CHAPTER 3

3.0 MANUFACTURING SYSTEM DESIGN
FOR DYNAMIC ANALYSIS

3.1 INTRODUCTION 16
3.2 REASONS TO CARRY OUT THE WORK 16
3.3 DEFINING MANUFACTURING SYSTEM 17
3.4 DEVELOPMENT OF A DYNAMIC MODEL 18
3.5 STRUCTURE OF THE DYNAMIC MODEL 18
3.6 MANUFACTURING SYSTEM ELEMENTS AND SUBSYSTEMS 23
3.7 SYSTEM SIMULATION 36
3.8 DISCUSSION 44
3.9 CONCLUSIONS 45
PAPERS PUBLISHED


3.1 INTRODUCTION

This chapter deals with the analysis of the dynamic behaviour of manufacturing systems under fluctuating market conditions through Industrial Dynamics approach. The main objective of this chapter is to design and analyse the behaviour of manufacturing systems in terms of their inputs, outputs under internal and external environment, subsystems and interconnecting networks to cater to the need of market conditions. The other objectives are developing mathematical model representing different elements of manufacturing systems using Industrial Dynamics approach and then studying the model behaviour through digital computer simulation.

3.2 REASONS TO CARRY OUT THE WORK

The objective of this thesis as identified from the point-of-view of managers whose goal is towards "productive manufacturing system design" through successful policies and networking. The main problem of manufacturing planning is to bring about desirable changes inhibiting unsought variations. Since manufacturing planning usually suffers from three weaknesses such as (a) lack of effectiveness (b) bad forecasts and (c) poor response to changes in markets, the management needs to complement planning through enhanced control. Industrial Dynamics [4] approach covers both planning and theory of control action.

Apart from the above stated reason, manufacturing systems are so complex [36] that a knowledge of the system elements taken separately is not sufficient. The interconnections and interactions between the elements of the system will be more important than the separate elements themselves. The manufacturing systems are highly dynamic in nature, as they encompass numerous ever changing dimensions. These characteristics of system complexity and time orientation of manu-
Manufacturing systems need an effective tool which should provide a basis for the design of more effective manufacturing systems. Since *Industrial Dynamics* is particularly most suited for the study of complex systems and dynamic problems and moreover is also a quantitative and experimental technique, this approach has been chosen for the study.

### 3.3 DEFINING MANUFACTURING SYSTEMS

To enrich the meaning of manufacturing systems, it is desirable to describe their basic characteristics by identifying the following five attributes:

1. System objectives (Performance criteria)
2. Environment
3. Resources (Inputs)
4. Activities including Outputs and
5. Management (Planning and control feedback)

#### 3.3.1 Manufacturing Systems and their Parameters

The manufacturing systems can be described by defining the parameters like manufacturing system inputs, outputs, system environment, functional subsystems, their interrelationships and the flow networks that combine all these subsystems.

#### 3.3.2 Inputs

Manufacturing system resources or inputs represent the variety of means under control that management can use to achieve its objectives. Included here are the human resources, available capital equipment, services from the suppliers, and money.
3.3.3 Activities including outputs

Normally the activities of manufacturing system include capacity utilisation, minimum WIP and outputs such as maximum throughput, customer services, return on investment, finished goods, payment of taxes & loans and waste disposal etc.,

3.3.4 Environment

The environment consists of all significant factors that affect the manufacturing system. Most significant among them are factors relating to

a) The economic environment
b) The natural environment
c) The Government
d) The social and economical environment
e) The technological environment.

3.4 DEVELOPMENT OF A DYNAMIC MODEL

Industrial dynamics approach used in this work helps for studying the behaviour of manufacturing systems and also shows how policies, decisions structure and delays are interrelated to influence the growth and stability. The dynamic mathematical model is written in a symbolic language to describe manufacturing systems. Model building has been started with a verbal description and then refined until it can be translated into mathematical language. The mathematical model developed would be a basis for investigations. This dynamic mathematical model deals with time-varying interactions.

3.5 STRUCTURE OF THE DYNAMIC MODEL

Before writing a mathematical equation a basic model structure or flow diagram is used to represent the nature of systems. The Fig.3.1 shows the model structure with features as detailed below:
Fig. 3.1 BASIC MODEL STRUCTURE
REPRESENTING DYNAMIC CONDITIONS

i. *Levels* indicate variables subject to fluctuation. Levels are the present values of these variables that have resulted from the accumulated differences between inflows and outflows. The levels determine the decisions that control flow rates.

ii. *Flows* that transport the contents of one level to another. Flow rates cause changes in levels.

iii. *Decision functions* that control the rates of flow between levels. These are called rate equations and standard policies.

iv. *Information channels* that connect the decision function to various levels. The information network is the connecting layer that interrelates the other networks.
3.5.1 Delays

Delays exist in all flow channels. The delay is a special category level. They are represented by a combination of rates and level equations. Delays have two characteristics, firstly the length of time expressing the delay and second the frequencies of outflow related to inflow rate. Different delays have the source of average delay 'D' with different transient response to changes in input rates.

The exponential delays are simple in form and they have adequate scope to fit the usual degree of knowledge about the actual system represented. A first order exponential delay as shown in Fig. 3.2 consists of a simple level which absorbs the difference between inflow and outflow and a rate of outflow depending on the level. The inflow rate is determined by some other part of a system.

\[
\text{OUTFLOW RATE} \quad (1.1 \text{ R, Refer Fig.3.2})
\]

\[
\text{OUT.KL} = \text{LEV.K}/\text{DEL}
\]

\[
\text{THE LEVEL STORED} \quad (1.2 \text{ L, Refer Fig.3.2})
\]

\[
\text{LEV.K} = \text{LEV.J} + \text{DT(\text{IN.JK-OUT.JK})}
\]
SYMBOLS EXPLANATION

OUT Outflow Rate
LEV Level stored in the delay
DEL A Constant
DT Solution Interval

3.5.2 System Equations

The model structure described in Fig. 3.4 to 3.10, leads to a simple set of equations that suffices for representing information feedback systems. The equation tells how to generate the system conditions for a new point of time for given conditions known from the previous point of time. The equations of the model are evaluated repeatedly to generate the sequence of steps at regular interval of time, DT, Fig 3.3. Level equations and rate equations generate the levels and the rates of the basic model structure. The interval time between solutions must be relatively short, determined by the dynamic characteristics of the real system that is being modeled.

Fig. 3.3 COMPUTING SEQUENCE FOR LEVEL CALCULATION
3.5.2.1 Symbols in Equations

Symbols given in the nomenclature represent quantities in equations of the model and are so chosen to have as much mnemonic significance as possible. Only groups of English letters and numerical are used to signify the variables and constants.

For example,

1. RCP Requisitions in Clerical Processing
2. RRR Requisitions Rate Received

3.5.2.2 Time Notations in Equations

To designate time, one or two capital letters are used following a variable and separated by a period, Fig.3.3. For example, the level requisitions at time J would be RCP.J, and at time K would be RCP.K. The rates are shown by double letter as JK or KL. Thus the requisition rate which existed during the interval from J to K is written as RRR.JK and the rate which will exist in the succeeding interval is RRR.KL.

3.5.2.3 Classes of Equations

The following list gives the various types of equations and constants represented by letters given in the brackets.

a. Level equations (L)
b. Rate equations (R)
c. Auxiliary equations (A)
d. Supplementary equations (S)
e. Initial value equations (N) and
f. Constants (C)
In this chapter, a complete list of equations developed for the model is given. The left hand side letter indicates the type of equation. These letters L, A, R, N, C, S, and X are used to indicate level, auxiliary, rate, initial condition, constant, supplementary output information, and continuation card respectively.

3.5.2.4 Computing Sequence

The computing sequence as shown in Fig. 3.3 is the continuous advance of time which is broken into small intervals of equal length DT (Delta Time). This interval must be short enough such that decisions made at the beginning of the interval will not be affected by any changes that occur during that interval. At the end of the interval, new values of levels are calculated and from these, new rates are determined for the next interval.

3.6 MANUFACTURING SYSTEM ELEMENTS AND SUBSYSTEMS

The system elements are the parts of manufacturing system whose performances contribute to achieve the objectives. The manufacturing system is divided into different major functional areas as given below.

3.6.1 Order(Sales) Processing

This part of the company which receives the details of incoming sales forecast/orders routes some orders to be filled from inventory and others to be manufactured to meet the demand. The order processing has been divided into two sections viz., (1) order filling and (2) inventory recording. The order filling section, Fig. 3.4, has information about inventory of finished products and takes decision whether or not an incoming order can be filled from inventory. The inventory recording section, Fig. 3.5, maintains records of inventory after adjusting the flow of goods in response to incoming orders.
Fig. 3.5 INVENTORY RECORDING

(A) \[ \text{MOIT}.K = (\text{ASI}.K + \frac{1}{\text{TIA}})(\text{DIF}.K - \text{AIF}.K + \text{ONI}.K - \text{OAI}.K) \]

(R) \[ \text{MOI}.K = (\text{MOIT}.K, \text{IF MOIT}.K \leq 0) \]

(X) \[ (0 \text{ IF MOIT}.K > 0) \]

(N) \[ \text{MOI} = \text{SFI} \]

(L) \[ \text{ASI}.K = (\text{ASI}.J + (\text{DT})(1/\text{TASI})(\text{SFI}.JK - \text{ASI}.J)) \]

(N) \[ \text{ASI} = \text{RFI} \]

(A) \[ \text{DIF}.K = (\text{CIR})(\text{RRS}.K) \]

(L) \[ \text{RRS}.K = (\text{RRS}.J + (\text{DT})(1/\text{TRS})(\text{RRR}.JK - \text{RRS}.J)) \]

(N) \[ \text{RRS} = \text{RRR} \]

(A) \[ \text{ONI}.K = (\text{ASI}.K)(\text{DMI}.K) \]

(A) \[ \text{OAI}.K = (\text{BLI}.K + \text{OPI}.K) \]
3.6.2 Manufacturing function

The manufacturing operation, Fig. 3.6, shows two flows of finished goods - one flow that go into inventory and the other to customers requirement and demand. The equations developed give the backlogs of orders and other related resources to be generated to meet out the demands arising due to the fluctuations of market. The manufacturing processes are approximated by two steps. The first step is a point at which labour is deployed and the rate of manufacturing is controlled and the second step is that point at which the delays in manufacturing are encountered.
Fig. 3.6 MANUFACTURING FUNCTION
\((L)\)  \(BLI.K = (BLI.J + (DT)(MOI.JK - PIO.JK))\)  \[2.26\]

\((N)\)  \(BLI = (RFI) (DNBL)\)  \[2.27\]

\((L)\)  \(BLC.K = (BLC.J + (DT)(RMO.JK - PCO.JK))\)  \[2.28\]

\((N)\)  \(BLC = (RRR - RFI) (DNBL)\)  \[2.29\]

\((A)\)  \(BLT.K = (BLI.K + BLC.K)\)  \[2.30\]

\((A)\)  \(MMBL.K = (LT.K((ONBLXCNPL)))\)  \[2.31\]

\((A)\)  \(MMB.K = MENP.K IF MMBL.K \geq MENP.K\)  \[2.32\]

\((X)\)  \(MMBL.K IF MMBL < MENP.K\)  \[2.33\]

\((A)\)  \(FLI.K = (BLI.K / BLT.K)\)  \[2.34\]

\((A)\)  \(FLCO.K = (BLC.K / BLT.K)\)  \[2.35\]

\((R)\)  \(PCO.KL = ((FLCO.K) (MBL.K) (CPL))\)  \[2.36\]

\((N)\)  \(PCO = (RRR - RFI)\)  \[2.37\]

\((R)\)  \(PIO.KL = ((FLI.K) (MBL.K) (CPL))\)  \[2.38\]

\((N)\)  \(PIO = RFI\)  \[2.39\]

\((A)\)  \(MEIP.K = (MENP.K - MBL.K)\)  \[2.40\]

\((A)\)  \(PEI.K = (MEIP.K) (CPL)\)  \[2.41\]

\((R)\)  \(PRI.KL = (PIO.KL + PEI.K)\)  \[2.42\]

\((N)\)  \(PRI = RFI\)  \[2.43\]

\((L)\)  \(OPI.K = (OPI.J + (DT)(PRI.JK - MRI.JK))\)  \[2.44\]

\((N)\)  \(OPI = (DP) (REI)\)  \[2.45\]

\((R)\)  \(MRI.KL = DELAY3(PRI.JK, DP)\)  \[2.46\]

\((L)\)  \(OPC.K = (OPC.J + (DT)(PCO.JK - SMO.JK))\)  \[2.47\]

\((N)\)  \(OPC = (DT) (RRR - REI)\)  \[2.48\]

\((R)\)  \(SMO.KL = DELAY3 (PCO.JK, DP)\)  \[2.49\]

\((L)\)  \(RMS.K = (RMS.J + (DT))\)  \[2.50\]

\((X)\)  \(RMR.JK-PRJ.JK-PCO.JK))\)  \[2.51\]

\((N)\)  \(RMR = (RRR) (CRMSH)\)  \[2.52\]

\((A)\)  \(DMI.K = (DP + BLI.K / PTO.JK)\)  \[2.53\]

\((A)\)  \(DMCO.K = (DP + BLC.K / PIO.JK)\)  \[2.54\]

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3.6.3 Material Order

The material ordering and delivery functions, Fig. 3.7 are developed using the delay (third order exponential delay) so that the plan of material flow can be properly generated. The raw materials desired at the factory against the adequacy of actual stock can be compared. The raw material purchasing rate will depend upon the rate of usage of materials in production and the delay in adjusting the inventory stock and the raw material flow. The necessary raw material purchase orders and the flow of materials to the shop floor are proportional to the average sales/demands of the products manufactured.

Fig. 3.7 MATERIAL ORDERING
3.6.4 Personnel Flow

The personnel flow, Fig. 3.8, is necessary to be adjusted to meet the varying flow of incoming orders from the customers and the resulting manufacturing rate which in turn is controlled by the labour input. The personnel loop consists of available manpower, hiring decision, initial training period and the level of manpower available for manufacturing. Several other concepts are developed in a series of auxiliary equations dealing with the desired manpower for the average manufacturing rate and the manpower necessary for adjusting the undesirable level of order back logs.
Fig. 3.8 PERSONNEL FLOW
\textbf{(L)} \quad \text{LIT}.K = (\text{LIT}.J + (\text{DT})(\text{LHR}.JK - \text{LEP}.JK)) \quad 4.60

\textbf{(N)} \quad \text{LIT} = 0 \quad 4.61

\textbf{(R)} \quad \text{LEP}.KL = \text{DELAY} 3(\text{LHR}.JK, DLT) \quad 4.62

\textbf{(L)} \quad \text{MENP}.K = (\text{MENP}.J + (\text{DT})(\text{LEP}.JK - \text{LDNR}.JK)) \quad 4.63

\textbf{(N)} \quad \text{MENP}.K = (\text{MENP}.J + (\text{DT})(\text{LEP}.JK - \text{LDNR}.JK)) \quad 4.64

\textbf{(L)} \quad \text{LLF}.K = (\text{LLF}.J + (\text{DT})(\text{LDNR}.JK)(\text{LTER}.JK)) \quad 4.65

\textbf{(N)} \quad \text{LLF} = 0 \quad 4.66

\textbf{(R)} \quad \text{LTER}.KL = \text{DELAY} 3(\text{LDNR}.JK, OLL) \quad 4.67

\textbf{(A)} \quad \text{LAS}.K = \text{RRS}.K /\text{CPL} \quad 4.68

\textbf{(A)} \quad \text{BLN}.K = (\text{RRS}.K)(\text{DNBL}) \quad 4.69

\textbf{(A)} \quad \text{LBLA}.K = ((\text{BLT}.K - \text{BLN}.K)/\text{CPL})(\text{TBLA}) \quad 4.70

\textbf{(A)} \quad \text{LDP}.K = (\text{LAS}.K + (\text{LBLA}.K - \text{MSIP}.K)) \quad 4.71

\textbf{(A)} \quad \text{LCI}.K = (\text{LDP}.K - \text{LAF}.K) \quad 4.72

\textbf{(A)} \quad \text{LAF}.K = (\text{LIT}.K + \text{MENP}.K) \quad 4.73

\textbf{(A)} \quad \text{LCR}.K = (1/\text{TLC})(\text{LCI}.K) \quad 4.74

\textbf{(A)} \quad \text{LHR}.KL = \text{LCR}.K \text{ IF } \text{LCR}.K \geq 0

\textbf{(X)} \quad = 0 \text{ IF } \text{LCR}.K < 0 \quad 4.75

\textbf{(N)} \quad \text{LHR} = 0 \quad 4.76

\textbf{(R)} \quad \text{LDNR}.KL = 0 \text{ IF } \text{LCR}.K \geq 0

\textbf{(X)} \quad = -\text{LCR} \text{ IF } \text{LCR}.K < 0 \quad 4.77

\textbf{(N)} \quad \text{LDNR} = 0 \quad 4.78

\textbf{(A)} \quad \text{MENT}.K = (\text{LIT}.K + \text{MENP}.K + \text{LLF}.K) \quad 4.79

\textbf{(L)} \quad \text{LCT}.K = (\text{LCT}.J + (\text{DT})(\text{LHR}.JK + \text{LDNR}.JK)) \quad 4.80

\textbf{(N)} \quad \text{LCT} = 0 \quad 4.81
3.6.5 Finance and Accounting

This model shows how financial flows can be added to a dynamic model to monitor the financial position. Invoices for finished products traverse third order delay before being converted to a flow of cash receipts. Equations for this purposes are developed to know the cash positions. Cash flow, Fig.3.9, for raw materials, wages and taxes are calculated. Cash flow towards profit and dividends is shown in Fig.3.10.

Fig. 3.9 FINANCE AND ACCOUNTING

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FGIR.KL = ((SFI.JK + SMO.JK) (CFGP)) \( \text{(R) 5.82} \)

FGIR = (RRR) (CFGP) \( \text{(N) 5.83} \)

AR.K = (AR.J + (DT)(FGIR.JK - FGCR.JK)) \( \text{(L) 5.84} \)

AR = (RRR) (CFGP) (DAR) \( \text{(N) 5.85} \)

FGCR.KL = DELAY 3(FGIR, JK, DAR) \( \text{(R) 5.86} \)

RMIR.KL = (RMR.K) (CRMP) \( \text{(R) 5.87} \)

RMIR = (RRR) (CRMP) \( \text{(N) 5.88} \)

AP.K = (AP.J+ (DT)(RMIR.JK - RMCE.JK)) \( \text{(L) 5.89} \)

AP = ((RRR) (CRMP) (DAP)) \( \text{(N) 5.90} \)

RMCE.KL = (AP.K)/ DAP \( \text{(R) 5.91} \)

RMCE = (RRR) (CRMP) \( \text{(N) 5.92} \)

LCE.KL = (MENT.K) (CMP) \( \text{(R) 5.93} \)

LCE = (MENP) (CWR) \( \text{(N) 5.94} \)

ITAX.KL = (CTAXR) (PBTR.K) \( \text{(R) 5.95} \)

SDIV.KL = SDL.K \( \text{(P) 5.96} \)

SDT.D.K = (SDTP.J + (DT)(SDIV.JK)) \( \text{(L) 5.97} \)

SDIV = (I-CTAXR)(RRR)((CFGP-CRMP)-(CWR/CPL)) \( \text{(N) 5.97 a} \)

CASB.K = (CASB.J + (DT)(FGCR.JK - RMCE.JK)) \( \text{(L) 5.98} \)

CASB = (CNCS) (CFGP) (RRR) \( \text{(N) 5.99} \)
Fig. 3.10 PROFIT AND DIVIDENDS

(A) SDC = (CRMP + (CWR / CPL))

(A) PBTR.K = ((SFJJK) (CFGP - SDC)

(X) NJPR.KL = -(LCE JK-(MRIJK + SMOJK)(CWR/CPL))

(R) NPTD.K = (NPTD,J + (DT) (NPR.JK))

(N) NPTD = 0

(L) SDL.K = (SDL,J + ((DT)/(1/TASDL)(NPRJK-SDL.J)))

(N) SDL = ((I.CTAXR)(RRR)(CEGP-(CRMP-(CWR/CPL))))
All the above subsystems are interrelated to develop a complete model and reduced to a common basis by recognizing that any manufacturing activity consists of flow of money, orders, materials, personnel and information as per the symbols given in the Nomenclature.

3.7 SYSTEM SIMULATION

The simulation programs written in the language, 'Turbo C', operate the model with selected inputs and record the outputs. The flow charts for these programs are given in Fig.3.11 & 3.12. The analysis of market fluctuations is done by feeding the data related to demand forecast, various delays like order processing, filling the orders, backlogs and shipment of goods. The program is used to study the behaviour of the model for the desired duration of the simulation run, through the output data and plots of the required variables. Variation in system parameters can be tested to identify the policies to which the system is sensitive. Changes in system organizations and policies can be made to improve the capacity utilisation, stability of employment, cash position, backlog variation and delivery delays without requiring large inventories and inventory fluctuations.

3.7.1 Test Run of the Model

An informative and the simplest test input for the study of system dynamics is the step function. This is a sudden rise in distribution caused by changing an external system input to a new value that is then held constant for the rest of the study. This program is tested for steady state input of 3000 (RRR) units per week and 20% (C=600/3000 units) sudden increase in the input which is held constant during the remaining testing period of 50 weeks (S). The program is so flexible to accommodate the study for a full year with periodic (sinusoidal) inputs at intervals of any suitably desired duration of an hour, day, week or month. The results displayed in Table 3.1 and 3.2 are for the above sets of values for selected parameters and step increase in sales. The figures 3.13 to 3.18 are the plotted graphical outputs graphs for the selected inputs, (RRR=3000, DT=0.5, S=50, C-20).
Fig. 3.11 FLOW CHART FOR MARKET FLUCTUATION ANALYSIS

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Fig. 3.12 ALGORITHM FOR SIMULATION OF FLOW RATES IN MANUFACTURING SYSTEMS

For i=0 to n
Print the selected variables

For i=0 to n calculate steady state values for levels and rates

Plot the n of selected variables

Values satisfied

No

Stop

Yes

Change policies to select new values for constraints

START

Input selected constants and steady state incoming order rate (RRB)

L=0 calculate steady state values for levels n rates

Changes observed in RRB

No

Stop

Yes

Input increase or decrease in RRB (C)

RRB1 = RRB(1+C/100)

Select solution interval (BT) and period of simulation (S)

No. of runs required

N=int(S/BT)

I = I+1

Yes

I< N

No

Convert the values for all variables using initial values & RRB

Convert these values to initial values

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Table 3.1

SOME OF THE SELECTED OUTPUT
FOR A STEP CHANGE IN RRR

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SOME OF THE SELECTED OUTPUTS
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Fig. 3.13 INVENTORY LEVELS AT FACTORY

Fig. 3.14 FACTORY BACKLOGS
Fig. 3.15 LEVELS OF RAW MATERIALS

Fig. 3.16 REQUISITIONS FILLED FROM INVENTORY & MANUFACTURED TO ORDER
Fig. 3.17 LABOUR FLOW

Fig. 3.18 CASH FLOWS
3.7.2 Presentation of the results

The results displayed are for a chosen time interval (DT) of half-a-week. Figure 3.13 shows the 20% step input for RRR and the resulting level of inventories. The desired inventory level slowly increased to a steady state of 14400 units, Fig.3.13, whereas the actual inventory remained at a value of 12,261 (Table 3.1). Based on these data, the inventory policy of holding stock of order requirement of four weeks (3000 units of RRR/week X 4 weeks = 12000) is framed. Figure 3.14 shows the relations between normal backlog and actual total backlog of orders. Since the actual total backlog is different from normal backlog, there is a need to generate additional manpower that would be necessary to reduce the backlog.

Figure 3.15 shows the raw material stock at the factory and the raw material wanted for manufacturing. The raw material stock remains steady throughout the test period for steady state input, Fig.3.15. But a corrective action has to be taken to set right the raw material stock to the desired level for a step increase in products demand. The ratios of requested order rates met from the actual inventory expressed as fractions of RRR to inventory are shown in the Fig.3.16. The comparison of the desired labour level with the actual labour level at the factory is presented in Fig.3.17. Because of total backlog, the desired labour will go on increasing until further actions are taken to adjust the labour level suitably. Figure 3.18 presents three cash flow variables namely cash balance, profit rate per week and net profit. Cash balance line shown in this figure indicates the rate of money generation.

3.8 DISCUSSION

A general model developed for the dynamic analysis of batch Manufacturing Systems is presented in this chapter. By testing this proposed model with the use of a computer, it is found that a change in any one of the
system variables affects many other system parameters and the performance. Study of system dynamics is not possible by conventional approach due to a very large number of interrelated variables. So it is concluded that, the approach followed in this thesis is indispensable to get a realistic analysis related to market conditions of any proposed manufacturing system. This new simulation program enabled the study of dynamic behaviour of manufacturing systems with respect to market conditions through the analysis of the model behaviour over a period of an year for the required levels of cash balance, inventory, profit rate, man power, total shipments to the customers etc.. In order to observe a plausible system behaviour of a manufacturing system, a certain parameters need to be assumed. The first parameter encountered in the equation is solution interval (DT). The behaviour of selected variables are observed for DT values of 0.125, 0.25, 0.5 and 1.0 week. Since the amplitudes of peak values of variables are observed during preliminary test run were high and significant for lower values of DT and vice versa, it is concluded that DT must be as short as possible. The model is tested for a sudden change in incoming order rate and for such an input rate it is found that labour requirement, inventories, cash balance and backlogs fluctuated a great deal.

Apart from this, variations in other system parameters could be incorporated to determine the policies to which the system is more sensitive. The management could concentrate on those parameters which affect the outputs considerably. Thus suitably framed policies based on dynamic response of the system enable to get the desired manufacturing rate to meet effectively the fluctuating market conditions.

3.9 CONCLUSIONS

It is concluded from the above discussion that the mathematical model developed had helped the dynamic analysis of the manufacturing system. Sufficient data about the variables of manufacturing are necessary for effective analysis of the dynamic behavior of manufacturing systems. It is also clear from the test results that the data of variables greatly influence the system performance. This proves that any manufacturing system can
be modelled and analysed through systems approach. This dynamic analysis of the behaviour of the designed manufacturing system under the chosen fluctuating condition of market had resulted in the desired outcome of the rate of manufacturing required, inventory of materials, manpower requirement and cash flows for the envisaged profit. Now the task is to draw out dynamic schedules for the manufacturing system to physically realise the above desired outcome. The sequence planning, capacity planning and scheduling procedures for batch manufacturing systems such as job shop, flexible manufacturing systems and cells are discussed in the Chapters 4-9.