of lead time durations (both order processing and transportation) at the raw materials section at factory.

Fig(6.8) above shows the planned and actual production quantities curves at the production section. Comparision between the two curves shows a great improvement in the situation over the previous experiment situation. In the present case we can see that apart from the inability to meet the planned production quantities in five of the early periods, the system actualy stabilized a great deal and only could not meet the planned production quantities on two occasions and in one of them it could actualy produce half of the required quantity. This improvement in the system is due to the improved inventory situation at the raw materials section at factory. The oscillation that was experienced at the early periods can be traced to the oscillation that was started earlier at the raw material division fig(6.9).

At this stage of the experiment we are going to introduce system two and assume that the perfect operational conditions which prevailed before will now give way to the normal disturbances of every day running of the system.

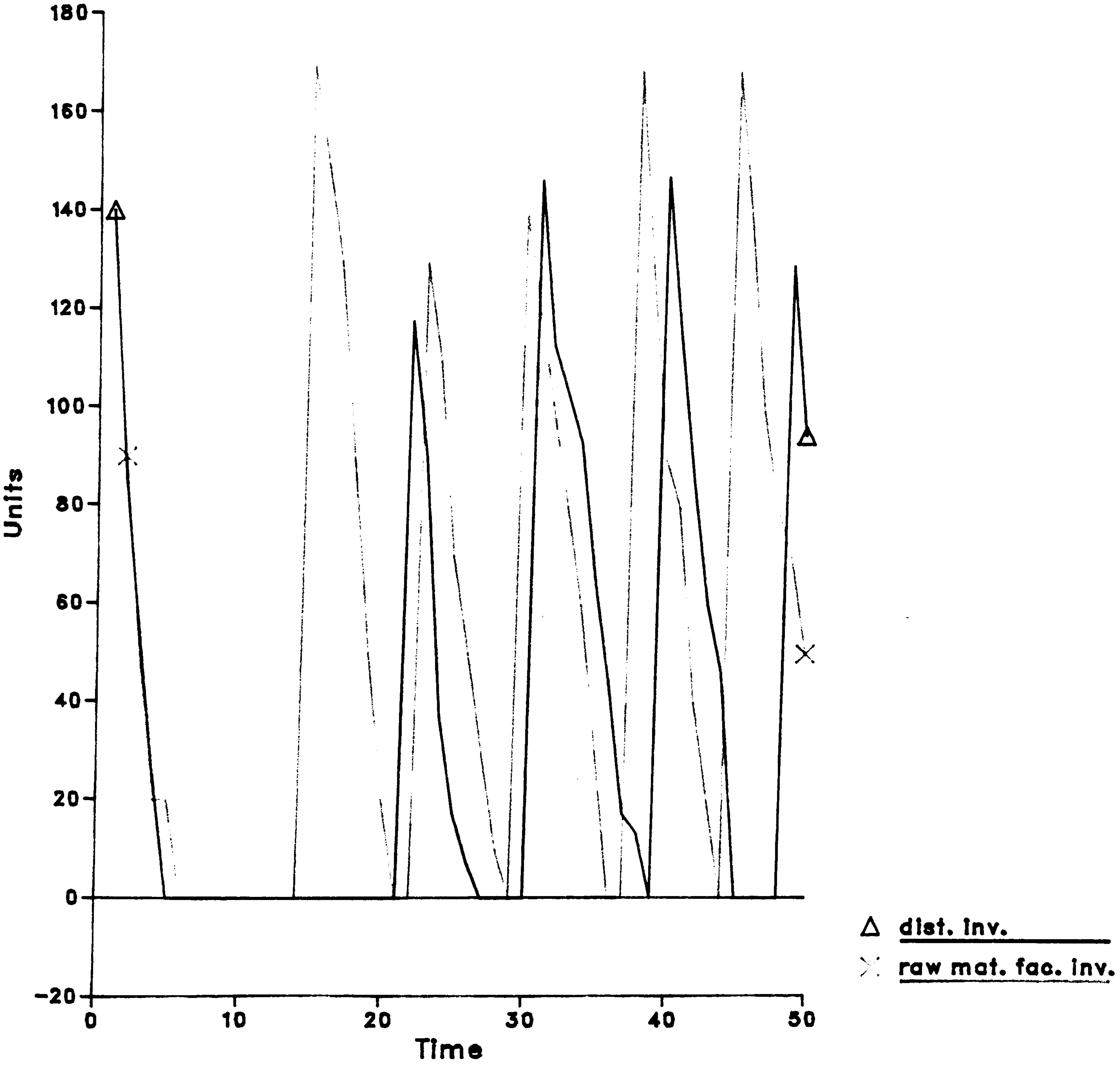

Fig.(6.10) Distributor and raw materials section at factory inventories - after adding system two (imperfect)

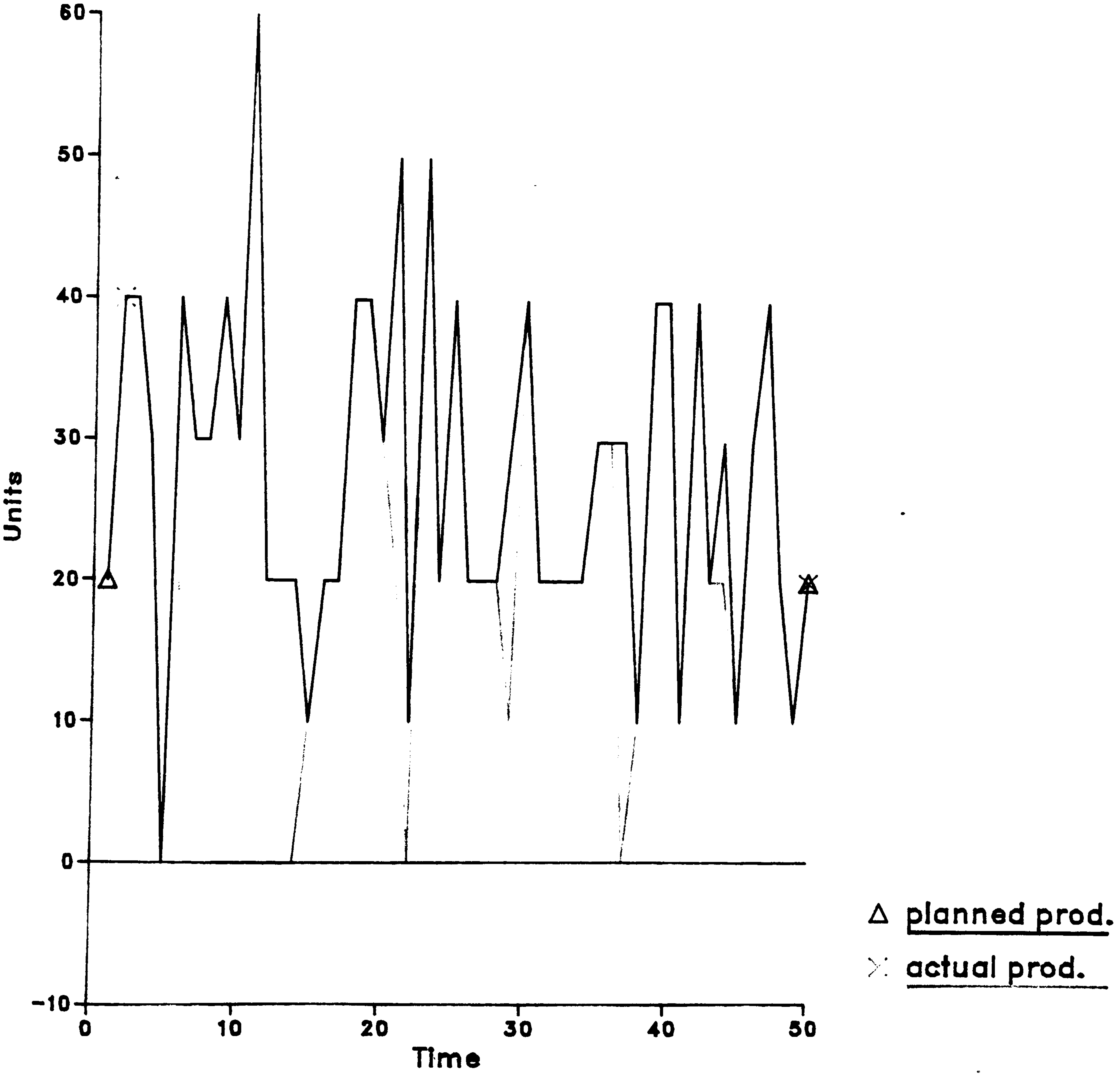

Fig.(6.11) Actual and planned production - after adding system two (imperfect)

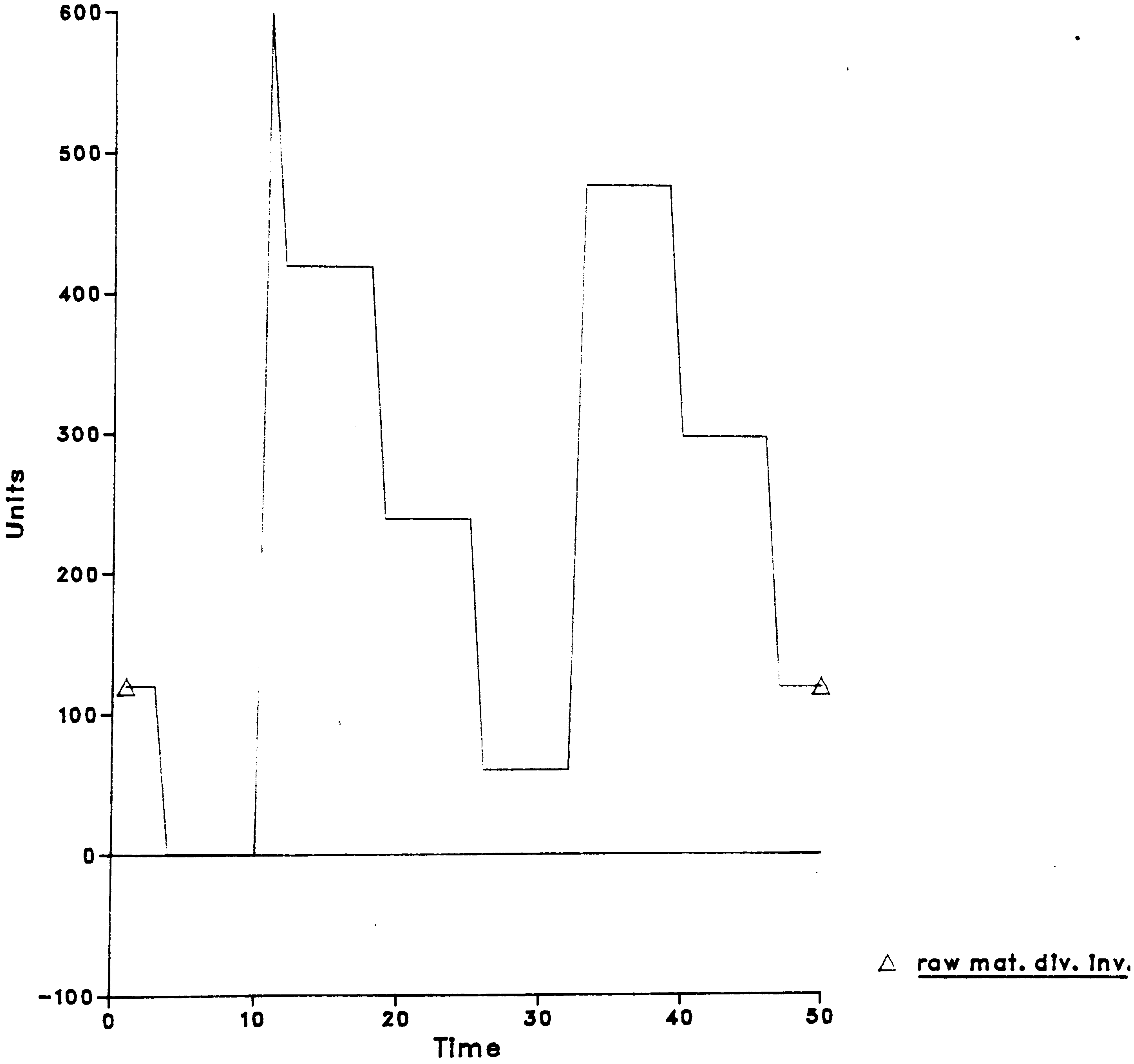

Fig.(6.12) Raw materials division inventory - after adding system two (imperfect)

Fig (6.10) in comparision with Fig (6.7) shows that the inventory situation has lost some of the benefits it gained by introducing the "perfect" system two and it is quite clear now how the stockouts have increased in the system. This was mainly caused by reduced coordination in the system, for although there was some cooperation between the distributor and system two, the distribution manager still had some suspesions about system's two role and the real benefits of its actions. This led him for not taking system's two instruction of increasing his initial inventory, and he only increased it by a fraction of what was suggested by system two (according to his own point of view and calculations he would not need a large increase besides extra inventory for him means extra cost). Another effect of bad communication channels is that the various divisional managers would have less knowledge of the difficulties that are facing other divisions, which at the end would affect their own divisions, and they normally assume that other divisional managers are in complete control of their operations and so they would not take any precautions to aviod these shortcomings.

In fig (6.10) we can also notice a similar situation occuring at the raw materials section at factory inventory. We can see that the manager had started his inventory with less than what was suggested by system two (same reasons as for the distributor) which resulted in an increase in the

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In fig (6.10) we can also notice a similar situation occurring at the raw materials section at factory inventory. We can see that the manager had started his inventory with less than what was suggested by system two (same reasons as for the distributor) which resulted in an increase in the number of stockouts during the early periods. These stockouts ould be reflected badly in the production plan as we are going to see from fig (6.11). Bad communications also led to the manager not anticipating the stockouts that his supplier (raw materials division) could experience and so not taking the necessary steps to safeguard against this danger. Another factor that contributed to the short comings at both inventories was that due to bad communications the issued instructions to reduce the processing and transpotation lead times were not implemented fully which resulted in increased lead times at both stations and hence increased oscillations.

Fig (6.11) shows that the production section could not meet the production plan quantities for fourteen periods. This is twice as many periods when the "perfect" system two was in operation.

The conclusion from the above experiment is that although the addition of system two to the operational level has meant a marked improvement in the overall system behaviour, other structural conditions such as bad communication and bad working realations or lack of trust among the various managers can cause many of the benefits of the structural improvements in the system to fade away. This highlights the importance of correctly situated and free of noise information transmission channels in the system at both the coordination and operational levels.

The oscillation that is still evident in the system is mainly at the early periods and due to the stockouts suffered by the materials division fig(6.12) because of the long lead time before it receives any replenishment order from the outside vendor.

In this experiment we can see that the overall oscillation in the system has been dampened by something like two thirds of its original magnitude.

An important characteristic of system two is that all the actions taken by it are outside the central channel of commands. That is to say that system two introduces its anti-oscillatory actions without having to call upon higher authority to impose them on the divisions. We see all the actions coming about through co-ordination between the divisions themselves due to the services of system two which are there to provide this co-ordination. This is exactly what Beer has designed system two to do.

It follows from this that in designing an organizational structure there must be an understanding beforehand that none of the communications between system two and the operational divisions should be taken as orders. As a matter of fact Beer suggests that these communications should be circulated on a special colour paper, and that all concerned would know that these papers had to do with co-ordination only.

System two must be carefully and properly designed, and within the context of the viable cybernetic model, a director of management systems within system two (corporate regulatory centre) needs to be identified and have his job cut out for him. Any person taking on this task requires special abilities of understanding and compassion and patience. The reason for this is that system one will always be fearful that the anti-oscillatory system two has been handed over to a power merchant. System two must present its oscillation damping activities as a homogeneous package with which system one may feel comfortable.

Through introducing a system two component into our model we have been able to show that the oscillation in the system has been decreased significantly but not enough to consider the system stabilized as a normally operational production inventory system.

6.6.1.3 The third experiment

The third experiment will introduce system three (the operations directorate) to the system which up to this stage has included the basic operational level and system two (regulatory center).

The experiment will be conducted by first introducing system three with assumed perfect operational conditions prevailing in the system. This implies that all system's three actions are going to be implemented to their maximum effectiveness. The secomd part of the third experiment will test the effectiveness of system three under assumed poor communication conditions.

As shown in the previous experiments, system two's actions to dampen the oscillations is not enough to extract all the sorurces of oscillation in the operational level and insure the stability and homeostasis of the whole system. This is due to system two's "co-ordination only" function and its limited authority (or even non-existent authority). What is needed to rectify the remaining oscillation in the operational level is an authority with the responsibility to make or cause fundamental changes in the behaviour and structure of the operational elements (divisions). These changes are ones that could not have been taken by system two because they represent commands that come from a higher level of authority and this authority is in the shape of the operational directorate (system three). In our third experiment we are going to introduce to our model a system three with its associated control actions which are aimed at attaining a complete control and synergy of the operational level.

a- As said before, one of the main jobs of system three is to insure that each individual division in the organization produces the output it is assigned to produce. But as we have just seen from the results of the second experiment, one of the important divisions in the organization, the distributor division, could not attain its full functional ability even after the introduction of system two to the model. One of the main reasons for this defficiency is the lead time for goods delivered at the distributor from factory. We assume that system three will rectify this situation by taking the decision of moving the complete location of the distributor (which we assumed earlier is located away from the firm's main location) to a site nearer to the main firm site, and this action will reduce the lead time taken by transportation of goods to a third of the previous lead time.

b- Also in its effort to improve the stability of the operational level, system three uses its power to intervene into the operational elements operations by issuing commands that lead to changes in the divisions' operational policies. The changes in these policies will affect the divisions outputs which then could be guided by system three towards overall synergy of the operational level. In this context we assume that system three orders the production manager to make fundamental changes in his plans to allow for contingencey production of goods to meet sudden changes in demand requested by the distributor who would then give a better service to the customers, and hence, improve the image of the firm. This change of policy is against the production manager's will because it is going to add to his operational costs.

c- System three directs the raw material division to improve its operations and to reduce the lead time for raw materials orders. This is done by instructing the raw materials division manager to negotiate new delivery timetables with the external raw material vendors, and by trying to reduce the time for processing orders inside the division.

e- Judging from the results of the previous experiments the stockouts that are occuring at the early periods of operations are the most prominent of all the stockouts that are occuring at the various divisions. This situation was partialy remedied by system two which tried to persuade the different inventory namagers to increase their initial inventories. It did not sucseed completely in attaining that objective due to the tendency of the managers to resist the increase in their inventories because of extra cost considerations. System three viewing the importance of this matter (through its interface with system two) takes the action of ordering the raw materials division, raw materials section at factory, and the distributor division to increase their initial inventory levels by a substantial margin (against their will and plans) to guard against early stockouts situations. In this case the operational elements (divisions) can not but obey this command because it is a control command backed by adequate authority which can prosecute any division if it sees necessary. This kind of commands comes through the central control information channel.

The initial conditions for the distributor division are: an initial inventory level of 230 units, and the lead time ordering and receiving produced goods from the factory warehouse now varies between zero and four. All other initial conditions are the same as in the first experiment. The initial inventory level for the raw materials section at factory is 230 units and the lead time between ordering and receiving replenishment materials from the raw materials division is 2 weeks. All other initial conditions are the same as in the first experiment.

The raw materials division initial inventory level is 230 units, and the lead time before receiving any replenishment order from the outside vendor is 2 weeks. All other initial conditions are the same as in the basic system.

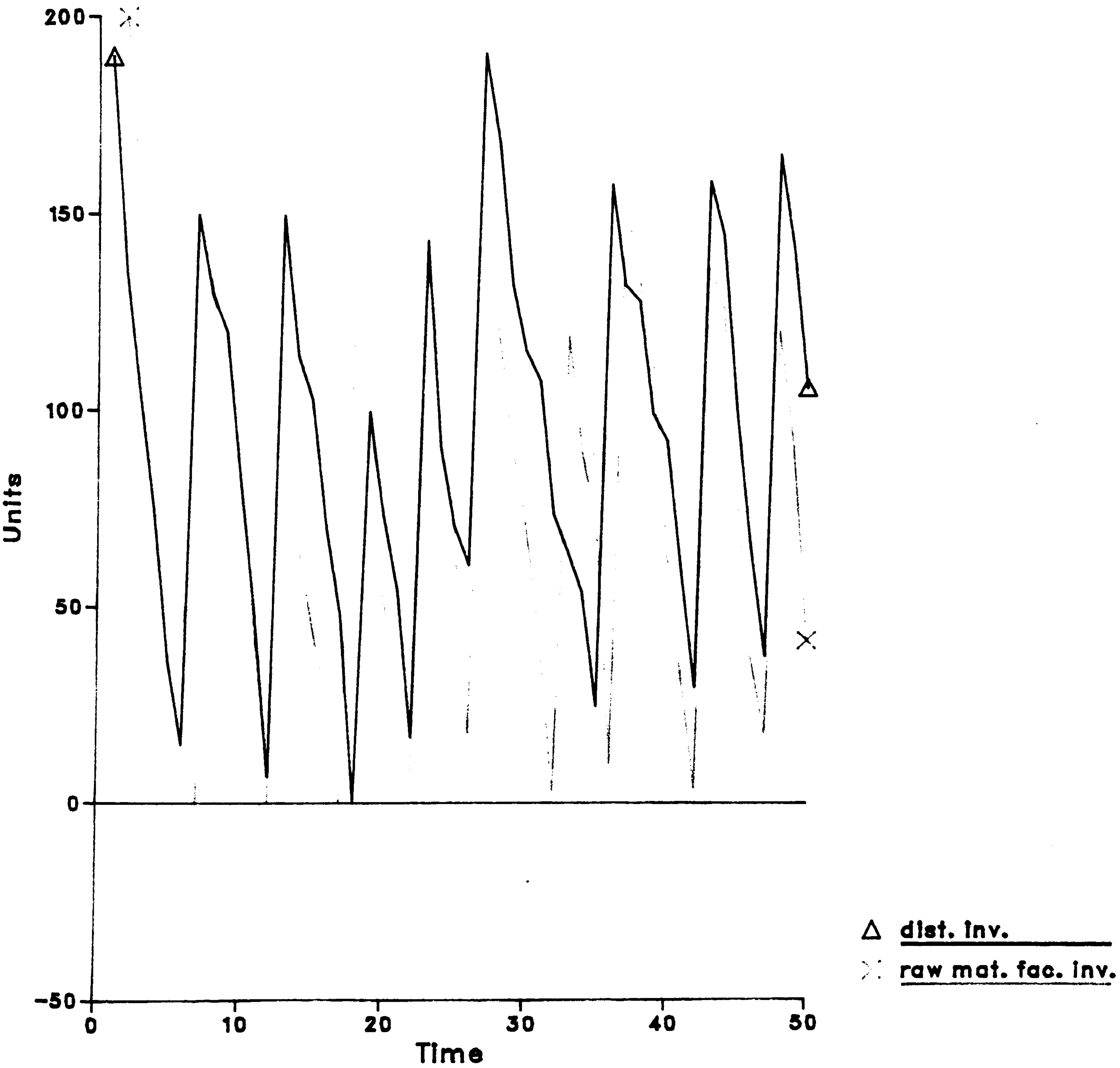


Fig.(6.13) Distributor and raw materials section at factory inventories - after adding system three (perfect)

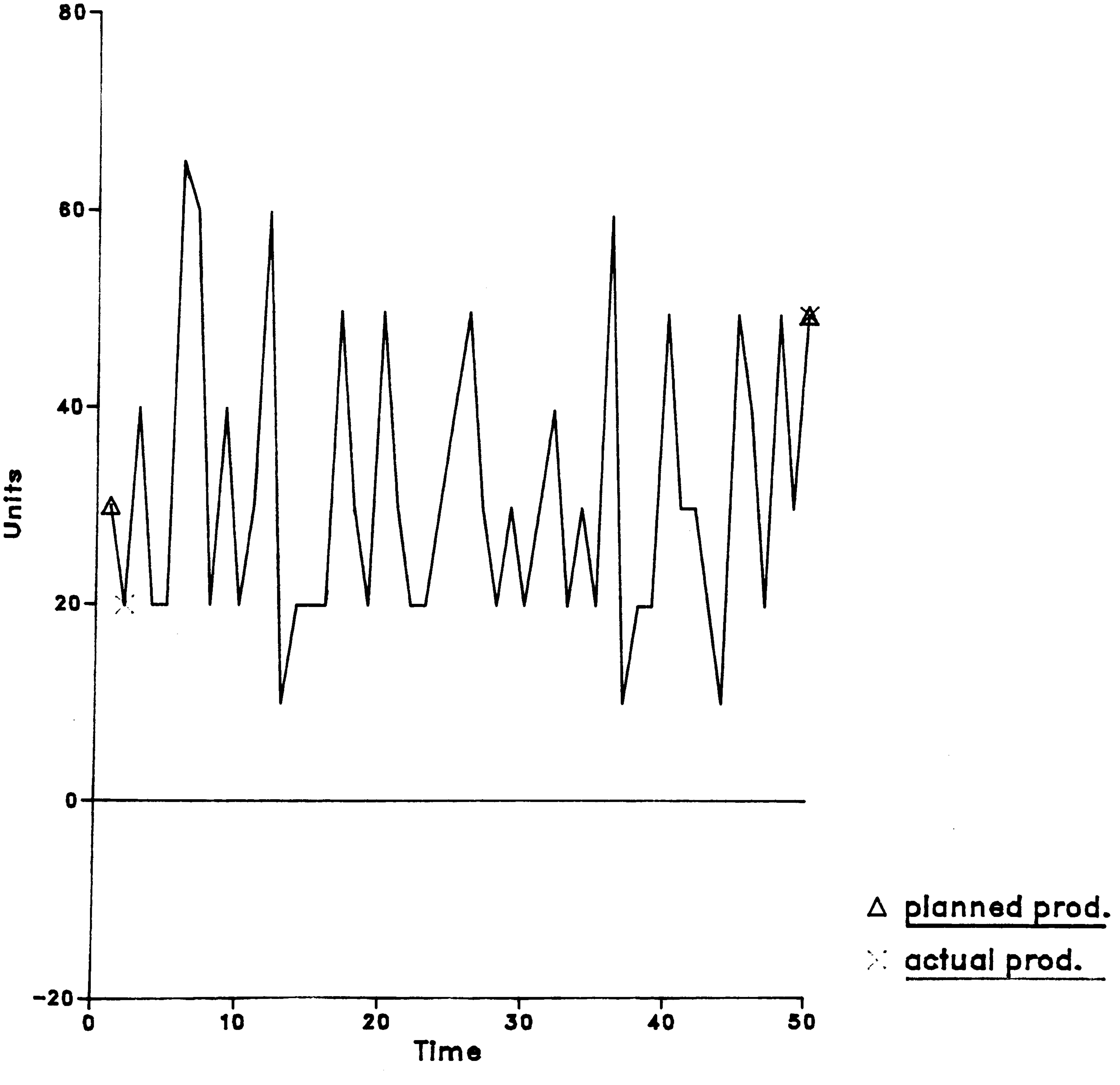


Fig.(6.14) Actual and planned production - after adding system three (perfect)

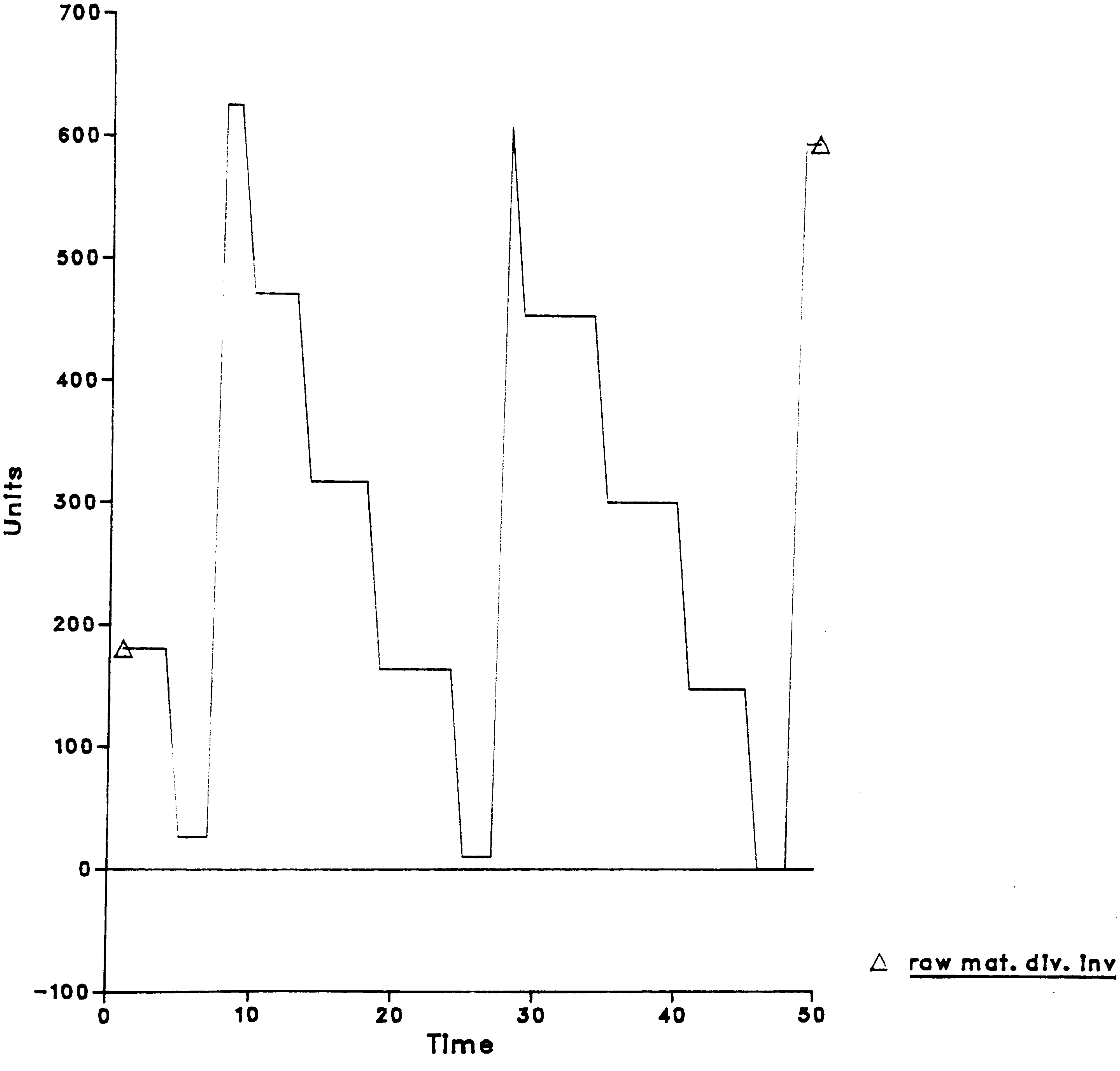


Fig.(6.15) Raw materials division inventory - after adding system three (perfect)

From fig (6.13) we can notice a great improvement in the distributor system over the previous experiments, and as a matter of fact it can be seen that the system has been able to offer a 100% level of service which is much to the satisfaction of customers and much to the improved image of the organization which would probably lead to a better place for it among other organizations in a competitive market. This improvement was made possible by the implementation of system's three actions which resulted in the reduction of lead times and the increase in the initial inventories the three divisions leading to the elimination of the early stockout menace at these inventories.

The inventory system at the raw materials section at factory also attained a very high level of stability and was able to supply the production section with the material needed for almost all the operational periods.

Fig (6.14) shows how the better situation at the raw materials division fig(6.15) and raw materials section at factory has been reflected in the production section ehich was able to meet the planned production quantities by nearly 100%. The two curves in fig (6.14) are now almost identical.

As mentioned before, the second stage of the third experiment is the introduction of system three with the assumption of the presence of operational disturbances in the system. These disturbances will be represented by less than perfect communication channels between the operational level and both the regulatory center and operations directorate. Also we are going to assume poor communication at the system two-three interface which will result in incomplete and disrupted information reaching system three about the oscillations present in the operational level.

This kind of disturbances in the system will have the effect of inadequate control commands being issued by system three to the operational level, besides even when the right commands are being issued the divisions will receive them in an incomplete or distorted form. All the new operational conditions will result in that the distributor, raw materials at factory section, and the raw materials division will increase their initial inventories by only a fraction of what was ordered by system three. The plan to reduce ordering processing in the organization put forward by system three will not be implemented fully now and hence all the system will experience an increase in lead times at the various points.

The initial conditions for this experiment are: an initial inventory level of 200 units for the distributor division, raw materials section at factory, and the raw materials division. The lead time before the distributer receives a replenishment order from factory warehouse varies between one and 5 weeks. The lead time before the raw materials section at factory receives an order from raw materils division is 2 weeks. The lead time before the raw materials division receives a replenishment order from outside vendor is 2 weeks.

All the other initial values of the model remain the same as for the first experiment.

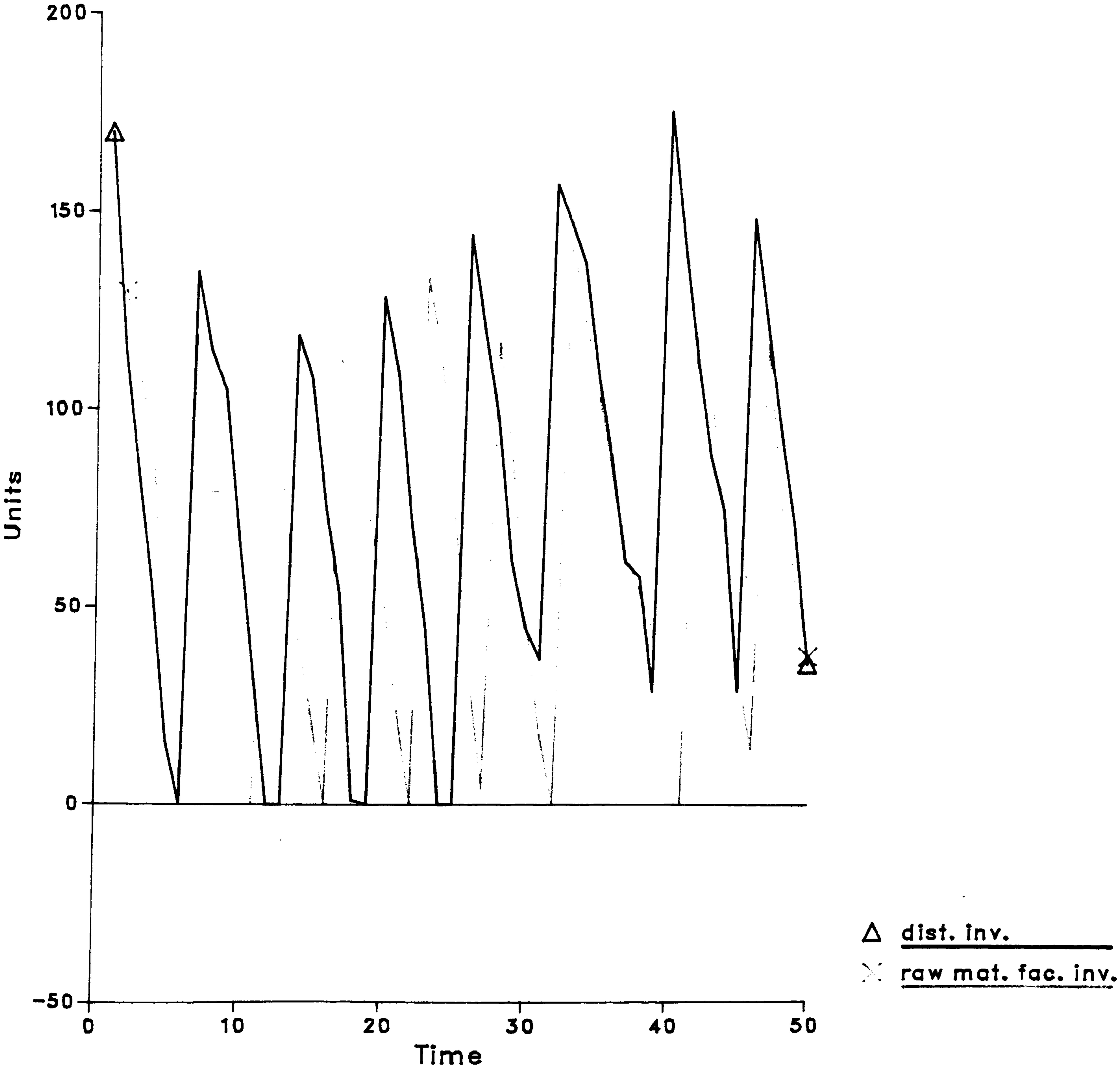


Fig.(6.16) Distributor and raw materials section at factory inventories - after adding system three (imperfect)

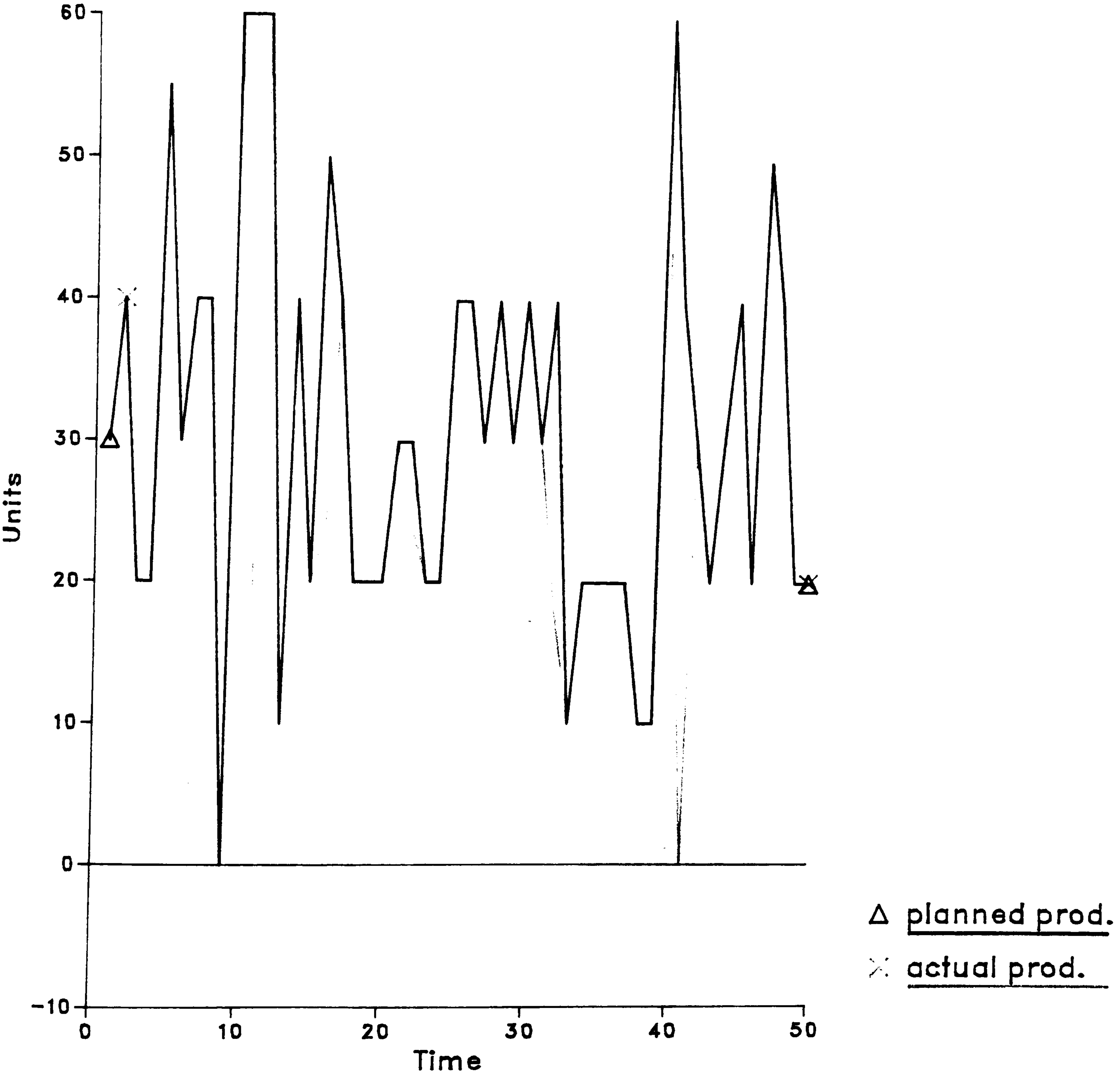


Fig.(6.17) Actual and planned production - after adding system three (imperfect)

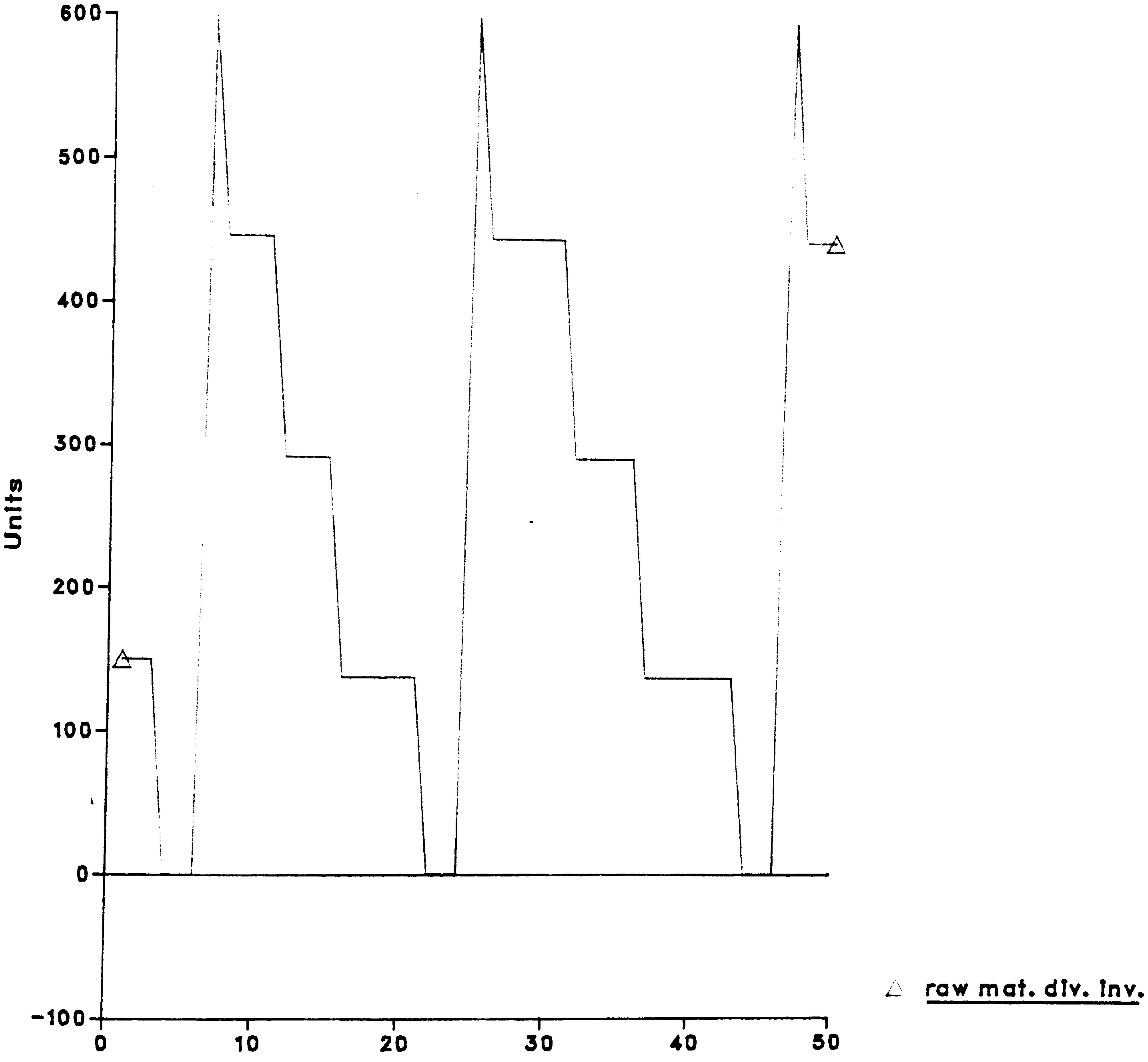


Fig.(6.18) Raw materials division inventory - after adding system three (imperfect)

Fig (6.16) shows that the implementation of system three actions when imperfect comunication and information channels are present in the system has not achieved the impact on system's behaviour it was destined to have. From fig(6.16), and by comparing the situation at the distributor's inventory with the situation under the perfect system three of the last experiment we can see that the inventory has not achieved a service level as spectacular as before. The inventory has suffered some stockouts especially at the early periods which was a direct result for the initial inventory not being increased by the desired quantity. Other stockouts are a result of shorcomings at the other inventories in the overall system fig(6.18).

Nevertheless, although the system has suffered some oscillation the level of service it offered is still quite well and acceptable considering the state of the system before introducing system three at all.

The raw materials section at factory also experienced a number of stockouts which are widely separated over the simulation horizon, and again although the system is not running as good as it did under a "perfect" system three the level of it offers is still quite acceptable.

Fig (6.17) above shows that the production section at factory has not suffered much from the bad effects of this experiment's conditions and managed to maintain a stabilized condition all the way over the simulation horizon. The two curves show that the deviation between the planned production quantities and the actual production quantities occured only in a small number of periods and only by a small margin. This is because the oscillations in the overall system have been effectively dampened (systems two and three actions) by the time they reached this point in the system.

To summarize, although the presence of information transmission problems have prevented system's three actions from actually being fully implemented, the system still managed to stay within an acceptable level of stability by utilising the partialy implemented system three actions.

All the actions that have been taken by system three so far were directed towards the control of the operational inventories in the system. An inventory which was overlooked was the factory warehouse which is considered as a non-operational inventory (i.e. does not have an inventory control policy of its own) and it was regarded as a complementary facility for the production section. Fig(6.19) shows the factory warehouse situation during the running of the perfect system three experiment. From the figure it can be seen that the level of the inventory has an rising trend as the simulation time advances, and by the end of the simulation horizon there was quite a high level of unused items in the warehouse. This situation although it does not have a bad effect on the operational level stability, does however put an extra cost burden on the organization since unused items in the inventory represent lost investment and leads to extra holding cost. To tackle this problem system three takes action to make changes in the production operation. This action by system three will be directed at the implementation phase of the production plan and not the actual planning phase. In this way system three insures that the production manager continues to enjoy a certain level of autonomy and it only interferes and restricts his autonomy when the overall system's synergy requires this.

System three's action is implemented by ordering the production section to produce half of the planned product at any certain period when the factory warehouse inventory at the previous period has ended with a level which is more or equal to one complete replenishment order from the distributor division. This kind of action will insure that at all times any order from the distributor will be satisfied as well as a reduction in the production level when there is more than needed stock in the factory warehouse. In this experiment we will assume the introduction of this action while the system is enjoying perfect operational conditions. All the initial conditions are the same as in the perfect system three experiment.

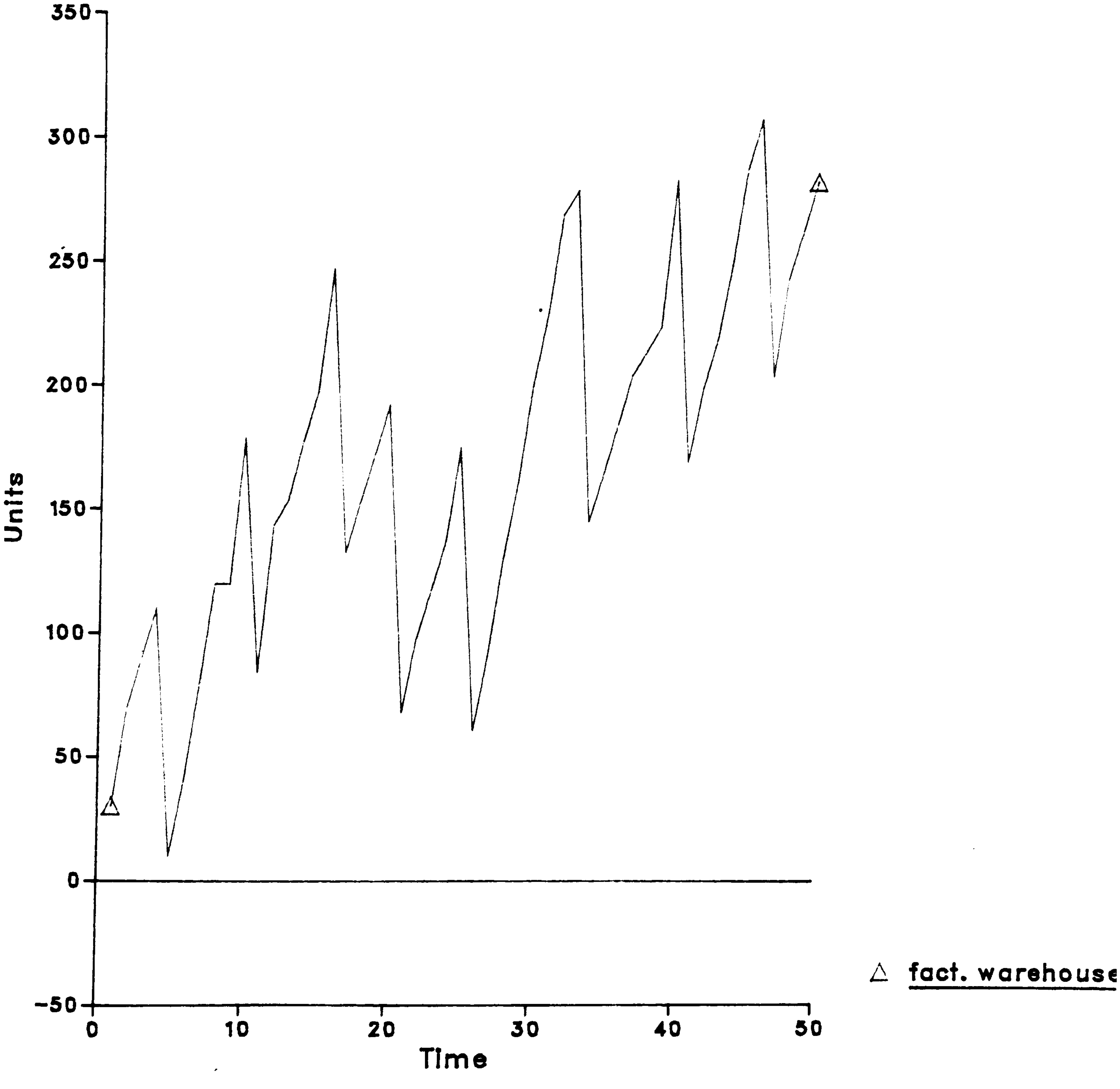


Fig.(6.19) Factory warehouse before system three's action

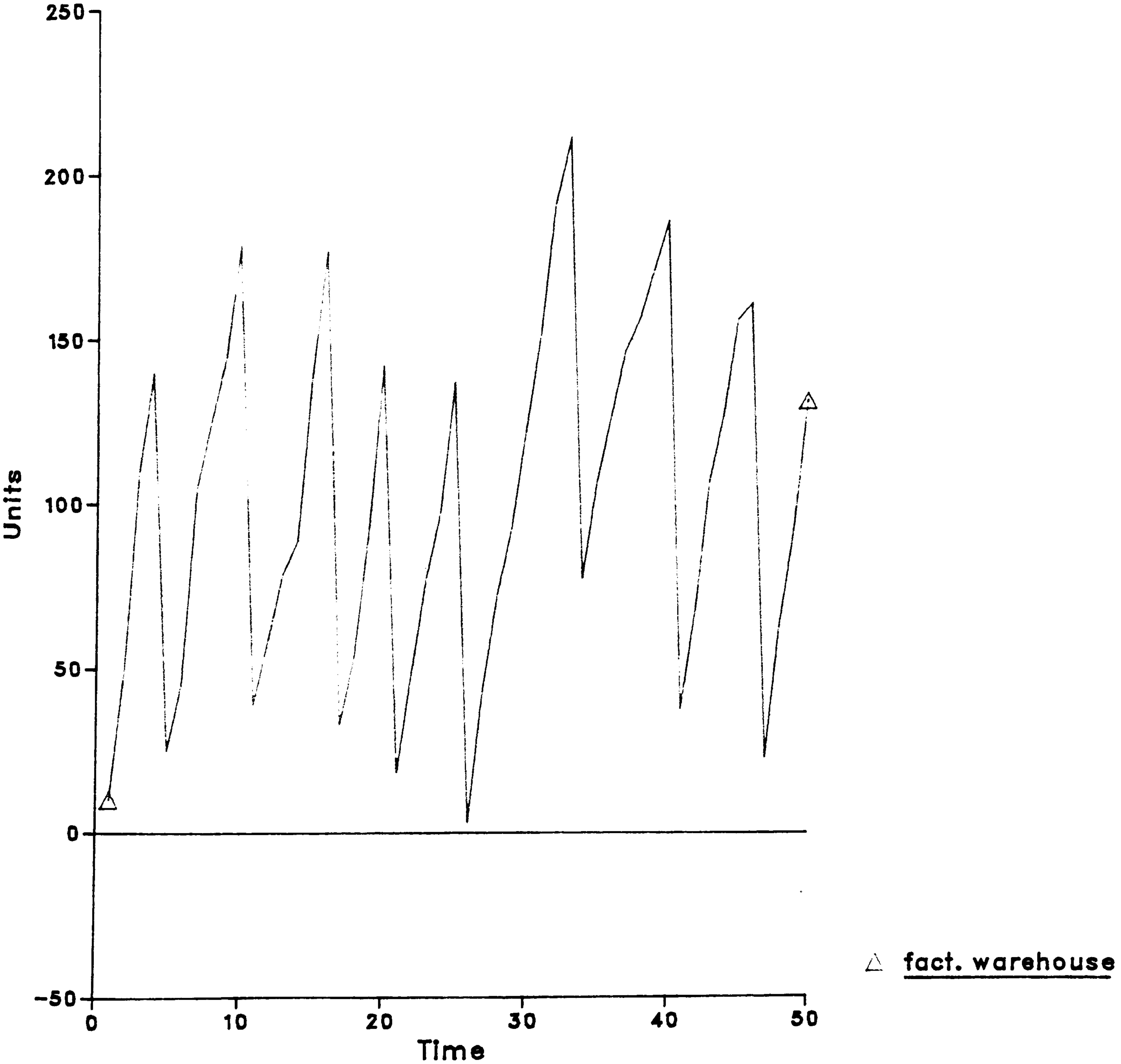


Fig.(6.20) Factory warehouse after system three's action

Fig(6.20) above show the inventory situation at the factory warehouse after the introduction of system three's action. By comparing this figure with fig(6.19) it can be seen that a great improvement has resulted in the warehouse situation and the rising trend of the inventory has disappeared. Also the inventory level at the last period is much lower now which represent a lower extra cost of operation.

The above indicate the utter importance of the divisional directorate (system three) position in the system which can produce good effects on the system's behaviour even with the presence of distabilizing effects in the internal structure.

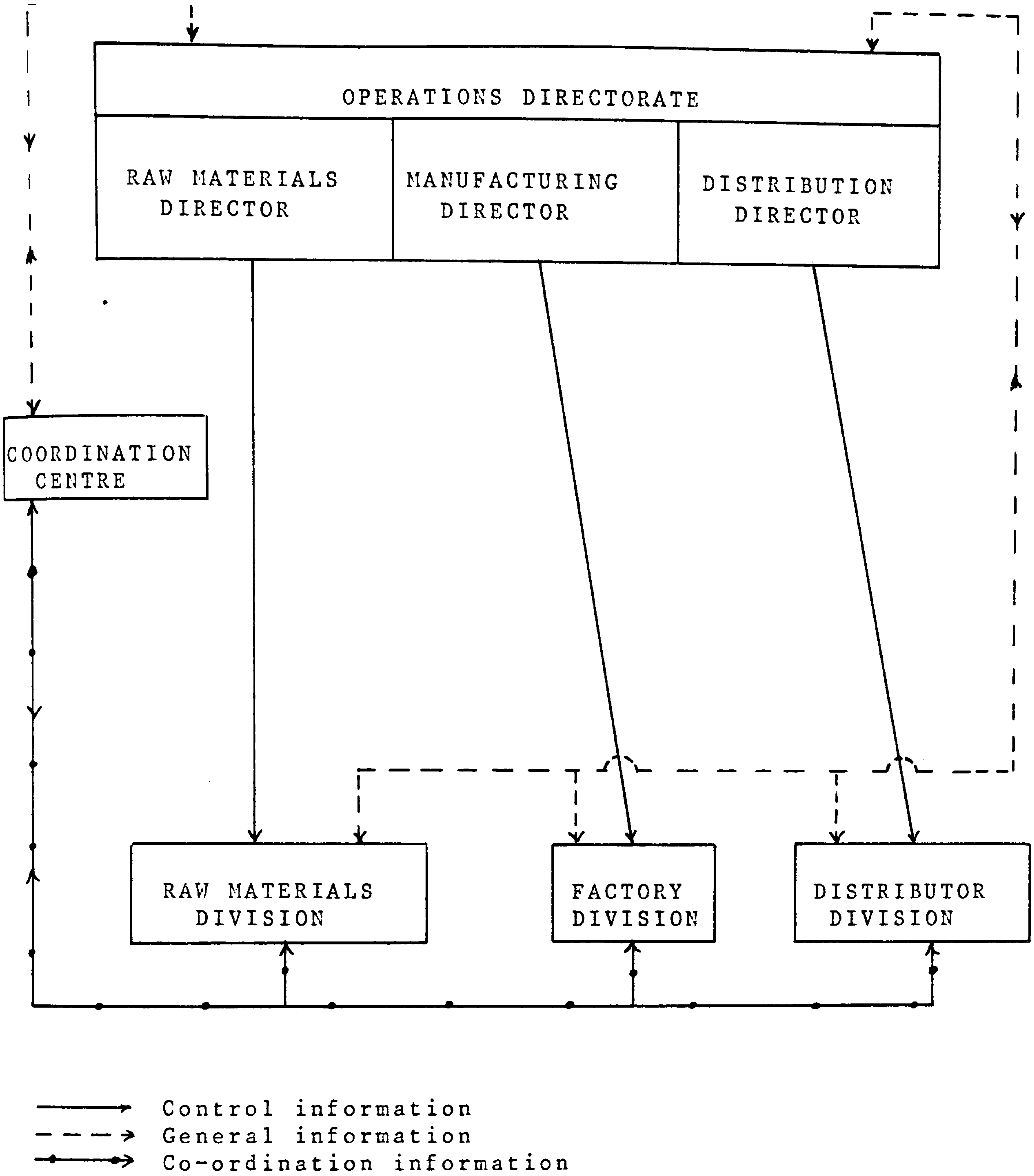
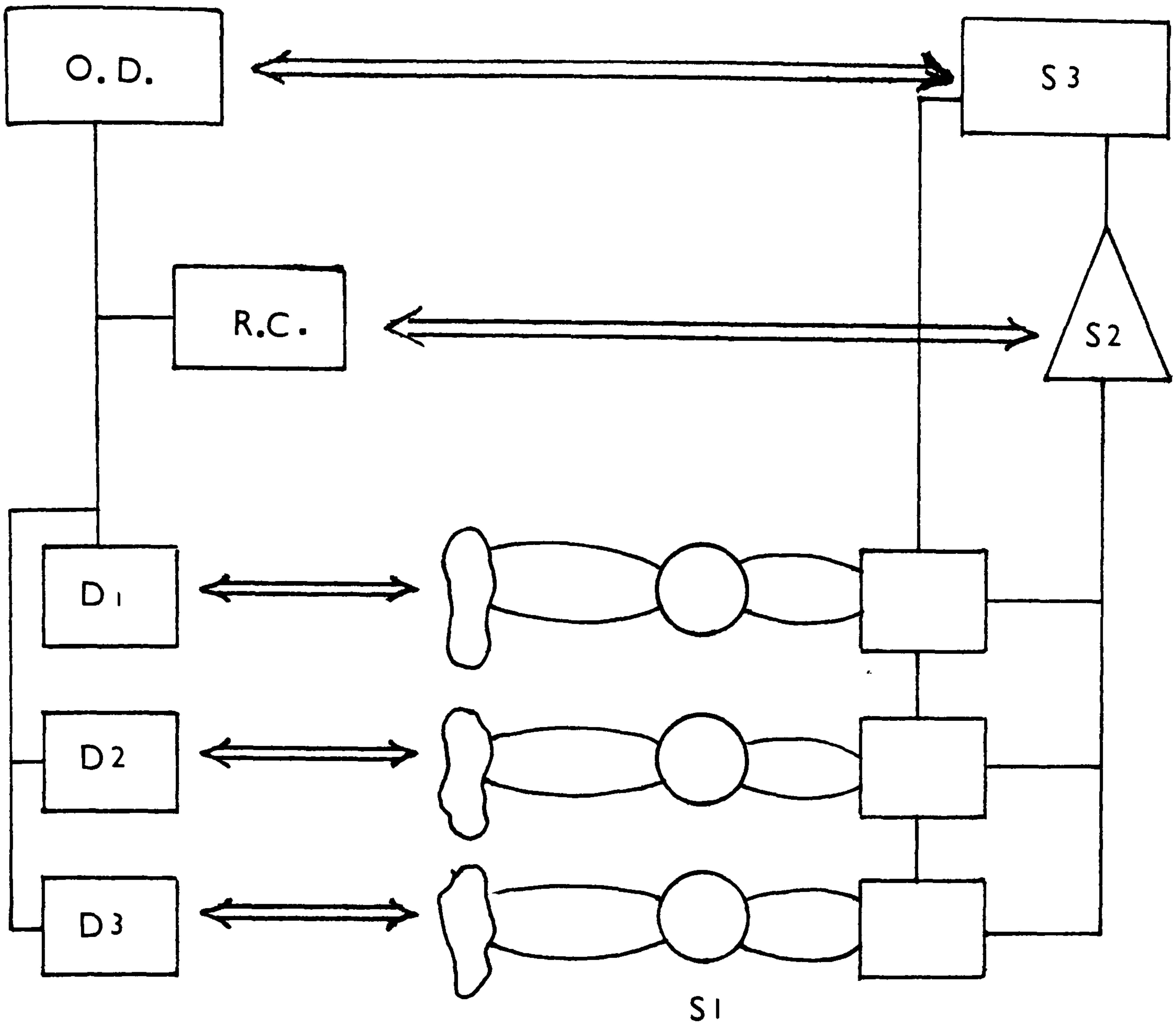


Fig.(6.21) Basic system with added coordination (system 2) and control (system 3) functions



O.D.	Operational directorate
R.C.	Regulatory centre
D1,D2, D3	Operational divisions one two and three
S1	System one
S2	System two
S3	System three
	Information (all kinds)

Fig.(6.22) A mapping between a basic operational industrial system and Beer's systems one, two, and three.

In general the system is now a far better one than the original system (no sytem two and three). It is now a more stabilized system, and the internal oscillation is now down to an acceptable level. As cybernetics indicates, there is a balance between the operational elements (divisions) maintaining enough autonomy in running their operations and at the same time sacrificing some of that autonomy for the benefit of the total synergy of the whole system.

The creation of the divisional directorate (system three) requires improved information channels to be established between the operational level divisions and system three.

The control commands generated by system three should not all be transmitted to system one on the command channels because that might cause some kind of resentment at the operational management level and cause a feeling that the upper management is interfering into their co-ordination efforts at the operational level. So if as much as possible of system's three commands comes through system two in the guise of suggestions and anti-oscillatory actions, it would be taken almost readly by the operational level managers since many of them if not all are themselves part of system two.

A usual way for system three to control the operational level is by concerning itself with the methods and procedures that the various operational elements utilize.

The first thing we might notice about this is that the complexity (variety) of the operational level is very high due to the multitude of operations it undertakes. To reduce the complexity of the situation, system three simply treat each operational element as a black box and worrying only about the putput of those boxes and ignors the internal workings of those units so long as their outputs are reasonable.

The most important function of Beer's viable system model is to facilitate maintenance of the continuous balance between autonomy of the parts and integration of the whole. The operations directorate (system three) has the very important job of maintaining a synergistic pattern of relationships among the various operational elements of the operational level (system one).

6.6.1.4 The fourth experiment

In the fourth experiment we are going to introduce to the system strong external and internal disturbances to study their effects on the system's behaviour. These disturbances are going to be introduced while the system is under assumed perfect operational conditions with systems two and three actions fully implemented.

The first phase of this experiment is to introduce a strong internal disturbance to the system. This disturbance will be represented by an exceptionally poor planning by the production section. In real situations this can be caused by many reasons e.g. bad forcasting information from the intelligence parts of the enterprise (system four in Beer's model). All the initial conditions for this experiment are the same as in the perfect system three experiment except for changes in the random number generator which generates the production plan forcast quantities in the model.

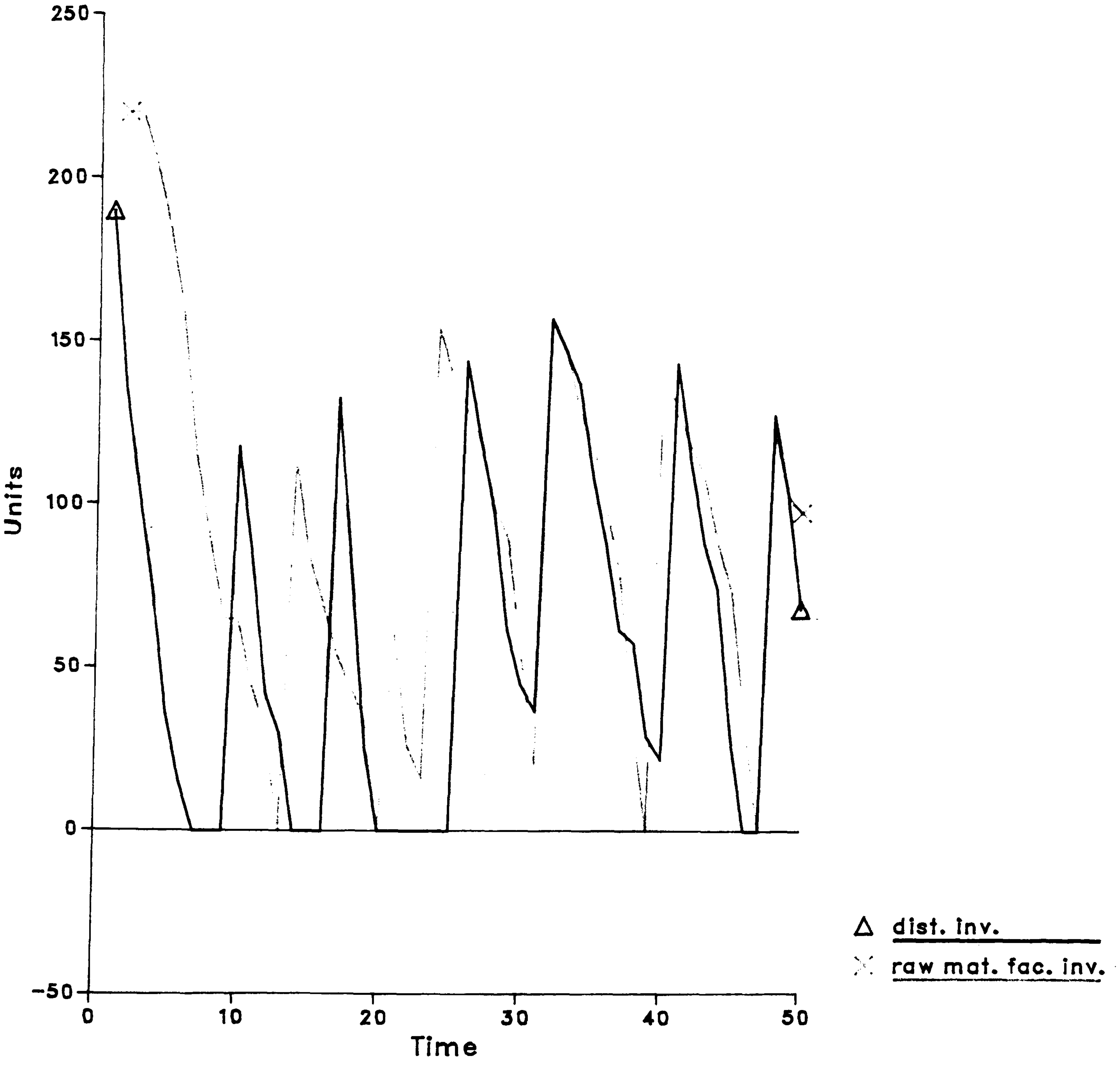


Fig.(6.23) Distributor and raw materials section at factory inventories - internal disturbance

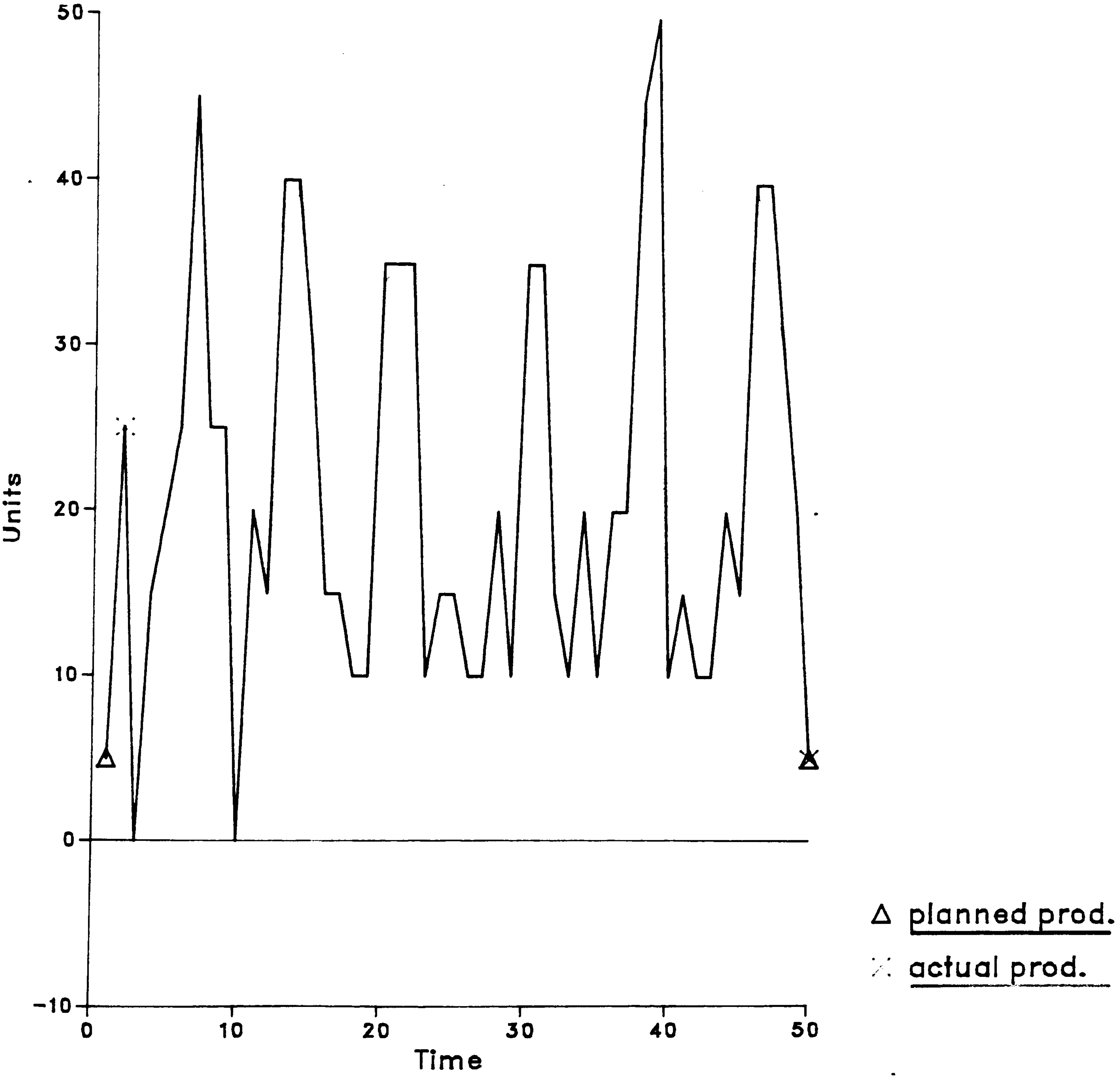


Fig.(6.24) Actual and planned production - internal disturbance

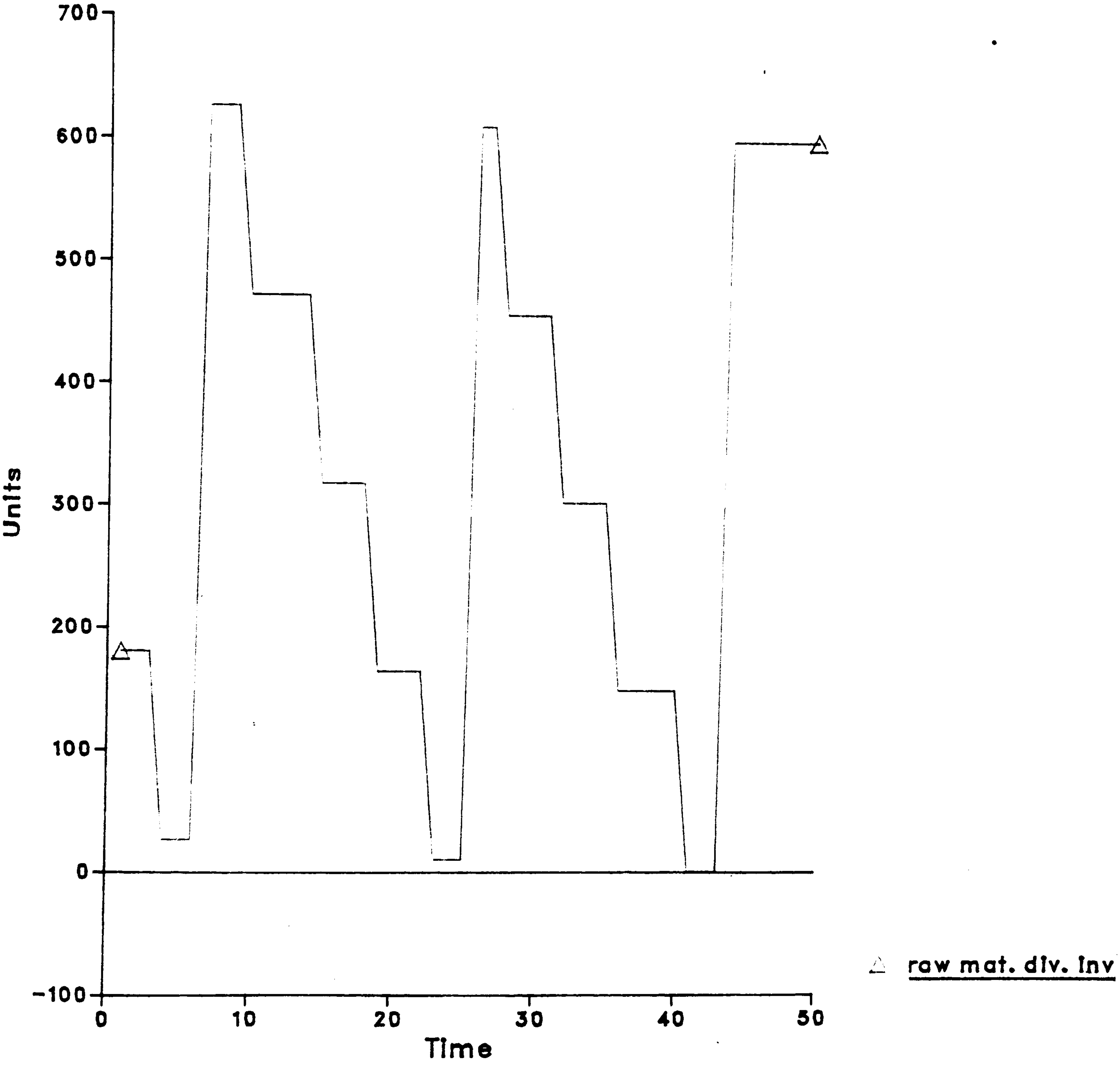


Fig.(6.25) Raw materials division inventory - internal disturbance

Fig(6.23) shows that as a result of the bad production plan (which led to reduced production quantities) the distributor division's inventory has suffered crashes on almost half of the operational periods. This was because of the direct dependence of the distributor's inventory on the quantities produced at the production section. The second curve in fig(6.23) and the curve in fig(6.25) both show that the situation at the raw materials section at factory and at the raw materials division were not effected by the disturbance at the production section because both inventories are stationed outside the source of the disturbance. Fig(6.24) shows that the actual production quantities were able to match the planned quantities since the planned quantities were smaller in size than usual and the supply of raw materials from the raw materials section were in abundance.

Similar strong internal disturbances in any of the other divisions in the system would have resulted in similar crashes in the overall system because of the interdependence of the various parts.

The second part of the fourth experiment introduces an extreme external disturbance to the system. This disturbance is represented by more than double the usual demand by customers placed at the distributor division. Like the previous experiment we assume that the system is under perfect operational conditions. As with all our experiments all the divisions' plans are fixed for the whole of the planning horizon and are based on forcasting information received from the intelligence system of the firm (system four). In this case we assume that system four has not anticipated the forthcomming rise in customers' demand. All the initial conditions for this experiment are the same as for the perfect system three experiment except for the random number generator for customers' demand will be changed for the purpose of this experiment.

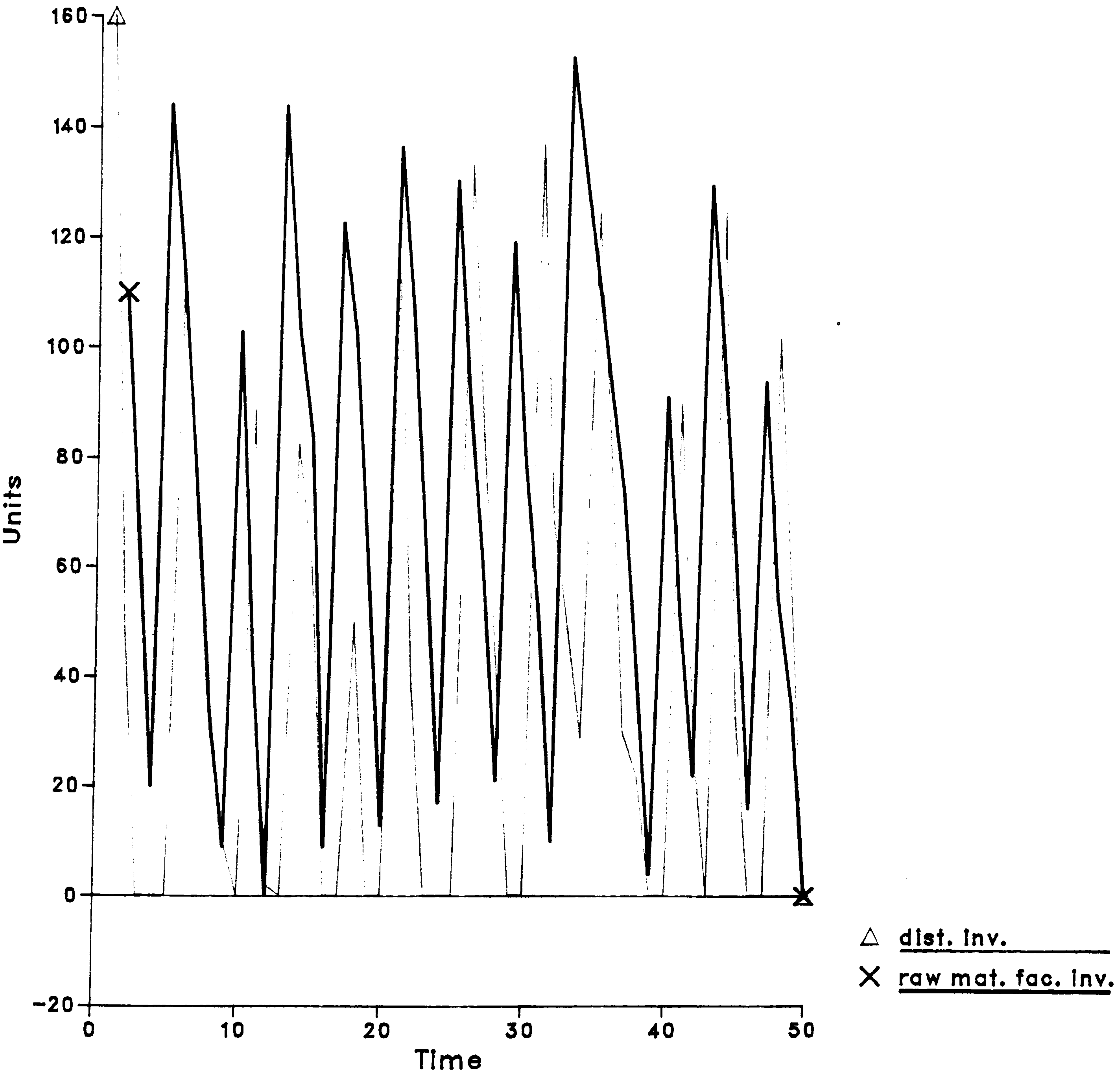


Fig.(6.26) Distributor and raw materials section at factory inventories - external disturbance

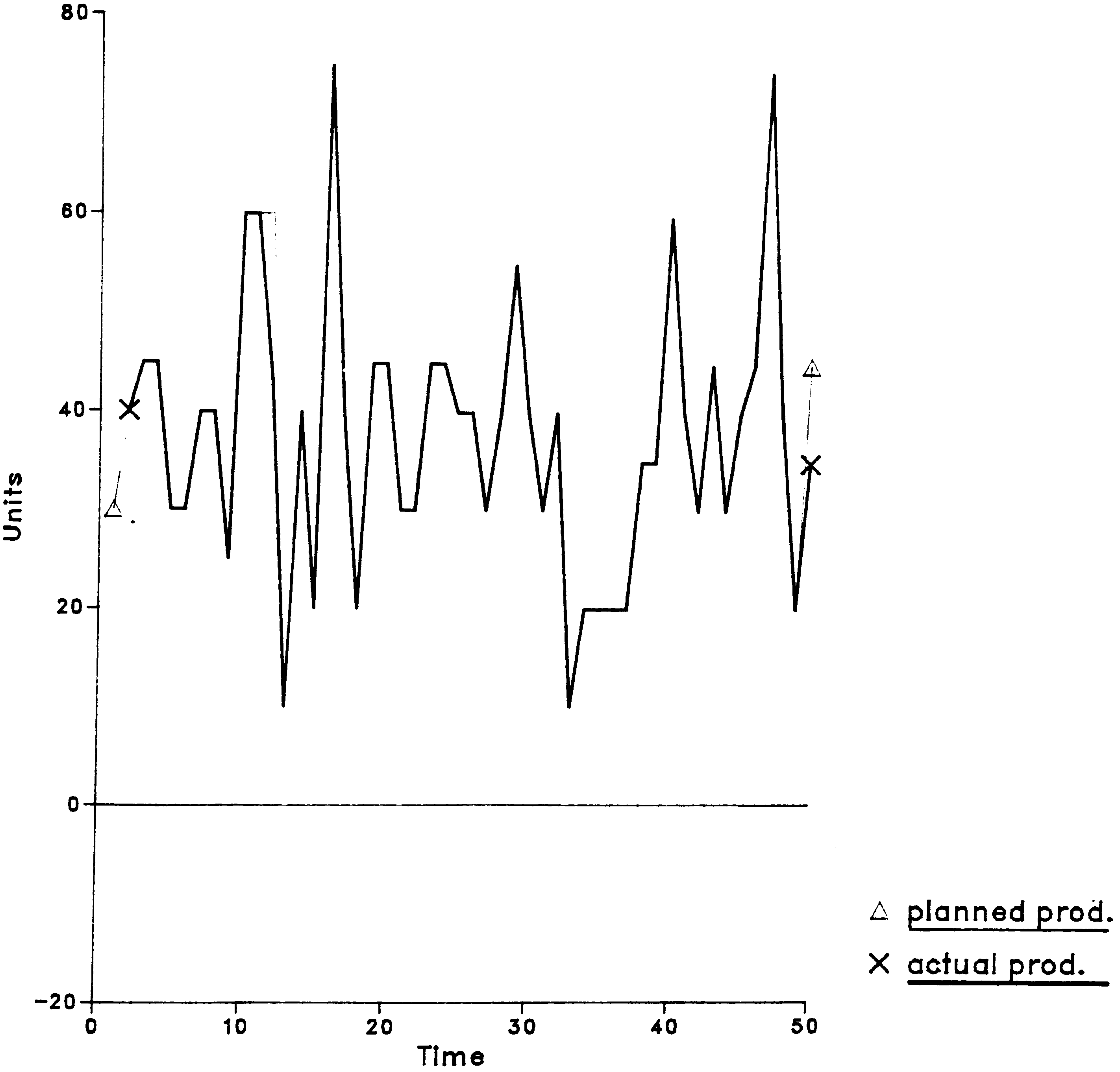


Fig.(6.27) Actual and planned production - external disturbance

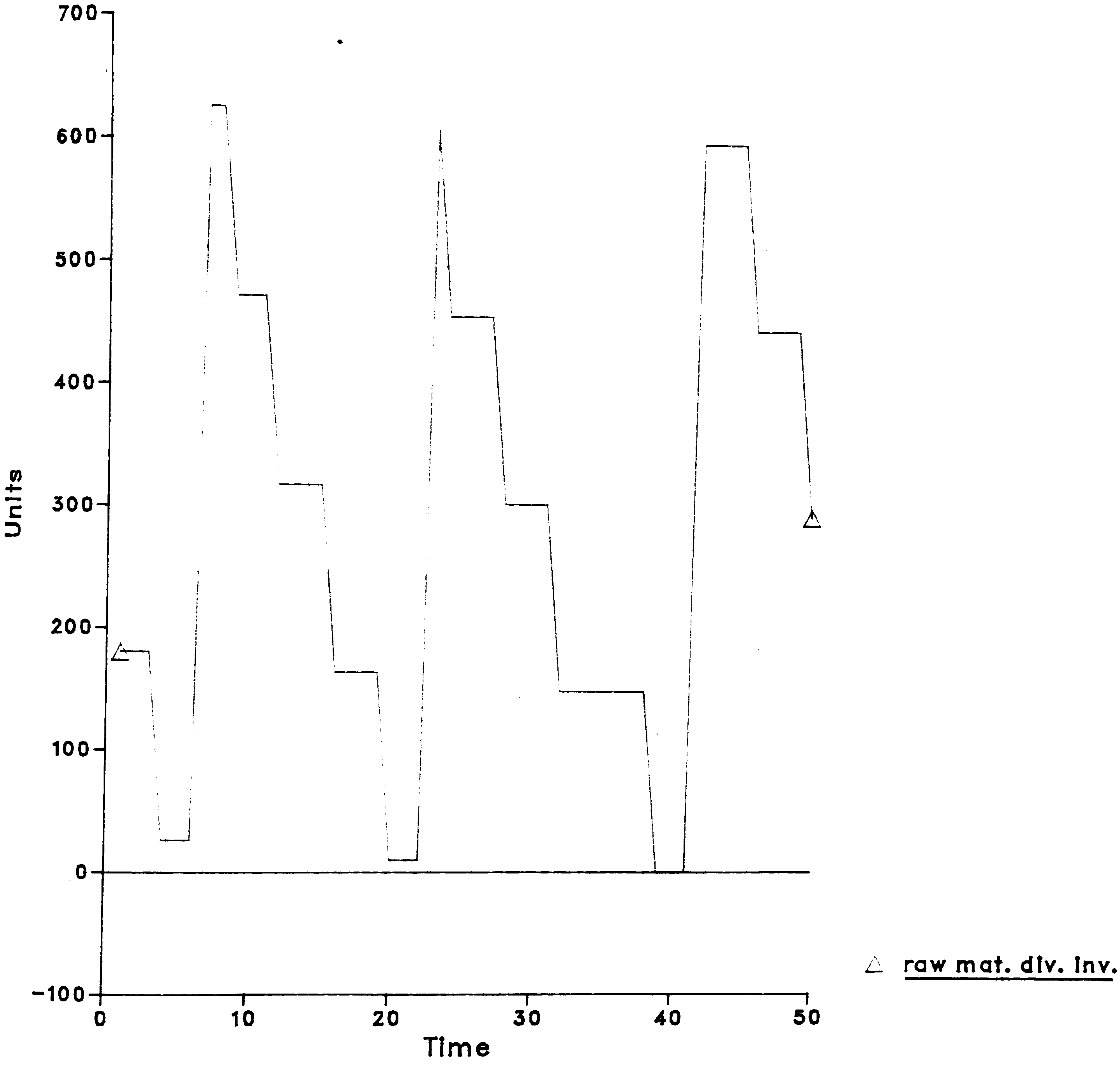


Fig.(6.28) Raw materials division inventory - external disturbance

Fig(6.26) above shows that the unexpected high demand by the customers have caused the distributor system to suffer from a large number of crashes over the simulation horizon. Figs(6.27),(6.28) show that the rest of the systems in the operational level did not suffer from this disturbance because they are situated outside its effects. However, although the other divisions worked normally, the crash in the distributor situation represents a crash for the whole system. This is because the distributor division represents the output of the system as an industrial organization.

The control apparatus at the operational level could not cope with this kind of disturbance because it was designed to tackle operational day-to-day disturbances and oscillations. Disturbances that occur because of faulty information or commands from higher level systems (systems four and five) are outside the powers of the control apparatus (system three) at the operational level, and require higher level control actions.

CHAPTER SEVEN

CONCLUSION

Management as an applied science aims at providing guidelines for effective problem solving in social systems.

In this context it is important for us to point out the facts, that for an applied science like management, (1), practice is the point of departure of any scientific activity; and (2), the management scientist looks for rules and models to design and construct the future and its reality. The activity of a manager is oriented towards complex systems; that means that there is the problem of handling complexity in practical management situations and therefore the need for adequate rules and models.

In this thesis it has been shown how managerial rules of action may be developed by making use of some ideas drawn from cybernetics.

Stafford Beer is an influential worker in the field of managegment cybernetics, and through his long research of organizations Beer developed what he calls a model of the viable system. This model represented an appealing cybernetic idea and although supported by many scientists and workers, remains largely theoretical. There was an attempt by Beer and some of his coleagues to apply his model to a national economy system (Chile) in the early seventies (Beer 1975), but that attempt was violently interrupted and although it gave a good indication of progress, there were not enough conclusive results due to the abrupt ending of the work. Because of the relative lack of concrete validation of Beer's viable system ideas, particularly as to organizations and ordinary bussiness firms, we undertook to use simulation methods as an approach to investigate the validity of his ideas to an industrial enterprise. The industrial activity of production-inventory control was chosen for the study as it represents one of the most important activities in an industrial system. A study based on other kinds of industrial activities (monetary, employment, maintenance etc.) would have probably led us to a similar set of conclusive results regarding the testing of applying Beer's ideas.

In our modelling approach we took as the basic existing organization structure, perhaps rather artificially, that existing prior to the introduction of Beer's systems two and three. This consisted of highly organized viable systems (divisions), with their main aims being to produce self-viability only, and not an overall system viability.

Instability or oscillation due to time lags is very common when dealing with interconnected sets of feedback loops. This was shown in the experimental work with our model of the feedback systems that controlled the activities of the different divisions, when the time lags and lead times caused a lot of oscillation. The delay was not in the decision taking process alone, but was included in the actions taken based on these decisions, such as delays in delivery, paperwork, etc. In the context of time lags and their effects on organizational stability, there is an analogy between the points of view of both cybernetics and industrial dynamics approaches. But there is a difference in dealing with the problem from the two sides, as is shown in our model and indeed in our previous models presented in chapter 3. In our view, the introduction of Beer's organizational concepts represents a better way than that offered by industrial dynamics for tackling the time lag problem in an organizational structure.

The implementation of policies should be done by the organization's operational parts with discretion and autonomy. Autonomy adds a huge flexibility to the system. It permits swift local responses to environmental demands and changes. However, care must be taken that the policies and practices of the parts remain consistent with the organization's global policies. These generally accepted principles are well supported by Beer's work and the findings of our study.

The division of jobs between the autonomous operational units in a business enterprise and the central co-ordinating and control management should not be determined once and for all in the design of an organization. This principle, much emphasised by Beer, is directed at removing rigid, uncompromising structures within organizations. The structure should be flexible, and according to environmental and internal development, responsibilities should be subjected to change in order to adapt to new environmental conditions and to guarantee the cohesion and survival of the business organization. The applying of the rules of viability as put forward by Beer help in designing a well balanced system.

The absorbtion of the complexity of organizational tasks is done in several recursive structural levels, each level exhibiting a degree of autonomy. More autonomy at lower levels (operational levels) increases the organization's capacity to absorb and cope with complexity and variety but, as said before, only as much autonomy should be allowed as is consistent with maintaining the cohesion of the organization.

Operational decisions should usually be made at the lowest possible level of recursion, where the necessary operational information is available and the fastest possible reaction to environmental disturbances is guaranteed.

As has been discussed and shown, the work with our

model confirms the approach developed by Stafford Beer that was aimed at supporting effective organization at all levels of recursive control. The criteria of his approach are:
(a) It must be recognized (by the higher control management) that commands have to be kept to a minimum consistent with the cohesion of the whole. In the experiments it was shown how system three (operational directorate) was very careful in applying its control actions, and it only intervened in the operational elements (divisions) operations when the oscillations in the system proved to be too strong to be dampened by the actions of system two (the corporate regulatory centre).
(b) Besides the fact that more commands imply more dimensions of bureaucratic control, they also imply less potential autonomy for lower structural levels. The more autonomy is constrained the less is the ability to respond to the demands of the environments, thus implying lower performance. However, the other extreme, where higher levels do not command at all, would imply lack of cohesion in the system and the inability to achieve overall policies. This was clearly shown in the first experiment when the operational elements enjoyed absolute autonomy with no control action from higher level management, a situation that led to disastrous effects on the system.

The core of Beer's design is aimed at minimizing bureaucratic control by:

1- Inducing self-regulation at the operational levels. That is, by increasing the abilities of all these levels to absorb by themselves the complexities emerging from their natural or induced inter-relations, without the intervention of the immediate higher level.

2- Giving the immediate higher level the capacity to monitor the general activities of the lower level, that is the capacity for both to get first hand information of the activities at the lower level with reference to its allocated discretion, and use this information to make adjustments over time.

The important conclusion that must be emphasised is that without constant attention to the synergy of the whole organization (system three's job), operational elements of the operational level of the system (which after all are viable systems by themselves) will follow their own tendencies towards autonomy until it pulls the organization apart.

In the process of building a simulation model of the operational part of Beer's viable system concept, we attempted to show that a good overall system performance cannot be attained by merely optimizing the individual performance of the operational units (operational elements) which constitute the operational level. We also attempted to show the importance of a co-ordination system (system two) which is designed to absorb and dampen the instability and oscillation in the system which results from the interactions of the operational elements and represents a common feature of any feedback mechanism that incorporates time lags. Our simulation work also incorporated the addition of an operational directorate (system three) as the final section of the operational part of an organization. This part of the simulation illustrated the importance of the operational directorate for bringing about changes which are aimed at the total synergy of the operational part.

Our modelling work did not include the other two systems (four and five) in Beer's model of the viable system. These systems are the part of the organization which is rsponsible for strategic planning and control, and their modelling require a completely different approach from the one we utilized. The modelling of system four and five could be a further future study complementing our present study.

In designing a business organization great care should be given to the human side of the operation. Most decision makers are people rather than machines, so the consideration of human behaviour and human nature is an important issue and, as brought out in the experiments, situations such as lack of trust between the various managers (decision makers) in the system could lead to disruptions and oscillations at the operational level. These oscillations cannot be treated by mechanical managerial rule because they are the result of human behaviour, and an approach based on a combination of behavioural science and management science should be adopted in such a case. We cannot design an effective control system for an organization without a true understanding of how people behave in organizations. The achievement of an organizational objective depends on the design of procedures and controls that are matched to the human elements in the system, and take account of their true characteristics.

In any organizational situation people (e.g. managers and decision makers) will react to some extent to the immediate pressures on them, but they will also react in view of what they perceive their true function to be. These can sometimes be in severe conflict. An example of that was demonstrated in the experiments through operational managers not liking or simply not agreeing with system two's instructions to increase their initial inventories because they were not in line with their individually percieved plans.

Also, during the policy implementation phase the design will require changes in attitude and behaviour on the part of the participants (especially at the operational level), and some policy implementation might provoke antagonism and rivalry among the participants. An effective organization must ensure that there are no unnecessary conflicts at this stage by providing the appropriate co-ordination systems in the design. However, it is appreciated that this is a difficult task indeed. Recently, workers in the field of hierarchical system theory (Singh and Hassan 1978,1980) have recognised some of the human behaviour phenomenan in an organization that have a degrading effect on the system performance. These workers have developed a number of methods and techniques for dealing with such problems in order to maintain the system's stability.

It was demonstrated (through the experimentation with imperfect information channels) how information is an essential concept for planning and controlling business organizations. An information system must be carefuly designed to provide all levels of the organization with facts they require (operational information at the operational level, coordination information at system two, and control information at system three). Furthermore, these facts should be delivered at the most appropriate time and with an acceptable level of accuracy so that if necessary the organization's behaviour can be adjusted by modifiying its inputs while the knowledge of the state of the system is current and not historic.

From the information point of view, the more effective the organization is, the less information is needed by higher managers to control the system. In the experiments many of the control actions, and indeed some of the coordination actions, would not have been needed if the oscillations in the operational system were not there or were weak enough to be tackled by the operational elements themselves. It can be seen from our model that the individual plans of the different divisions contained measures that were designed to take care of any anticipated disturbance that might face the operation of each particular division. These plans will spare the higher management from the trouble of dealing with smaller disturbances and oscillations at the operational level. That is to say the operational system has autonomy to give closure to a wide range of information loops. This conclusion is particularly important because of the usually limited information processing capacity of managers.

Information is not only a function of the intentions of an individual but also of the organizational structure in which he operates. For a given level of performance, the more effective the organization is the less information is necessary for the control process. If managers develop a better appreciation of control processes, it is likely that they will benefit through more effective definition, design, and implementation of information systems.

Bad or noisy information and communication channels have a doubly bad effect on the system. On one hand they hamper the transmission of correct information about the state of the operational level to the higher control management, which as a result might lead to improper or incomplete control decisions. On the other hand, even when proper control and coordination actions have been taken, bad communication channels may lead to these actions reaching the operational level in a distorted form that can lead to improper interpretation of these actions by the operational units, and hence to bad implementation. These two effects of poor information channels were highlighted in experiments two and three when they caused degradation in the operational level's performance despite near optimality of all other conditions.

From some of experiment three's results we can see that the overall system was working in a viable way after the introduction of "perfect" systems two and three, and it dealt very effectively with the oscillations that were evedent at the operational level. However, after introducing assumed strong internal/external disturbances to the system (very bad planning by individual divisions, and extreme levels of external demand) we found that the viable structure could not cope. This supports the conclusion that a viable system, and at least one which is modelled on Beer's ideas can only maintain its viability within a certain context of internal and external conditions. Outside these conditions the system can not maintain itself unless dramatic changes are made or occur to its internal structure and its immediate environment.

Beer's model structure bears a high resemblance to hierarchical theory structures except that in an ordinary hierarchical structure the coordinator responsible for the coordination at the lower operational level is situated on the main command and control lines that come down from the higher management of the system. Besides his coordination activities the coordinator also undertakes control activities which are directed at the lower level. In Beer's hierarchical structure the coordination system (system two) has no control authority at all, and that is why it is not situated on the main command and control lines between the higher levels and the operational level.

Finally the results of all the simulation runs on aggregate serve to show that what we have set out to achieve - validating Stafford Beer's ideas of systems one, two and three for a typical industrial enterprise - was achieved, though only by using a hypothetical model and variables.

The use of a computer simulation model, for reasons stated earlier (see the introduction), has meant that our conclusions are necessarily limited by this kind of approach. We would not expect, of course, our model to be an exact replication of the real world, most models are simplifications to some degree, and our model is not an exception. In addition, we must emphasise that our model was built to represent a certain theory (Stafford Beer's theory) about a management situation, which in itself might not exactly represent a real life situation. However, we believe that the features of our model do posses at least a reasonable degree of relevance to the phenomena modelled, and hence, the conclusions that we drew are of high importance and benefit to anyone who is concerned about the nature of business organizational structures. We also believe that in our attempt to validate Stafford Beer's work we have met with a good degree of success, which should reflect the importance and impact of Beer's cybernetic ideas on the management of business organizations. We cannot, of course, completely validate this kind of belief, but we argue that our model was based upon the existing and well established theory in the scientific literature of management, economics and mathematics.

Also, at this point, it must be said that although we agree with Stafford Beer's basic ideas about applying his model to basic industrial systems, we have some reservations concerning Beer's declaration of the ability of his model to accommodate all kinds of viable systems in the world. We think that in many existing systems, and particularly with natural systems, it is quite difficult, if not impossible to identify which parts of the system represent Beer's systems one to five.

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APPENDIX A:

Description of the industrial dynamics model

The basic structure of the model (following industrial dynamics methodology)is represented in terms of levels interconnected by rates of flow, and a system of equations is used to describe this structure.

Basically the system of equations consists of two types of equations governing the change of levels and rates. Other types of equations such as auxiliary and initial value equations are also used to supplement the level and rate equations in describing the system's behaviour.

The system of equations controls the changing interactions of a set of variables (which we are trying to study) as time advances. This implies that the equations will be computed periodically to yield the successive new states of the system.

The continuous advance of time is broken into small intervals of equal length DT (time increment). During any DT we assume that the values of flow rates would be constant, and in this case DT should be short enough so that the non-changing rates over it would give a satisfactory approximation of continuously varying rates in actual systems.

At the end of each DT, new values of levels are calculated, and from these, new rates (decisions) are determined for the next interval, that means that rates for the incoming interval are based on present and past information.

The equations are written in terms of the time steps P, N, and F, standing for past, present (now), and future time points. At point N in time, the equations are evaluated, and here we assume that the progress has just reached time N, but that the equations have not yet been solved for levels at time N, nor for rates over the period N-F.

After evaluating the levels at time N, and the rates for the interval N-F, time is progressed. That is , the time points P, N, F, are moved ahead one time interval (DT). Point N levels just calculated are re-labeled as point P levels, the N-F period rates become P-N rates, and the entire computation sequence can then be repeated to obtain a new state of the system at a time that is one DT later than the previous state.

In general, what the model does is trace the course of the system through time, and the interactions within the system follow the description that has been set down in the equations of the model.

Initial value equations are used to initialize the computing sequence of the model from an assumed point of equilibrium.

The major activities that are represented in the model are: retailer, manufacturer, raw material, advertising, and profit calculating sections.

The retailer, manufacturer, and raw material represent the basic activities of the enterprise model (operational activities), the distributor section has been omitted for simplification purposes.

The other activities which are incorporated complement the operational activities in giving the model a total system behaviour pattern. The advertising and customer section would provide the model with the important context of outside interaction, and the profit section would serve as an indicator of system performance.

To start the evaluation sequence of the model's equations, there must be initial values for a certain number of the variables. The best way of running an industrial dynamics model of this kind, is to start from a steady state condition. Because of that steady state and the assumed equilibrium of the system, all the rates of flow in supply lines between the various sections of the model except for the profit section are going to be equal to the rate RRR (requisitions received at the retailer from customers). This rate will be given a certain value (of the experimenter's choice). The independent input rate GNC (generation of needs of customers) is also going to be supplied with a certain value.

The initial value for any level is going to equal the inflow rate into this level multiplied by the time delay in which this level is able to fulfill orders, information, material, people, or money outflow from it.

In the profit section the profit rate will not need an initial value, because it is going to be calculated as an auxiliary variable after the start of the model running.

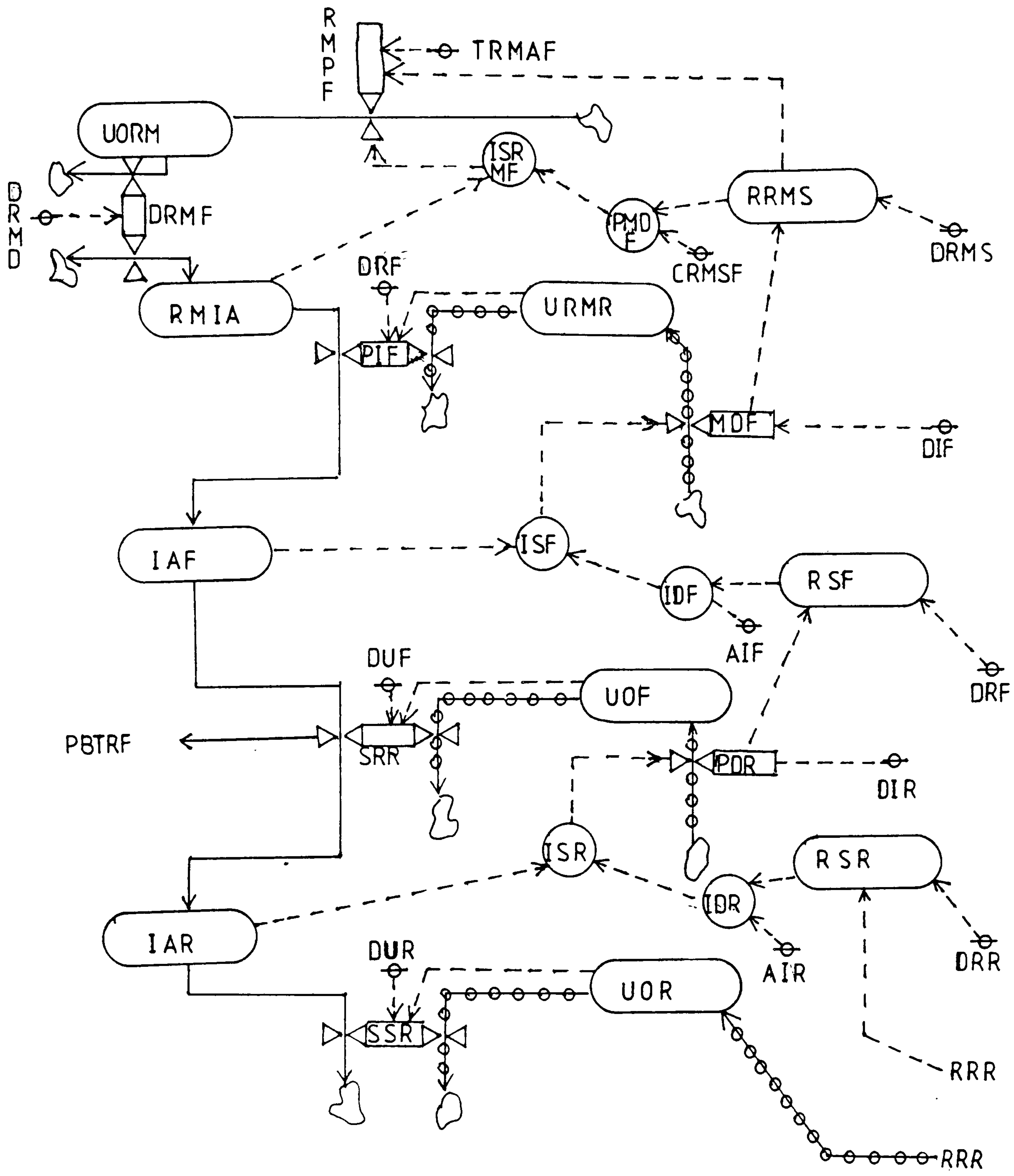

Fig.(a.1) Flow digram of the I. D. model

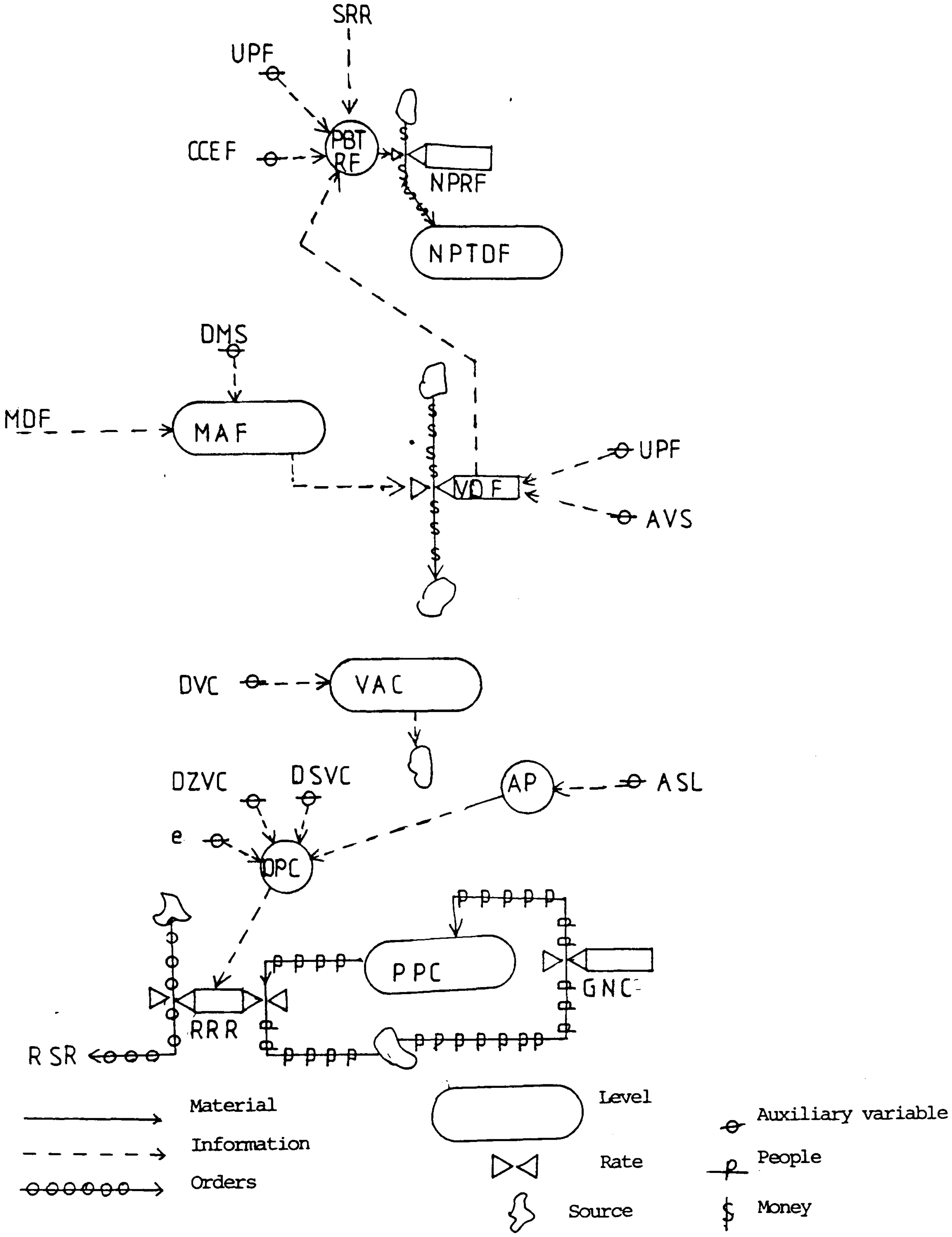
SRR
UPF
CCEF
PBT RF
NPRF
NPTDF
DMS
MDF
MAF
VDF
UPF
AVS
DVC
VAC
DZVC
DSVC
AP
ASL
e
DPC
PPC
GNC
RRR
RSR
Material
Information
Orders
Level
Rate
Source
Auxiliary variable
People
Money

Fig.(a.1) cont.

The equations of the model

The equations are going to be given section by section, and they are going to be labeled with:

L for level equations

R for rate equations

A for auxiliary equations

A dictionary of all the notation used in the equations is given at the end of the section.

Equations of the retailer section:

UOR.N = UOR.P + (DT) (RRR.PN - SSR.PN) ______________ L

RSR.N = RSR.P + (DT) 1/DRR (RRR.PN - RSR.P) __________ L

IAR.N = IAR.P + (DT) (SSR.PN - SSR.PN) _______________ L

UOF.N = UOF.P + (DT) (PDR.PN - SRR.PN) ______________ L

IDR = (AIR) (RSR.N) __________ A

ISR = IDR.P - IAR.N ____________ A

SSR.NF = UOR.N / DIR ____________ R

PDR.NF = (ISR.N / DIR) + RSR.N __________ R

Equations of the factory section:

UOF.N = UOF.P + (DT) (PDR.PN - SRR.PN) ________________ L

RSF.N = RSF.P + (DT) 1/DRF (PDR.PN - RSF.N) ____________ L

IAF.N = IAF.P + (DT) (PIF.PN - SRR.PN) _____________ L

IDF = (AIF) (RSF.N) _________ A

ISF = IDF - IAF.N _________ A

```
SRR.NF = UOF.N / DUF __________ R

MDF.NF = (ISF / DIF) + RSF.N __________ R
```

Equations of the raw materials section:

```
URMR.N = URMR.P + (DT) (MDF.PN - PIF.PN) ____________ L

RRMS.N = RRMS.P + (DT) 1/DRMS (MDF.PN - RRMS.P) ________ L

UORM.N = UORM.P + (DT) (RMPF.PN - DRMF.PN) _________ L

RMIA.N = RMIA.P + (DT) (RMPF.PN - PIF.PN) __________ L

RMDF = (RRMS.N) (CRMSF) ________ A

ISRMF = RMDF - RMIA.N ___________ A

PIF.NF = URMR.N / DPF __________ R

RMPF.NF = ISRMF / TRMAF +RRMS.N __________ R
```

Equations of the advertising and customer section:

```
MAF.N = MAF.P + (DT) 1/DMS (MDF.PN - MAF.P) _________ L

VAC.N = VAC.P + (DT) 1/DVC (VDF.PN - VAC.P) __________ L

PPC.N = PPC.P + (DT) (GNC.PN - RRR.PN) ___________ L

AP.N = VAC.N / ASL ____________ A

VDF.NF = (MAF.N) (UPF) (AVS) ___________ A

RRR.NF = PPC.N / DPC.N ____________ R

GNC.NF = (GNC.PN) (1 + CHGNC) ____________ R
```

Equations of the profit section:

```
PBTRF = (SRR.PN) (UPF) - (CCEF + VDF.PN) ___________ A

NPRF.NF = 0.6 (PBTRF) ___________ R
```

Dictionary of the notation used:

Levels of the model

UOR : unfilled orders (requisitions) at retailer.

RSR : requisitions smoothed at retailer.

IAR : inventory actual at retailer.

UOF : unfilled orders at factory.

RSF : requisitions smoothed at factory.

IAF : inventory actual at factory.

RRMS : requisitions of raw materials smoothed.

UORM: unfilled orders of raw materials at outside supplier.

RMIA : raw materials inventory actual.

PPC: pool of prospective customers.

VAC : advertising awarness at customers.

MAF : manufacturing average rate at factory.

URMR : unfilled requisitions of raw materials .

Rates of the model

SSR : shipments of items sent from retailer to customers.

PDR : purchasing decision at retailer.

SRR : shipments of items received at retailer.

MDF : manufacturing decision at factory.

PIF : production rate for inventory at factory.

RMPF : raw materials purchase decision at factory.

DRMF : delivery of raw materials to factory.

RRR : requisitions received at retailer from customers.

GNC: generation of needs at customers.

VDF : advertising decision at factory.

NPRF : net profit rate at factory.

Auxiliary variables

AP: advertising pressure.

DP: delay in purchasing at customers.

IDR : inventory desired at retailer.

ISR : inventory shortage at retailer.

IDF : inventory desired at factory.

ISF : inventory shortage at factory.

RMDF : raw materials inventory desired at factory.

ISRMF : inventory shortage of raw materials at factory.

PBTRF : profit before tax rate at factory.

Parameters (constants) of the model

DT : time increment constant.

DUR : delay in fulfilling unfilled requisitions at retailer.

DRR : delay in smoothing requisitions at retailer.

DIR : delay in inventory adjustment process at retailer.

AIR : time in which the inventory desired at retailer is able to fulfill requisitions from customers.

DUF : delay in fulfilling unfilled requisitions at factory.

DRF : delay in smoothing requisitions at factory.

DPF : delay in production at factory.
DIF : delay in inventory adjustment at factory.
AIF : time in which the inventory desired at factory is able to fulfill requisitions from retailer.
AVS : advertising fraction of sales.
DV: delay in advertising awareness buildup at customers.
DZV : delay for zero advertising.
DSV : delay for saturated advertising.
CRMSF : time in which the inventory desired of raw materials at factory is able to fulfill production needs at factory.
TRMAF : delay in inventory adjustment of raw materials.
DRMD : delay in raw materials delivery to factory from supplier

DRMS : delay in smoothing requisitions at raw materials.
DMS : delay in manufacturing average rate smoothing.
UPF : unit price at factory.
CCEF : constant cash expenditurs rate at factory.

Program listing for I. D. model in section 4.7

```
c  The program simulates a commodity manufacturer_
c retailer model based on industrial dynamics methodology.
c The results show the effects of change in customers'
c need for this commodity on the behaviuor of the model's
c components
c
c
c
      integer time
c
c
      dimension uor(400),rsr(400),ziar(400),uof(400),rsf(400),
&               ziaf(400),urmr(400),rrms(400),uorm(400),rmia(40,0),

&               ppc(400),vac(400),zmaf(400),ssr(400),
c
c
&            pdr(400),srr(400),zmdf(400),pif(400),rmpf(400),
&            drmf(400),rrr(400),gnc(400),vdf(400),znprf(400),
c
&            ap(400),dpc(400),time(400),chgnc(400)
c
c
c
c  read values of chgnc
c
      do 1005 i = 1,400
      1005 read (90,,end = 111)chgnc(i)
c
c
c  parameters (constants) of the model
c
 111  dt = 0.5
      drr = 8.0
      dir = 4.0
      dur = 1.0
      air = 6.0
      duf = 1.0
      drf = 8.0
      dpf = 4.0
      drms = 8.0
      dif = 4.0
      aif = 4.0
      trmaf = 4.0
      crmsf = 4.0
      drmd = 3.0
      upf = 100.0
      avs = 0.06
      dms = 4.0
      dvc = 6.0
      dzv = 60.
```

```
      dsv = 15.0
      ccef = 5000.0
      asl = 600.0
c
c
c  initial conditions of the model
c
      uor(1) = dur*100.0
      rsr(1) = 100.0
      ziar(1) = air*100.0
      ssr(1) = 100.0
      pdr(1) = 100.0
      srr(1) = 100.0
      uof(1) = duf*100.0
      rsf(1) = 100.0
      ziaf(1) = aif*100.0
      zmdf(1) = 100.0
      urmr(1) = dpf*100.0
      pif(1) = 100.0
      rrms(1) = 100.0
      rrr(1) = 100.0
      zmaf(1) = pdr(1)
      vdf(1) = zmaf(1)*upf*avs
      vac(1) = vdf(1)
      ap(1) = vac(1)/asl
      dpc(1) = dsv+((dzv-dsv)*exp(-ap(1)))
      ppc(1) = rrr(1)*dpc(1)
      gnc(1) = 100.0
      rmpf(1) = 100.0
      rmia(1) = pdr(1)*crmsf
      uorm(1) = drmd*100.0
      drmf(1) = 100.0
      time(1) = 1
c
c
c  time increment loop
c
      do 10 i = 1,400
      j = i+1
      time(j) = time(i)+1
c
c
c  level equations of the model
c
c
      uor(j) = uor(i)+dt*(rrr(i)-ssr(i))
      rsr(j) = rsr(i)+(dt/drr)*(rrr(i)-rsr(i))
      ziar(j) = ziar(i)+dt*(srr(i)-ssr(i))
      uof(j) = uof(i)+dt*(pdr(i)-srr(i))
      rsf(j) = rsf(i)+(dt/drf)*(pdr(i)-rsf(i))
      ziaf(j) = ziaf(i)+dt*(pif(i)-srr(i))
      urmr(j) = urmr(i)+dt*(zmdf(i)-pif(i))
      rrms(j) = rrms(i)+(dt/drms)*(zmdf(i)-rrms(i))
```

```
      uorm(j) = uorm(i)+dt*(rmpf(i)-drmf(i))
      rmia(j) = rmia(i)+dt*(rmpf(i)-pif(i))
      zmaf(j) = zmaf(i)+(dt/dms)*(zmdf(i)-zmaf(i))
      vac(j) = vac(i)+(dt/dvc)*(vdf(i)-vac(i))
      ppc(j) = ppc(i)+dt*(gnc(i)-rrr(i))
c
c
c
c
c  auxiliary equations of the model
c
c
      zidr = air*rsr(j)
      zisr = zidr-ziar(j)
      zidf = aif*rsf(j)
      zisf = zidf-ziaf(j)
      rmdf = rrms(j)*crmsf
      isrmf = rmdf-rmia(j)
      ap(j) = vac(j)/asl
      dpc(j) = dsv+((dzv-dsv)*exp(-ap(j)))
      pbtrf = srr(i)*upf-(ccef+vdf(i))
c
c
c
c
c  rate equations of the model
c
      ssr(j) = uor(j)/dur
      pdr(j) = (zisr/dir)+rsr(j)
      srr(j) = uof(j)/duf
      zmdf(j) = (zisf/dif)+rsf(j)
      pif(j) = urmr(j)/dpf
      rmpf(j) = isrmf/trmaf+rrms(j)
      drmf(j) = uorm(j)/drmd
      vdf(j) = zmaf(j)*avs*upf
      rrr(j) = ppc(j)/dpc(j)
      znprf(i) = 0.6*(pbtrf)*0.1
      gnc(j) = gnc(1)*(1+chgnc(i))
      10 continue
c
c
c
c
c
c  printing  obtained values of levels and rates for
c  the whole simulation time
c
      do 50 k = 1,400
      write (52,60) time(k),ziar(k),ziaf(k),uof(k),
&     zmaf(k),uor(k)
 60   format (2x,i10,2x,f10.3,2x,f10.3,2x,f10.3,2x,
&        f10.3,2x,f10.3)
      write (53,70) time(k),ssr(k),zmdf(k),pif(k),
```

```
&      pdr(k),rrr(k)
 70    format (2x,i10,2x,f10.3,2x,f10.3,2x,f10.3,2x,
&         f10.3,2x,f10.3)
 50    continue
       call exit
       end
```

APPENDIX B:

Program listing for model in section 4.8

```
c The program simulates a manufactring inventory system
c to highlight the importance of changes in policies
c and lead times on system behaviour.
c
c
c read values of
c
 1    read (40,,end = 111) n,ir,iw,lw,lf
 111  if (ir) 2,2,3
 2    a = 1.0
      go to 4
 3    a = ir/100.0
 4    if (iw) 5,5,6
 5    b = 1.0
      go to 7
 6    b = iw/100.0
 7    ri = 100.0
      ro = 100.0
      ws = 100.0
      wi = 200.0
      wo2 = 100.0
      wo1 = 100.0
      fr = 100.0
      write (54,29)
      write (54,30)
c
c start of loop for weekly computations
c
      do 24 i = 1,n
      read (20,,end = 222) kweek,sales
 222  if (i-kweek) 8,9,8
 8    write (54,32)
      go to 25
c
c compute retailer inventory level and order
c
 9    rrec = ws
      rinv = ri+rrec-sales
      if (rinv) 10,10,11
 10   rinv = 0.0
 11   rord = sales+((100.0-rinv) * a)
      if (rord) 12,12,13
 12   rord = 0.0
 13   if (lw-1) 15,14,15
 14   wship = rord
```

```
      go. to 16
 15   wship = ro
c
c compute distributor inventory level and order
c
 16   wrec = fr
      winv = wi+wrec-wship
      if (winv) 17,17,18
 17   winv = 0.0
 18   word = wship+((200.0-winv) * b)
      if (word) 19,19,20
 19   word = 0.0
 20   if (lf-1) 22,21,22
 21   frate = wol
      go to 23
 22   frate = wo2
c
c print results of current week
c
 23   write (54,33) i,sales,rrec,rinv,rord,wship,wrec,
&     winv,word,frate
c
c update next week ordering and factory rate
c
      ri = rinv
      ro = rord
      ws = wship
      wl = winv
      wo2 = wol
      wol = word
      fr = frate
 24   continue
 25   continue
 29   format (3x,'week',16x,'retailer',12x,'distributer'
&     ,8x,'factory')
 30   format (3x,'no.',5x,'sales  rec',5x,'inv',3x,'order'
&     ,3x,'ship',5x,'rec',3x,'inv',3x,'order',3x,'rate')
 32   format ('wrong data')
 33   format (2x,i2,7x,4f6.0,2x,f7.0,3x,3f6.0,2x,f7.0)
      call exit
      end
```

APPENDIX C:

Description of simple inventory model simulation flow chart

In fig. (c.1) below the initial conditions are set in block one; inventory on hand = Q, amount due in = zero, time due in = zero, and t=1 where t=1,2,3,....,50. When block two is reached, the answer is NO, and the process proceeds to block four to generate a random value of demand (d) for period (week) one. At the end of period one, inventory on hand is diminished by (d), unless (d) exceeds the amount available, in which case the amount of inventory on hand becomes zero. This calculation is preformed at block five. At block six, a test is made to determine whether a replenishment order Q is to be placed. If so the amount due in becomes Q and after a value for lead time is generated at block seven, time due in becomes t+1. If a replenishment order is not placed, the process proceeds directly to block nine, where time would be incremented by one time period, and the process returns to block two. The simulation run continues until t=50, where it terminates.

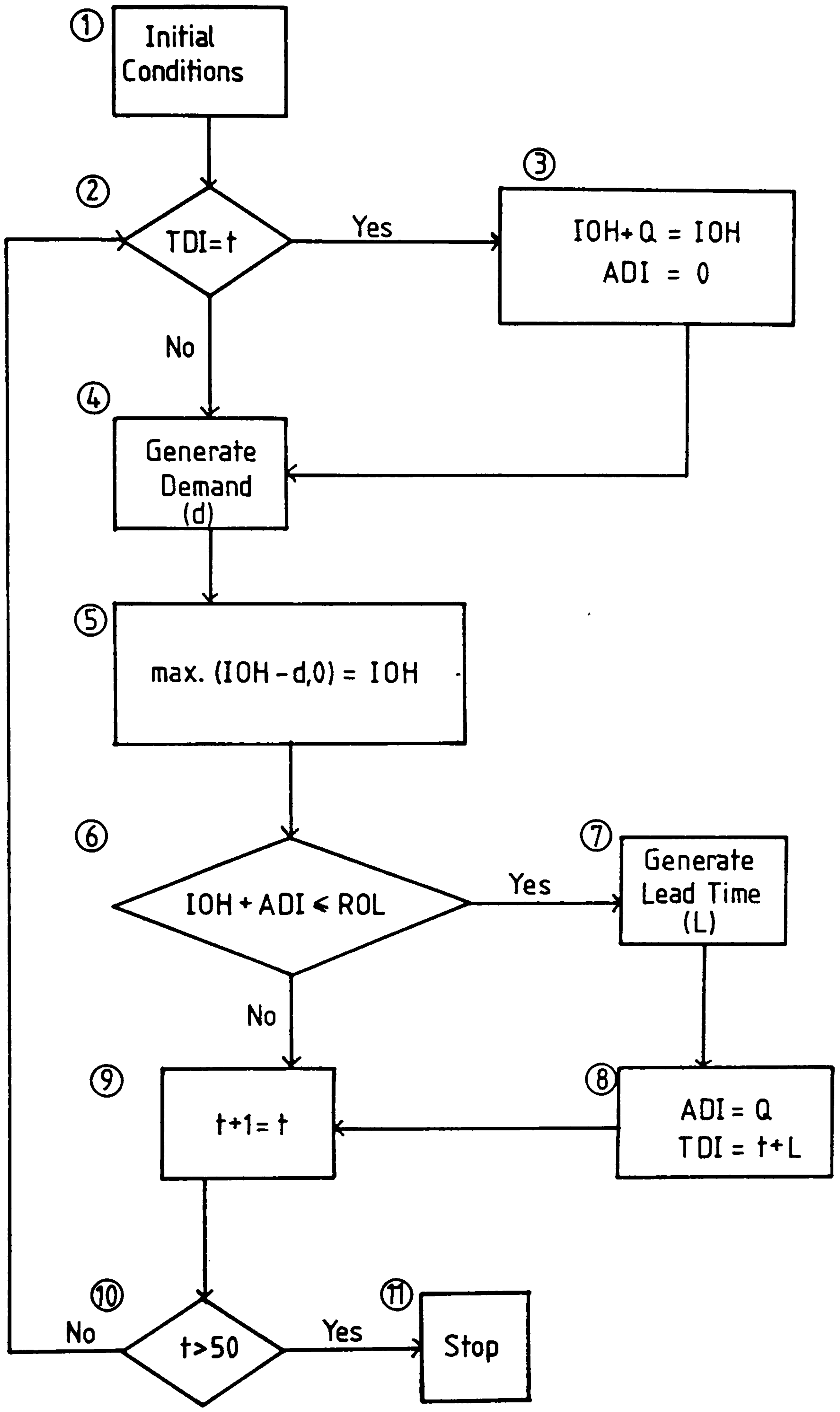

Fig.(c.1) Flow chart of simple fixed reorder level, fixed quantity inventory system

Extra characteristics of the model

The model's flow chart only shows the basic sequence of the simulation and does not indicate where to collect statistical data on the operating chracteristics of the system (which we consider of major importance in this simulation). In the computer program of the model, we could (and would) extract any kind of statistical data we require. For example, we can keep a tally at block five of the level of inventory on hand at the end of each period, as well as of the number of stock outs. Other data such as the numbers of reorders can also be calculated, and then all the data can be summarized into frequency distributions along with their means, standard deviations and other statistical quantities of interest. The model also calculates the major costs associated with inventory keeping which are: holding cost, re-order cost, and stockout cost together with the total cost, and this enables the observer to conduct experiments with different cost parameters, and compare the changes in the outcome of different cases.

The model's computer program output also supplies data of both demand and inventory on hand values for each period (week) in the simulation, which can be used to produce a graphical representation of the demand and inventory situation during the simulation run.

Program listing for the inventory model in section 5.2.

```
c The program simulates a reorder level policy
c inventory model for the duration of 50 weeks, with
c demand and lead time being randomly generated. The
c program also calculates the three major inventory
c costs; holding cost, stockout cost, and reorder cost
c as well as the total cost
c
c
      dimension d(60),l(60)
      common d,l
      integer h,q,rol,ioh,adi,tdi,t,y,z,d,l,arq,
&     aaih,tad,x,arc,atsc
c
c
c   read values of inventory policy prameters
c
      read (22,,end = 111) h,q,rol,ioh
c
 111  adi = 0
      tdi = 0
      nso = 0
      arq = 0
      nro = 0
      aaih = 0
      tad = 0
c
c   read values of inventory costs
c
      read (42,,end = 222) hc,rc,sc
c
c
c   generation of demand and lead time values by
c   subroutines
c
 222  call demand
      call  lead
c
      t = 1
      i = 1
c
c   print values of demand and inventory status
c
      write (0,100)
      write (0,110)
 5    if (tdi.ne.t) go to 10
      ioh = ioh+q
      arq = arq+q
      adi = 0
```

```
 10    y = ioh-d(i)
       if (y.gt.0) go to 20
       ioh = 0
       nso = nso+1
       go to 30
 20    ioh = y
 30    x = ioh+adi
       if (x.gt.rol) go to 40
       adi = q
       nro = nro+1
       tdi = t+l(i)
 40    write (0,120) t,d(i),ioh
       write (55,300) t,d(i),ioh
       t = t+1
       if (t.gt.h) go to 50
       aaih = aaih+ioh
       tad = tad+d(i)
       i = i+1
       go to 5
 50    aasl = aaih/50.0
       aahc = aasl/hc
       arc = nro*rc
       atsc = nso*sc
       atioc = atsc+aahc+arc
c
c  print results for the whole simulation run
c
       write (10,150)
       write (10,200) tad
       write (10,210) arq
       write (10,220) aasl
       write (10,230) nro
       write (10,240) nso
       write (10,260) aahc
       write (10,270) arc
       write (10,280) atsc
       write (10,290) atioc
c
c
 100   format (5x,'period',7x,'demand per',7x,
&       'inventory')
 110   format (20x,'week',12x,'on hand')
 120   format (7x,i3,8x,i6,12x,i6)
 150   format (//)
 200   format (5x,'Total annual demand :',i6/)
 210   format (5x,'Annual rep. quantity :',i6/)
 220   format (5x,'Average annual stock level :
&      ',f7.2/)
 230   format (5x,'Number of rep. orders :',i2/)
 240   format (5x,'Number of stockouts :',i2/)
 260   format (5x,'average annual holding cost :
&      ,'f7.2/)
 270   format (5x,'annual replenishment cost :
```

```
&     ,'i6/)
 280  format (5x,'annual total stockout cost :
&     ,'i6/)
 290  format (5x,'annual total inventory operating cost :
&     ,'f7.2)
 300  format (i3,5x,i6,5x,i6)
      call exit
      end

      subroutine demand
      common d,l
      integer d
      dimension d(60),l(60)
      nr = 1111
      it = 1
      ir =-91
      ix = 200*it+ir
      do 10 i = 1,50
      irn = ix*nr/10000
      nr = ix*nr-irn*10000
      if ( nr.gt.0.and.nr.lt.1001) go to 1
      if (nr.gt.1000.and.nr.lt.4001) go to 2
      if (nr.gt.4000.and.nr.lt.7001) go to 3
      if (nr.gt.7000.and.nr.lt.9001) go to 4
      if (nr.gt.9000.and.nr.lt.9501) go to 5
      if (nr.gt.9500) go to 6
 1    d(i) = (((nr-0)/1000.) * 100)+0
      go to 10
 2    d(i) = (((nr-1000.)/3000.) * 100)+100
      go to 10
 3    d(i) = (((nr-4000.)/3000.) * 100)+200
      go to 10
 4    d(i) = (((nr-7000.)/2000.) * 100)+300
      go to 10
 5    d(i) = (((nr-9000.)/500.) *100)+400
      go to 10
 6    d(i) = (((nr-9500.)/500.) * 100)+500
 10   continue
      return
      end

      subroutine lead
      common d,l
      integer l
      dimension l(60),d(60)
      nr = 6123
      it = 6
      ir =-91
      ix = 200*it+ir
      do 20 i = 1,50
      irn = ix*nr/10000
      nr = ix*nr-irn*10000
      if (nr.gt.0.and.nr.lt.501) go to 1
```

```
      if (nr.gt.500.and.nr.lt.1001) go to 2
      if (nr.gt.1000.and.nr.lt.4001) go to 3
      if (nr.gt.4000.and.nr.lt.8501) go to 4
      if (nr.gt.8500.and.nr.lt.9501) go to 5
      if (nr.gt.9500) go to 6
1     l(i) = 1
      go to 20
2     l(i) = 2
      go to 20
3     l(i) = 3
      go to 20
4     l(i) = 4
      go to 20
5     l(i) = 5
      go to 20
6     l(i) = 6
20    continue
      return
      end
```

the input data:

```
 50 800 350 200

 6 100 100 4
```

the program output:

```
     period        demand per        inventory
                     week             on hand
        1            103                97
        2            558               339
        3            310                29
        4            295                 0
        5            396               404
        6            211               193
        7            208                 0
        8            207                 0
        9            105               695
       10            375               320
       11            334                 0
       12            438                 0
       13            127                 0
       14            363               437
       15            117               320
       16            337                 0
       17            228                 0
       18            526                 0
       19            555               245
       20            263                 0
       21            209                 0
       22            379                 0
       23            280               520
       24            534                 0
```

```
    25          204          0
    26          105          0
    27          248          0
    28          234        566
    29          368        198
    30          177         21
    31           89          0
    32          349          0
    33          100        700
    34          102        598
    35          291        307
    36          218         89
    37          268          0
    38           43          0
    39          299          0
    40           71        729
    41          324        405
    42          319         86
    43          253          0
    44          149          0
    45          467          0
    46          347        453
    47          288        165
    48          261          0
    49          252          0
    50          355        445


Total annual demand : 13284

Annual rep. quantity :  8800

Average annual stock level : 158.32

Number of rep. orders :11

Number of stockouts :26

average annual holding cost :  26.39

annual replenishment cost :  1100

annual total stockout cost :  2600

annual total inventory operating cost :3726.39
```

APPENDIX D:

Calculation of minimum total cost for inventory decision model in section 5.3

To minimize the total annual inventory cost, the manager has to determine the optimal reorder level ROL (when to order), and the optimal order quantity Q (how much to order). In this process the manager is faced with the following argument; if the order quantity is large as opposed to small, fewer orders would be placed and fewer stockouts would occur (smaller stokout cost), since a stockout can occur only during lead time, and there would be fewer lead times; however, more inventory would need to be carried, which would increase the annual inventory holding cost. On the other hand, with smaller order quantities, the inventory cost would decrease but the stockout cost would increase, since more stockouts would occur (more orders would be placed). As the reorder level increases, more orders are received when the inventory level is above zero, which implies that the average inventory level increases and the stockouts decrease. It is exactly the converse when the reorder level decreases. Thus the total annual inventory cost is a function of both the reorder quantity and the reorder level, and the manager has to simultaneously determine both of them to minimize the total annual inventory cost (Bestwick 1979, Edward 1981).

Since ROL and Q are both functions of demand and lead time, which are random variables, the manager should be satisfied to determine a ROL and Q that would minimize the expected total annual inventory cost (Erhardt 1984).

The total expected annual inventory cost ETAIC(ROL,Q) can be expressed as the sum of three costs:

ETAIC(ROL,Q) = AOC + EASC + EAIHC

AOC = Annual order cost

= Order cost * expected annual demand/Q

EASC = Expected annual stockout cost

= Stockout cost * Expected annual demand/Q

* Expected number of stockouts/cycle

To determine the expected number of stockouts/cycle ENS, note that a stockout occurs only when the demand during lead time is greater than ROL. Thus ENS is a function of ROL.

$$\mathrm{ENS(ROL)} = \sum_{y=\mathrm{ROL}}^{\infty} (y - \mathrm{ROL})\ h(y)$$

$$= \sum_{y=\mathrm{ROL}}^{\infty} (y - \mathrm{ROL})\ P(Y = y)$$

Where Y is demand during lead time and h(y) is the probability distribution of demand during lead time.

EAIHC = Expected annual inventory holding cost.

= Holding cost * expected inventory level/cycle.

To determine the expected inventory level/cycle, note that the expected inventory level/cycle would be ROL + Q/2 if lead time was zero. That is suppose Q units are ordered and received immediatly when the inventory level reaches ROL. The average inventory level would consist of ROL units plus one-half of what is ordered each time. Since lead time is not zero, but a random variable, demand for the product during lead time may occur, so the expected inventory level will be reduced by an amount equal to the expected demand during lead time (ray 1982, Sphices 1982).

$$EVI(ROL,Q) = ROL + \frac{Q}{2} - E(Y)$$

The equation for the expected annual inventory cost ETAIC(ROL,Q) can be represented as:

$$ETAIC(ROL,Q) = ORC * \frac{D}{Q} + SOC * \frac{D}{Q} \left[\sum_{y=ROL}^{\infty} (y - ROL) \; P(Y=y) \right]$$

$$+ HC \left[ROL + \frac{Q}{2} - E(Y) \right]$$

Calculating the optimal ROL and Q

To find the optimal ROL and Q, we follow the following procedure:

Take the partial derivative of ETAIC(ROL,Q) with respect to ROL and Q, set the results equal to zero, and solve the resulting equations iteratively until convergence is achieved.

$$P(Y>ROL) = 1 - H(ROL) = \frac{HC * Q}{SOC * D} \qquad (1)$$

$$Q = \sqrt{2(ORC * D + SOC * D\,[ENS(ROL)])\,/HC} \qquad (2)$$

The optimal values of ROL and Q must satisfy equations (1) and (2) simultaneously. Since ROL and Q are integers when demand is a discrete random variable, equations (1) and (2) cannot be satisfied exactly (Taha 1980, Bestwick 1979).

The optimal ROL and Q values must be such that the probability that the demand during lead time is greater than ROL is (HC.Q/SOC.D). This assumes HC.Q less than or equal to SOC.Q since the quotient (HC.Q/SOC.D) represents a probability.

The algorithm for the calculation of optimal Q and optimal ROL follows the following steps:

1- Read in the probability distribution of demand during lead time.

2- Calculate the cumultive distribution of demand during lead time from the probability distribution.

3- Calculate the expected demand during lead time.

$$E(Y) = \sum_{y=0}^{M} yh(y) = \sum_{y=0}^{M} y\ P(Y= y)$$

where M is the maximum demand during lead time.

4- Calculate the expected number of stockouts for ROL=1,4,3,....,M.

$$ENS(ROL) = \sum_{y=ROL}^{M} (y-ROL)\ h(y)$$

$$= \sum_{y=ROL}^{M} (y-ROL)\ P(Y=y)$$

5- Calculate the probability that the demand during lead time will exceed the reorder level ROL, for ROL=1,2,3,...,M. That is calculate $P(Y > ROL)$.

6- Let ROL=M, then the expected number of stockouts ENS(ROL) will be zero.

7- Calculate $Q = \sqrt{2D\ (ORC + SOC\ [\ ENS(ROL)\ ])\ /HC}$.

8- Let Q1 be the largest integer less than or equal Q.

9- Calculate $C = \dfrac{HC * Q1}{SOC * D}$.

10- Let ROL1 be the smalest integer value of Z such that P(Y > Z) less than or equal to C.

11- If ROL1 is equal to ROL, go to step 10; otherwise, set ROL=ROL1 and return to step 5. If the process does not converge in 50 iterations, go to step 10.

12- The integers ROL1 and Q1 are only approximations of the continous optimal values, so calculate ETAIC(ROL,Q) for ROL=ROL1-1, ROL1, ROL1+1 and Q=Q1-1, Q1, Q1+1. This will assure that the minimum ETAIC is attained and chosen.

In the case that the distribution of demand during lead time is not supplied, it can be calculated from the distributions of demand and lead time which are usually available (Cham 1982).

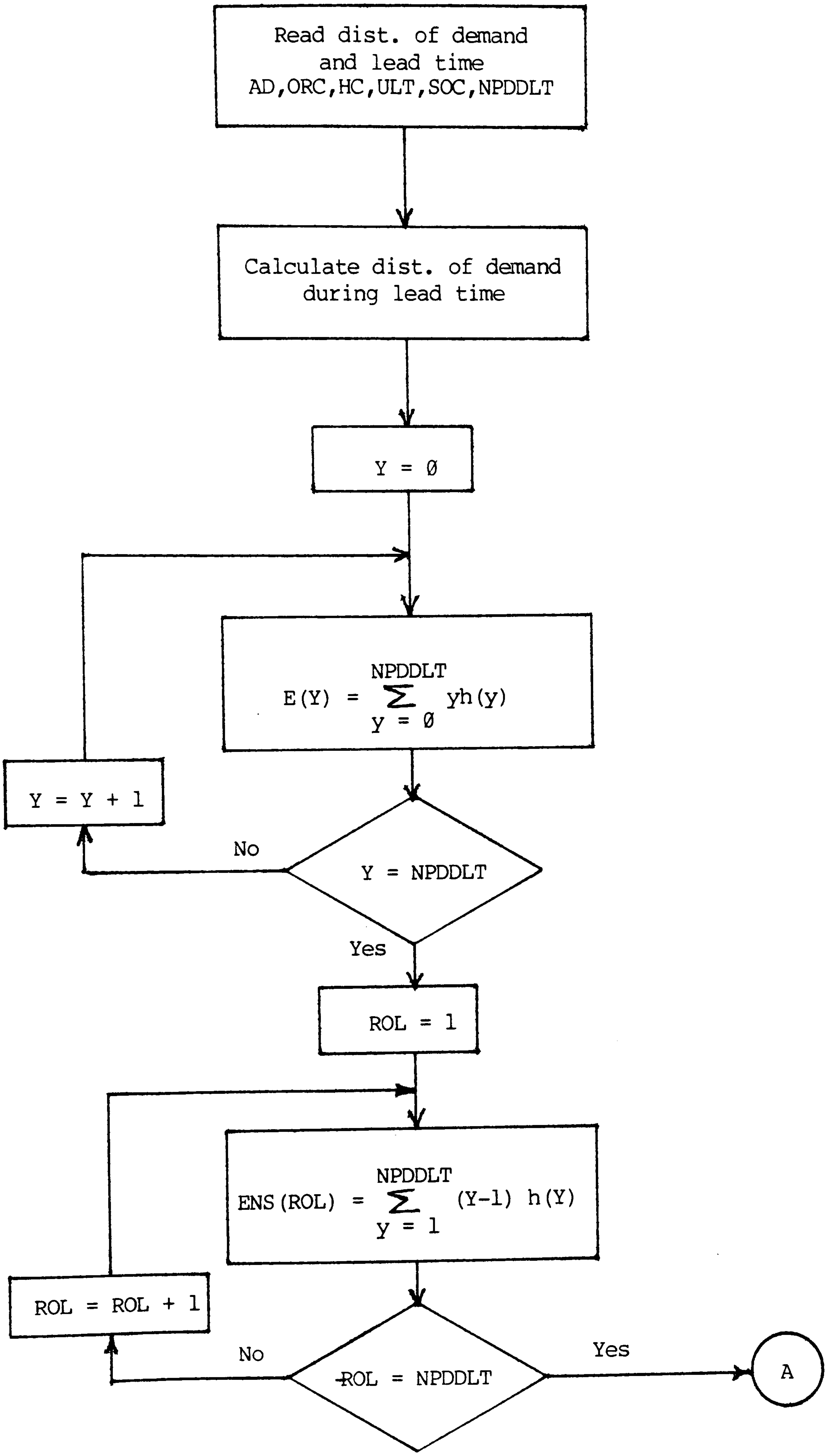

Fig.(d.1) Flowchart for model in section 5.3
(optimal Q, ROL)

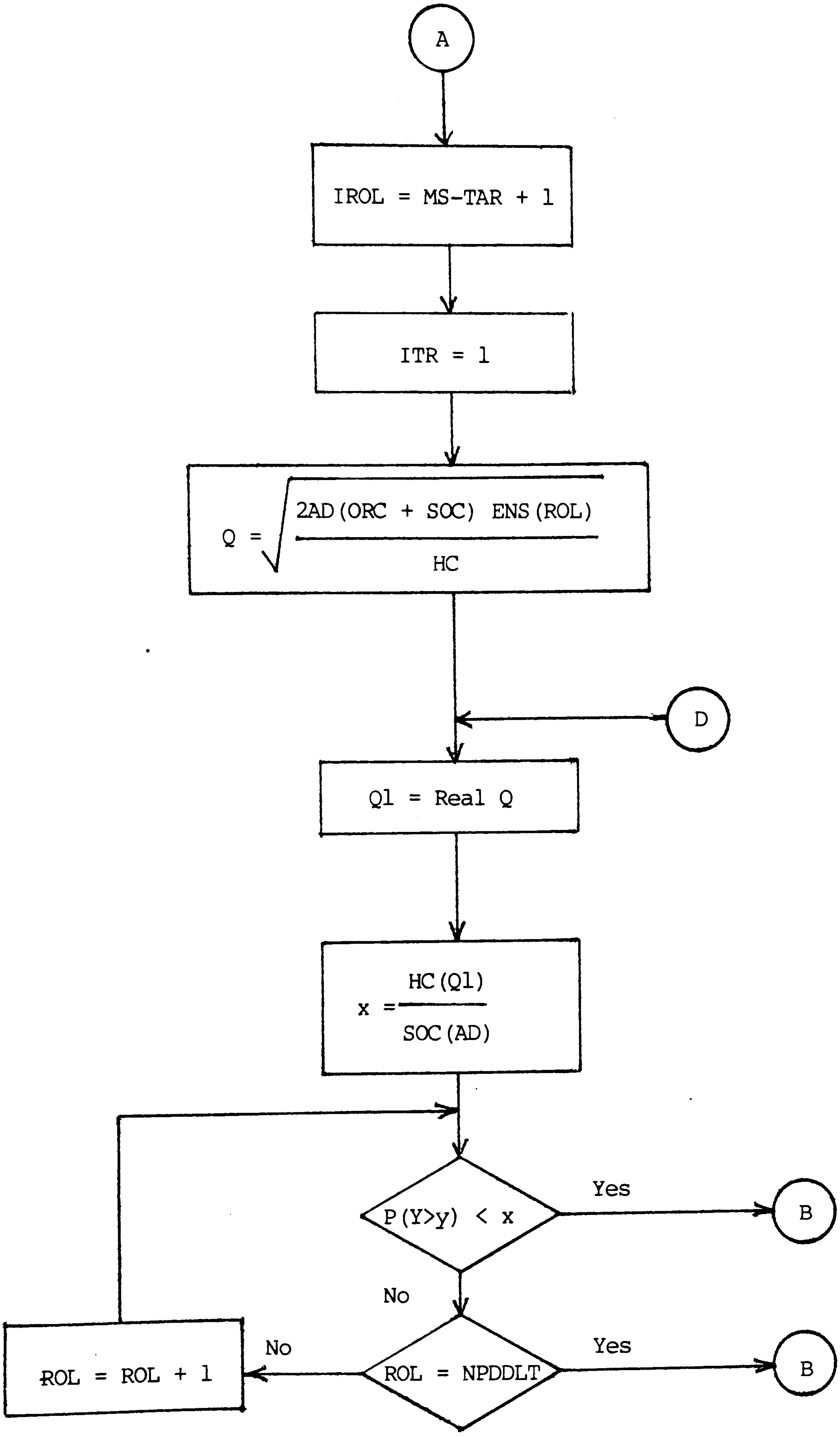
A
IROL = MS-TAR + 1
ITR = 1
$Q = \sqrt{\frac{2AD(ORC + SOC)\ ENS(ROL)}{HC}}$
D
Q1 = Real Q
$x = \frac{HC(Q1)}{SOC(AD)}$
P(Y>y) < x
Yes
B
No
ROL = NPDDLT
Yes
B
No
ROL = ROL + 1

Fig.(d.1) Cont.

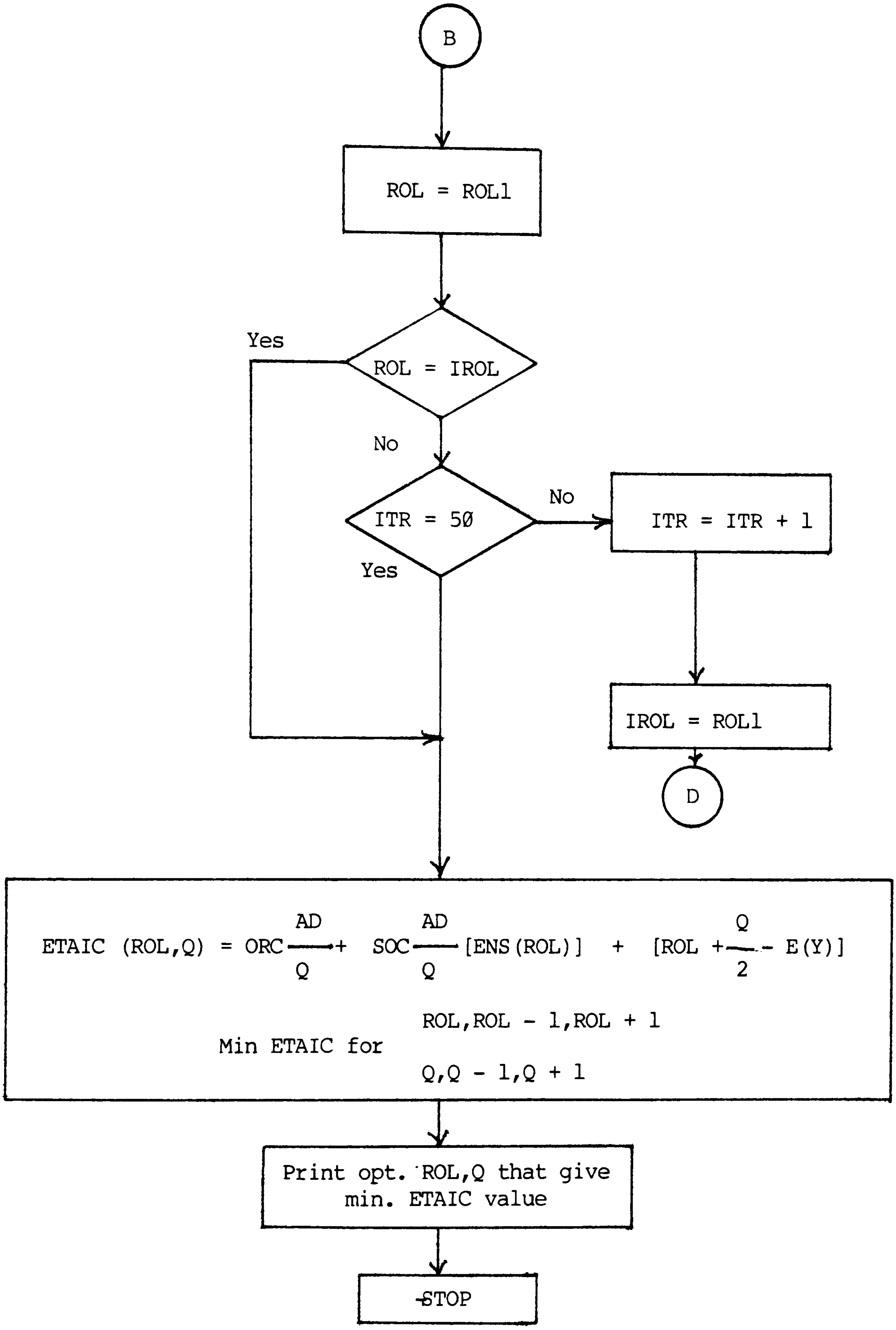
B
ROL = ROL1
Yes
ROL = IROL
No
ITR = 50
No
ITR = ITR + 1
Yes
IROL = ROL1
D
ETAIC (ROL,Q) = ORC AD/Q + SOC AD/Q [ENS(ROL)] + [ROL + Q/2 - E(Y)]
Min ETAIC for
ROL,ROL - 1,ROL + 1
Q,Q - 1,Q + 1
Print opt. ROL,Q that give min. ETAIC value
STOP

Fig.(d.1) Cont.

Program listing for inventory decision model in section 5.3.

```
c  The program calculates The optimal order quantity and
c  reorder level for a multi_period inventory model with
c  probabilistic demand, lead time and demand during lead time
c
c
      integer ql,rol,roll,c,e,d,dlt,t
c
c
      dimension eatc(30,30),pdltgrol(50),cddlt(50),
&          dlt(50),kdlt(50),pdd(20),cdd(20),pdlt(20),
&          lt(20),klt(20),d(20),cdlt(20),ens(20),
&           pddlt(20)
c
c
c
      read (44,,end = 11) orc,soc,hc,ad,npddlt
 11   spdlt = 0
      do 100 k = 1,npddlt
      read (56,,end = 111) pddlt(k)
      spdlt = spdlt+pddlt(i)
      cddlt(i) = spdlt
 100  continue
c
c
c  calculate expectet demand during lead time
c
 111  edlt = 0
      do 150 k = 1,npddlt
 150  edlt = edlt+(k-1)*pddlt(k)
c
c  calculate expected number of stock_outs
c
      do 200 rol = 1,npddlt
      ens(rol) = 0
      do 200 k = rol,npddlt
      ens(rol) = ens(rol)+(k-rol)*pddlt(k)
 200  continue
c
c  calculate the probability that demand during lead
c  time will exceed the re_order level
c
      do 300 rol = 1,npddlt
 300  pdltgrol(rol) = 1.0-cddlt(rol)
c
c  initialize re_order level at maximum demand during
c  lead time
c
      irol = npddlt
```

```
      itr = 1
c
c  calculate the re_order quantity from the given
c  re_order level
c
 350  q = sqrt(( 2*ad*(orc+soc*ens(irol)))/hc)
      ql = q
c
c  calculate the optimal re_order level from the given
c  re_order quantity
c
      x = (hc*ql)/(soc*ad)
      do 400 rol = 1,npddlt
      if (pdltgrol(rol).le.x) go to 410
 400  continue
 410  roll = rol
c
c  check to see if convergence has been obtained
c
      if (roll.eq.irol) go to 500
      if (itr.eq.50) go to 500
      itr = itr+1
      irol = roll
      go to 350
c
c
c  based on the approximate optimal q amd rol, calculate
c the actual optimal Q and actual optimal ROL by
c examining the expected total annual cost at points
c aorund the approximate optimal Q and ROL
c
 500  do 700 i = 1,3
      c = ql-2+i
      do 600 j = 1,3
      e = roll-2+j
      eatc(c,e) = orc*(ad/c)+soc*(ad/c)+ens(e)+hc*(e+c/
&     2.0-edlt)
      if (i.gt.1.and.j.gt.1) go to 550
      f = eatc(c,e)
 550  if (eatc(c,e).gt.f) go to 600
      f = eatc(c,e)
 600  continue
 700  continue
c
c
      write (52,800) c
 800  format ('the optimal number to order is',4x,i6)
      write (52,900) e
 900  format ('the optimal re_order level is',4x,i6)
      write (53,1000)ql
 1000 format (i6)
      call exit
      end
```

the program input data:

```
 20.0 50.0 15.0 60 5

 0.15
 0.20
 0.30
 0.20
 0.15
```

the program output:

```
 the optimal number to order is        13
 the optimal re_order level is         7
```

APPENDIX E:

Description of the model's dynamic programing method used for production scheduling in section 5.4

Given a certain demand profile (through forcasting , based on past data, or on experimentation data for simulation purposes) for the N coming periods, the production manager would have to determine the amount to produce at the start of each period.

To illustrate the method used, take as an example the table below of demands for six periods.

period,i	demand,di
1	8
2	4
3	6
4	2
5	10
6	4

The dynamic programing approach (Crutu 1971, Demardo 1982, Wagner 1980) assumes that the process has reached the start of period n, with a certain amount of inventory K, and since the inventory should be zero at the end of this period we let fn(K), which is the minimum policy cost for the nth period be:

$$fn(K)=0 \qquad \text{for } K=dn$$

or

$$fn(K)=20 + 5(dn-K) \quad \text{for } K=0,1,2,\ldots.,dn-1$$

where:

dn: The demand at period N

K: Ending inventory

The cost is zero when K=dn because there is no production cost, and no holding cost. Also let Xn(K), which is the optimum number to produce at the start of period n when the entering inventory is K be:

$$Xn(K)=0 \qquad \text{for } K=dn$$

or

$$Xn(K)=dn-K \qquad \text{for } K=0,1,2,\ldots.,dn-1$$

Since the ending inventory for period n should be zero, the entering inventory for the same period can only take the values of 0,1,2,3,4 (see demand table). So if the entering inventory for period n is K, then 4-K units should be produced for use during the nth period. This is illustrated in the following table:

K	f6(K)	X6(K)
0	40	4
1	35	3
2	30	2
3	25	1
4	0	0

let:

PCi (j) = cost to produce j units during any period

= 0 for j=0

or

= 20 + 5j for j=1,2,...

where i=1,2,3,..,n

EICi(j)= cost of j units of ending inventory during period i

= j for j=1,2,... and i=1,2,..,n

Now we backup to the start of the fifth period, and assume that periods five and six are the only ones under consideration. The problem now is to determine the number of units to produce at the start of period five to minimize the total production and inventory cost over the periods five and six. So if the fifth period is entered with an amount of inventory K, the maximum amount that can be produced in order to have zero inventory at the end of the sixth (last) period is the sum of demands for the periods five and six minus K. Likewise at least d5-K units must be produced if K is less than d5, otherwise the minimum amount that must be produced is zero unit. So the optimal amount to produce at the start of period five, given an entering inventory K, is that amount Z that yields f5(K),where:

$$f5(K) = \min_{\max(0,d5-K) \leqslant Z \leqslant d5+d6-K} [PC5(Z) + EIC5(K+Z-d5) + f6(K+Z-d5)]$$

where $K = 0,1,2,....,d5+d6$

$$= \min_{\max(0,10-K) \leqslant Z \leqslant 10+4-K} [PC5(Z) + (K+Z-10)] + f6(K+Z-10)]$$

for $K = 0$

$$f5(0) = \min_{10 \leqslant Z \leqslant 14} [(20+5(Z) + (Z-10) + f6(Z-10)]$$

$K = 0,1,2,...,14$

Then we substitute for all values of Z (1 to 14) and f5(0) would be the least value of the substitutions as shown bellow:

$$f5(0) = \min \begin{bmatrix} Z = 10 : & 20 + 50 + 0 + 40 = 110 \\ Z = 11 : & 20 + 55 + 1 + 35 = 111 \\ Z = 12 : & 20 + 60 + 2 + 30 = 112 \\ Z = 13 : & 20 + 65 + 3 + 25 = 113 \\ Z = 14 : & 20 + 70 + 4 + 0 = 94 \end{bmatrix}$$

$= 94$

and $X5(0) = 14$

The above means that if the fifth period is entered with zero units of inventory the minimum policy for periods five and six is $f5(0)=94$ and is obtained by producing 14 ($X5(0)$) units at the start of period five.

If $K = 1$

$$f5\ (I) = \min_{9 \leqslant Z < 13} [20 + 5(Z) + (Z-9) + f6(Z-9)]$$

And this will yield $f5(1) = 89$

$X5(1) = 13$

The same is applicable to the rest of the periods until we reach period one

$$fi(0) = \min_{\max(0,d1) \leqslant Z \leqslant \sum_{j=1}^{6} dj} [PC1(Z) + (Z-d1) + f2(Z-d1)]$$

and that will yield $f1(0) = 236$

$X1(0) = 20$

So if the ith period was entered with an inventory of K, the minimum cost for the periods i,i+1,...,n is:

$$fi(K) = \min_{\max(0,di-K) \leqslant Z \leqslant \sum_{j=i}^{6} dj-K} [PCi(Z) + EICi(K+Z-di) + fi+1(K+Z-di)]$$

and the optimal amount to produce at the start of period i is:

Xi(K) = value of Z that will minimize fi(K).

Description of the production planning program algorithm

For readers to fully understand the procedure used in the model's structuring and flowchart, as well as its computer program, a glosarry of the notation used is provided as follows:

N : Number of periods.

MAXIL : Maximum ending inventory level for each period.

MAXP : Maximum production during any period.

D(I) : Demand for the Ith period, where I=1,2,...,N

PC(I,J) : Cost to produce J units during period I, where I=1,2,...,N and J=1,2,..,MAXP.

EIC(I,J) : Cost of J units of ending inventory in period I for I=1,2,..,N and J=1,2,..,MAXIL.

f(I,K) : Minimum cost for the Ith through the Nth period when the ending inventory for period (I-1) is (K-1), where I=1,2,..,N and k=1,2...,min$\left[\sum_{J=1}^{N} D(J)+1, MAXIL+1\right]$

X(I,K) : Optimal amount to produce in the Ith period using the overall optimal policy, where I=1,2,..,N.

I0 : Inventory level at the start of period one.

The model program algorithm

The first step in the program is to read in the values of N, MAXIL , MAXP, I0, and D(I).

Steps two-four initialize the minimum cost for the last period and calculate the optimal amount to produce at the start of the last period.

Step two : K=1

Step three : f(N,K) = PC(N , D(N)-K+1)

X(N,K) = D(N) - K+1

Step four : If K = D(N) + 1, proceed to step five; otherwise, increase K by one and return to step three.

Steps five-nine calculate the minimum cost to operate from any given period through the last period. These steps calculate the optimal amount at the start of each period for every possible amount of entering inventory.

Step five : I=N-1

Step six : K=1

Step seven : Calculate:

$$f(I , K) = \min_{Z} [PC(I,Z) + EIC(I , K+Z-D(I)-1) + f(I+1 , K+Z-D(I))]$$

where $Z \geqslant \max(0 , D(I)-K+1)$

$$Z \leqslant \min(MAXP, \sum_{j=1}^{N} D(J)-K+1, D(I)+MAXIL-K+1)$$

$X(I,K)$ = value of Z that yields $f(I,K)$

Step eight : If $K = \min(\sum_{j=1}^{N} D(J)+1 , MAXIL+1)$

go to step nine; otherwise, increase K by one and return to step seven.

Step nine : If I=1, proceed to step ten; otherwise decrease I by one and return to step six.

Steps ten-fourteen calculate the optimal amount to produce at the start of periods 1,2,..,N, if the first period is started with I0 units of inventory and zero units are in inventory at the end of period N.

Step ten : XSTAR(1) = X(1,I0+1)

Step eleven : NEI = I0 + 1

I = 2

Step twelve : calculate:

NNEI = XSTAR(I-1) - D(I-1) + NEI

XSTAR(I) = X(I,NNEI)

Step thirteen : NEI = NNEI

Step fourteen : If I=N proceed to step fifteen; otherwise, increase I by one and return to step twelve.

Step fifteen : Print results; Total cost to operate 1,2,...,N periods, and optimal amount to produce at the start of each period.

The program is designed to handle a maximum pf fifty periods and one hundred units of ending inventory for each period.

If desired, the program can easily be modified to handle any number of periods (M), with any maximum amount of ending inventory (MAXIL) for each period by changing the dimension and integer statement accordingly.

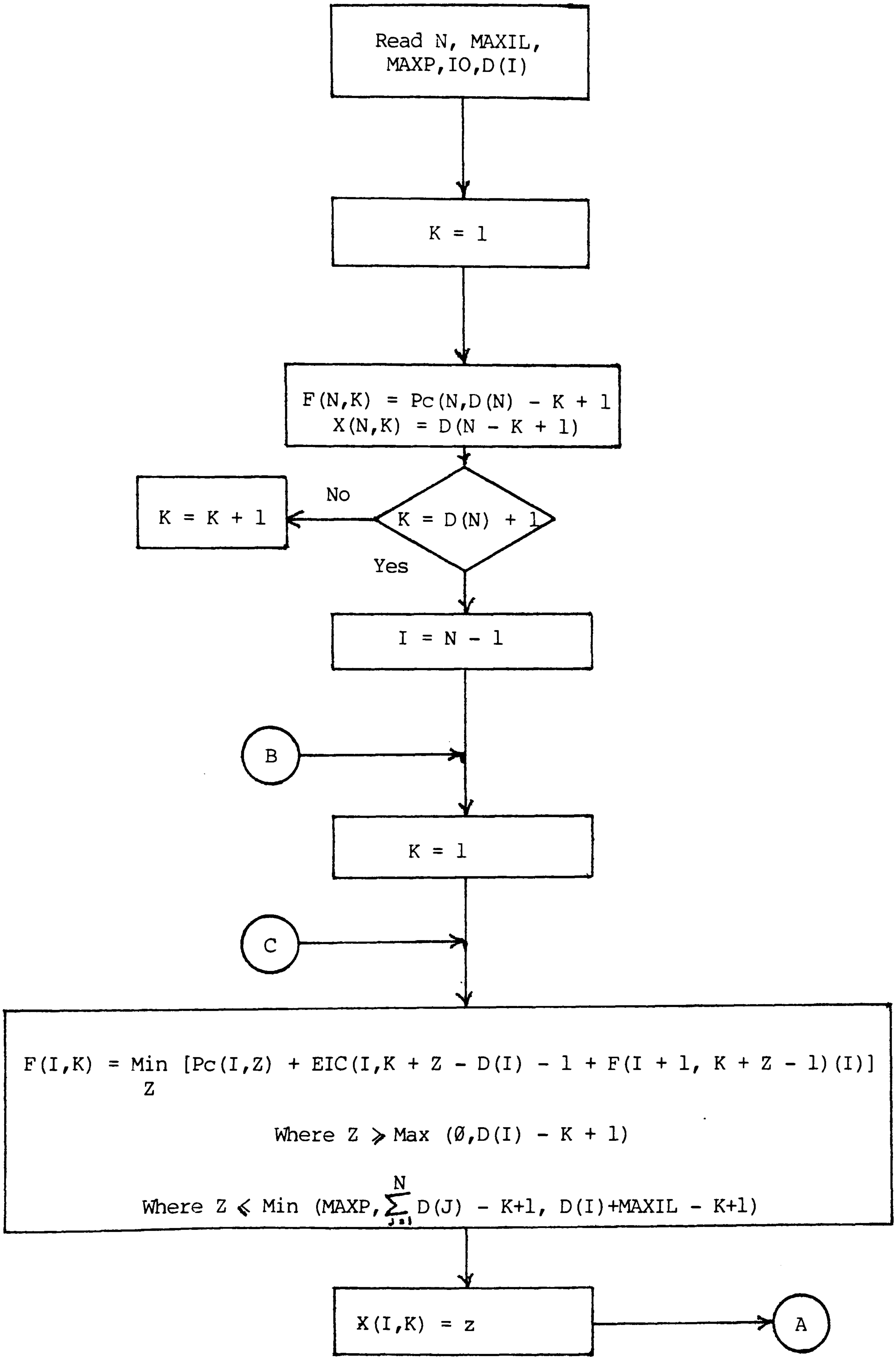

Fig.(e.1) Flowchart for model in section 5.4
(production scheduling)

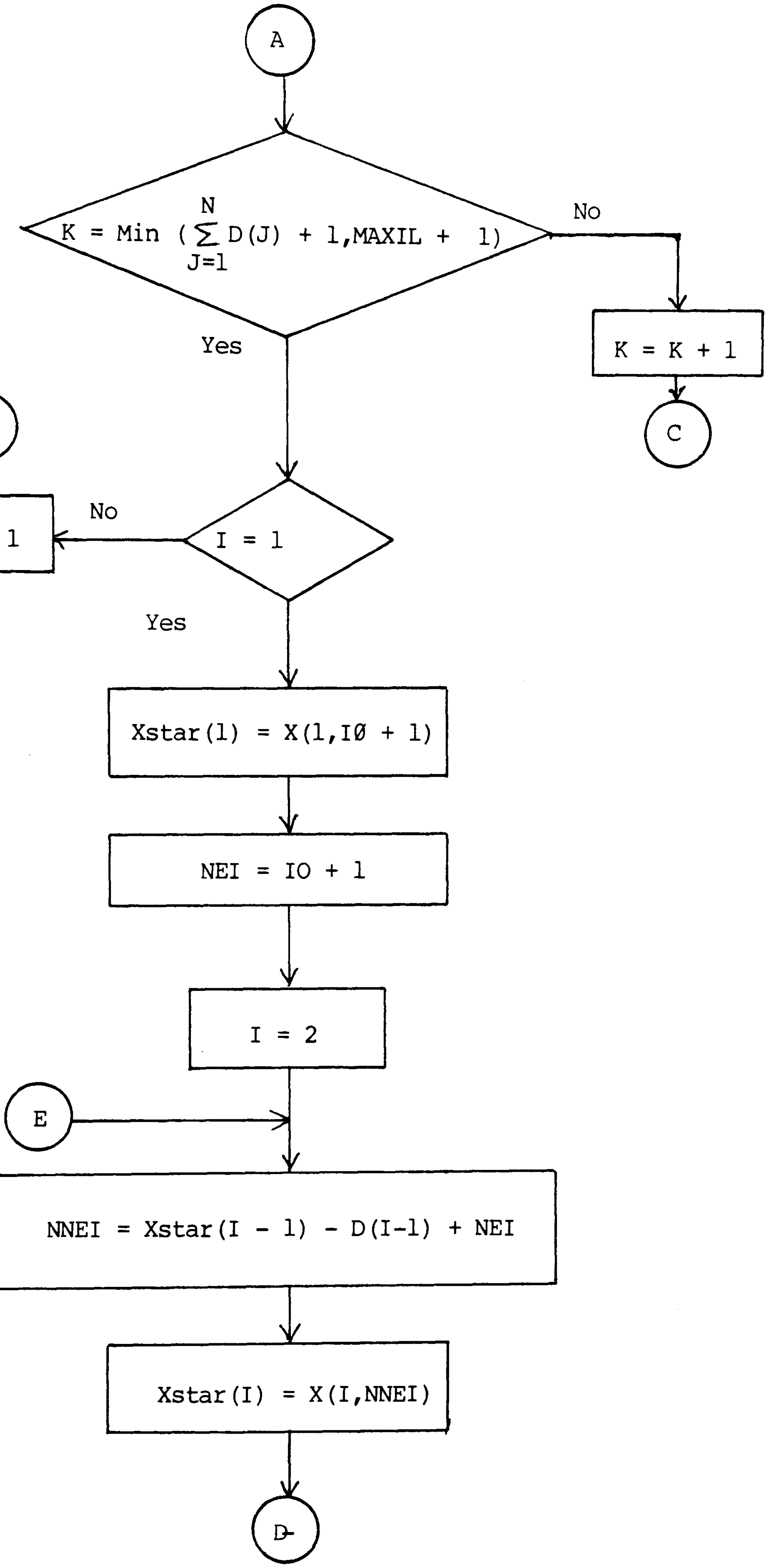
A
K = Min ($\sum_{J=1}^{N}$ D(J) + 1,MAXIL + 1)
No
K = K + 1
C
Yes
B
I = I - 1
No
I = 1
Yes
Xstar(1) = X(1,IØ + 1)
NEI = IO + 1
I = 2
E
NNEI = Xstar(I - 1) - D(I-1) + NEI
Xstar(I) = X(I,NNEI)
D

Fig.(e.1) Cont.

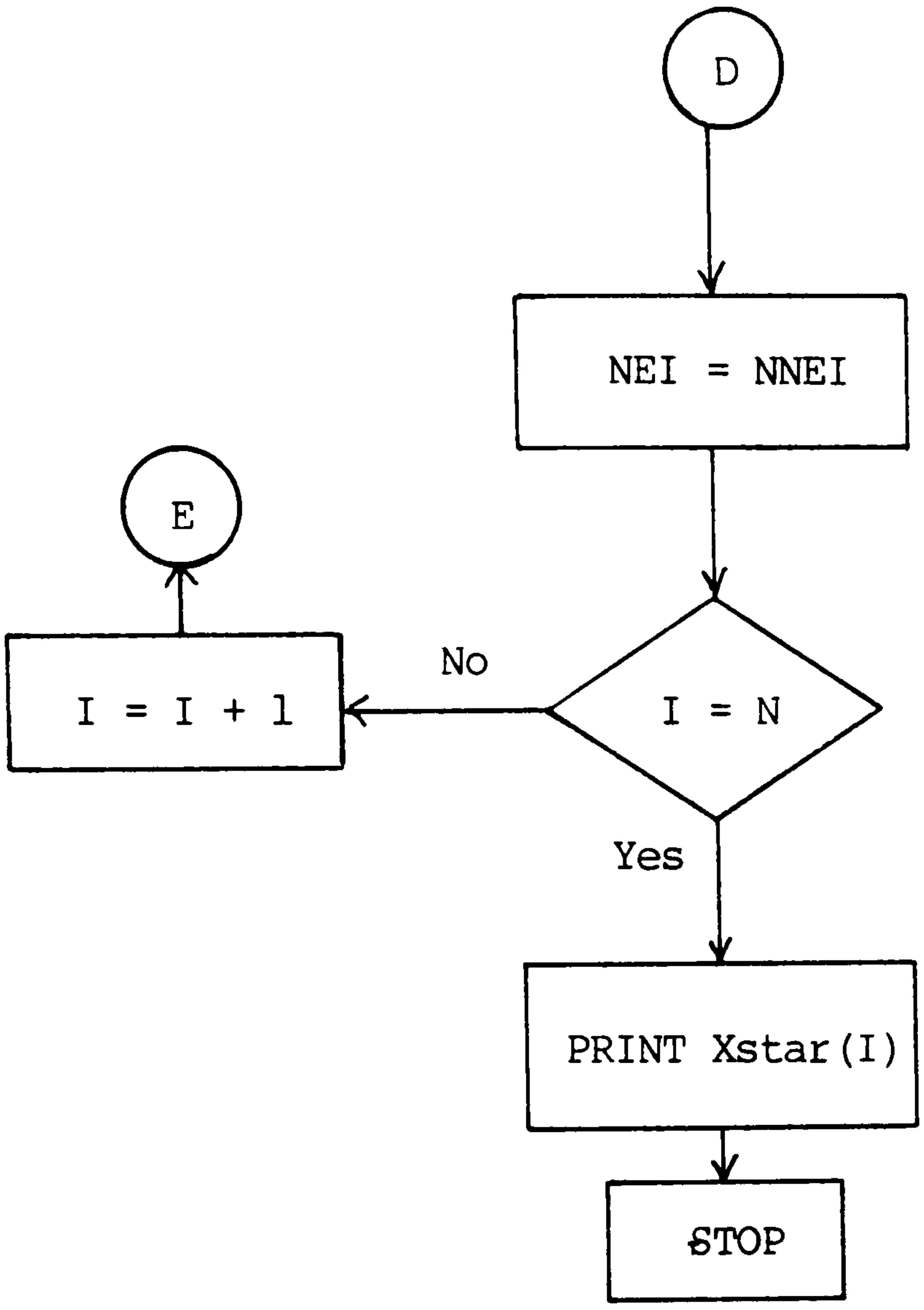

Fig.(e.1) Cont.

Program listing for production scheduling model in section 5.4

```
c the program represents a production scheduling
c model in which the optimal amount to produce at
c the start of each period is calculated. The
c program handels a maximum of 50 periods and
c 100 units of ending inventory in each period
c
c
      dimension f(50,101),oap(50,101),d(50),pc(50,101),
&      hc(50,101),oapl(50)
      integer d,oap,oapl,z,sum,dn,dnpl
      do 1000 i = 1,10
c
c
c read from external file.
c
      do 2000 j = 1,100
      pc(i,j) = 20+5*j
      hc(i,j) = j
 2000 continue
 1000 continue
      read (07,,end = 111)n,maxil,maxp,io
 111  do 2 k = 1,n
 2    read (43,,end = 222) d(k)
 222  maxpl = maxp+1
      nml = n-1
      maxil1 = maxil+1
      dnpl = d(n)+1
      dn = d(n)
      if (d(n).eq.0) go to 5
c
c
c initialize the minimum cost for the last period,and
c calculate the optimal amount to produce athe start
c of the last period
c
      do 4 k = 1,dn
      f(n,k) = pc(n,d(n)-k+1)
 4    oap(n,k) = d(n)-k+1
c
c
c calculate the minimum cost to operate from any given
c period through the last period,and calculate the
c start of each period for every possible amount of
c entering inventory
c
 5    f(n,dnpl) = 0
```

```
      oap(n,dnpl) = 0
      do 16 ii = 1,nml
      i = n-ii
      sum = 0
      do 6 j = i,n
 6    sum = sum+d(j)
      sum = sum+1
      if (sum.lt.maxill) go to 7
      minlim = maxill
      go to 8
 7    minlim = sum
 8    do 16 k = 1,minlim
      if (d(i)-k+1.le.0) go to 10
      llim = d(i)-k+1
      f(i,k) = pc(i,llim)+0+f(i+1,1)
      oap(i,k) = d(i)-k+1
      llim = llim+1
      go to 11
 10   llim = 0
      f(i,k) = hc(i,k-d(i)-1)+f(i+1,k-d(i))
      oap(i,k) = 0
      llim = llim+1
 11   if(maxp.gt.sum-k) go to 12
      if(maxp.gt.d(i)+maxill-k) go to 13
      maxlim = maxp
      go to 14
 12   if(sum-k.gt.d(i)+maxill-k) go to 13
      maxlim = sum-k
      go to 14
 13   maxlim = d(i)+maxill-k
      go to 14
 14   if(llim-1.eq.maxlim) go to 16
      do 15 z = llim,maxlim
      hold = pc(i,z)+hc(i,k+z-d(i)-1)+f(i+1,k+z-d(i))
      if(f(i,k).le.hold) go to 15
      f(i,k) = hold
      oap(i,k) = z
 15   continue
 16   continue
c
c
c calculate the optimal amount to produce at the start
c of periods 1,2,3,...,n, when the first period is started
c with io units of inventory and the ending inventory of
c the last period is to be zero
c
      oapl(1) = oap(1,io+1)
      nei = io+1
      do 18 i = 2,n
      nei2 = oapl(i-1)-d(i-1)+nei
      oapl(i) = oap(i,nei2)
 18   nei = nei2
      do 30 i = 1,n
```

```
 30   write (54,40) i,oapl(i)
 40   format (1x,'the optimal amount to produce in period'
&     ,i6,2x,'is',i6)
      call exit
      end
```

the input data:

```
  6 100 100 0

  8 4 6 2 10 4
```

the program output:

```
   the optimal amount to produce in period     1  is     20
   the optimal amount to produce in period     2  is     0
   the optimal amount to produce in period     3  is     0
   the optimal amount to produce in period     4  is     0
   the optimal amount to produce in period     5  is     14
   the optimal amount to produce in period     6  is     0
```

APPFNDIX F:

Procedure for calculating the EOQ with price discounts for model in section 5.5

To calculate the optimal EOQ with price discounts we assume that the raw materials vendor has on offer the following price discounts:

1- If one orders in lot sizes B1 (QB1), the price (P2) will be a certain percentage of the original price per unit (P1).

2- If one orders in even larger sizes B2 (QB2), the price (P3) will be even a less percentage of the original price (P1).

The procedure is first to calculate Q3 using P3; if it is greater than QB2, then order Q3. If it is less than QB2, then (using P3) it is infeasible.
Next, calculate Q2 using P2. If Q2 is greater than QB2, then order QB2. If Q2 is less QB2 but greater than QB1, i.e. QB1<Q2<QB2, then compare TC2 with TCB2.

If TC2 > TCB2, then order QB2
If TC2 < TCB2, then order Q2

If Q2 < QB1, calculate Q1

If Q1 > QB1, then compare TCB1 with TCB2

If TCB1 > TCB2, then order QB2

If TCB1 < TCB2, then order QB1

If Q1 is less than QB1, then compare TC1 with TCB1 with TCB2, and order the quantity corresponding to the minimum total cost.

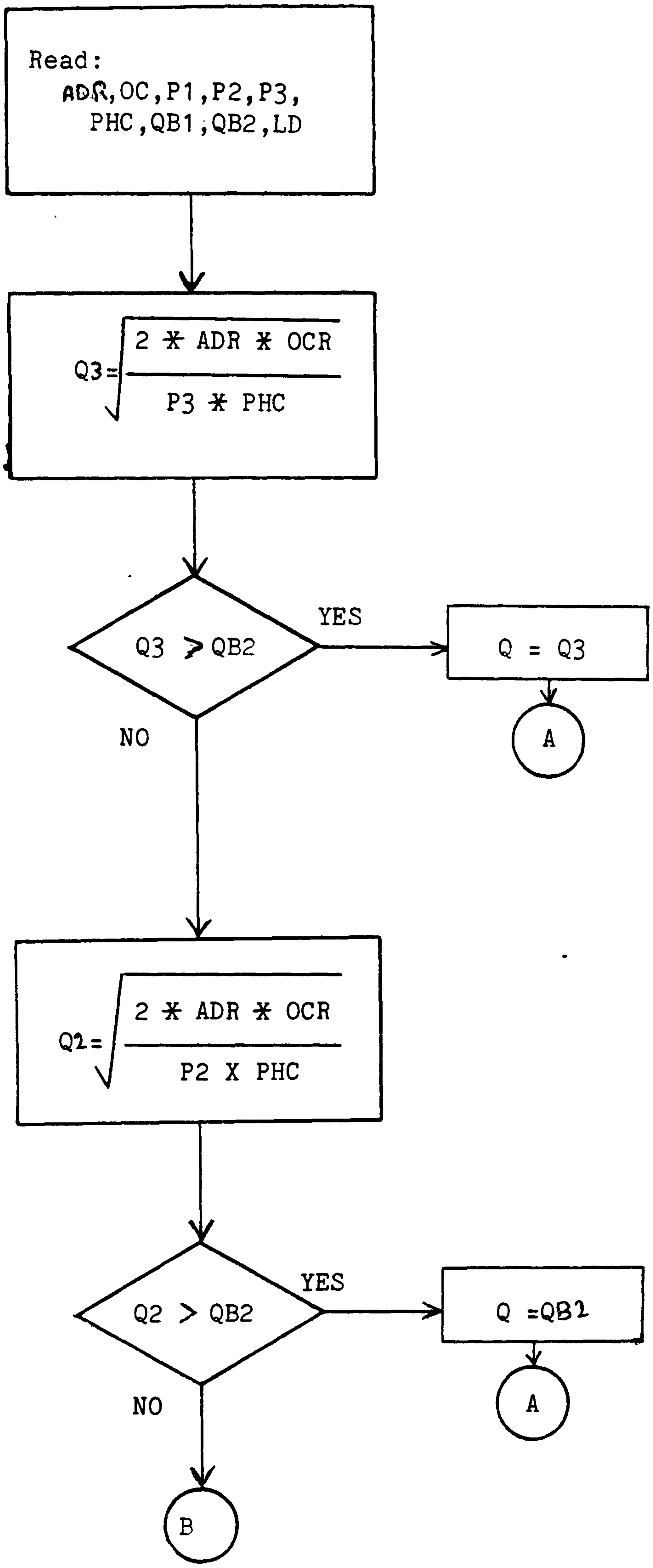

Fig.(f.1) Flowchart for model in section 5.5
(price discount)

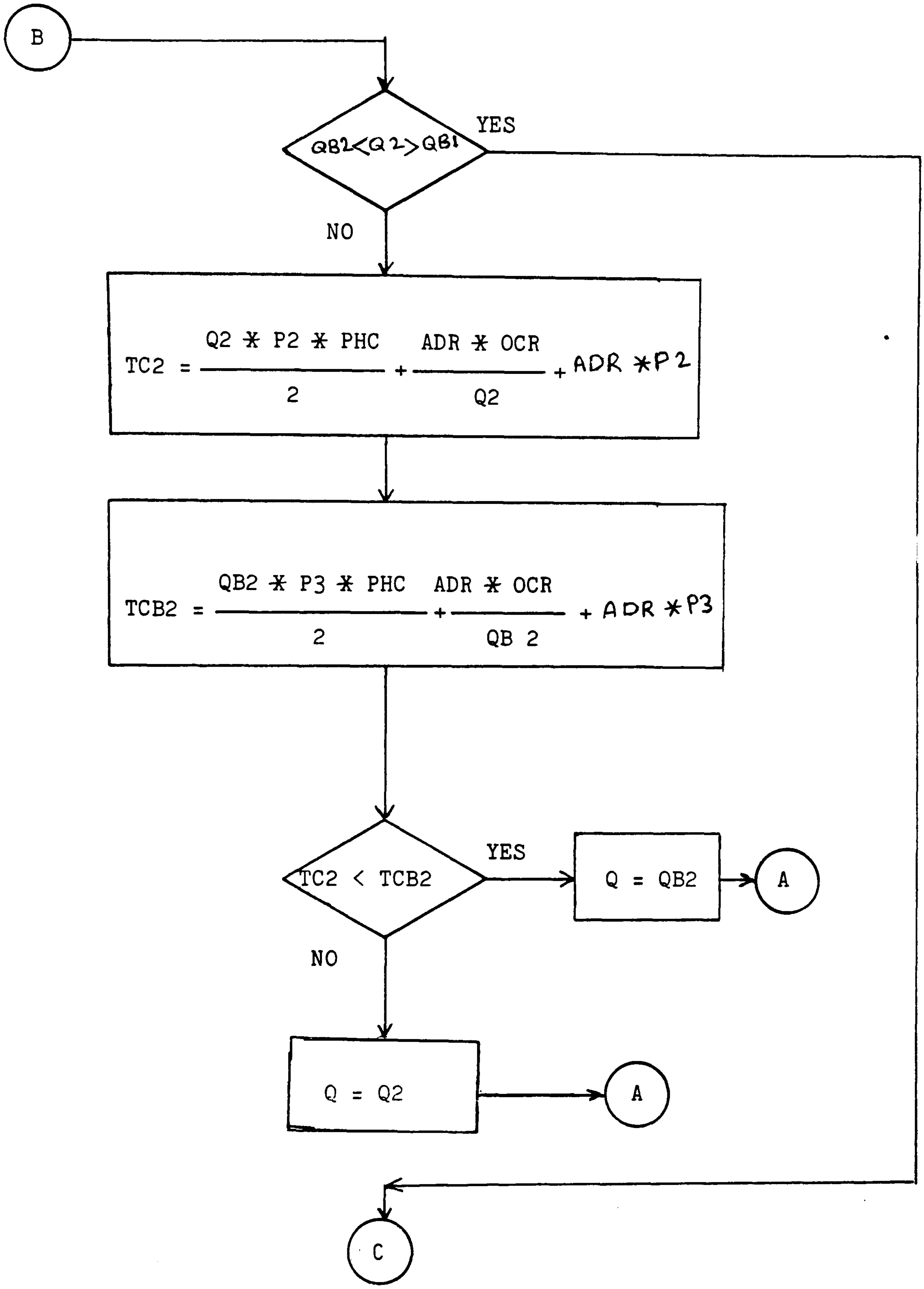
B
QB2<Q2>QB1
YES
NO
TC2 = $\frac{Q2 * P2 * PHC}{2} + \frac{ADR * OCR}{Q2}$ + ADR *P2
TCB2 = $\frac{QB2 * P3 * PHC}{2} + \frac{ADR * OCR}{QB\ 2}$ + ADR *P3
TC2 < TCB2
YES
NO
Q = QB2
A
Q = Q2
A
C

Fig.(f.1) Cont.

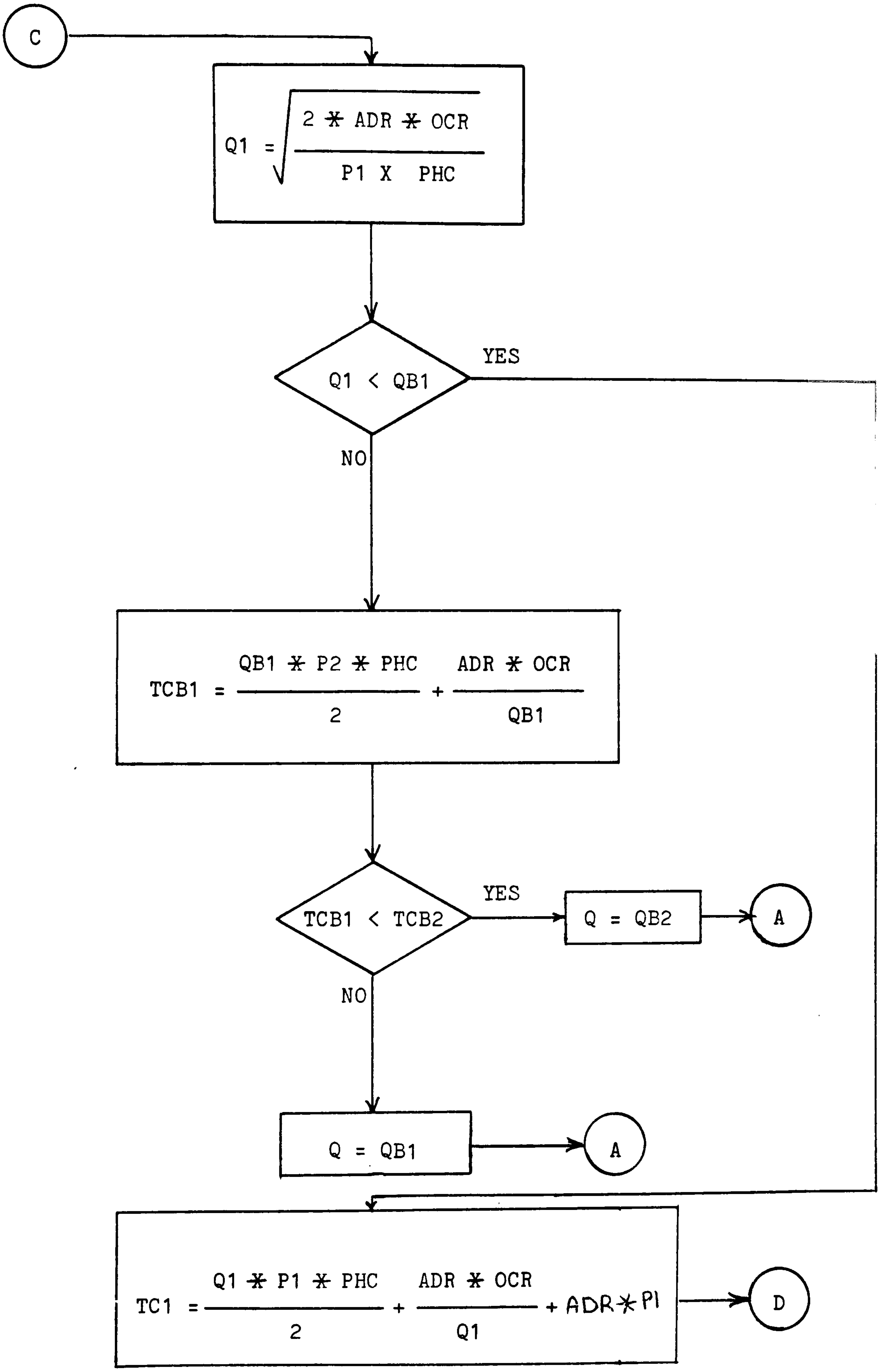
C
Q1 =
2 * ADR * OCR
P1 X PHC
Q1 < QB1
YES
NO
TCB1 =
QB1 * P2 * PHC
2
+
ADR * OCR
QB1
TCB1 < TCB2
YES
Q = QB2
A
NO
Q = QB1
A
TC1 =
Q1 * P1 * PHC
2
+
ADR * OCR
Q1
+ ADR*P1
D

Fig.(f.1) Cont.

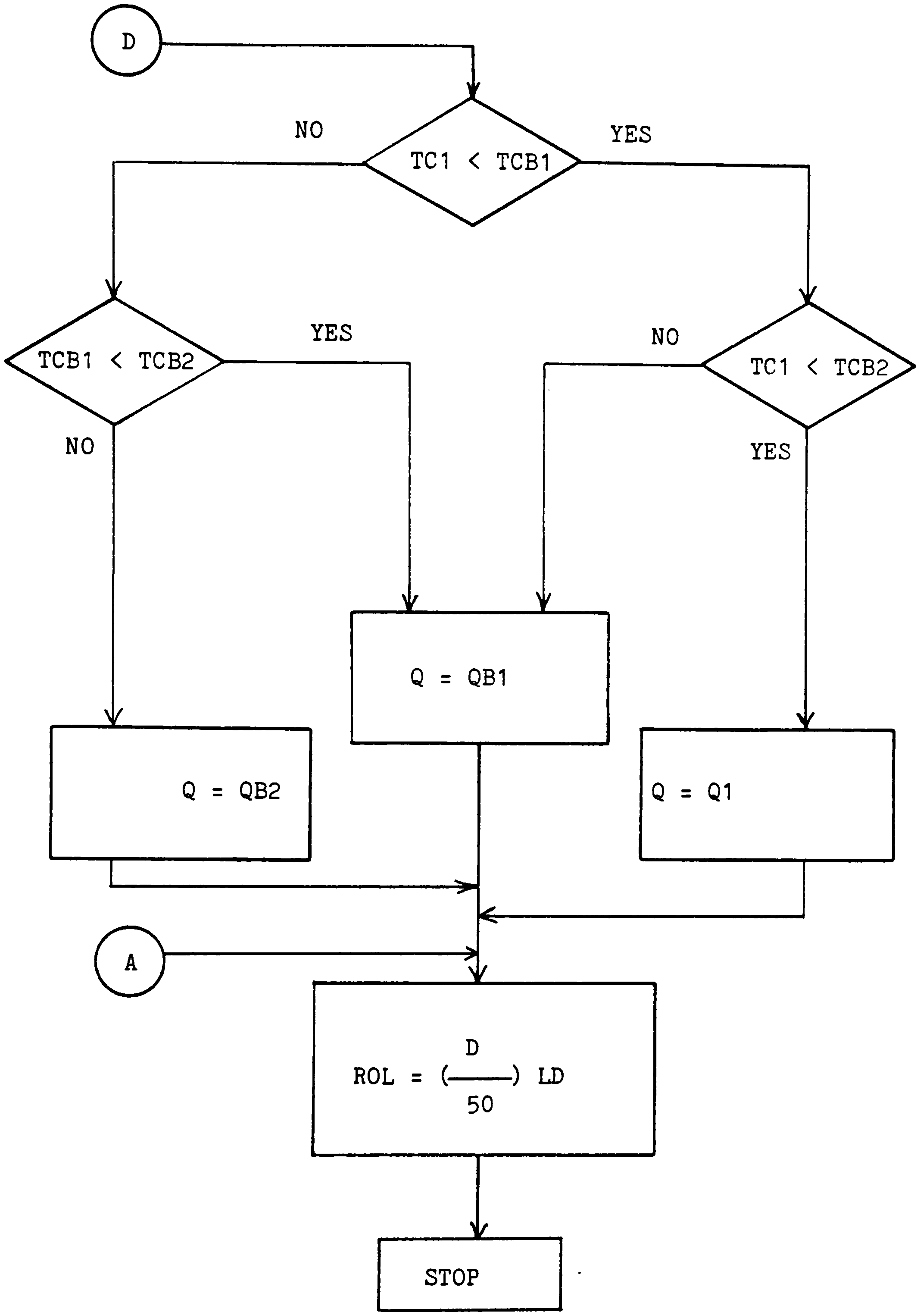
D
TC1 < TCB1
NO
YES
TCB1 < TCB2
YES
NO
NO
TC1 < TCB2
YES
Q = QB1
Q = QB2
Q = Q1
A
ROL = (D/50) LD
STOP

Fig.(f.1) Cont.

Program listing for model in section 5.5

```
c The program calculates the economic order quantity
c for a deterministic inventory model with
c price discounts
c
c
c read parameters of inventory and price discount
c
      read (11,,end=111)dr,ocr,p1,p2,p3,phc,qb1,qb2
c
111   qr3 = sqrt((2*dr*ocr)/(0.80*phc))
      if (qr3.lt.qb2) go to 10
      qr = qr3
      go to 110
c
 10   qr2 = sqrt((2*dr*ocr)/(0.90*phc))
      if (qr2.lt.qb2) go to 20
      qr = qr2
      go to 110
c
 20   if (qr2.gt.qb1) go to 30
      go to 50
 30   tc2 = ((qr2*p2*phc)/2) + ((dr*ocr)/qr2) + (dr*p2)
c
      tcb2 = ((qb2*p3*phc)/2) + ((dr*ocr)/qb2) + (dr*p3)
      if (tc2.lt.tcb2) go to 40
      qr = qb2
      go to 110
 40   qr = qr2
      go to 110
c
 50   qr1 = sqrt((2*dr*ocr)/(1.0*phc))
      if (qr1.lt.qb1) go to 60
      tcb1 = ((qb1*p2*phc)/2) + ((dr*ocr)/qb1)
      if (tcb1.lt.tcb2) go to 70
      qr = qb2
      go to 110
c
 70   qr = qb1
      go to 110
c
 60   tc1 = ((qr1*p1*phc)/2) + ((dr*ocr)/qr1) + (dr*p1)
      if (tc1.lt.tcb1) go to 80
      if (tcb1.lt.tcb2) go to 90
      qr = qb2
      go to 110
c
```

```
 80   if( tcl.lt.tcb2) go to 100
 90   qr = qbl
      go to 110
 100  qr = qrl
c
c print value of economic order quantity
c
 110  write (30,120) qr
 120  format (5x,'The EOQ is:',f10.2)
      call exit
      end
```

input data:

```
60.0 5.0 1.0 .90 .80 .10 30.0 200.0
```

the program output:

```
    The EOQ is:    200.00
```

APPENDIX G:

Description of the program notation and flowchart used for model in section 6.1

Glossary of the notation

ADIR : Amount due in at raw material.

ADIRF : Amount due in at raw material factory.

ADR : Annual demand at raw material.

APF : Actual production at factory.

ARQ : Annual reorder quantity.

DR : Demand at raw material.

DRF : Demand at raw material factory.

FW : Factory warehouse.

HCRF : Holding cost at raw material factory.

IADD : Inventory added at factory.

IOHD : Inventory on hand at distributor.

IOHR : Inventory on hand at raw material.

IOHRF : Inventory on hand at raw material factory.

LT : Lead time at distributor.

LTR : Lead time at raw material.

LTRF : Lead time at raw material factory.

QR : Reorder quantity at raw material.

QRF : Reorder quantity at raw material factory.

ROLR : Reorder level at raw material.

ROLRF : Reorder level at raw material factory.

SDLTRF : Standard deviation for lead time at raw material factory.

TDIR : Time due in at raw material.

TDIRF : Time due in at raw material factory.

Other notation used in the program and not found in the above glossary belong to the previously described models and can be found in the glossaries attached to them.

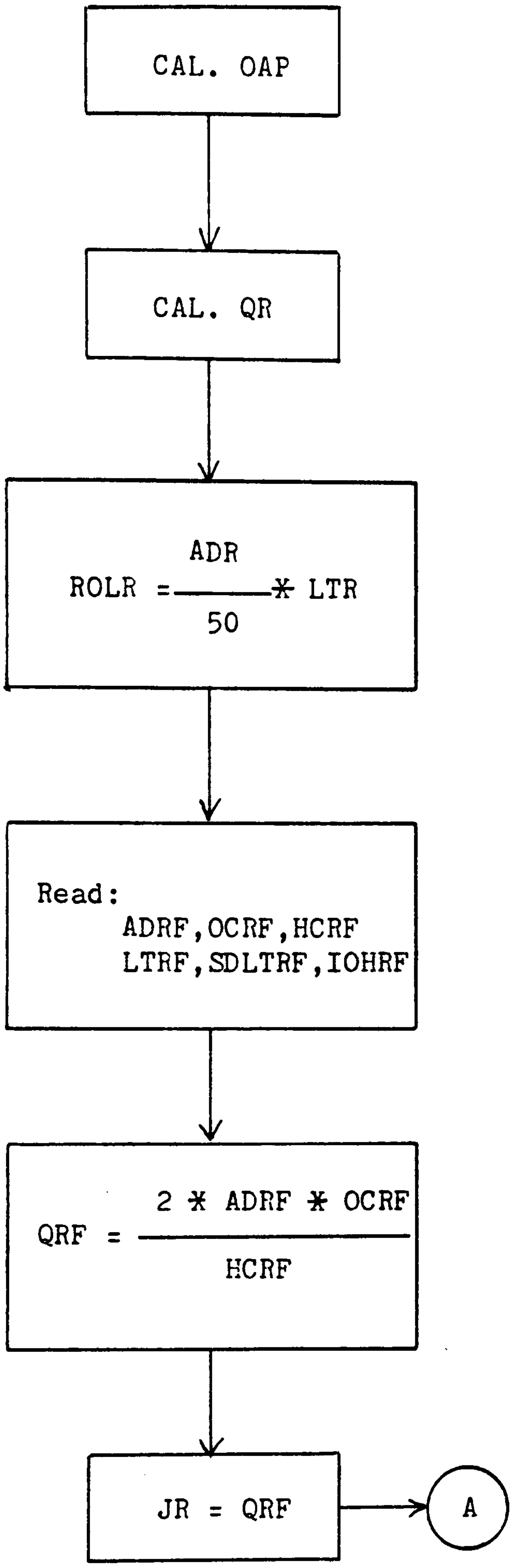

Fig.(g.1) Flowchart for model in section 6.2

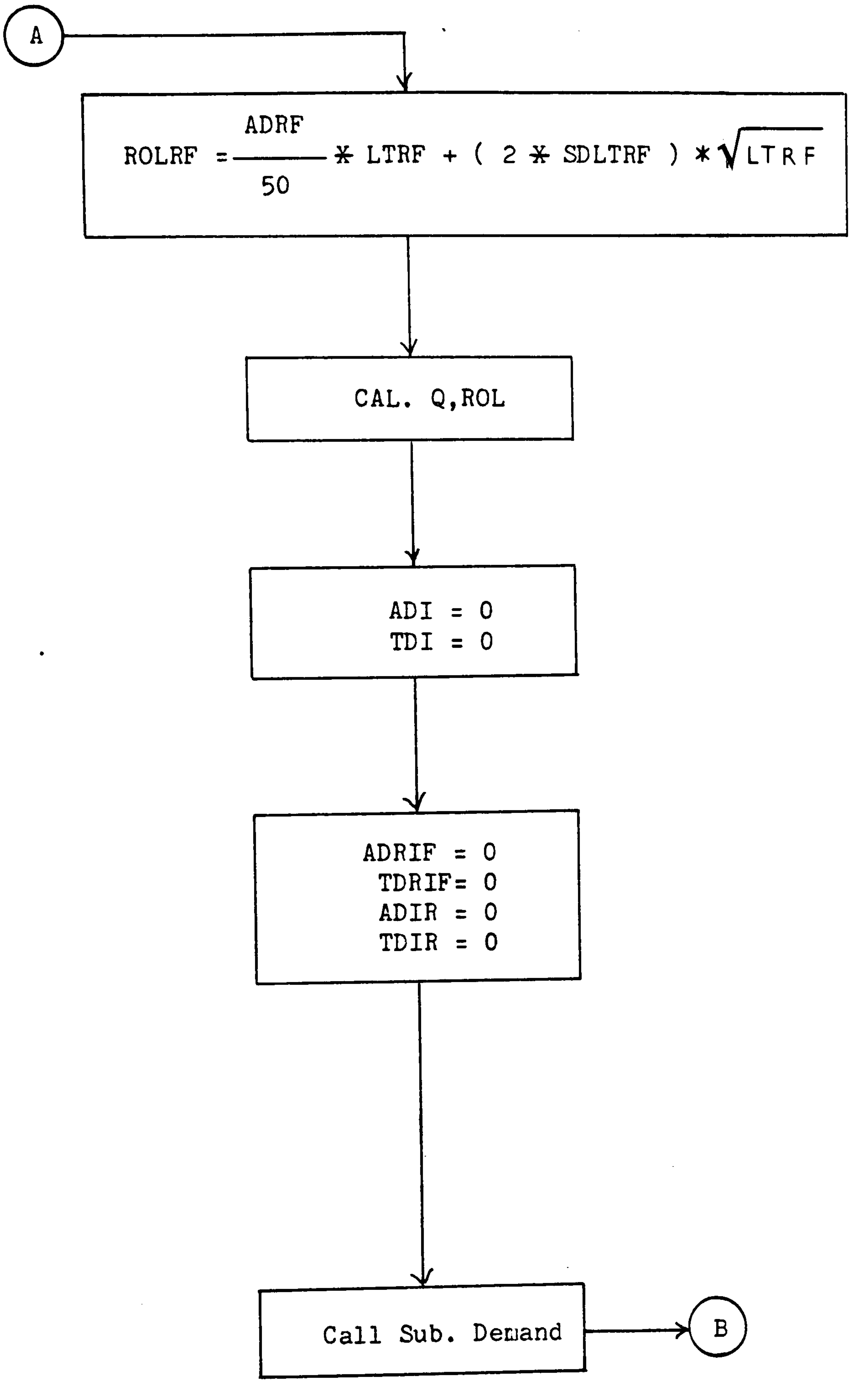
A
ROLRF = ADRF / 50 * LTRF + (2 * SDLTRF) * √LTRF
CAL. Q,ROL
ADI = 0
TDI = 0
ADRIF = 0
TDRIF= 0
ADIR = 0
TDIR = 0
Call Sub. Demand
B

Fig.(g.1) Cont.

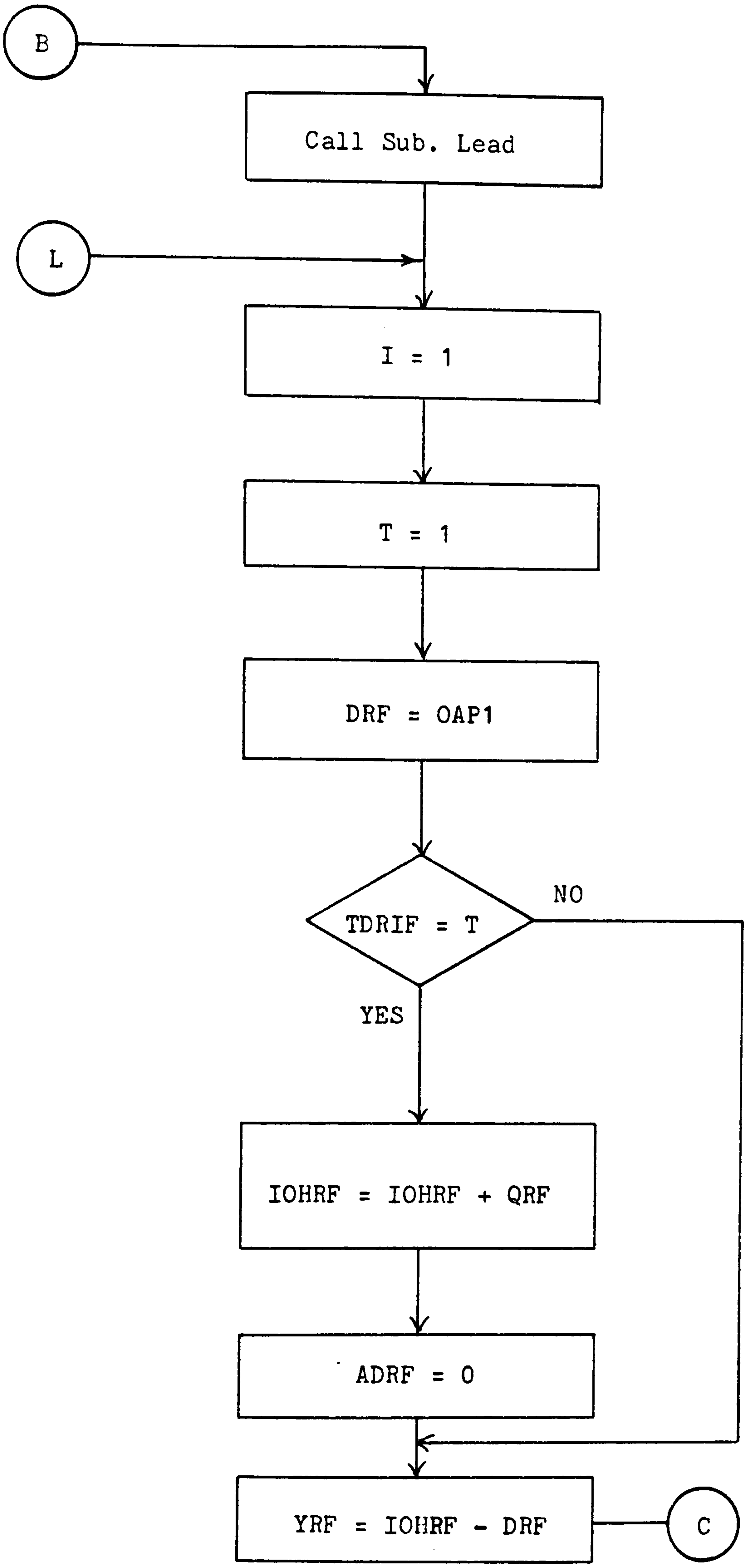
B
Call Sub. Lead
L
I = 1
T = 1
DRF = OAP1
TDRIF = T
NO
YES
IOHRF = IOHRF + QRF
ADRF = 0
YRF = IOHRF - DRF
C

Fig.(g.1) Cont.

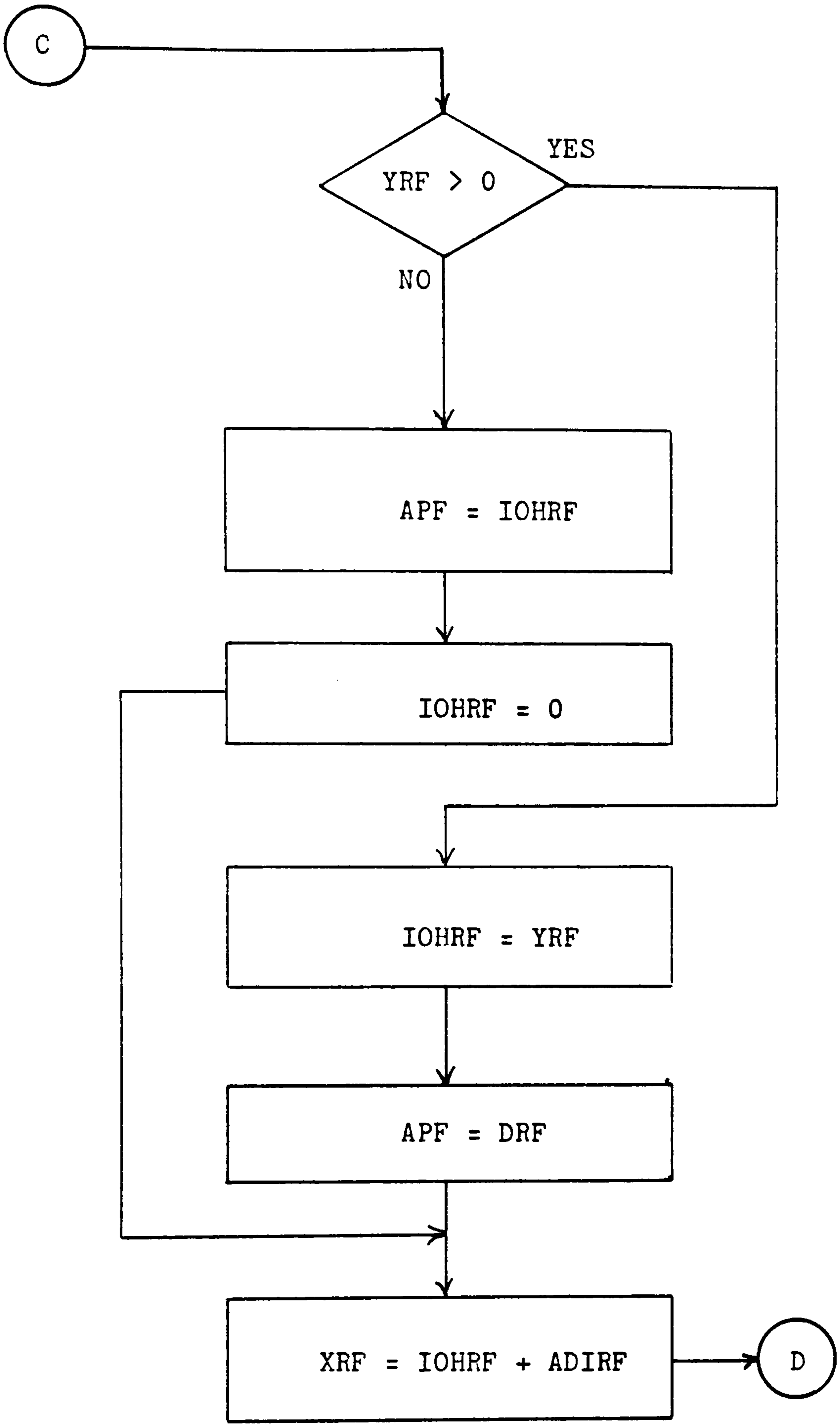
C
YRF > 0
YES
NO
APF = IOHRF
IOHRF = 0
IOHRF = YRF
APF = DRF
XRF = IOHRF + ADIRF
D

Fig.(g.1) Cont.

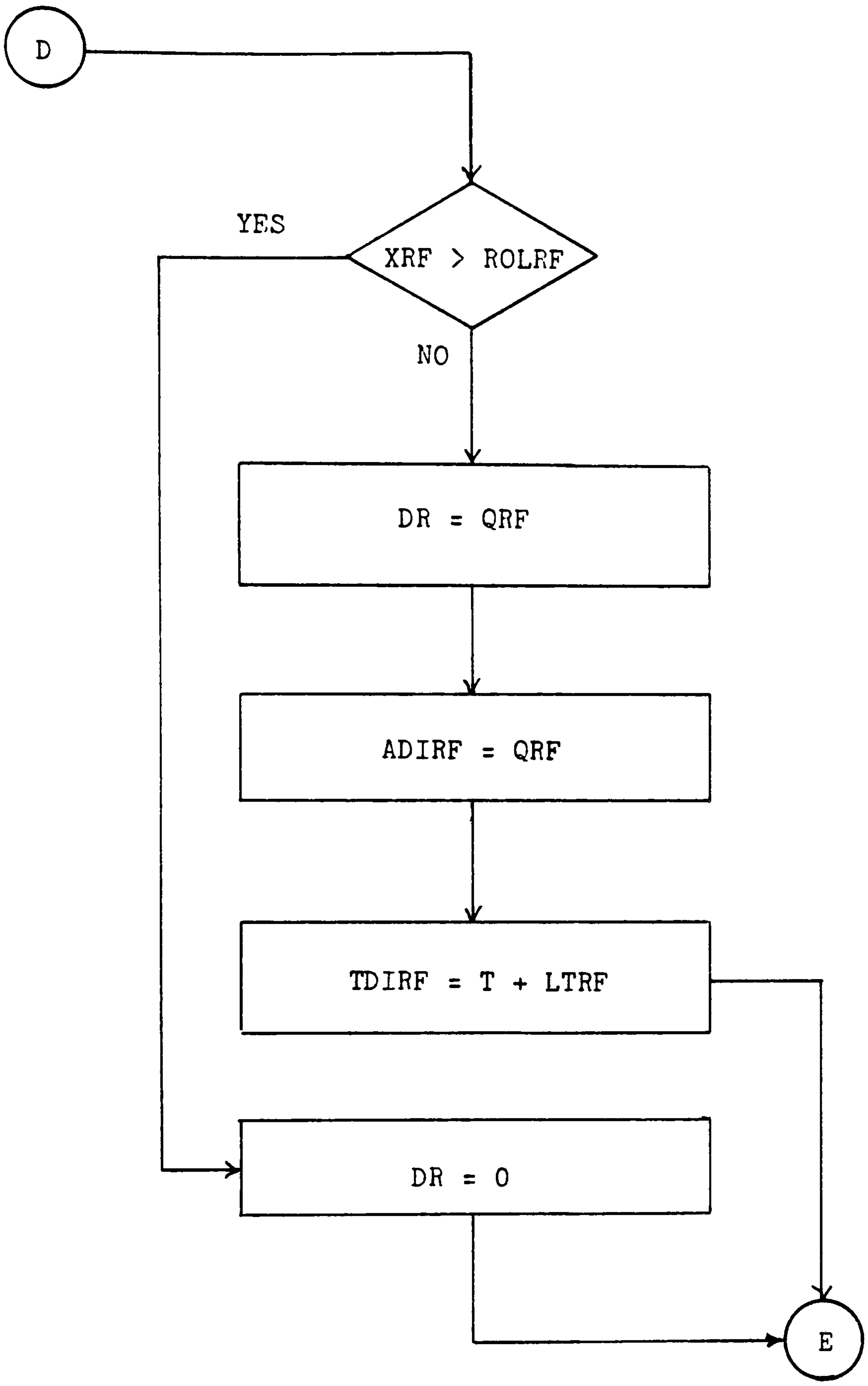

Fig.(g.1) Cont.

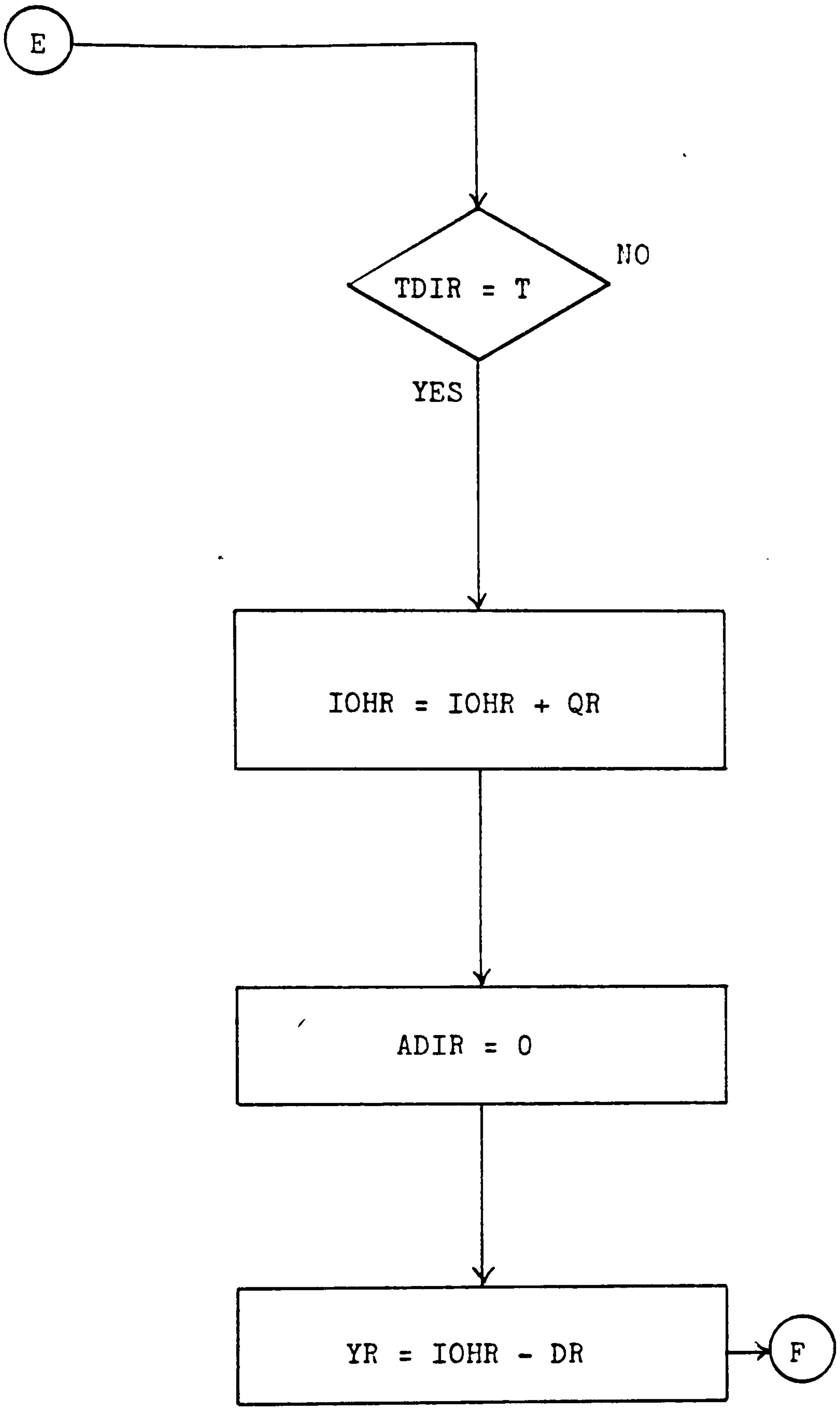

Fig.(g.1) Cont.

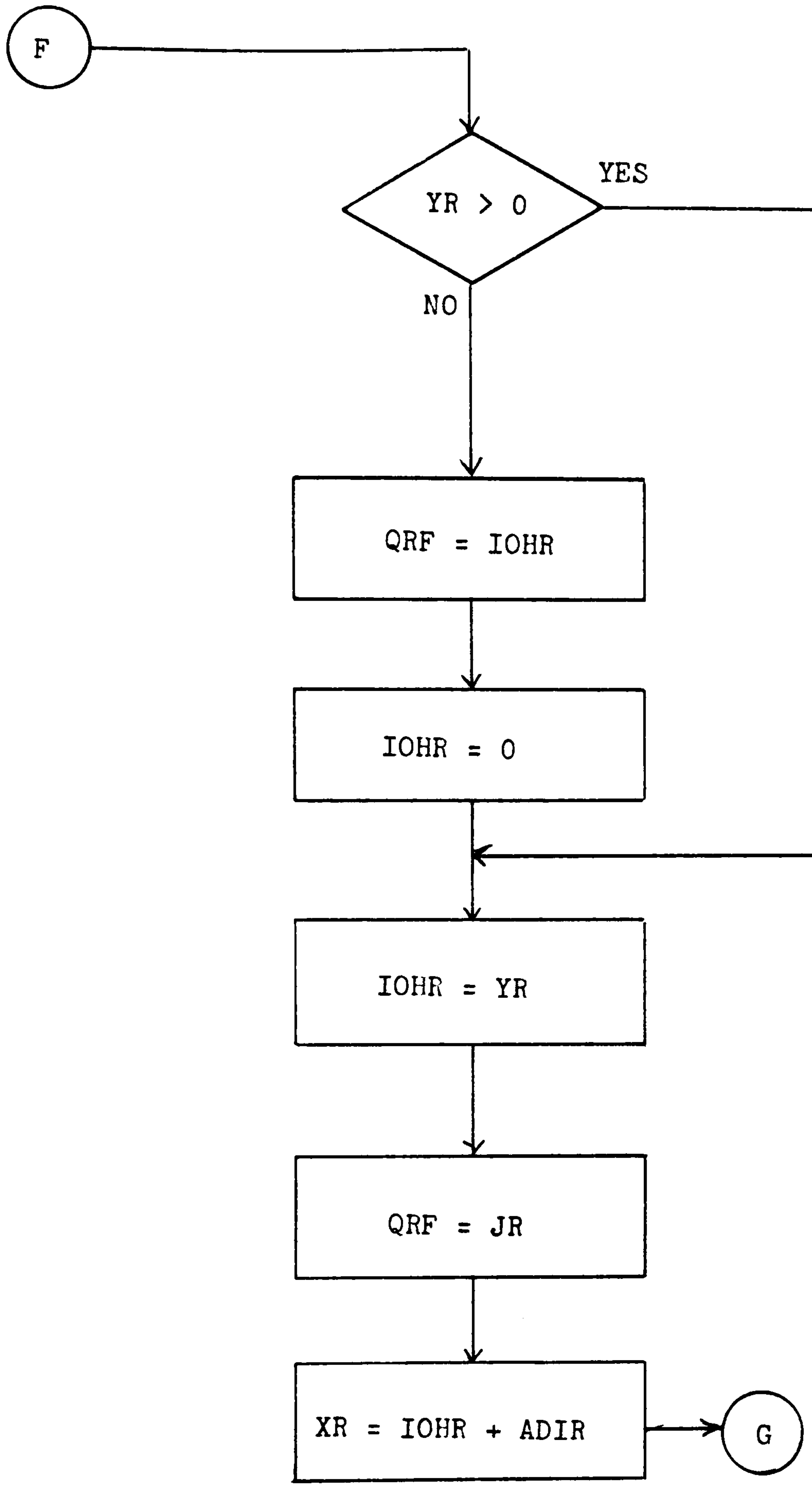

Fig.(g.1) Cont.

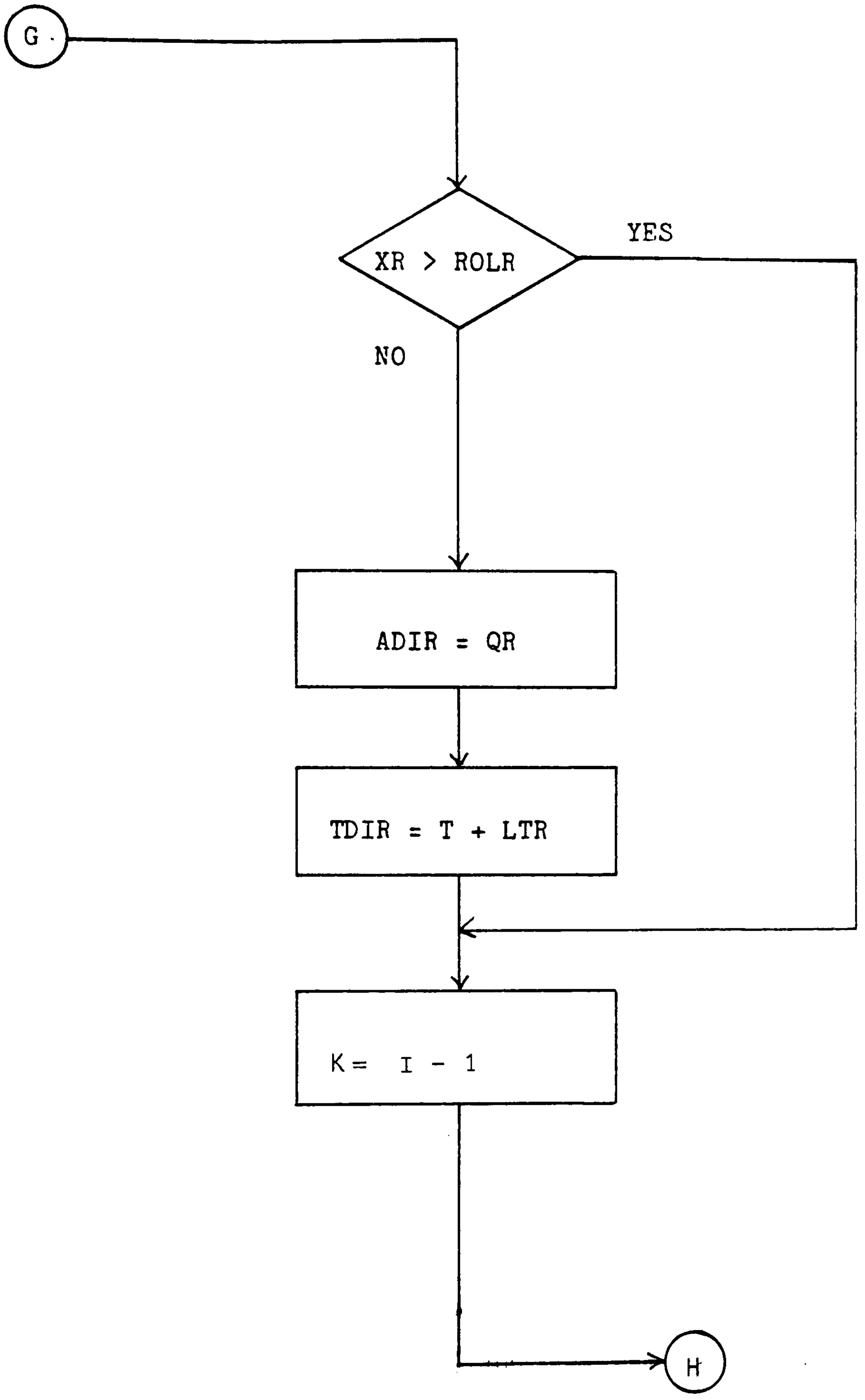

Fig.(g.1) Cont.

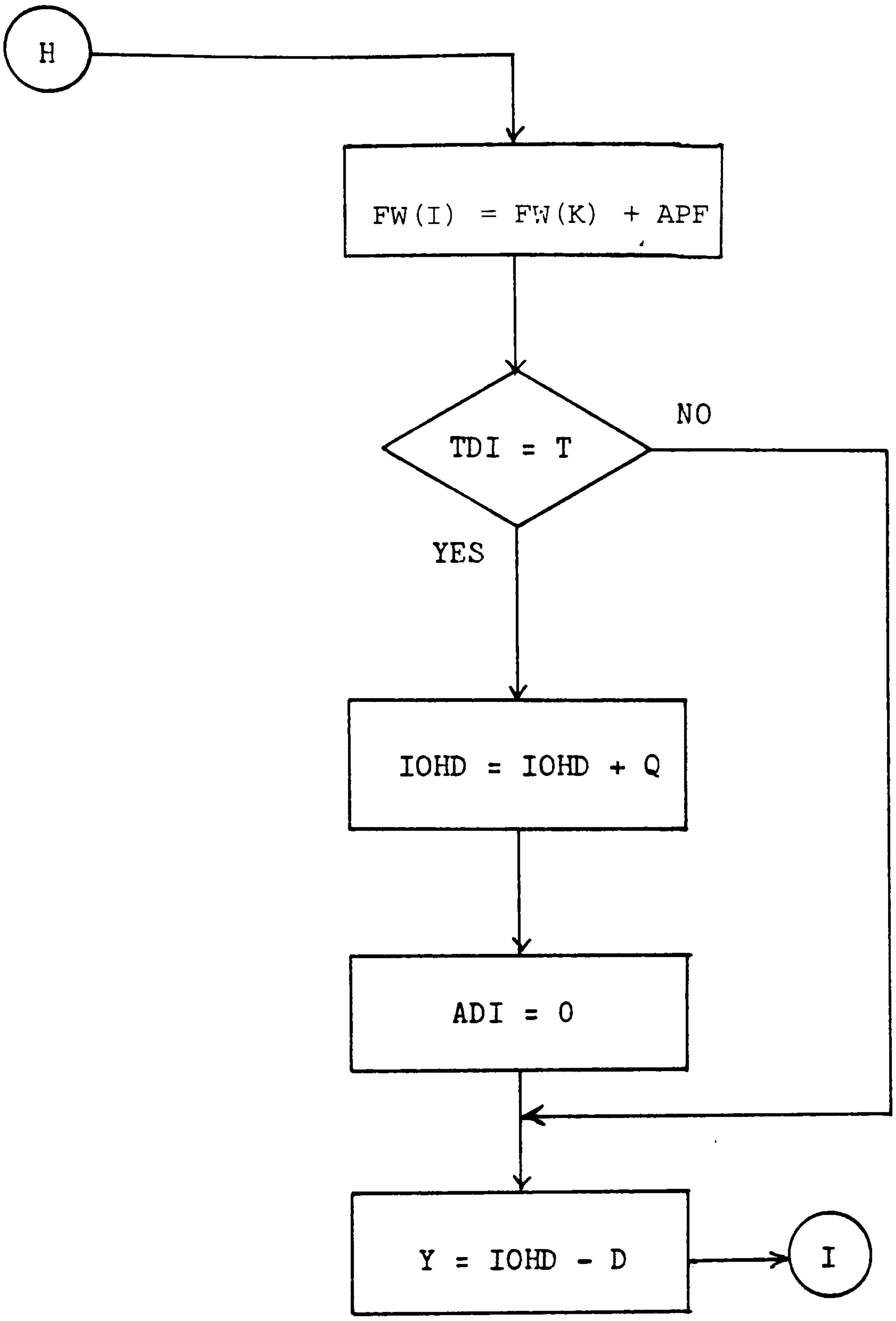

Fig.(g.1) Cont.

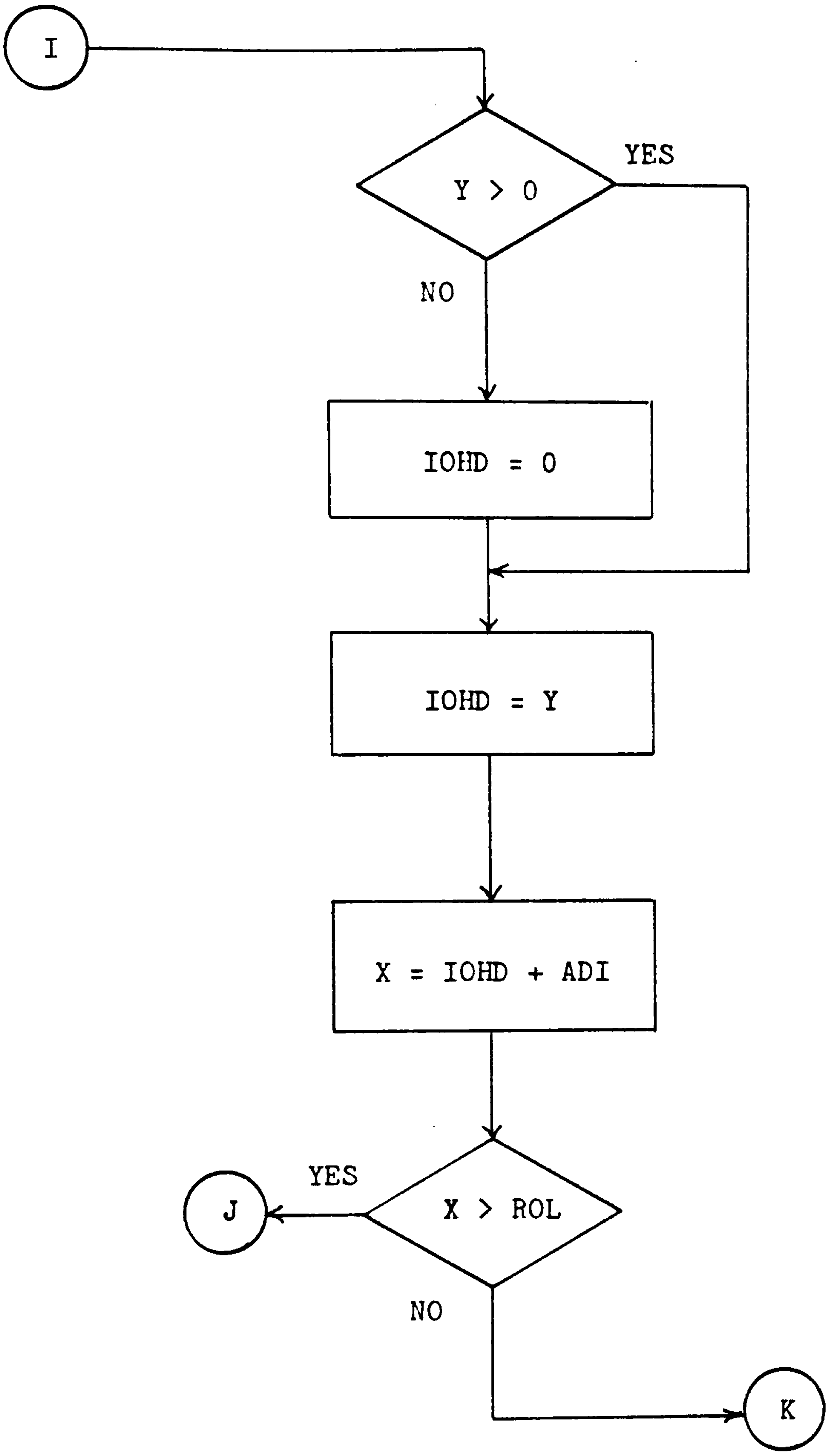

Fig.(g.1) Cont.

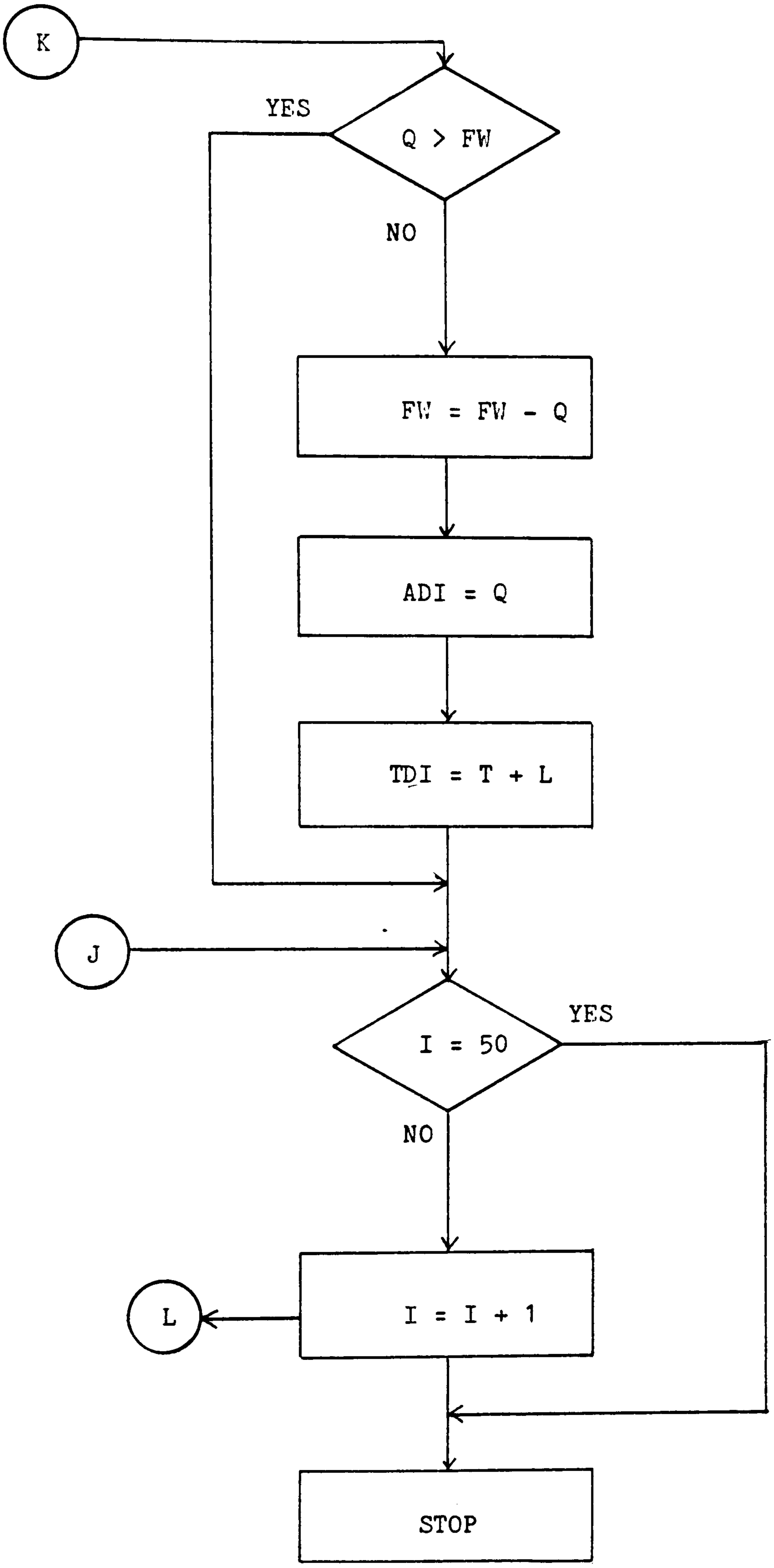

Fig.(g.1) Cont.

Program listing for main model in chapter six.

```
c The program simulates the operational level of a
c business organization which includes raw materials,
c factory, raw materials at factory, and distributor
c sections. The results represent the overall behaviour
c of the system and the effects of adapting co_ordination
c and control actions on that behaviour
c
      integer t,drf,dr,qrf,qr,rolrf,rolr,ltrf,ltr,xr,xrf,
&              yr,yrf,adirf,adir,tdirf,tdir,d,oap,oapl,z,
&              sum,dn,dnpl,h,q,rol,iohd,adi,tdi,y,x,l,ql,
&              roll,c,e,dlt,apf,sdltrf,pol,fw
c
       dimension f(50,101),oap(50,101),pc(50,101),hc(50,101),
&           oapl(50,inv(50,fw(50),drf(50),dr(50),eatc(30,30),
&           pdltgrol(100),cddlt(100),ens(100),pddlt(100),
&           dlt(100),kdlt(100),pdd(50),cdd(50),pdlt(50),
&           cdlt(50),lt(50),klt(50)
      common d(50),l(50)
      do 1000 i = 1,10
      do 2000 j = 1,100
      pc(i,j) = 20+5*j
      hc(i,j) = j
 2000 continue
 1000 continue
      read (80,,end = 111)n,maxil,maxp,io
 111  call policy
 3    maxpl = maxp+1
      nml = n-1
      maxill = maxil+1
      dnpl = d(n)+1
      dn = d(n)
      if (d(n).eq.0) go to 5
      do 4 k = 1,dn
      f(n,k) = pc(n,d(n)-k+1)
 4    oap(n,k) = d(n)-k+1
 5    f(n,dnpl) = 0
      oap(n,dnpl) = 0
      do 16 ii = 1,nml
      i = n-ii
      sum = 0
      do 6 j = i,n
 6    sum = sum+d(j)
      sum = sum+1
      if (sum.lt.maxill) go to 7
      minlim = maxill
      go to 8
```

```
 7    minlim = sum
 8    do 16 k = 1,minlim
      if (d(i)-k+1.le.0) go to 10
      llim = d(i)-k+1
      f(i,k) = pc(i,llim)+0+f(i+1,1)
      oap(i,k) = d(i)-k+1
      llim = llim+1
      go to 11
 10   llim = 0
      f(i,k) = hc(i,k-d(i)-1)+f(i+1,k-d(i))
      oap(i,k) = 0
      llim = llim+1
 11   if(maxp.gt.sum-k) go to 12
      if(maxp.gt.d(i)+maxill-k) go to 13
      maxlim = maxp
      go to 14
 12   if(sum-k.gt.d(i)+maxill-k) go to 13
      maxlim = sum-k
      go to 14
 13   maxlim = d(i)+maxill-k
      go to 14
 14   if(llim-1.eq.maxlim) go to 16
      do 15 z = llim,maxlim
      hold = pc(i,z)+hc(i,k+z-d(i)-1)+f(i+1,k+z-d(i))
      if(f(i,k).le.hold) go to 15
      f(i,k) = hold
      oap(i,k) = z
 15   continue
 16   continue
c
      oapl(1) = oap(1,io+1)
      nei = io+1
      iadd = 0
      do 18 i = 2,n
      nei2 = oapl(i-1)-d(i-1)+nei
      oapl(i) = oap(i,nei2)
 18   nei = nei2
      read (81,,end = 222) adr,ocr,p1,p2,p3,phc,qb1,qb2,
&                          ltr,iohr
c
 222  read (82,,end = 333) adrf,ocrf,hcrf,ltrf,sdltrf,
&                          iohrf
c
 333  qr3 = sqrt((2*adr*ocr)/(0.80*phc))
      if (qr3.lt.qb2) go to 19
      qr = qr3
      go to 110
c
 19   qr2 = sqrt((2*adr*ocr)/(0.90*phc))
      if (qr2.lt.qb2) go to 20
      qr = qr2
      go to 110
c
```

```
 20   if (qr2.gt.qb1) go to 30
      go to 50
 30   tc2 = ((qr2*p2*phc)/2)+((adr*ocr)/qr2)+(adr*p2)
c
      tcb2 = ((qb2*p3*phc)/2)+((adr*ocr)/qb2)+(adr*p3)
      if (tc2.lt.tcb2) go to 40
      qr = qb2
      go to 110
 40   qr = qr2
      go to 110
c
 50   qr1 = sqrt((2*adr*ocr)/(1.0*phc))
      if (qr1.lt.qb1) go to 60
      tcb1 = ((qb1*p2*phc)/2)+((adr*ocr)/qb1)
      if (tcb1.lt.tcb2) go to 70
      qr = qb2
      go to 110
c
 70   qr = qb1
      go to 110
c
 60   tc1 = ((qr1*p1*phc)/2)+((adr*ocr)/qr1)+(adr*p1)
      if (tc1.lt.tcb1) go to 80
      if (tcb1.lt.tcb2) go to 90
      qr = qb2
      go to 110
c
 80   if( tc1.lt.tcb2) go to 100
 90   qr = qb1
      go to 110
 100  qr = qr1
c
 110  rolr = (adr/50) * ltr
c
      qrf = sqrt((2*adrf*ocrf)/(hcrf))
      jr = qrf
      rolrf = ((adrf/50) * ltrf)+((1 * sdltrf) *
&     sqrt (ltrf))
c
      adi = 0
      tdi = 0
      nso = 0
      arq = 0
      nro = 0
      aaih = 0
      tad = 0
c
c
      read (83,,end = 444) ad,orc,soc,hcd,npddlt,iohd
c
      spdlt = 0
      444 do 500 k = 1,npddlt
      read (84,,end = 555) pddlt(k)
```

```
      spdlt = spdlt+pddlt(k)
      cddlt(k) = spdlt
 500  continue
c
      555 edlt = 0
      do 510 i = 1,npddlt
 510  edlt = edlt+(i-1)*pddlt(k)
c
c
c
      do 520 rol = 1,npddlt
      ens(rol) = 0
       do 520 i = rol,npddlt
      ens(rol) = ens(rol)+(i-rol)*pddlt(i)
 520  continue
c
      do 530 rol = 1,npddlt
      k = rol
 530  pdltgrol(rol) = 1.0-cddlt(rol)
c
      irol = npddlt
      itr = 1
c
c
 540  q = sqrt(( 2*ad*(orc+soc*ens(irol)))/hcd)
      ql = q
c
      s = (hcd*ql)/(soc*ad)
      do 550 rol = 1,npddlt
      if (pdltgrol(rol).le.x) go to 560
 550  continue
 560  roll = rol
c
      if (roll.eq.irol) go to 570
      if (itr.eq.50) go to 570
      itr = itr+1
      irol = roll
      go to 540
c
 570  do 600 i = 1,3
      c = ql-2+i
      do 590 j = 1,3
      e = roll-2+j
      eatc(i,j) = orc*(ad/c)+soc*(ad/c)+ens(e)+hcd*(e+c/
&     2.0-edlt)
      if (i.gt.1.and.j.gt.1) go to 580
      g = eatc(i,j)
 580  if (eatc(i,j).gt.g) go to 590
      g = eatc(i,j)
 590  continue
 600  continue
      q = c
      rol = e
```

```
c
      adirf = 0
      tdirf = 0
      adir = 0
      tdir = 0
      iadd = 0
c
      call demand
      call lead
c
      do 5000 i = 1,50
      t = i
      drf(i) = oapl(i)
      if (tdirf.ne.t) go to 120
      iohrf = iohrf+qrf
      adirf = 0
 120  yrf = iohrf-drf(i)
      if (yrf.gt.0) go to 130
      apf = iohrf
      iohrf = 0
      go to 140
 130  iohrf = yrf
      apf = drf(i)
 140  xrf = iohrf+adirf
      if (xrf.gt.rolrf) go to 150
      dr (i) = qrf
      adirf = qrf
      tdirf = t+ltrf
      go to 160
 150  dr(i) = 0
 160  if (tdir.ne.t) go to 170
      iohr = iohr+qr
      adir = 0
 170  yr = iohr-dr(i)
      if (yr.gt.0) go to 180
      qrf = iohr
      iohr = 0
      go to 190
 180  iohr = yr
      qrf = jr
 190  xr = iohr+adir
      if (xr.gt.rolr) go to 210
      adir = qr
      tdir = t+ltr
 210  k = i-1
      fw(i) = fw(k)+apf
      if (tdi.ne.t) go to 230
      iohd = iohd+q
      adi = 0
 230  y = iohd-d(i)
      if (y.gt.0) go to 240
      iohd = 0
```

```
      go to 250
240   iohd = y
250   x = iohd+adi
      if (x.gt.rol) go to 260
      if (q.gt.fw(i)) go to 260
      fw(i) = fw(i)-q
      adi = q
      tdi = t+l(i)
260   write (52,220) t,iohd,iohrf,iohr,oapl(i),apf,fw(i)
5000  continue
220   format (2x,i6,2x,i6,2x,i6,2x,i6,2x,i6,2x,i6,2x,i6)
      call exit
      end

      subroutine demand
      common d,l
      integer d
      dimension d(50),l(50)
      nr = 1111
      it = 1
      ir =-91
      ix = 200*it+ir
      do 10 i = 1,50
      irn = ix*nr/10000
      nr = ix*nr-irn*10000
      if ( nr.gt.0.and.nr.lt.1001) go to 1
      if (nr.gt.1000.and.nr.lt.4001) go to 2
      if (nr.gt.4000.and.nr.lt.7001) go to 3
      if (nr.gt.7000.and.nr.lt.9001) go to 4
      if (nr.gt.9000.and.nr.lt.9501) go to 5
      if (nr.gt.9500) go to 6
1     d(i) = (((nr - 0)/1000.) * 10) + 0
      go to 10
2     d(i) = (((nr - 1000.)/3000.) * 10) +10
      go to 10
3     d(i) = (((nr - 4000.)/3000.) * 10 ) + 20
      go to 10
4     d(i) = (((nr - 7000.)/2000.) * 10 ) + 30
      go to 10
5     d(i) = (((nr - 9000.)/500.) * 10 ) + 40
      go to 10
6     d(i) = (((nr - 9500.)/500.) * 10 ) + 50
10    continue
      return
      end

      subroutine lead
      common d,l
      integer l
      dimension l(50),d(50)
      nr = 6123
      it = 6
      ir =-91
```

```
      ix = 200*it+ir
      do 20 i = 1,50
      irn = ix*nr/10000
      nr = ix*nr-irn*10000
      if (nr.gt.0.and.nr.lt.501) go to 1
      if (nr.gt.500.and.nr.lt.1001) go to 2
      if (nr.gt.1000.and.nr.lt.4001) go to 3
      if (nr.gt.4000.and.nr.lt.8501) go to 4
      if (nr.gt.8500.and.nr.lt.9501) go to 5
      if (nr.gt.9500) go to 6
1     l(i) = 5
      go to 20
2     l(i) = 6
      go to 20
3     l(i) = 7
      go to 20
4     l(i) = 8
      go to 20
5     l(i) = 9
      go to 20
6     l(i) = 10
20    continue
      return
      end

      subroutine policy
      common d,l
      integer d
      dimension d(50),l(50)
      external random_£uniform(descriptors)
      do 10 i = 1,50
      call random_£uniform(x)
      p = abs(x-int(x)) * 10000
      d(i) = int(p)
      if ( d(i).gt.0.and.d(i).lt.1001) go to 1
      if (d(i).gt.1000.and.d(i).lt.4001) go to 2
      if (d(i).gt.4000.and.d(i).lt.7001) go to 3
      if (d(i).gt.7000.and.d(i).lt.9001) go to 4
      if (d(i).gt.9000.and.d(i).lt.9501) go to 5
      if (d(i).gt.9500) go to 6
1     d(i) = (((d(i) - 0)/1000.) * 10) + 0
      go to 10
2     d(i) = (((d(i) - 1000.)/3000.) * 10) +10
      go to 10
3     d(i) = (((d(i) - 4000.)/3000.) * 10 ) + 20
      go to 10
4     d(i) = (((d(i) - 7000.)/2000.) * 10 ) + 30
      go to 10
5     d(i) = (((d(i) - 9000.)/500.) * 10 ) + 40
      go to 10
6     d(i) = (((d(i) - 9500.)/500.) * 10 ) + 50
10    continue
      return
```

```
      end
```

changes to the program as result of adding systems two and three

```
 210   k = i-1
      fw(i) = fw(k)+apf
c
      if (tdi.ne.t) go to 230
      iohd=iohd+s
      adi=0
 230  y=iohd-d(i)
      if (y.gt.0) go to 240
      iohd = 0
      go to 250
 240  iohd = y
 250  x=iohd+adi
      if (x.gt.rol) go to 261
      if (q.gt.fw(i)) go to 260
      fw(i) = fw(i) - q
      adi = q
      s = q
      tdi = t + l(i)
      go to 261
 260  oapl(i+1) = oapl(i+1) + (maxp * 0.5)

 261  if (fw(i).ge.q) go to 270
```

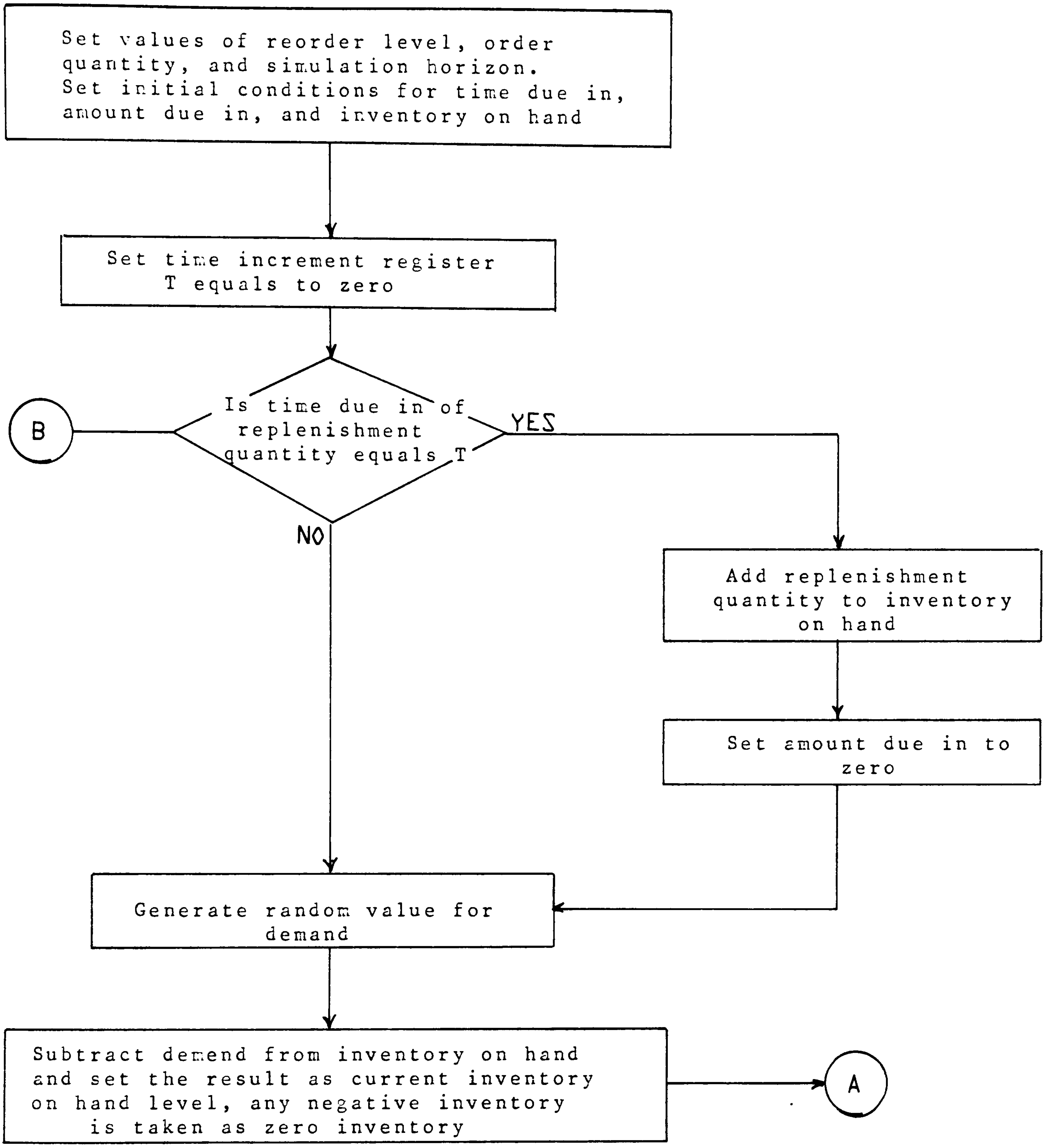

Fig.(5.1) Flow diagram of inventory system

```
      go to 250
240   iohd = y
250   x = iohd+adi
      if (x.gt.rol) go to 260
      if (q.gt.fw(i)) go to 260
      fw(i) = fw(i)-q
      adi = q
      tdi = t+l(i)
260   write (52,220) t,iohd,iohrf,iohr,oapl(i),apf,fw(i)
5000  continue
220   format (2x,i6,2x,i6,2x,i6,2x,i6,2x,i6,2x,i6,2x,i6)
      call exit
      end

      subroutine demand
      common d,l
      integer d
      dimension d(50),l(50)
      nr = 1111
      it = 1
      ir =-91
      ix = 200*it+ir
      do 10 i = 1,50
      irn = ix*nr/10000
      nr = ix*nr-irn*10000
      if ( nr.gt.0.and.nr.lt.1001) go to 1
      if (nr.gt.1000.and.nr.lt.4001) go to 2
      if (nr.gt.4000.and.nr.lt.7001) go to 3
      if (nr.gt.7000.and.nr.lt.9001) go to 4
      if (nr.gt.9000.and.nr.lt.9501) go to 5
      if (nr.gt.9500) go to 6
1     d(i) = (((nr - 0)/1000.) * 10) + 0
      go to 10
2     d(i) = (((nr - 1000.)/3000.) * 10) +10
      go to 10
3     d(i) = (((nr - 4000.)/3000.) * 10 ) + 20
      go to 10
4     d(i) = (((nr - 7000.)/2000.) * 10 ) + 30
      go to 10
5     d(i) = (((nr - 9000.)/500.) * 10 ) + 40
      go to 10
6     d(i) = (((nr - 9500.)/500.) * 10 ) + 50
10    continue
      return
      end

      subroutine lead
      common d,l
      integer l
      dimension l(50),d(50)
      nr = 6123
      it = 6
      ir =-91
```