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AN INDUSTRIAL DYNAMICS STUDY OF AN ELECTRONIC EQUIPMENT COMPANY

A THESIS

Presented to

The Faculty of the Graduate Division

by

Arthur Luedtke, Jr.

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial Engineering

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AN INDUSTRIAL DYNAMICS STUDY OF AN ELECTRONIC EQUIPMENT COMPANY

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CHAPTER I

INTRODUCTION

There is a large number of companies confined within the broad term "electronics industry." The model presented in this study is concerned with a company specializing in the manufacture of electronic equipment. Since this model employs proprietary financial information, the actual name of the company will not be disclosed.

The company under consideration has six product lines. Each product line is subject to fluctuations which are determined by the nature of its particular demand. However, in each of the product lines a typical relationship between production rate and inventory is as shown in Figure 1.

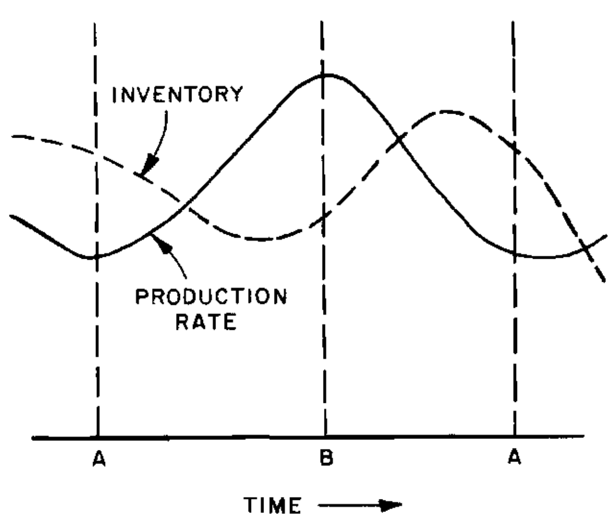

Figure 1. Production-Inventory Relationship

It is significant that inventory peaks occur after the production rate peaks and before the production rate minimum. This means that part of the customer demand is being filled from inventory. Therefore, the production rate at the time marked A is lower than the rate of sales, whereas the production rate at B is higher than the rate of sales. Production rate is, therefore, varying more widely than sales. This cause-and-effect relationship between sales, production rate, and inventory has convinced certain members of management that similar fluctuations exist among other significant variables, and that ultimately the financial success of the company depends upon the proper control of these interrelationships.

Objectives

The purpose of this study is to develop a simulation model for analyzing the effects of some selected variables on the company's overall performance. The simulation model will be developed by means of the industrial dynamics technique originated by Professor J. W. Forrester and his associates at the Massachusetts Institute of Technology[7]. The selected variables are: (1) the exogenous input to the model represented by requisition receiving rate, and (2) structural model parameters such as raw material price, productivity of labor, and wage rate. The company's performance is measured in terms of accounts payable, accounts receivable, actual inventory, backlog total, cash balance, profit before taxes, and raw materials inventory.

Scope and Limitations

The general model to be developed is to portray the time-varying behavior of the company over a fifty-two week period. The model considers only eight sectors within the company which are as follows: (1) customer sales ordering, (2) order filling, (3) inventory ordering, (4) manufacturing, (5) labor, (6) material ordering, (7) cash flow, and (8) profit.

It is assumed in the model that customer ordering is independent of the actions taken by the company in meeting the customer's delivery requirements. This assumption can be made because the company's delivery dates are consistent with the delivery dates of other companies within the electronics industry. If delivery dates should become excessive at a later date then provisions would have to be made in the model to reflect the changes. These ordering patterns may be determined from past history and projected by forecasting methods to give us an input which activates the model.

Prior Research

The field of mathematical economics, commonly called econometrics, has a rich history of attempts to analyze economic systems or components of an economic system. R. G. D. Allen's[1] text, Mathematical Economics, summarizes past attempts to analyze economic systems using classical mathematics. Models developed by economists such as Harrod[8], Domar[5], Phillips[17], Hicks[9], Samuelson[19], and Kalecki[12] represent attempts to describe dynamic economic behavior using a limited number of variables.

A review of these models, however, reveals serious practical limitations of classical mathematical methods for the analysis of large-scale dynamic systems. When compared with the computer simulation approach to model building, classical mathematical methods have the following limitations: (1) the number of variables must be relatively small, (2) the effects of delays between variables are not considered, and (3) the relationships between variables are assumed to be continuous functions. These difficulties are easily overcome in the computer simulation approach. The number of variables may be as large as several hundred, the provision for delays adds to the realism of the models, and discontinuous relationships can be handled easily by means of table functions.

There have been many recent attempts to analyze large-scale dynamic economic systems using computer simulation. The econometric model of the United States economy developed by Duesenberry, Fromn, Klein, and Kuh[6] is a representative example of such analysis at the macroeconomic level of aggregation. A number of simulation models concerned with description of particular industries also have been developed. Examples of these models are the shoe, leather, and hide industries study of Cohen[4], the lumber industry study of Balderston and Hoggatt[2], the nuclear fuel manufacturing industry study of Hurford[11], and the copper and aluminum industries study of Schlager[20].

Economic simulation models also have been developed which are sufficiently detailed as to consider individual consumers as basic components of the economic system. The simulation model of Orcutt, Greenberger, Korbel, and Rivlin[15] is representative of models at this level of detail. Models concerned with detailed description of a firm as a component of the overall economic system have been developed by Bonini[3], Tonge[21], Hoggatt[10], Nord[14], Kinsley[13], and Packer[16], and are representative of economic models at the microeconomic level of economic system analysis.

Analog computers have been used in the past for simulating both economic and engineering models. Because the flow diagram of an analog model contains elements which represent terms in the classical mathematical model, the analog model flow diagram assists in visualization of the behavior of the physical system. However, other characteristics of analog computers, such as scaling problems, model size limitations, and noise level effects on accuracy, limit their capability relative to large-scale system analysis.

In 1961, Forrester[7] presented a simulation method which he had developed and named "Industrial Dynamics." This simulation method considers any or all of six basic flows, namely: information, labor, equipment, orders, materials, and money. The simulation computation is in the form of linear difference equations. The model equations are of three main types: level, rate, and auxiliary. The level equations algebraically sum inflows and outflows at points of interest in the six or less basic flows. The rate equations specify the rate of inflow to or outflow from each level, and the auxiliary equations are mathematical representations of the decision processes employed in the real-world system. The auxiliary equations serve as inputs to the rate equations, and therefore, affect the flow rates.

In 1963, Pugh[18] wrote a manual entitled <u>DYNAMO User's Manual</u> which describes a digital computer simulation language specifically developed for programming industrial dynamics models. Pugh states that DYNAMO consists of approximately 10,000 instructions written in machine language and that its development required six man-years of effort. He also states that DYNAMO can handle models containing as many as 1,400 equations, which provides an indication of the model size capability.

Procedure

The material discussed in the succeeding chapters of this study is concerned with the realization of objectives stated earlier. Chapter II deals with preliminary model formulations. Chapter III discusses the development of some 140 model equations. Chapter IV presents the discussion of simulation results. Chapter V contains conclusions and recommendations for further research.

CHAPTER II

PRELIMINARY MODEL FORMULATION

Model Description

In industrial dynamics, a large number of variables may be considered for inclusion in a model. These variables are divided into two parts: (1) a set of "endogenous" variables which are concerned with the structure of the model, and (2) a set of "exogenous" variables which describe environmental conditions affecting the model.

Any industrial dynamics model, however complex, consists of three parts:

1. Input, which is represented by a set of exogenous variables.

2. The structure of the simulated system which is represented by a set of endogenous variables.

3. Output which consists of a time dependent printout and plot of the values of selected endogenous and/or exogenous variables.

Figure 2 shows graphically the relationships between the three parts of an industrial dynamics model. Input is represented by an exogenous variable "X"; the structure of the simulated system is represented by the endogenous variables "A", "B", "C", and "D"; and the output is represented by the selected variables "A" and "D".

The first consideration in construction of a model is the scope of the system to be simulated. This scope may later be enlarged or reduced, but an initial determination of the general outline of the bound-

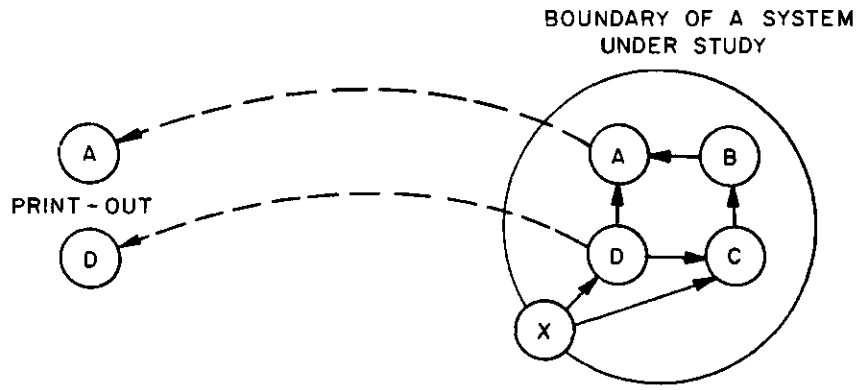

Figure 2. Industrial Dynamics Model Concept

aries of the system must be established. In this research the general boundary of the system is the company. Selected parameters within the company will be considered as the endogenous variables. A few, but by no means all, examples of the endogenous variables are order filling, inventory ordering, manufacturing, and labor. Other endogenous variables will be discussed as the model is developed.

The second consideration is the establishment of one or more exogenous variables. In this model the variable which exerts the most influence over the behavior of the company and over which the company exerts negligible influence is customer ordering. Customer ordering is the result of a number of factors, a few of which are budget, seasonality, availability, rate of obsolescence, and quality. The interaction of these and other factors produces an erratic and extremely seasonal demand pattern which affects all companies within the industry. As a result of these interactions, customer ordering will be considered the only exogenous variable in the model.

Delta Time

Inherent in any dynamic problem is the concept of incremental time, that is, the span from one time period to the next. In industrial dynamics this incremental time is known as "Delta Time" (DT). Time lagging one period in the past is represented by the letter, "J"; present time is known as "K", and time one increment into the future is time "L" as shown in Figure 3.

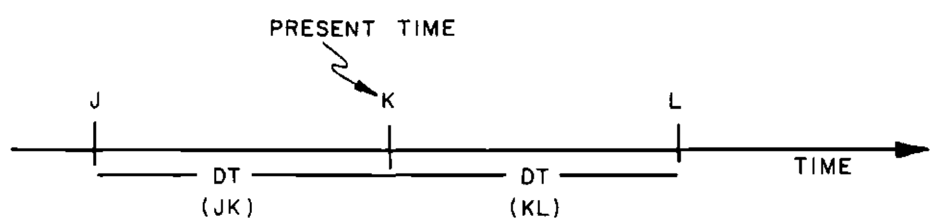

Figure 3. DYNAMO Time Concept

Delta Time may be established as large or as small as desired, but it is to be remembered that any decision made at the start of a period must apply without change throughout the period. If the decision does not apply throughout the period, then DT should be decreased until it does. In this study DT is taken as one-fourth of a week (approximately 1.25 days). Delta Time may be readily changed even after completion of the model; however, it may not be changed during an actual run of the program.

Level Equations

Resources such as men and materials are placed into the model by "level" equations. Levels may be considered as tanks or boxes which hold an amount of the resources, and they are represented on the flow diagram by a rectangle such as shown in Figure 4.

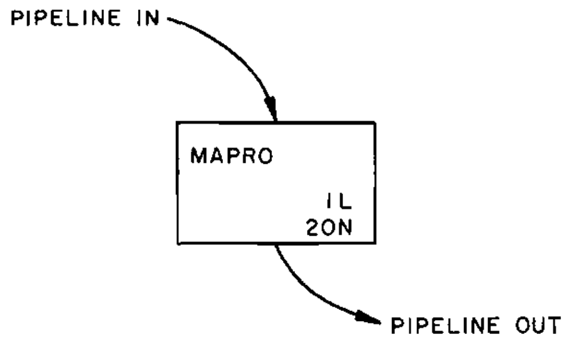

Figure 4. DYNAMO Level Symbol

The present level (K) is always equal to the level one time period ago (J) plus or minus the rate of the particular resource flowing into or out of the level during the intervening time (JK). This statement forms the basis for all level equations.

Each type of resource has its own distinct symbol showing its flow into and out of a particular level. For example, Professor Forrester distinguishes five types of flows other than information flow, namely: materials, orders, money, personnel, and capital equipment. The symbols which are used in the construction of industrial dynamics models are shown below.

Information	--------------------
Material	____________________
Orders	-O-O-O-O-O-O-O-O-O-O-O
Money	-$-$-$-$-$-$-$-$-$-$-$
Personnel	====================

Capital Equipment,

Tools, factories

Rate Equations

The flow of a resource into or out of a level is known as a "rate." The rate equation may be considered as a valve on a pipeline which permits resources to flow from one tank into another tank. This rate decision is represented by the symbol of a butterfly valve, as shown in Figure 5.

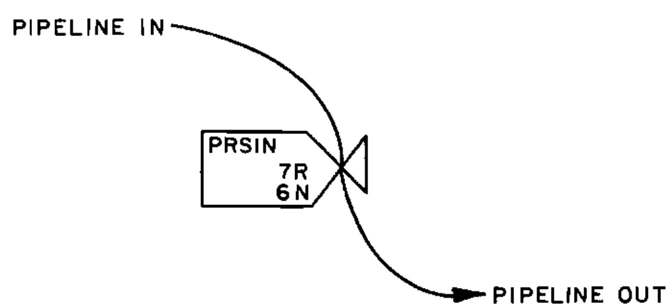

Figure 5. DYNAMO Rate Symbol

The rate for the future time interval (KL) is always dependent upon the state of the levels at the present time (K) and the rate of flows during the incremental time just past (JK).

Auxiliary Equations

In the real world, decisions are seldom based upon the state of just one flow or one level: rather the states of several flows and rates are usually combined along with certain parameters. The auxiliary equations "tie" the levels, pipelines, and rates together. They represent auxiliary decisions in the flow of information within the model.

Auxiliary equations are represented by circles. The flow of information (from levels, rates and other auxiliary variables) is represented by broken arrows, as shown in Figure 6. Auxiliary variables are always

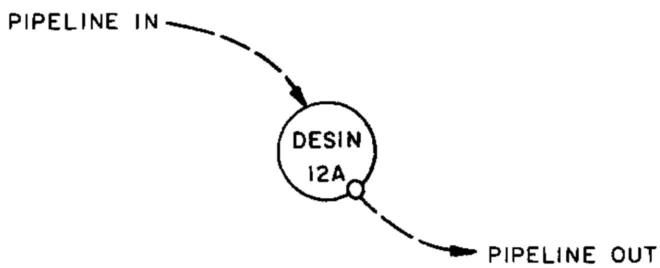

Figure 6. DYNAMO Auxiliary Symbol

computed at the present time (K) from the latest information available, i.e., time K from levels, time JK from rates, and time K from other auxiliaries. An auxiliary symbol must always have information flow in and information flow out (except in the case of the exogenous variable where information may only flow out).

Initial Conditions

As in the case of differential and difference equations, initial conditions for the system under study must be established. Each level and rate equation requires an initial condition. As auxiliary values are computed from information received from level, rate, and other auxiliary equations, they require no initial conditions. The auxiliary equations are simply centers of information exchanges.

Constants

A constant may be specified in the body of a level, rate, or auxiliary equation; or it may be expressed as a separate parameter of the system. For example, Delta Time is a parameter of the system and is expressed as:

$$DT = 0.25$$

Equation Format

Dynamo requires each equation to follow a specified format. The formats available for use are listed in the Dynamo User's Manual[18], page 52. Adequate formats exist to express most algebraical equations with a little rearrangement. Certain special function formats also are available. Each format is numbered and this number must be punched into the first space available on the IBM card. Each number is followed by the letter representing the type of equation, e.g., L for level, R for rate, A for auxiliary, N for initial condition, and C for constant.

CHAPTER III

THE MODEL

Introduction

A formal mathematical model will now be developed that describes in detail the relationships shown in Figure 7. This will be done in eight sections, namely: (1) Order Filling, (2) Inventory Ordering, (3) Manufacturing, (4) Material Ordering, (5) Labor, (6) Customer Ordering, (7) Cash Flow, and (8) Profit.

Special conditions and assumptions, if any, will be discussed in detail within their respective sections. The model will involve about seventy active variables plus some thirty initial-condition equations. Approximately twenty-eight constants are needed to define the total system.

Each section will have an associated flow chart on which are shown the more important variables and their interrelationships with one another. Conventional Dynamo notation is used on each of the flow charts.

Order Filling

The first equations to be developed will be concerned with the receipt of orders and their subsequent filling either from inventory or through manufacturing to customer order. The functions to be represented are shown in Figure 8. Inventory of finished goods and criteria for determining whether or not an incoming order can be filled from inventory are included in this section of the model.

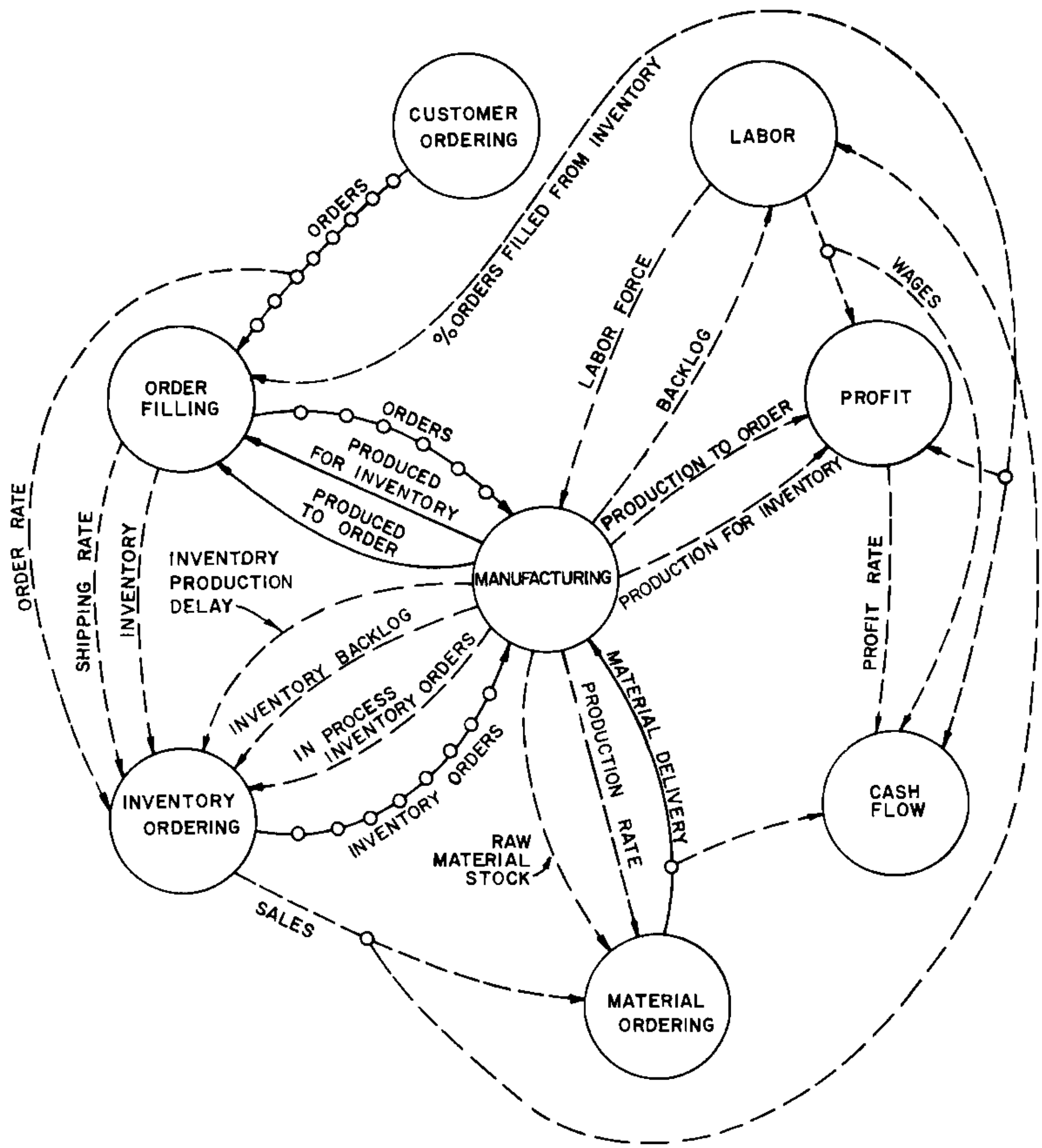

Figure 7. A Flow Diagram of Major Sections of the Mathematical Model

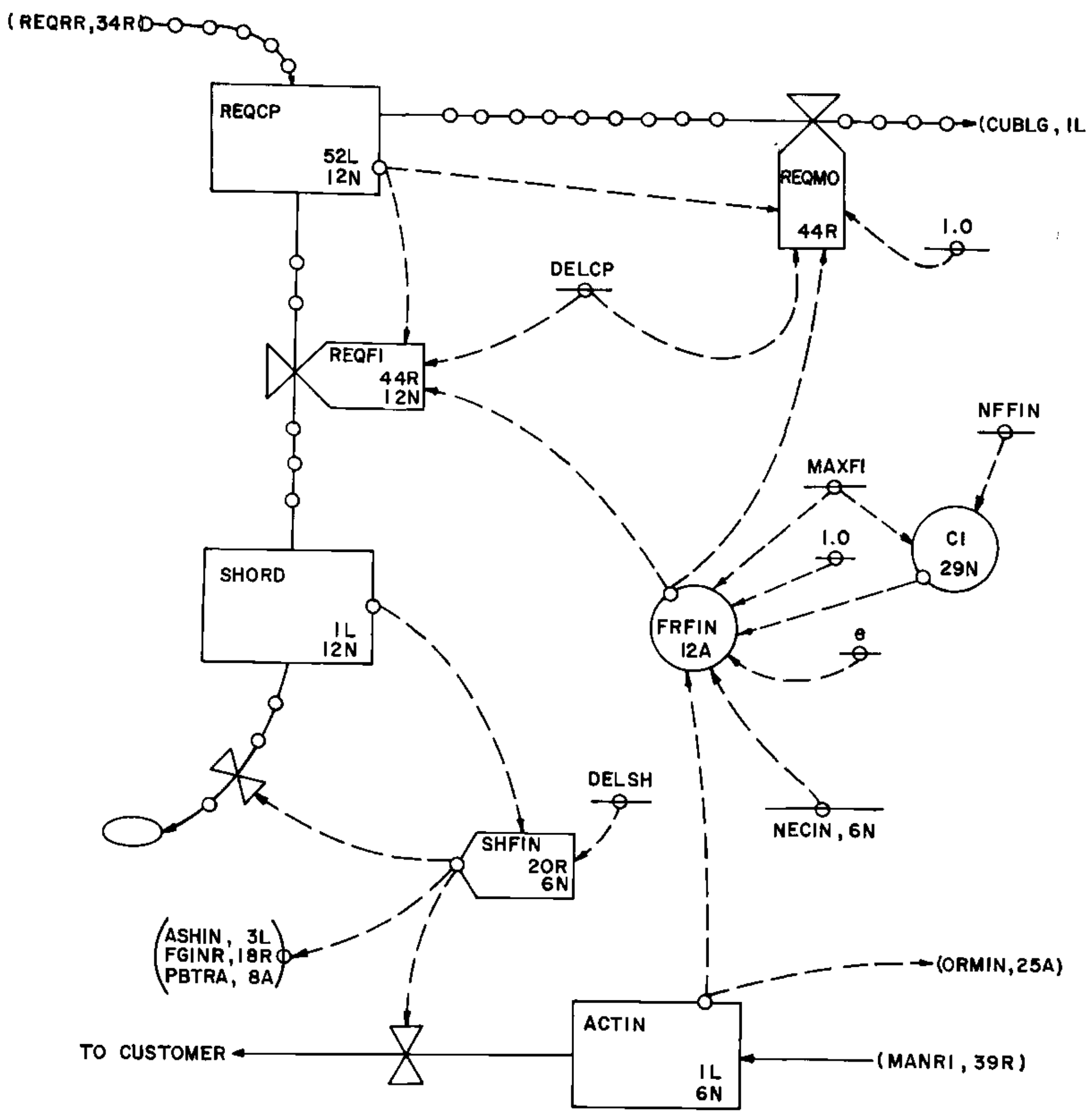

Figure 8. A Flow Diagram of the Order Filling Section

Equation (1) gives the level of incoming requisitions in clerical processing within the company REQCP, into which flow incoming orders REQRR, and out of which flow orders to be filled from inventory REQFI and orders to be manufactured to customer specification REQMO.

52L REQCP.K=REQCP.J+(DT)(REQRR.JK-REQFI.JK-REQMO.JK+0.0) (1)

12N REQCP=(REQRR)(DELCP) (2)

Equation (1) is the standard form of level equation with one inflow rate and two outflow rates. It generates the number of unprocessed orders within the company. Requisitions from customers REQRR flow in and requisitions to be filled from inventory REQFI and to be manufactured to order REQMO flow out.

Initially, REQCP is given as equal to the incoming flow of orders REQRR multiplied by an average clerical processing delay DELCP. This relationship is shown in equation (2).

Unfilled orders to ship from inventory SHORD are defined by the level equation (3).

1L SHORD.K=SHORD.J+(DT)(REQFI.JK-SHFIN.JK) (3)

12N SHORD=(REQFI)(DELSH) (4)

In equation (4) the initial steady-state level of shipping orders SHORD equals the steady-state flow of orders which can be filled from inventory multiplied by the average delay in making shipments DELSH.

Rate of orders shipped from inventory SHFIN is represented in equation (5) as a fixed fraction of the backlog SHORD.

20R SHFIN.KL=SHORD.K/DELSH (5)

6N SHFIN=REQFI (6)

C DELSH=1 week (7)

Equation (6) gives the initial value of the rate of orders shipped from inventory SHFIN, which, in the steady-state must equal the rate of orders to be filled from inventory REQFI.

Inventory of finished products is given by the level equation (8).

1L ACTIN.K=ACTIN.J+(DT)(MANRI.JK-SHFIN.JK) (8)

6N ACTIN=605 (9)

In this model inventory of finished products ACTIN is taken as 605 equivalent product units. This figure represents 80 percent of the total inventory as shown on the company's balance sheet.

Requisition rate of orders filled from inventory REQFI is represented by equation (10).

44R REQFI.KL=(FRFIN.K)(REQCP.K)/DELCP (10)

12N REQFI=(NFFIN)(REQRR) (11)

To obtain the rate of orders that can be filled from inventory REQFI, the total level of orders REQCP is multiplied by the fraction that can be shipped from inventory FRFIN and divided by the delay in clerical processing DELCP. The initial value of the rate REQFI, as given in equation (11), is the normal fraction that can be shipped from inventory NFFIN multiplied by the initial steady-state flow rate REQRR.

The average time necessary to route orders is here taken as one week.

C DELCP=1 week (12)

The rate of orders sent to the manufacturing department REQMO is simply the fraction that cannot be filled from inventory.

44R REQMO.KL=(SUBST.K)(REQCP.K)/DELCP (13)

7A SUBST.K=1-FRFIN.K (14)

To complete the order-filling sector, we need to establish the fraction of orders that can be filled from inventory FRFIN. This is intended to be a variable associated with the aggregate flow of orders for all items in the product lines. In general, we can expect that the smaller the inventory the more inadequate FRFIN will be. As the inventory drops, a larger and larger fraction of the incoming-order flow will be manufactured to customer order rather than being filled from inventory.

Figure 9 shows the kind of curvilinear relationship that is probable between the fraction of requisitions that can be filled from inventory FRFIN and the variable level of inventory represented by the ratio ACTIN/NECIN. Several considerations form the basis for this curve. Certain items in the product lines are so specialized that they are never carried in finished inventory. Therefore, there is an upper fraction MAXFI beyond which the fraction of orders to be filled from inventory cannot rise. Another significant characteristic of the curve will be the fraction of orders that can normally be filled from inventory NFFIN when inventory is at some particular level. The fraction NFFIN will always be less than the maximum fraction MAXFI. Otherwise, inventory would be unnecessarily high.

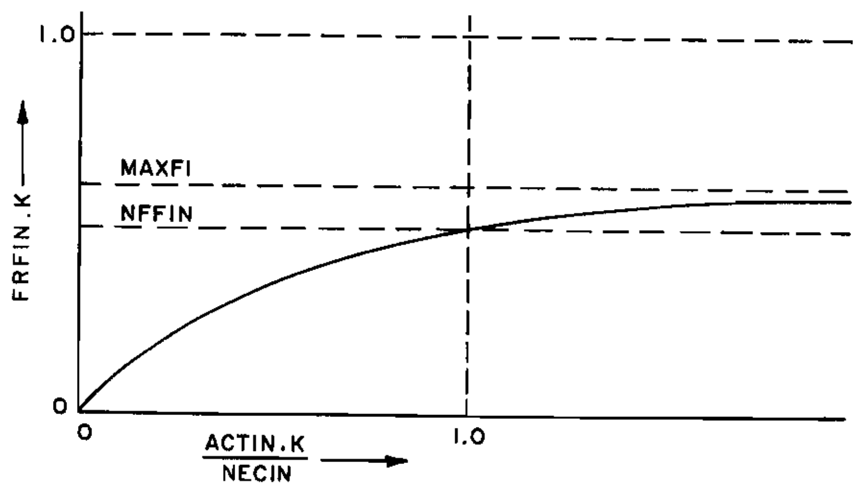

Figure 9. Requisitions Filled from Inventory

Figure 9 implies that as total aggregate inventory rises, the split fraction FRFIN rises slowly to approach the limit MAXFI, which represents the items that might conceivably be found in inventory. As inventory declines, the split fraction FRFIN falls slowly at first and then more and more rapidly as zero inventory is approached and no requisitions can be filled from inventory. The system is set up so that those requisitions that cannot be filled from inventory will be sent to the factory to be made to customer order.

The relationship, as shown in Figure 9, giving the split fraction FRFIN when inventory is known, could be provided in either of two ways in the model. A table of values for FRFIN could be stored for several levels of inventory and then intermediate values could be found by interpolation. Alternatively a mathematical relationship which has the form of the curve in Figure 9 could be used. This latter procedure will be followed whereby the split fraction is determined by equations (15) through (18).

```
12A    FRFIN.K=(MAXFI)(ROUND.K)                         (15)

7A     ROUND.K=1-WHOLE.K                                (16)

28A    WHOLE.K=(1)EXP(-HALVE.K)                         (17)

44A    HALVE.K=(C1)(ACTIN.K)/NECIN                      (18)
```

An exponential function of this kind has one degree of freedom represented by the constant C1. The constant C1 should be chosen so that the curve will go through the value NFFIN in Figure 9 when inventory equals the value of NECIN.

```
29N    C1=(1)LOGN(REMOV.K)                              (19)

48A    REMOV.K=MAXFI/(MAXFI-NFFIN)                      (20)
```

Equations (19) and (20) are initial conditions equations that define a constant which will cause the curve of Figure 9 to pass through the desired point at the specified value of NFFIN. The constant NFFIN must have a value less than MAXFI.

From considerations of the plans for inventory stocking and the fraction of orders that might conceivably be filled from inventory MAXFI is taken as 0.6.

C   MAXFI=0.6   (21)

From past inventory practices and estimates of the requirements for adequate service for customers NFFIN is taken as 0.5.

C   NFFIN=0.5   (22)

Figure 9 has been established on the assumption that in steady-state system condition we expect to operate the ACTIN equal to NECIN, and, therefore, with a split fraction equal to NFFIN. In fact, this is the definition of NFFIN. Accordingly, NECIN is a constant whose value should be that of the initial steady-state inventory ACTIN.

6N   NECIN=ACTIN   (23)

Equation (23) completes the part of the model which relates incoming orders to shipments filled from inventory and to shipments manufactured to customer order.

Inventory Ordering

The inventory ordering section is shown in Figure 10. Examination of records and discussion with executives concerned with ordering showed three principal factors influencing inventory replenishment. The first was the average rate at which inventory was being depleted by shipment to customers. The second was the adjustment to bring actual inventory to its desired level. The third was a recognition of the orders for inventory in process in the factory and the factory lead time for filling inventory orders.

Equation (24) combines the pertinent factors for orders to be

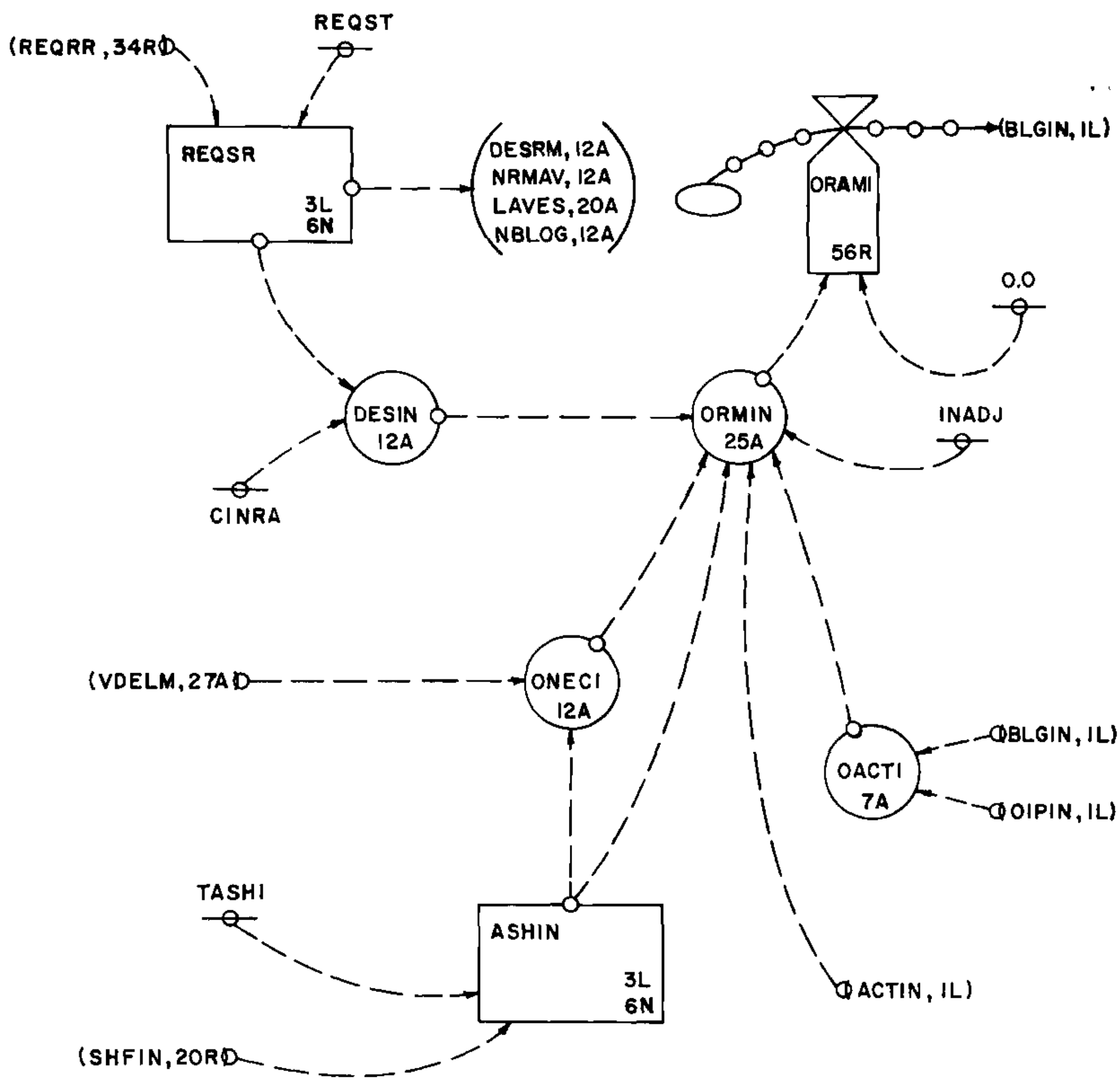

Figure 10. A Flow Diagram of the Inventory Ordering Section

produced for inventory ORMIN.

25A   ORMIN.K=ASHIN.K+(1/INADJ)(DESIN.K-ACTIN.K+ONECI.K-OACTI.K

+0.0+0.0)   (24)

The first term in the equation is the average shipping rate from inventory ASHIN. Use of the short term average is more proper and more realistic. The terms within parentheses on the right-hand side of equation (24) give the difference between desired and actual inventory plus the difference between necessary and actual inventory orders in process at the factory. This inventory discrepancy is adjusted by ordering a fraction of the discrepancy per week. The fraction is given by the adjustment time constant INADJ. The numerical value of INADJ will determine the rapidity with which inventory adjustments are made, and is here taken as six weeks.

C   INADJ=6 weeks   (25)

Equation (24) is an auxiliary rather than a rate equation because it is tentative. Its purpose is to prevent a negative flow of orders to the factory. Some circumstances arise where excess inventory will lead equation (24) to generate a negative order rate. This condition would occur at a time when there are no orders in the factory backlog to cancel, and is, therefore impossible. The actual rate is given by equation (26).

56R   ORAMI.KL=CLIP(ORMIN.K,0,ORMIN.K,0)   (26)

A first-order exponential averaging equation will be used to convert the shipment rate from inventory into the average shipment rate that was used in equation (24).

3L ASHIN.K=ASHIN.J+(DT)(TASHI)(SHFIN.JK-ASHIN.J) (27)

6N ASHIN=REQFI (28)

The average inventory shipping rate is intended to reflect very recent shipments from inventory. A short averaging time is therefore appropriate, such as two weeks.

C TASHI=2 weeks (29)

Desired inventory DESIN will be taken as the constant CINRA multiplied by the requisition smoothing rate REQSR.

12A DESIN.K=(CINRA)(REQSR.K) (30)

The constant CINRA is here taken as equal to four weeks of sales.

C CINRA=4 weeks (31)

Equation (30) requires an average level of sales REQSR. This is obtained in the following way.

3L REQSR.K=REQSR.J+(DT)(1/REQST)(REQRR.JK-REQSR.J) (32)

6N REQSR=REQRR (33)

Averaging of the incoming-order rate was necessary because week-by-week order flow fluctuates widely. Most of such flow rates must be averaged before making management decisions. This averaging may be a formal numerical process or may be an intuitive or psychological averaging of the flow of available information. Equation (32) shows that each week a fraction REQST of the difference between the current and aver ge sales is used to correct the level of average sales. In the steady-state, average sales REQSR will equal the incoming sales rate REQRR as given in equation (33).

The average time for incoming orders is taken as thirteen weeks.

C REQST=13 weeks (34)

The normal number of items on order for inventory in process at the factory ONECI would be the average inventory shipping rate ASHIN multiplied by the manufacturing delay for inventory in the factory VDELM.

12A ONECI.K=(ASHIN.K)(VDELM.K) (35)

The actual orders in process in the factory for inventory OACTI will be the sum of two components, the backlog of orders not yet started BLGIN and the orders in the process of manufacture OIPIN.

7A OACTI.K=BLGIN.K+OIPIN.K (36)

The description of the inventory ordering section is now completed. Next the manufacturing section of the company will be described.

Manufacturing

The manufacturing operation is represented by two flows, one for goods that go to inventory and the other for goods manufactured to customer order. In actual practice these are intermixed in the same production lines, but in the model they will be treated separately to provide the necessary variables representing each of the two flows. Consequently, Figure 11 shows two backlogs of orders and two production delays. Since in the process being represented the inventory orders and the customer backlog orders were intermixed, there will be no priority given to either of the production lines.

Equation (37) gives the backlog of orders to be manufactured for inventory.

IL BLGIN.K=BLGIN.J+(DT)(ORAMI.JK-BLGRR.JK) (37)

6N BLGIN=480 (38)

In equation (38) the initial value for the backlog of orders for inventory is given as 480 equivalent product units. This is 60 percent of the total backlog of the company.

The backlog of work in progress for goods being manufactured to customer order is given by equation (39).

1L CUBLG.K=CUBLG.J+(DT)(REQMO.JK-PCORD.JK) (39)

6N CUBLG=320 (40)

We now allocate manufacturing manpower to each of the order flows. In normal operation the two backlogs are intermixed which implies that manpower is to be allocated in proportion to each of the backlogs. However, there may be times when the available labor can produce more items than are in the backlogs during a period in which the work force is

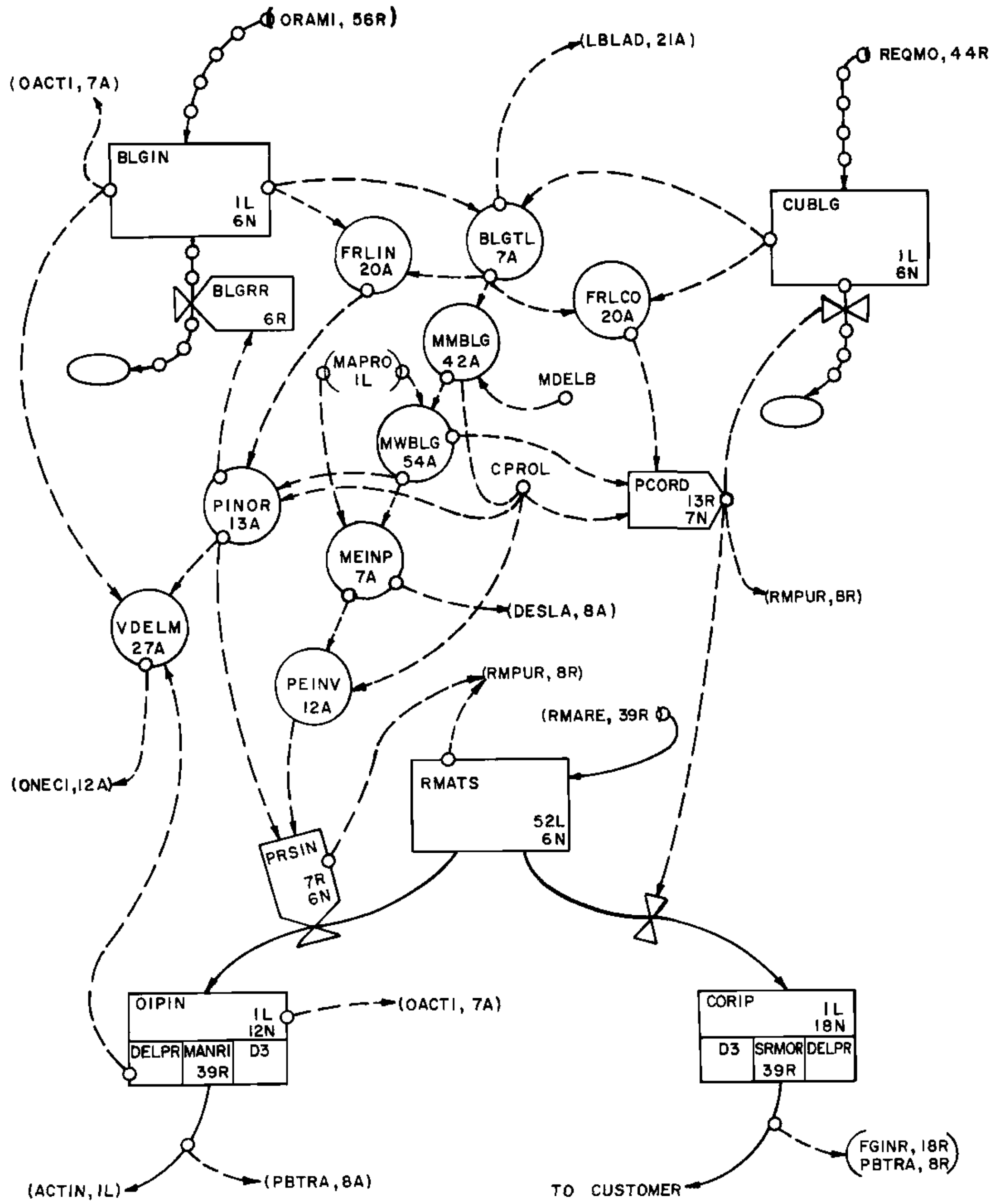

Figure 11. A Flow Diagram of the Manufacturing Section

being reduced. At such times the backlogs should not become negative, instead the excess labor should be devoted to making inventory. Equations (41) through (47) refer to the allocation of manufacturing manpower.

Equation (41) makes available the total backlog of orders.

7A BLGTL.K=BLGIN.K+CUBLG.K (41)

Both backlogs must not drop below a length equivalent to some minimum production scheduling time. This minimum delay in the backlogs defines the maximum production rate, which in turn tells us the maximum manpower that can be effectively assigned to backlog reduction. Excess labor will make unordered items for inventory.

42A MMBLG.K=BLGTL.K/(MDELB)(CPROL) (42)

In equation (42) the total backlog BLGTL is divided by the minimum delay in backlog MDELB necessary for scheduling the work to give the maximum rate at which orders can enter production.

The resulting rate is then divided by the labor productivity CPROL to give the maximum work force that can be assigned to production for the reduction of backlog.

The minimum scheduling time is taken as one week.

C MDELB=1 week (43)

Productivity is taken as 107 units per man/week.

C CPROL=107 (44)

A control equation necessary to determine the number of men to work on backlog reduction is given by equation (45).

54A MWBLG.K=CLIP(MAPRO.K,MMBLG.K,MMBLG.K,MAPRO.K) (45)

The number of men to be used for backlog reduction are proportional to the backlog sizes. The fraction in each backlog is given by equations (46) and (47).

20A FRLIN.K=BLGIN.K/BLGTL.K (46)

20A FRLCO.K=CUBLG.K/BLGTL.K (47)

The fraction of men available for work on customer orders is given by equation (47). This fraction multiplied by labor productivity CPROL gives the following production rate on items for customer orders.

13R PCORD.KL=(FRLCO.K)(MWBLG.K)(CPROL) (48)

7N PCORD=REQRR-REQFI (49)

In the same manner, production rate on inventory backlog orders is calculated. It is here considered as an auxiliary equation because it will be used in several other equations.

13A PINOR.K=(FRLIN.K)(MWBLG)(CPROL) (50)

6R PINOR.K=BLGRR.KL (51)

The actual items produced for inventory PRSIN will be the sum of those manufactured to fill inventory orders PINOR plus those manufactured to occupy excess labor above the number who can work in response to backlog orders PEINV. The excess workers and the rate at which they can produce will first be calculated using equations (52) and (53).

7A MEINP.K=MAPRO.K-MWBLG.K (52)

12A PEINV.K=(MEINP.K)(CPROL) (53)

Total production rate for inventory PRSIN is given by the sum of the two components already calculated.

7R PRSIN.KL=PINOR.K+PEINV.K (54)

6N PRSIN=REQFI (55)

The production process is here approximated in two steps. The first is the point at which labor is applied, and therefore controls the rate at which the orders in process for inventory OIPIN, equations (56) and (57), and the customer orders in process CORIP, equations (60) and (61), are stated in production. Secondly, the production start rate MANRI, equations (58) and (59), and SRMOR, equations (62) and (63), are followed by their respective production process delays before the finished goods become available.

1L OIPIN.K=OIPIN.J+(DT)(PRSIN.JK-MANRI.JK) (56)

12N OIPIN=(DELPR)(REQFI) (57)

39R MANRI.KL=DELAY3(PRSIN.JK,DELPR) (58)

Production delay for inventory DELPR is here represented as a third-order exponential delay of average length six weeks.

C DELPR=6 weeks (59)

1L CORIP.K=CORIP.J-(DT)(PCORD.JK-SRMOR.JK) (60)

18N CORIP=(DPCOR)(REQRR-REQFI) (61)

39R SRMOR.KL=DELAY3(PCORD.JK,DPCOR) (62)

Production delay for customer order DPCOR is here represented as a third-order exponential delay of average length twelve weeks.

C DPCOR=12 weeks (63)

The raw-material level RMATS is produced by the raw-material receiving rate RMARE and two depletion rates, namely: production rate starts for inventory PRSIN, and production rate starts for customer orders PCORD.

52L RMATS.K=RMATS.J+(DT)(RMARE.JK-PRSIN.JK-PCORD.JK+0) (64)

6N RMATS=148 (65)

The total delay in the manufacturing department is needed in decisions elsewhere within the system. The delay consists of two parts, namely: the delay which an order experiences waiting in the backlog, and the delay in the actual production. Equation (66) gives the delay expected for inventory production VDELM as the size of the backlog BLGIN divided by the rate at which the backlog is being depleted PINOR plus the actual manufacturing delay DELPR.

27A VDELM.K=(BLGIN.K/PINOR.K)+DELPR (66)

Likewise, the delay for manufacturing to customer order DMCOR is composed of the variable delay that the order experiences in the backlog CUBLG/PCORD plus the constant manufacturing delay DPCOR.

27A DPCOR.K=(CUBLG.K/PCORD.JK)+DPCOR (67)

Even though production rates are proportional to the backlogs, the delays in producing to inventory DELPR and to customer orders DPCOR are different. This is due to the nature of the demand of each of the products being manufactured for inventory PINOR and to customer order PCORD.

Material Ordering

The rates at which materials enter and are used within the company, and the policies governing changes in the status of materials are important parts of the system being studied. Since the availability of materials does control a number of decisions within the manufacturing operation, the equations for the ordering of materials and the materials delivery delay are included in this section. The flow diagram for the material ordering section is shown in Figure 12.

The material-ordering equations are developed in the following paragraphs. The concept of raw materials desired at the factory DESRM is defined by equation (68) as the product of requisitions smoothing rate REQSR multiplied by the raw material supply constant CRMSP.

12A DESRM.K=(REQSR.K)(CRMSP) (68)

The raw material supply constant is taken as five weeks.

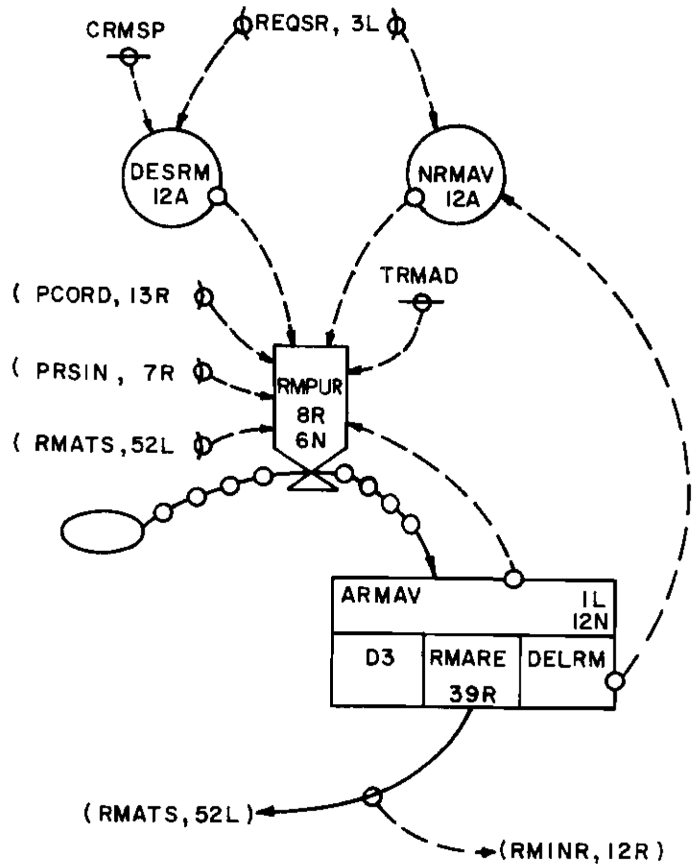

Figure 12. A Flow Diagram of the Material Ordering Section

C CRMSP=5 weeks (69)

The raw-material purchasing rate RMPUR depends upon the rate of usage of materials in production PCORD and PRSIN and contains a term MABEL for adjusting the inventory stock and the raw material pipeline content.

8R RMPUR.KL=PCORD.JK+PRSIN.JK+MABEL.K (70)

24A MABEL.K=(1/TRMAD)(DESRM.K-RMATS.K+NRMAV.K-ARMAV.K+0+0) (71)

6N RMPUR=REQRR (72)

The time constant TRMAD controls the rate at which inventory and pipeline discrepancies will be corrected, and is taken as eight weeks.

C TRMAD=8 weeks (73)

The necessary raw-material orders and material in transit in the material supply pipeline NRMAV are proportional to the average level of business activity REQSR and the length of the pipeline DELRM.

12A NRMAV.K=(REQSR.K)(DELRM) (74)

Here the orders are passed through a third-order delay from which the materials return to factory raw-material stock. This requires a level equation, its initial-value equation, and the designation of its delay function:

1L ARMAV.K=ARMAV.J+(DT)(RMPUR.JK-RMARE.JK) (75)

12N ARMAV=(REQRR)(DELRM) (76)

39R RMARE.KL=DELAY3(RMPUR.JK,DELRM) (77)

The average delay in procuring raw materials DELRM is taken as three weeks.

C DELRM=3 weeks (78)

Labor

The labor supply and the policies governing the changes in labor force are important parts of the system under study. Of primary concern is the interaction between the varying flow of incoming orders from the customers and the resulting manufacturing rate, which in turn is controlled by the labor force and adjustment.

The labor section shown in Figure 13 consists of a labor pool, a hiring decision LHRRA, an initial training period LINTR, the level of manpower available for production LENPR, a dismissal decision LADNR, and employees who have received termination notices but have not yet left the payroll LATER.

1L LINTR.K=LINTR.J+(DT)(LHRRA.JK-LENPR.JK) (79)

6N LINTR=0 (80)

39R LENPR.KL=DELAY3(LHRRA.JK,DLATR) (81)

Under the steady-state conditions, when there are no changes in levels of activity within the system, the number of trainees will be zero, as given in equation (80). Equation (81) specifies the rate at which

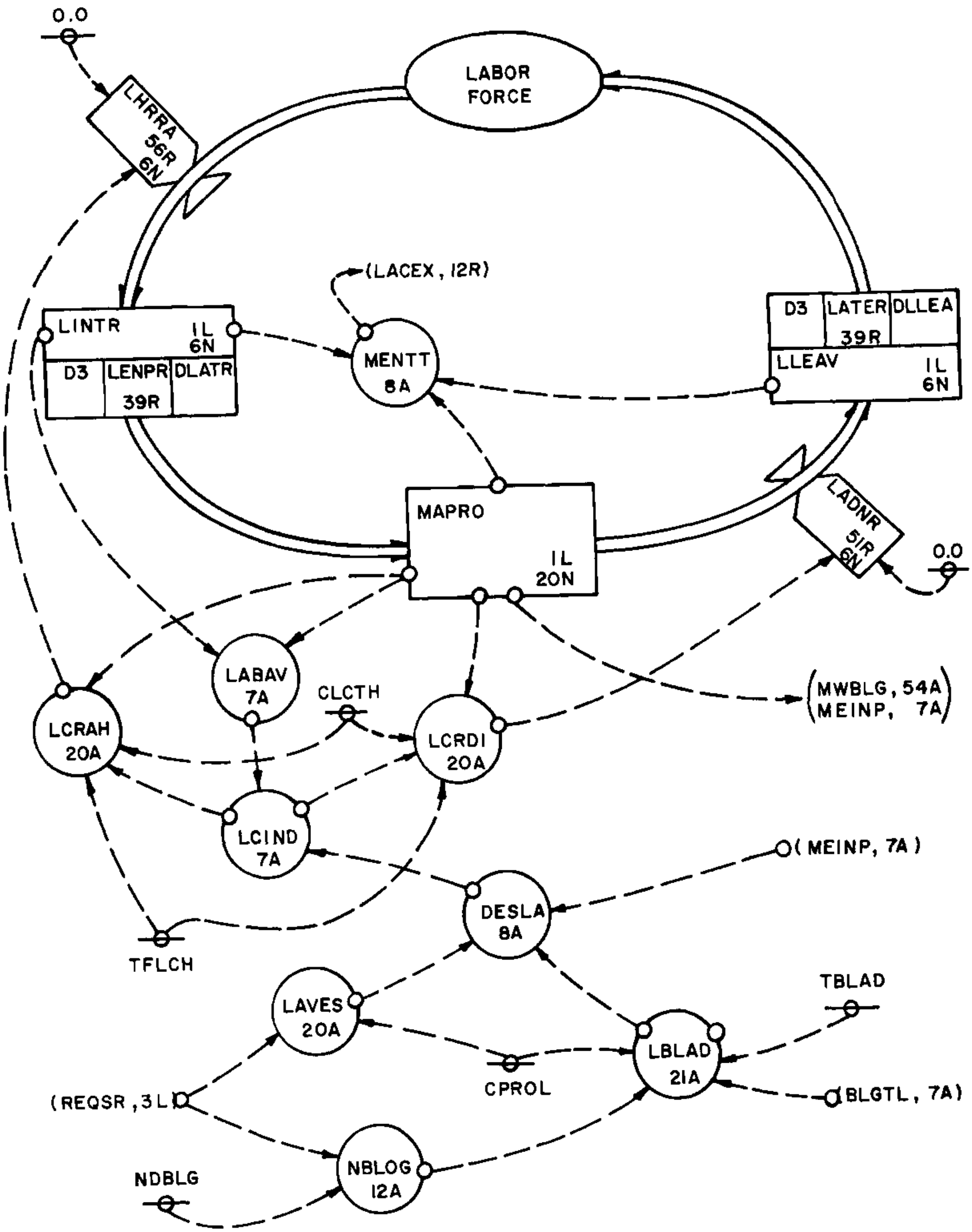

Figure 13. A Flow Diagram of the Labor Section

labor enters production LENPR. The nonproductive training interval is used here both as training and as a method of representing the inefficiencies attendant on an increasing production rate.

The training delay DLATR is taken as two weeks.

C DLATR=2 weeks (82)

The number of active production workers MAPRO is given by the level equation (83).

1L MAPRO.K=MAPRO.J+(DT)(LENPR.JK-LADNR.JK) (83)

20N MAPRO=REQRR/CPROL (84)

The initial level of production manpower MAPRO as given by equation (84) is equal to the steady-state constant level of business activity REQRR divided by the productivity of labor CPROL.

The labor-termination rate LATER is given by equations (85) through (87).

1L LLEAV.K=LLEAV.J+(DT)(LADNR.JK-LATER.JK) (85)

6N LLEAV=0 (86)

39R LATER.KL=DELAY3(LADNR.JK,DLLEA) (87)

Equation (85) gives the number of persons in termination status. Equation (86) indicates that this number is zero in steady-state production conditions. Equation (87) defines the outflow rate LATER, which is the rate at which labor is leaving the payroll. The termination delay is considered as a nonproductive period in which salaries will be paid.

The delay in labor leaving DLLEA is taken as one week.

C DLLEA=1 week (88)

We now turn to the desired labor force and the hiring and layoff rates. First, there is a labor level that will produce at the average level of the incoming-order rate.

20A LAVES.K=REQSR.K/CPROL (89)

Equation (89) gives the number of workers who could produce at the incoming average order rate.

Next is a consideration of the backlog conditions within the company. Backlog NBLOG is expressed as the product of requisitions smoothing rate REQSR and normal delay in backlog NDBLG.

12A NBLOG.K=(REQSR.K)(NDBLG) (90)

The normal delay in backlog NDBLG is taken as twelve weeks.

C NDBLG=12 weeks (91)

Since the actual backlog BLGTL will often be different from the normal backlog NBLOG, we must generate the amount of labor LBLAD that is necessary to adjust the backlog to the desired level at some specified correction rate.

21A LBLAD.K=(1/DOTTY.K)(BLGTL.K-NBLOG.K) (92)

12A DOTTY.K=(CPROL)(TBLAD) (93)

Equation (92) gives the man-weeks of work necessary to correct the backlog to its normal value. The numerator must be divided by the period of time over which the correction is to be accomplished DOTTY to give the number of men who are to be employed for the purpose of adjusting the backlog. The constant DOTTY is defined as the product of the constant labor productivity CPROL and the time required for backlog adjustment TBLAD. The adjustment time period TBLAD is taken as twenty weeks.

C TBLAD=20 weeks (94)

It is now possible to determine the desired level of labor at the factory. The desired level of labor DESLA consists of three parts, namely: the labor necessary to produce at the average sales rate LAVES, the labor necessary to adjust the backlog level LBLAD, which may be either positive or negative, and a reduction by the number of workers who are producing for inventory beyond the rate covered by inventory production orders MEINP.

8A DESLA.K=LAVES.K+LBLAD.K-MEINP.K (95)

The desired labor level DESLA minus the available labor level LABAV gives the excess or deficit in the present level of production manpower LCIND.

7A LCIND.K=DESLA.K-LABAV.K (96)

In equation (96) the available labor force LABAV is required. The available labor LABAV consists of men actually producing MAPRO and labor in training LINTR.

7A LABAV.K=MAPRO.K+LINTR.K (97)

In addition, another possible factor in the labor force hiring-layoff decision has been included. Managers within the company follow the practice of making no employment change until the labor discrepancy has reached some percentage of the work force. When employment differs by more than the percentage or threshold, hiring or layoff takes place until employment again falls within the threshold. Since it may later become desirable to study the effect of such an employment-change threshold, the necessary terms will now be incorporated.

Equations (98) through (103) indicate the threshold and the rate at which discrepancies in the work force are corrected.

20A LCRAH.K=JERRI.K/TFLCH (98)

14A JERRI.K=LCIND.K-(CLCTH)(MAPRO.K) (99)

Equations (98) and (99) are closely interrelated and it is desirable to discuss equation (99) first. In equation (99) the threshold for hiring and layoff is given by the percentage CLCTH multiplied by the present labor force MAPRO. The desired labor change JERRI is the difference between the labor change indicated LCIND and the threshold. In equation (98) the labor change rate for hiring LCRAH is defined as desired labor change JERRI, divided by the time constant TFLCH.

The time constant TFLCH, which represents the rapidity in making the labor change, is taken as ten weeks.

C TFLCH=10 weeks (100)

Because the hiring threshold is not to be ordinarily used, the normal value of CLCTH will be taken as zero.

C CLCTH=0 (101)

Figure 14 shows the way in which the hiring and layoff rates depend on the labor excess or deficit LCIND. If there is no inactive threshold, the horizontal section of the curve disappears and the sloping sections connect.

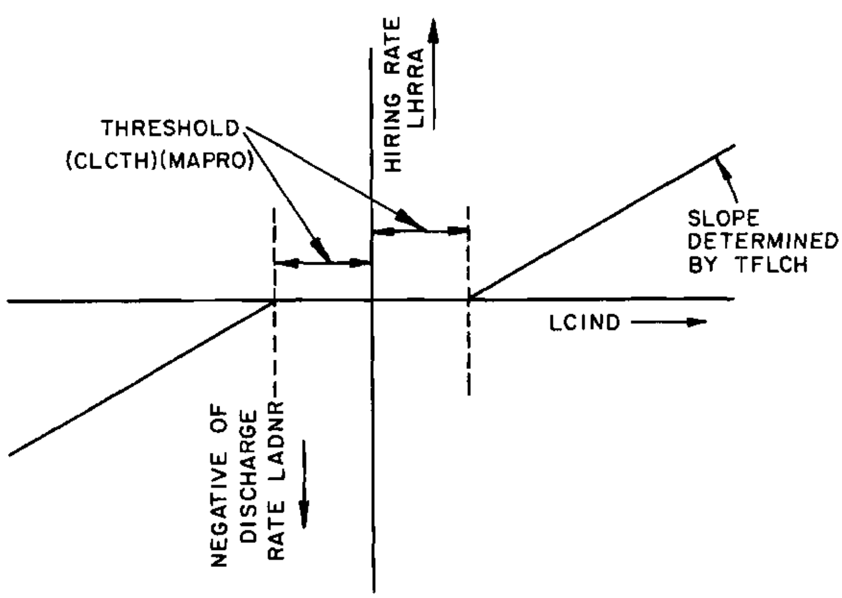

Figure 14. Hiring and Layoff Rate Versus Indicated Labor Change

Equation (102) ensures that the labor hiring rate LHRRA will always be positive.

56R LHRRA.KL=CLIP(LCRAH.K,0,LCRAH.K,0) (102)

6N LHRRA=0 (103)

The layoff rate LCRDI is established in a similar way as in equations (98) through (103) with two exceptions. First, the threshold is entered with a positive sign to reduce a negative output from equation (96). Second, equation (106) reverses the sign to give a position discharge rate when there is too large a work force.

20A LCRDI.K=BOBBI.K/TFLCH (104)

14A BOBBI.K=LCIND.K+(CLCTH)(MAPRO.K) (105)

51R LADNR.KL=CLIP(0,-LCRDI.K,LCRDI.K,0) (106)

6N LADNR=0 (107)

To facilitate the calculation of cash flow for payrolls, the total number of men on the payroll is determined in equation (108).

8A MENTT.K=LINTR.K+MAPRO.K+LLEAV.K (108)

Customer Ordering

Customer ordering will be considered as the exogenous input to the system. It can be either constant or variable. In our system, customer ordering will be represented by the requisition receiving rate REQRR.

Requisitions follow a seasonal trend tending to have annual percentage increases ranging from twenty to thirty-five percent each year. A plot of requisitions versus time appears in Figure 15.

Requisition receiving rate REQRR activates the model. A description

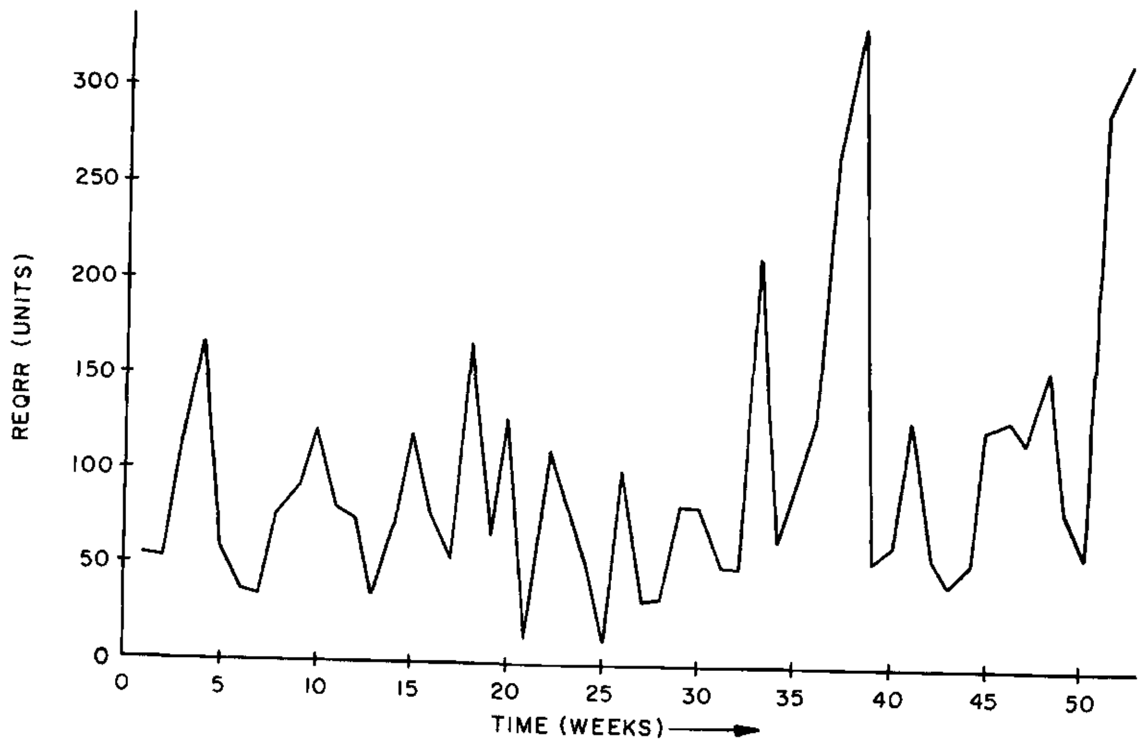

Figure 15. Requisition Receiving Rate Versus Time

of the equations describing REQRR follows:

59R REQRR.KL=TABHL(YTAB,COUNT.K,1,52,1) (109)

C YTAB=55/53/118/165/62/37/35/77/87/119/80/75/35/69/121/77/56/

X1 167/67/130/12/114/82/56/15/99/34/34/82/82/52/52/214/65/99/125/

X2 270/331/56/62/128/60/43/55/125/130/121/159/83/62/294/321 (110)

In order to activate the model, the values from Figure 15 had to be read into the computer. In this connection, it was necessary to provide a means for comparing actual time with the time being summed in the Table HL. This requirement was accomplished using equation (111) and equation (112).

1L COUNT.K=COUNT.J+(DT)(1+0) (111)

6N COUNT=1 (112)

Cash Flow

Cash flow is shown in Figure 16. Cash position and the cash flow rates do not enter into the essential decisions of the system. The primary purpose for including cash flow is to provide an indication of the degree of agreement between the actual cash flow and the cash flow as provided by the simulated model.

The equations which follow give the raw-material invoice rate RMINR, the level of accounts payable ACCTP, and the rate of cash expenditure for raw materials RMCEX.

12R RMINR.KL=(RMARE.JK)(CRMPR) (113)

1L ACCTP.K=ACCTP.J+(DT)(RMINR.JK-RMCEX.JK) (114)

6N ACCTP=$581,631 (115)

20R RMCEX.KL=ACCTP.K/DACTP (116)

Equation (113) gives the raw-material invoice rate RMINR as the product of raw material receiving rate RMARE multiplied by the raw material price per unit of product CRMPR. The raw-material cost CRMPR is taken as $400.

C CRMPR=$400 (117)

Equation (114) accumulates the difference between invoices re-

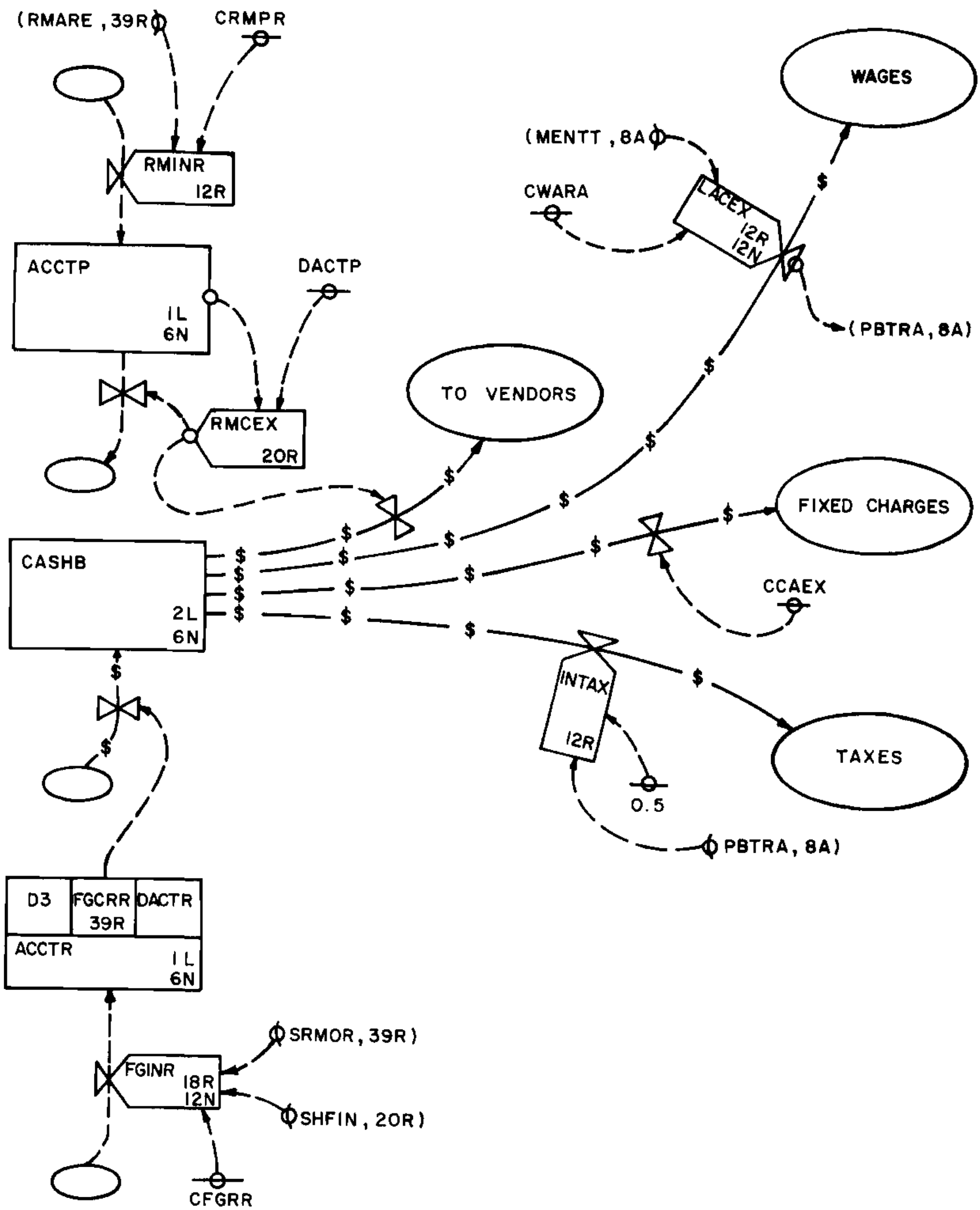

Figure 16. A Flow Diagram of the Cash Flow Section

ceived RMINR and invoices paid RMCEX. Equation (115) gives initial value of accounts payable ACCTP as $581,631. Equation (116) specifies the rate of payment for material RMCEX as a fraction of the accounts payable ACCTP. An average invoice payment interval DACTP has been taken as four weeks.

C DACTP=4 weeks (118)

Cash received for goods delivered will be handled in a slightly different but equivalent way. Invoices for finished goods traverse a third-order delay (at the customer) before being converted to a flow of cash receipts.

18R FGINR.KL=(CFGPR)(SHFIN.JK+SRMOR.JK) (119)

12N FGINR=(REQRR)(CFGPR) (120)

1L ACCTR.K=ACCTR.J+(DT)(FGINR.K-FGCRR.JK) (121)

6N ACCTR=$1,134,074 (122)

39R FGCRR.JK=DELAY3(FGINR.JK,DACTR) (123)

In equation (119) the finished goods invoice rate FGINR is defined as the product of shipments from inventory SHFIN plus the shipments to customer order SRMOR by the price per unit of product CFGPR.

The unit price CFGPR used in this model is $1,000.

C CFGPR=$1,000 (124)

Equation (120) gives the initial value of the invoice rate FGINR as the total sales rate REQRR multiplied by the unit price CRGPR. Equation (121) gives the level of account receivable ACCTR. Equation (122) is the initial level of accounts receivable ACCTR and is given as $1,134,074. Equation (123) represents the finished goods cash receipt rate FGCRR and is shown as a third-order delay. The cash receipt rate FGCRR includes billing, mailing of invoices, the time necessary for the customer to initiate payment, and the time to receive a check and deposit it. This total all-inclusive delay DACTR is taken as six weeks.

C DACTR=6 weeks (125)

Equations (126) and (127) describe the labor cash expenditure LACEX.

12R LACEX.KL=(MENTT.K)(CWARA) (126)

12N LACEX=(MAPRO)(CWARA) (127)

Equation (126) calculates the cost of labor LACEX as the total number of employees MENTT multiplied by the weekly wage rate CWARA. The wage rate CWARA is taken as $124.

C CWARA=$124. (128)

The basis for income taxes INTAX is developed in equation (129).

12R INTAX.KL=(0.5)(PBTRA.K) (129)

Equation (129) gives income taxes INTAX as fifty percent of the profit before tax rate PBTRA.

All cash flow rates have already been defined, so cash balance

CASHB is given by the level equation (130).

2L CASHB.K=CASHB.J+(DT)(FGCRR.JK-RMCEX.JK-LACEX.JK-CCAEX-INTAX.JK

+0.0) (130)

6N CASHB=\$66,880 (131)

The constant cash expenditure CCAEX is taken as \$30,000.

C CCAEX=\$30,000 (132)

Equation (131) establishes the initial value for cash balance CASHB as \$66,880. The number of weeks of cash receipts that are to be kept in the cash balance CNCAS is taken as one week.

C CNCAS=1 week (133)

Profit

In this model a simple computation of current profit rate will be generated to be used as an indicator of system performance. The profit section is shown in the flow diagram of Figure 17.

Standard inventory cost is first generated as an initial-condition equation based on constants already incorporated.

27N STINC=(CWARA/CPROL)+CRMPR (134)

Items in inventory are valued at the direct labor cost per unit plus material cost per unit.

The profit before tax rate is calculated as follows:

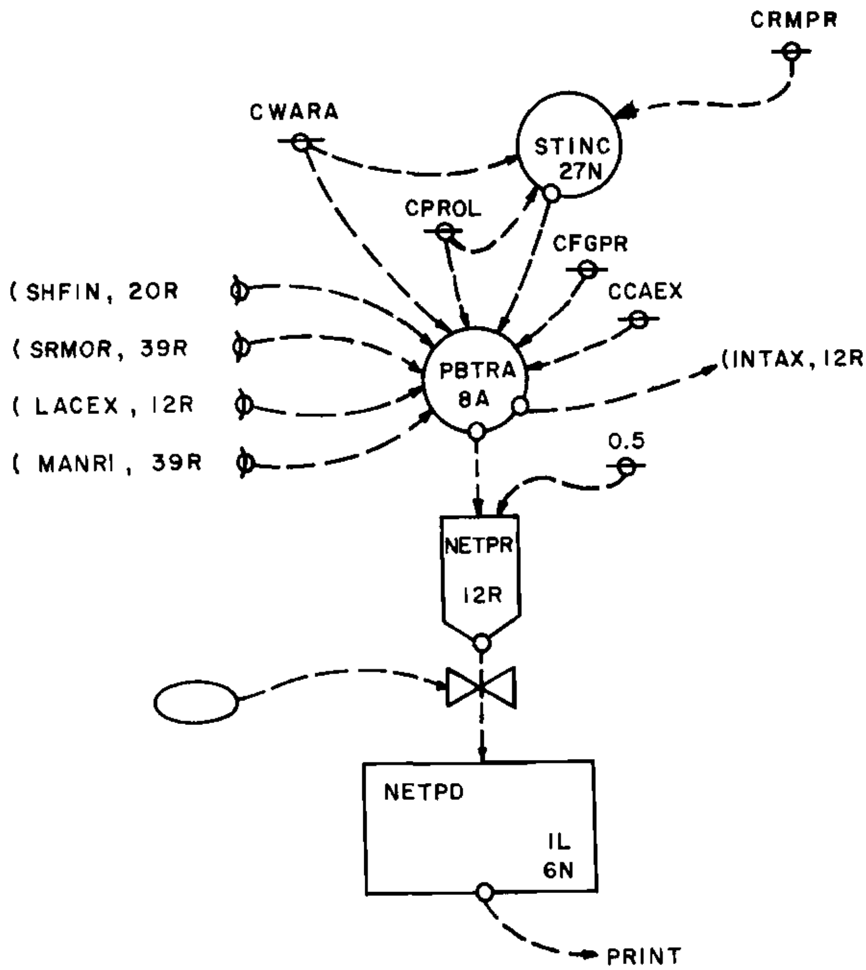

Figure 17. A Flow Diagram of the Profit Section

8A PBTRA.K=RESTA.K+BLOOD.K-CCAEX (135)

12A RESTA.K=(SUBST.K)(REPLA.K) (136)

7A SUBST.K=SHFIN.JK+SRMOR.JK (137)

7A REPLA.K=CFGPR-STINC (138)

14A BLOOD.K=-LACEX.JK+(BLITZ.K)(BLAME.K) (139)

7A BLITZ.K=MANRI.JK+SRMOR.JK (140)

20A BLAME.K=CWARA/CPROL (141)

In equation (135) the profit before taxes PBTRA is calculated as the difference between gross profit RESTA and the total cost of goods produced BLOOD and the constant cash expenditure CCAEX. Gross profit RESTA is then defined by equations (136) through (138) and is the sum of the production for inventory SHFIN plus the production to customer order SRMOR multiplied by the cost of goods sold CFGPR less the standard inventory costs STINC. Equations (139) through (141) provide the total labor cost of goods produced BLOOD.

Net profit rate NETPR is taken as half of the profit before tax rate PBTRA.

12R NETPR.KL=(0.5)(PBTRA.K) (142)

1L NETPD.K=NETPD.J+(DT)(NETPR.JK+0.0) (143)

6N NETPD=$257,725 (144)

Equation (143) is a level equation that accumulates net profit to date NETPD as an indicator of system performance. This level is set initially to $257,725 in equation (144).

The preceding equations complete the description of the system under study and concludes the discussion of the model.

CHAPTER IV

SIMULATION RESULTS

General Description

It was stated in Chapter II that any industrial dynamics model, however complex, consists of three parts, namely: input, the structure of the simulated system, and output. A review of these three parts in the final specification of the model seems to be in order.

The basic input to the model is the requisitions receiving rate REQRR as given by equations (110) through (112). Data appearing in the table YTAB are based on actual company experience.

The structure of the model is described in detail in Chapter III. In as many instances as possible, the initial values of all variables were established on the basis of year-end results as shown on the company's operation statement and balance sheet for the year previous to the simulation period. Table 1 indicates the initial values of each variable of interest in the model.

Table 1. Initial Values of Selected Variables in the Model

Variable	Symbol	Initial Value
Accounts Payable ($)	ACCTP	581,631
Accounts Receivable ($)	ACCTR	1,134,074
Actual Inventory (Units)	ACTIN	605
Backlog Total (Units)	BLGTL	800
Cash Balance ($)	CASHB	66,880
Profit Before Taxes ($)	PBTRA	507,525
Raw Material Stock (Units)	RMATS	148

The output of a DYNAMO system simulation can be in the form of a tabulation of scaled values of specified variables, a scaled plot of specified variables, or both. A DYNAMO system possesses sufficient capacity to print 140 variables as frequently as each simulation interval or to plot 10 or fewer variables as frequently as each simulation interval.

In the model, 20 variables were tabulated and plotted. The variables of primary interest were accounts payable ACCTP, accounts receivable ACCTR, actual inventory ACTIN, total backlog BLGTL, cash balance CASHB, profit before taxes PBTRA, and raw materials stock RMATS. However, variables such as inventory backlog BLGIN, finished goods cash receipt rate FGCRR, labor dismissal notice rate LADNR, and total men MENTT, were also considered.

Basic Model Results

All output from the model was in the form of 20 variables printed out on a bimonthly basis for a total simulation period of fifty-two weeks. Figure 18 is a reduced-scale illustration of the fifty-two weeks of printed output for existing policies of the model. Figure 19 is a reduced-scale illustration of the plotted output for the total simulation period, as produced by the DYNAMO simulation system.

Regarding the primary variables of interest in the model, Figure 18 indicates that accounts payable ACCTP decreased steadily until the twentieth week and then rose steadily to reach a final value corresponding to 30.2 percent of its initial value. Accounts receivable ACCTR alternately increased and decreased throughout the fifty-two week simulation

TIME	ACCTP	ACCTR	ACTIN	BLGIN	BLGTL	CASHB	CUBLG	FGCRR	LACEX	LADAR
	MAPRO	MENTT	NETEC	PBTRA	RECRR	RMATS	RMCEX	RMPLR	SHCRD	STINC
E+00	E+03	E+03	E+00	E+00	E+00	E+03	E+00	E+03	E+00	E-03
	E+00	E+00	E+03	E+03	E+00	E+00	E+03	E+00	E+00	E+00
.000	581.63	1134.1	605.00	480.0	800.0	66.88	320.0	55.000	63.74	.0000
	.5140	.5140	257.73	2.936	55.00	148.00	145.41	70.88	27.500	401.16
2.000	383.06	1134.0	605.18	416.0	746.2	-129.25	330.3	55.000	64.97	.0000
	.5161	.5239	260.63	3.030	118.00	150.17	95.77	69.09	28.866	401.16
4.000	268.95	1152.8	580.90	359.8	745.9	-251.85	387.2	55.190	66.19	.0000
	.5239	.5338	269.22	18.912	62.00	165.36	67.24	76.22	56.658	401.16
6.000	205.14	1197.7	539.70	395.1	805.0	-335.36	409.9	59.014	67.88	.0000
	.5342	.5474	286.41	9.025	35.00	191.72	51.29	69.67	34.832	401.16
8.000	169.25	1188.0	540.50	392.2	799.6	-370.16	407.4	64.210	69.41	.0000
	.5473	.5598	290.42	2.470	87.00	221.32	42.31	68.75	28.688	401.16
10.000	146.56	1178.5	527.90	345.7	782.9	-386.49	437.2	63.969	70.72	.0000
	.5595	.5703	296.34	11.426	80.00	243.88	36.64	72.63	43.632	401.16
12.000	132.64	1192.8	499.02	363.8	823.9	-401.84	460.0	63.177	72.20	.0000
	.5704	.5823	308.44	10.358	35.00	263.37	33.16	70.67	38.317	401.16
14.000	125.15	1187.7	490.90	377.4	834.6	-405.69	457.2	64.357	73.63	.0000
	.5823	.5938	315.05	4.053	121.00	282.84	31.29	65.96	29.818	401.16
16.000	120.19	1186.0	473.36	366.2	850.1	-406.62	483.9	63.905	75.12	.0000
	.5935	.6058	323.08	11.243	56.00	298.05	30.05	71.41	39.000	401.16
18.000	117.31	1193.6	451.23	386.5	902.3	-409.09	515.7	63.844	76.85	.0000
	.6058	.6197	333.50	14.690	67.00	311.32	29.33	76.50	46.782	401.16
20.000	116.56	1217.7	414.50	459.4	1016.9	-414.68	558.5	65.454	79.56	.0000
	.6205	.6416	349.24	15.827	12.00	325.14	29.14	76.59	44.443	401.16
22.000	117.89	1222.7	397.76	526.1	1098.2	-411.16	572.1	68.653	82.64	.0000
	.6421	.6681	360.76	9.909	82.00	340.59	29.47	76.54	33.771	401.16
24.000	119.17	1217.4	387.21	536.3	1125.0	-401.86	588.7	69.613	86.17	.0000
	.6683	.6950	370.66	8.463	14.00	352.15	29.79	74.31	29.150	401.16
26.000	120.06	1195.4	399.18	487.9	1062.2	-388.13	574.3	68.562	88.35	.0000
	.6940	.7125	375.58	4.674	34.00	358.24	30.01	74.72	25.009	401.16
28.000	119.93	1176.5	416.05	420.6	968.5	-378.40	547.9	65.448	[illegible].05	.6777
	.7113	.7181	380.20	2.693	82.00	357.44	29.58	72.84	19.797	401.16
30.000	119.28	1164.8	432.91	356.5	892.9	-375.27	536.4	62.129	88.88	3.4566
	.7136	.7166	385.00	8.713	52.00	352.49	29.82	74.82	29.664	401.16
32.000	118.80	1171.8	442.15	298.0	814.0	-381.26	516.0	60.557	88.04	5.3986
	.7042	.7100	393.72	8.219	214.00	348.24	29.70	78.43	29.279	401.16

TIME	ACCTP	ACCTR	ACTIN	BLGIN	BLGTL	CASHB	CLBLG	FGCRR	LACEX	LADAR
	MAPRO	MENTT	NETEC	PBTRA	RECRR	RMATS	RMCEX	RMPLR	SHCRD	STINC
34.000	118.80	1206.7	419.23	288.0	843.5	-396.04	555.4	61.622	86.83	1.0467
	.6981	.7003	410.60	22.679	99.00	346.98	29.70	80.65	47.976	401.16
36.000	120.72	1248.9	389.85	371.9	960.0	-409.28	588.1	67.141	87.02	.0000
	.6978	.7018	431.34	21.654	270.00	352.71	30.18	88.36	49.490	401.16
38.000	124.24	1319.1	307.22	568.5	1349.3	-423.18	780.8	74.362	91.41	.0000
	.7044	.7372	464.42	49.344	56.00	365.78	31.06	107.25	91.541	401.16
40.000	132.63	1395.3	225.34	996.6	1875.4	-428.95	878.8	86.557	100.93	.0000
	.7417	.8140	504.62	22.687	128.00	395.68	33.16	98.72	40.829	401.16
42.000	143.25	1370.6	216.52	1200.8	2139.4	-392.04	938.5	96.140	112.99	.0000
	.8167	.9112	522.15	12.940	43.00	429.62	35.81	97.87	26.368	401.16
44.000	149.73	1310.6	241.17	1135.3	2076.2	-343.05	941.0	93.783	123.28	.0000
	.9102	.9942	531.60	6.709	125.00	445.30	37.45	100.87	18.526	401.16
46.000	153.12	1263.9	269.30	1027.5	2015.9	-308.80	988.4	84.750	130.84	.0000
	.9918	1.0552	541.50	15.355	121.00	440.18	38.28	112.85	34.493	401.16
48.000	157.59	1262.1	279.56	920.2	1971.0	-302.15	1050.7	77.669	136.87	.0000
	1.0538	1.1038	559.56	21.545	83.00	428.34	39.40	122.11	43.834	401.16
50.000	165.95	1275.9	297.67	827.4	1888.1	-309.38	1060.7	76.750	141.21	.0000
	1.1025	1.1388	579.65	16.531	294.00	422.47	41.49	126.91	35.508	401.16
52.000	175.87	1312.7	284.39	901.8	2026.3	-327.25	1224.6	78.588	145.94	.0000
	1.1385	1.1769	607.03	46.028	321.00	422.41	43.97	155.44	96.577	401.16

Figure 18. Tabulated Output for the Fifty-Two Week Simulation Period

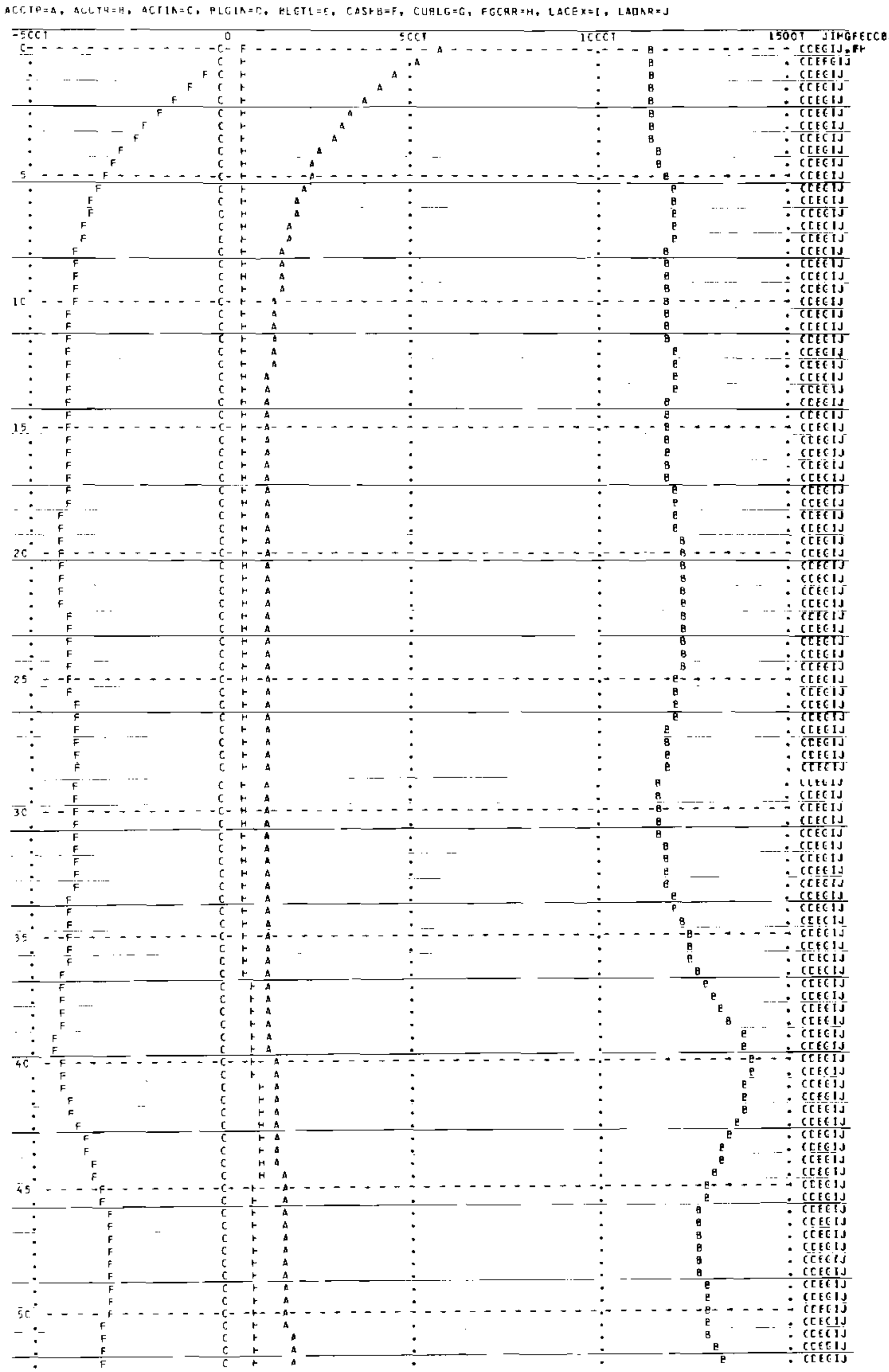

Figure 19. Plotted Output for the Fifty-Two Week Simulation Period

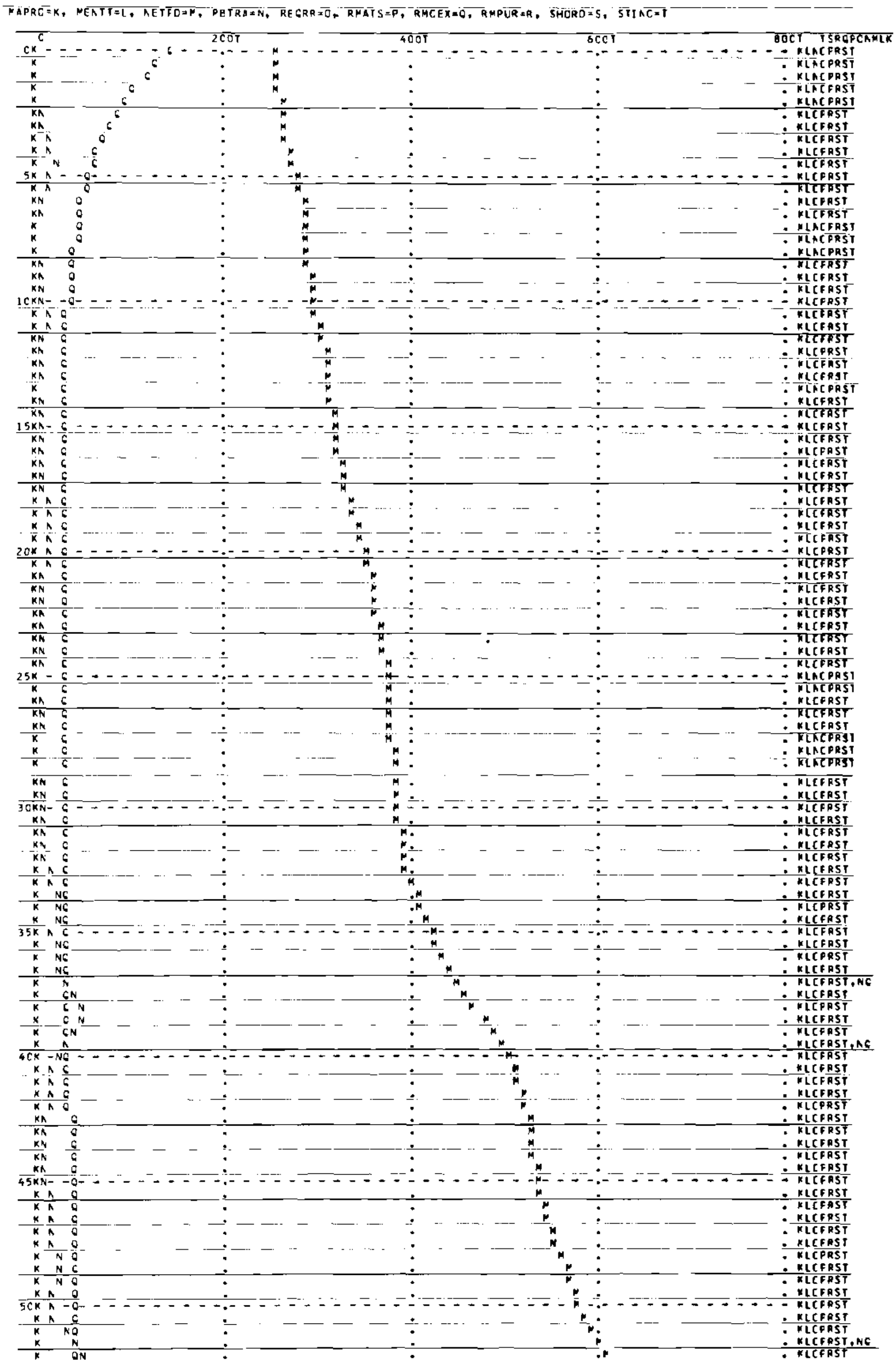

Figure 19. (Continued)

period and reached its peak in the fifty-second week at a value approximately 1.2 times its initial value. Actual inventory ACTIN alternately increased and decreased, reaching a final value approximately equal to 47 percent of its initial value. Backlog BLGTL experienced increases and decreases reaching its peak in the fifty-second week at a value 2.5 times its initial value. Cash balance CASHB alternately increased and decreased from the first week to the fifty-second week to a final value approximately 6 times less than its initial value. Profit before taxes PBTRA alternately increased and decreased to its final value 40 percent greater than its initial value. Raw material stock RMATS increased steadily with only slight fluctuations to a final value 3 times greater than its initial value. Table 2 is a comparison of actual and simulated company activity for the fifty-two week simulation period.

Table 2. A Comparison of Actual and Simulated Company Variables

Variable	Value at End of 1965 Fiscal Year		
	Symbol	Actual Value	Simulated Value
Accounts Payable ($)	ACCTP	960,623	175,870
Accounts Receivable ($)	ACCTR	1,409,696	1,312,700
Actual Inventory (Units)	ACTIN	996	284
Backlog Total (Units)	BLGTL	1,700	2,026
Cash Balance ($)	CASHB	112,142	-327,250
Profit Before Taxes ($)	PBTRA	699,959	697,600
Raw Material Stock (Units)	RMATS	243	422

Actual accounts payable for the fifty-two week period was $960,623, whereas simulated accounts payable was $175,870. Although this represents a difference of $784,753 between actual and simulated results, a brief consideration of the means by which the actual accounts payable was generated leads to the conclusion that such a difference could reasonably have been expected. Actual accounts payable consisted of at least five cash requirements not included in the model, namely: $66,000 for vacation and holidays, $66,000 for profit sharing, $61,000 for commissions, $64,000 for payroll taxes, and approximately $500,000 accounts payable from subsidiaries. When these requirements are removed from the actual accounts payable a balance of $203,623 remains. Since actual accounts payable is now $203,623 and simulated accounts payable was $175,870, the correspondence between actual and simulated accounts payable is considered good.

Actual accounts receivable for the fifty-two week period was $1,409,696, whereas simulated accounts receivable was $1,312,700. As actual accounts receivable are based on overall company operation, and includes factors outside the model boundaries, correspondence between actual and simulated accounts receivable is considered good.

Since total backlog, actual inventory, and raw material stock are dependent upon one another, they will be discussed collectively. Actual backlog for the fifty-two week period was 1,700 units, whereas simulated backlog was 2,026 units. Actual inventory for the same period was 996 units, whereas simulated actual inventory was 284 units. In addition, actual raw material stock was 243 units, whereas simulated raw material stock was 422 units. These variations are significant in that they indicate a discrepancy within the model. A detailed review of the model uncovered one primary reason for the extreme variation between actual and simulated results, namely, within the labor section of the model no provisions were made for overtime, second shifts, or a variable work week. As seen from the simulation results, backlog and raw material stock are increasing, whereas the actual inventory is decreasing. Addition to the model of provisions for handling these contingencies would undoubtedly result in much closer agreement between actual and simulated results.

Actual cash balance for the fifty-two week period was $112,142, whereas simulated cash balance was a minus $327,500. Although this represents a difference of $439,642 between actual and simulated results, a brief consideration of the means by which the value for the variable was generated indicates the reason for this imbalance. Constant cash expenditures (expenses) were initially assumed to be $30,000. A re-evaluation indicates that the expenses were actually closer to $21,400 per week. This means that an additional $447,200 in cash becomes available. Under this condition, actual cash balance remains at $112,142, whereas simulated cash balance becomes $118,700. Because the simulated cash balance considers only selected sectors within the company, it is not unreasonable that it is slightly higher than the actual cash balance. Therefore, the correspondence between actual and simulated cash balance is considered good.

Actual profit before taxes was $699,959, whereas simulated profit before taxes was $697,600. Therefore, the correspondence between actual and simulated profit before taxes is considered good.

Sensitivity Analysis

In an attempt to determine model sensitivity, changes were made to several of what were considered to be the more influential variables affecting company activities. Tables 3, 4, and 5 illustrate the response to these changes.

Table 3. A Comparison of Final Values for Sensitivity Analysis

	ACCTP MAPRO	ACCTR MENTT	ACTIN NETPF	BLGIN RBTRA	BLGTL REQRR	CASHB RMATS	CUBLG RMCEX	FGCRR RMPUR	LACEX SHORD	LADNR STINC
CRMPR=400	175.87 1.14	1312.70 1.18	284.39 607.03	801.80 46.03	2026.30 321.00	-327.25 422.41	1224.60 43.97	78.59 155.44	145.94 86.58	00.00 401.16
CRMPR=262	115.19 1.14	1312.70 1.18	284.39 867.35	801.80 63.56	2026.30 321.00	- 72.61 422.41	1224.60 28.80	78.59 155.44	145.94 86.58	00.00 263.16
CRMPR=292	128.39 1.14	1312.70 1.18	284.39 810.76	801.80 59.75	2026.30 321.00	-127.97 422.41	1224.60 32.10	78.59 155.44	145.94 86.58	00.00 293.16
CRMPR=324	142.45 1.14	1312.70 1.18	284.39 750.40	801.80 55.68	2026.30 321.00	-187.01 422.41	1224.60 35.61	78.59 155.44	145.94 86.58	00.00 325.16
CRMPR=360	158.28 1.14	1312.70 1.18	284.39 682.44	801.80 51.11	2026.30 321.00	-253.44 422.41	1224.60 39.57	78.59 155.44	145.94 86.58	00.00 361.16
CRMPR=440	193.46 1.14	1312.70 1.18	284.39 531.58	801.80 40.95	2026.30 321.00	-401.05 422.41	1224.60 48.36	78.59 155.44	145.94 86.58	00.00 441.16
CRMPR=484	212.80 1.14	1312.70 1.18	284.39 448.58	801.80 35.36	2026.30 321.00	-482.24 422.41	1224.60 53.20	78.59 155.44	145.94 86.58	00.00 485.16
CRMPR=532	233.91 1.14	1312.70 1.18	284.39 358.03	801.80 29.26	2026.30 321.00	-570.81 422.41	1224.60 58.48	78.59 155.44	145.94 86.58	00.00 533.16

Table 4. A Comparison of Final Values for Sensitivity Analysis

ACCTP	ACCTR	ACTIN	BLGIN	BLGTL	CASHB	CUBLG	FGCRR	LACEX	LADNR
MAPRO	MENTT	NETPD	PBTRA	REQRR	RMATS	RMCEX	RMPUR	SHORD	STINC
CPROL=107, CWARA=124									
175.87	1312.70	284.39	801.80	2026.30	-327.25	1224.60	78.59	145.94	00.00
1.14	1.18	607.03	46.03	321.00	422.41	43.97	155.44	86.58	401.16
CPROL=122, CWARA=124									
175.87	1312.70	284.39	801.80	2026.30	-326.98	1224.60	78.59	128.00	00.00
1.00	1.03	607.34	46.05	321.00	422.41	43.97	155.44	86.58	401.02
CPROL=107, CWARA=142									
175.87	1312.70	284.39	801.80	2026.30	-327.56	1224.60	78.59	167.12	00.00
1.14	1.18	606.67	46.00	321.00	422.41	43.97	155.44	86.58	401.33
CPROL=122, CWARA=142									
175.87	1312.70	284.39	801.80	2026.30	-327.26	1224.60	78.59	146.58	00.00
1.00	1.03	607.02	46.03	321.00	422.41	43.97	155.44	86.58	401.16

Table 5. A Comparison of Final Values for Different Initial Inputs

ACCTP	ACCTR	ACTIN	BLGIN	BLGTL	CASHB	CUBLG	FGCRR	LACEX	LADNR
MAPRO	MENTT	NETPD	PBTRA	REQRR	RMATS	RMCEX	RMPUR	SHORD	STINC
Normal Random System Input									
169.84	345.30	460.50	961.60	1879.00	2064.40	917.37	93.53	153.67	.0000
1.20	1.24	1606.10	30.58	179.91	702.10	42.46	128.35	61.22	401.16
Actual System Input									
175.87	1312.70	284.39	801.80	2026.30	-327.25	1224.60	78.59	145.94	00.00
1.14	1.18	607.03	46.03	321.00	422.41	43.97	155.44	86.58	401.16

Table 3 illustrates the results of varying the constant raw materials price CRMPR. The initial value of CRMPR is $400 and is varied by 10 percent to obtain values ranging from $262 to $532. Values shown within the table are the results of eight different computer runs and represent a fifty-two week simulation period.

The model experienced no sensitivity to changes to the constant raw materials price CRMPR. If CRMPR was decreased, profits increased and accounts payable decreased, whereas if CRMPR increased, profits decreased and accounts payable increased. All variables reacted as expected to a change in the constant raw materials price.

Table 4 illustrates the results of varying the constant productivity of labor CPROL and the constant wage rate CWARA. The table contains the basic model values, values where CPROL and CWARA are varied separately, and values when they are varied simultaneously.

The model again experienced no sensitivity. As shown in Table 4, all variables responded negligibly to changes in the constant productivity of labor CPROL and the constant change rate CWARA.

Table 5 illustrates the results of varying the input to the system. In this case, requisition receiving rate REQRR was changed to reflect a normal random input to the model by means of the following equation.

34R REQRR.KL=(1)NORMRN(130,42) (109)

As shown in Table 5, the model experienced extreme sensitivity to a change in the form of input which activated it. Results for a normal random entry of orders into the model are certainly more favorable to the company than the actual system input. For example, with normal random input, cash balance CASHB is $2,064,400. On the other hand, with actual system input cash balance CASHB is a minus $327,250. The beneficial effect of the normal random input is due to a more gradual inflow of orders and consequent ability of the labor force to more rapidly meet the overall system demand.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study was concerned with an industrial dynamics model of an actual company specializing in the manufacture of electronic equipment. The model developed consists of approximately 144 equations which describe the behavior of eight sections of the company activity, namely: (1) Order Filling, (2) Inventory Ordering, (3) Manufacturing, (4) Material Ordering, (5) Labor, (6) Customer Ordering, (7) Cash Flow, and (8) Profit.

The model is aggregate in nature. For example, requisition receiving rate was determined by dividing the total dollar value of all orders received during the week by the average selling price of a typical unit. It should be noted that this average selling price is based on approximately one thousand different products whose actual selling prices ranged from 20 dollars to 50,000 dollars. In addition, the productivity of labor has been assumed to be constant throughout the simulation period. The constant productivity of labor was determined by dividing the total dollar value of shipments for the year by the total number of employees at the end of the year. It should be noted that in the aggregation process no distinction was made between production and non-production employees. These examples show that without aggregation the model discussed in this study would require a prohibitive number of equations. On the other hand, because of the aggregation, disparities between actual and simulated results can be expected.

Three types of simulation experiments, whose purpose was to illustrate model behavior under actual and varying conditions, were conducted.

The first set of experiments was designed to simulate as closely as possible the behavior of an actual company. In this case, some of the final values of simulation experiments differed from actual values by a considerable margin. On the other hand, it was possible to account for the causes of disparities between the real world situation and its simulated model. The disparities observed were due to the following conditions: (1) the input to the system represented an aggregate value of six separate product lines, (2) similarly, initial conditions and constants were based on total company operation, and (3) the model structure was limited to some selected sections of the company and a number of equally important sections have been omitted.

The second set of experiments was designed to test the sensitivity of the model structure to changes in selected model variables such as the constant raw materials price, the constant productivity of labor, and the constant wage rate. The system response to changes in these variables was negligible.

The third set of experiments was designed to test the response of the model to changes in the requisition receiving rate which constituted the exogenous variable in the simulated system. In this case, the actual observed requisition receiving rate was replaced by an equivalent normal random input. The simulation results showed that the model is extremely sensitive to the form of exogenous variable.

In general, the behavior of the simulated company model was consistent with actual company experience. Considering the high degree of aggregation employed in model formulation, the results obtained were effective in providing a better understanding of the complex direct and indirect system relationships among variables.

Recommendations for Further Research

The following areas of additional research are recommended:

1. This study was based on only eight sections of company activity. It is suggested that the model be extended to include such additional sections as the capital structure of the company, and provisions for depreciation and annual capital expenditure. In addition, the aggregated input to the model could be shown in the form of separate inputs for each product line.

2. Information presently available within the company only partially meets requirements of model construction. For example, the choice of values for delay, constants, and initial conditions was, in most cases, only partially documented. Therefore, it is unreasonable to expect at the present time that the simulation model developed could give detailed consideration to specific decision areas since insufficient recorded information was available from which basic relationships could be identified. Therefore, the need exists for research into identifying the type of information that should be recorded as well as the desired interval of data collection.

3. It is recommended that extensive submodels be developed for each section of company activity in order to evaluate the effect of aggregation by means of sensitivity analysis. For example, the initial

submodel could have as many as one hundred variables. Subsequent sensitivity analysis may disclose that only a small fraction of the initially selected variables is necessary for the purpose of overall model formulation.

APPENDIX A

A LISTING OF THE SIMULATED COMPANY MODEL EQUATIONS

```
58R   REQRR.KL=TABHL(YTAB,COUNT.K,1,52,1)                                 110
C     YTAB*=55/53/118/165/62/37/35/77/87/119/80/75/35/69/121/77/56/167/6  110
X1    7/130/12/114/82/56/14/99/34/34/82/82/52/52/214/65/99/125/270/331/5  110
X2    6/62/128/60/43/55/125/130/121/159/83/62/294/321                     110
1L    COUNT.K=COUNT.J+(DT)(1+0)                                           111
6N    COUNT=1                                                             112
52L   REQCP.K=REQCP.J+(DT)(REQRR.JK-REQFI.JK-REQMO.JK+0.0)                1
12N   REQCP=(REQRR)(DELCP)                                                2
1L    SHORD.K=SHORD.J+(DT)(REQFI.JK-SHFIN.JK)                             3
12N   SHORD=(REQFI)(DELSH)                                                4
20R   SHFIN.KL=SHORD.K/DELSH                                              5
6N    SHFIN=REQFI                                                         6
C     DELSH=1                                                             7
1L    ACTIN.K=ACTIN.J+(DT)(MANRI.JK-SHFIN.JK)                             8
6N    ACTIN=605                                                           9
44R   REQFI.KL=(FRFIN.K)(REQCP.K)/DELCP                                   10
12N   REQFI=(NFFIN)(REQRR)                                                11
C     DELCP=1                                                             12
44R   REQMO.KL=(SUBST.K)(REQCP.K)/DELCP                                   13
7A    SUBST.K=1-FRFIN.K                                                   14
12A   FRFIN.K=(MAXFI)(ROUND.K)                                            15
7A    ROUND.K=1-WHOLE.K                                                   16
28A   WHOLE.K=(1)EXP(-HALVE.K)                                            17
44A   HALVE.K=(C1)(ACTIN.K)/NECIN                                         18
29N   C1=(1)LOGN(REMCV)                                                   19
48A   REMCV.K=MAXFI/(MAXFI-NFFIN)                                         20
C     MAXFI=0.6                                                           21
C     NFFIN=0.5                                                           22
6N    NECIN=ACTIN                                                         23
25A   ORMIN.K=ASHIN.K+(1/INADJ)(DESIN.K-ACTIN.K+DNECI.K-OACTI.K+0.0+0.0)  24
X1                                                                        24
C     INADJ=6                                                             25
51R   ORAMI.KL=CLIP(ORMIN.K,0,ORMIN.K,0)                                  26
3L    ASHIN.K=ASHIN.J+(DT)(1/TASHI)(SHFIN.JK-ASHIN.J)                     27
6N    ASHIN=REQFI                                                         28
C     TASHI=2                                                             29
12A   DESIN.K=(CINRA)(REQSR.K)                                            30
C     CINRA=4
3L    REQSR.K=REQSR.J+(DT)(1/REQST)(REQRR.JK-REQSR.J)                     32
6N    REQSR=REQRR                                                         33
C     REQST=13                                                            34
12A   DNECI.K=(ASHIN.K)(VDELM.K)                                          35
7A    OACTI.K=BLGIN.K+CIPIN.K                                             36
1L    BLGIN.K=BLGIN.J+(DT)(ORAMI.JK-BLGRR.JK)                             37
6N    BLGIN=480                                                           38
1L    CUBLG.K=CUBLG.J+(DT)(REQMO.JK-PCORD.JK)                             39
6N    CUBLG=320                                                           40
7A    BLGTL.K=BLGIN.K+CUBLG.K                                             41
42A   MMBLG.K=BLGTL.K/((MDELB)(CPROL))                                    42
C     MDELB=1                                                             43
C     CPROL=107                                                           44
51A   MWBLG.K=CLIP(MAPRO.K,MMBLG.K,MMBLG.K,MAPRO.K)                       45
20A   FRLIN.K=BLGIN.K/BLGTL.K                                             46
20A   FRLCC.K=CUBLG.K/BLGTL.K                                             47
13R   PCORD.KL=(FRLCC.K)(MWBLG.K)(CPROL)                                  48
7N    PCORD=REQRR-REQFI                                                   49
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```
13A     PINCR.K=(FRLIN.K)(MWBLG.K)(CPRCL)
6R      BLGRR.KL=PINCR.K
7A      MEINP.K=MAPRC.K-MWBLG.K
12A     PEINV.K=(MEINP.K)(CPRCL)
7R      PRSIN.KL=PINCR.K+PEINV.K
6N      PRSIN=RECFI
1L      OIPIN.K=OIPIN.J+(DT)(PRSIN.JK-MANRI.JK)
12N     OIPIN=(DELPR)(RECFI)
39R     MANRI.KL=DELAY3(PRSIN.JK,DELPR)
C       DELPR=6
1L      CCRIP.K=CCRIP.J+(DT)(PCORD.JK-SRMOR.JK)
18N     CCRIP=(DPCOR)(RECRR-RECFI)
39R     SRMCR.KL=DELAY3(PCCRD.JK,DPCOR)
C       DPCCR=12
52L     RMATS.K=RMATS.J+(DT)(RMARE.JK-PRSIN.JK-PCORD.JK+0.0)
6N      RMATS=148
27A     VDELM.K=(BLGIN.K/PINCR.K)+DELPR
27A     DMCCR.K=(CUBLG.K/PCCRD.JK)+DPCCR
12A     DESRM.K=(RECSR.K)(CRMSP)
C       CRMSP=5
8R      RMPLR.KL=PCCRD.JK+PRSIN.JK+MABEL.K
24A     MABEL.K=(1/TRMAD)(DESRM.K-RMATS.K+NRMAV.K-ARMAV.K+0.0+0.0)
C       TRMAD=8
6N      RMPLR=RECRR
12A     NRMAV.K=(RECSR.K)(DELRM)
1L      ARMAV.K=ARMAV.J+(DT)(RMPUR.JK-RMARE.JK)
12N     ARMAV=(RECRR)(DELRM)
39R     RMARE.KL=DELAY3(RMPUR.JK,DELRM)
C       DELRM=3
1L      LINTR.K=LINTR.J+(DT)(LHRRA.JK-LENPR.JK)
6N      LINTR=0.0
39R     LENPR.KL=DELAY3(LHRRA.JK,DLATR)
C       DLATR=2
1L      MAPRO.K=MAPRC.J+(DT)(LENPR.JK-LADNR.JK)
20N     MAPRO=RECRR/CPRCL
1L      LLEAV.K=LLEAV.J+(DT)(LADNR.JK-LATER.JK)
6N      LLEAV=0
39R     LATER.KL=DELAY3(LADNR.JK,DLLEA)
C       DLLEA=1
20A     LAVES.K=REQSR.K/CPRCL
12A     NBLCG.K=(RECSR.K)(NDBLG)
C       NDBLG=12
21A     LBLAD.K=(1/DCTTY.K)(BLGTL.K-NBLOG.K)
12A     DCTTY.K=(CPRCL)(TBLAD)
C       TBLAD=20
8A      DESLA.K=LAVES.K+LBLAD.K-MEINP.K
7A      LCIND.K=DESLA.K-LABAV.K
7A      LABAV.K=LINTR.K+MAPRC.K
20A     LCRAH.K=JERRI.K/TFLCH
14A     JERRI.K=LCIND.K+(-CLCTH)(MAPRO.K)
C       TFLCH=10
C       CLCTH=0.0
51R     LHRRA.KL=CLIP(LCRAH.K,0,LCRAH.K,0)
6N      LHRRA=0
20A     LCRDI.K=BCBBI.K/TFLCH
14A     BCBBI.K=LCIND.K+(CLCTH)(MAPRO.K)
51R     LADNR.KL=CLIP(0,-LCRDI.K,LCRDI.K,0)
6N      LADNR=0
```

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8A     MENTT.K=LINTR.K+MAPRC.K+LLEAV.K                                        108
12R    RMINR.KL=(RMARE.JK)(CRMPR)                                             113
1L     ACCTP.K=ACCTP.J+(DT)(RMINR.JK-RMCEX.JK)                                114
6N     ACCTP=581631                                                           115
20R    RMCEX.KL=ACCTP.K/DACTP                                                 116
C      CRMPR=400                                                              117
C      DACTP=4                                                                118
18R    FGINR.KL=(CFGPR)(SHFIN.JK+SRMOR.JK)                                    119
12N    FGINR=(REQRR)(CFGPR)                                                   120
1L     ACCTR.K=ACCTR.J+(DT)(FGINR.JK-FGCRR.JK)                                121
6N     ACCTR=1134074                                                          122
39R    FGCRR.KL=DELAY3(FGINR.JK,DACTR)                                        123
C      CFGPR=1000.00                                                          124
C      DACTR=6                                                                125
12R    LACEX.KL=(MENTT.K)(CWARA)                                              126
12N    LACEX=(MAPRC)(CWARA)                                                   127
C      CWARA=124                                                              128
12R    INTAX.KL=(0.5)(PBTRA.K)                                                129
2L     CASHB.K=CASHB.J+(DT)(FGCRR.JK-RMCEX.JK-LACEX.JK-CCAEX-INTAX.JK+0.0    130
X1     )                                                                      130
6N     CASHB=66880                                                            131
C      CCAEX=30000                                                            132
C      CNCAS=1                                                                133
27N    STINC=(CWARA/CPRCL)+CRMPR                                              134
8A     PBTRA.K=RESTA.K+BLOCD.K-CCAEX                                          135
12A    RESTA.K=(REDID.K)(REPLA.K)                                             136
7A     REDID.K=SHFIN.JK+SRMOR.JK                                              137
7A     REPLA.K=CFGPR-STINC                                                    138
14A    BLOCD.K=-LACEX.JK+(BLITZ.K)(BLAME.K)                                   139
7A     BLITZ.K=MANRI.JK+SRMOR.JK                                              140
20A    BLAME.K=CWARA/CPRCL                                                    141
12R    NETPR.KL=(0.5)(PBTRA.K)                                                142
1L     NETPD.K=NETPD.J+(DT)(NETPR.JK+0.0)                                     143
6N     NETPD=257725                                                           144
PRINT  1)ACCTP/2)ACCTR/3)ACTIN/4)BLGIN/5)BLGTL/6)CASHB/7)CUBLG/8)FGCRR/9)    146
X1     LACEX/10)LADNR                                                         146
PLOT   ACCTP=A,ACCTR=B,ACTIN=C,BLGIN=D,BLGTL=E,CASHB=F,CUBLG=G,FGCRR=H,LA     145
X1     CEX=I,LADNR=J                                                          145
PLOT   MAPRC=K,MENTT=L,NETPD=M,PBTRA=N,REQRR=O,RMATS=P,RMCEX=Q,RMPUR=R,SH     145
X1     ORD=S,STINC=T                                                          145
PRINT  1)MAPRC/2)MENTT/3)NETPD/4)PBTRA/5)REQRR/6)RMATS/7)RMCEX/8)RMPUR/9)    146
X1     SHORD/10)STINC                                                         146
SPEC   DT=0.25/LENGTH=52/PRTPER=2/PLTPER=0.5                                  147
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APPENDIX B

A GLOSSARY OF SYMBOLS USED

ACCTP	accounts payable
ACCTR	accounts receivable
ACTIN	actual inventory
ARMAV	actual raw material available
ASHIN	average shipments from inventory
BLGIN	backlog for inventory
BLGRR	backlog reduction rate
BLGTL	backlog total
CASHB	cash balance
CCAEX	constant cash expenditure
CFGPR	constant finished goods price
CI	defined constant
CINRA	coefficient for inventory ratio
CLCTH	constant labor change
CNCAS	constant normal cash supply
CORIP	customer orders in process
CPROL	constant productivity of labor
CRMPR	constant raw material price
CRMSP	constant raw material supply
CUBLG	customer backlog
CWARA	constant wage rate

DACTP	delay in accounts payable
DACTR	delay in accounts receivable
DELCP	delay in clerical processing
DELPR	delay in production to inventory order
DELRM	delay in procuring raw materials
DELSH	delay in shipping
DESIN	desired inventory
DESLA	desired labor
DESRM	desired raw materials
DLATR	delay in labor training
DLLEA	delay in labor leaving
DMCOR	delay in manufacturing to customer order
DPCOR	delay in production to customer order
DT	time interval between solutions
e	base of natural logarithm
FGCRR	finished goods cash receipt rate
FGINR	finished goods invoice rate
FRFIN	fraction of requisitions filled from inventory
FRLCO	fraction of labor on customer orders
FRLIN	fraction of labor on inventory orders
INADJ	inventory adjustment time
INTAX	income tax
LABAV	labor to be available
LACEX	labor cash expenditures
LADNR	labor dismissal notice rate
LATER	labor terminating

LAVES	labor for average sales
LBLAD	labor for backlog adjustment
LCIND	labor change indicated
LCRAH	labor change rate for hiring
LCRDI	labor change rate for discharging
LENPR	labor entering production
LHRRA	labor hiring rate
LINTR	labor in training
LLEAV	labor leaving
MANRI	manufacturing rate for inventory
MAPRO	men actually producing
MAXFI	maximum fraction filled from invento
MDELB	maximum delay in backlog reduction
MEINP	men for excess inventory production
MENTT	men total
MMBLG	men maximum for work on backlog
MWBLG	men for work on backlog
NBLOG	normal backlog
NDBLG	normal delay in backlog
NECIN	necessary inventory at fractory
NETPD	net profit to date
NETPR	net profit rate
NFFIN	normal fraction of requisitions filled from inventory
NRMAV	normal amount of raw material available
OACTI	orders actual for inventory

OIPIN	orders in process for inventory
ONECI	orders necessary for inventory
ORAMI	orders actual manufactured for inventory
ORMIN	orders to be manufactured for inventory
PBTRA	profit before tax rate
PCORD	production to customer order
PEINV	production excess for inventory
PINOR	production of inventory orders
PRSIN	production rate starts for inventory
REQCP	requisitions in clerical processing
REQFI	requisitions filled from inventory
REQMO	requisitions manufactured to order
REQRR	requisitions receiving rate
REQSR	requisition smoothing rate
REQST	requisition smoothing time
RMARE	raw material received
RMATS	raw material stock
RMCEX	raw material cash expenditure
RMINR	raw material invoice rate
RMPUR	raw material purchased
SHFIN	shipments from inventory
SHORD	shipping orders
SRMOR	shipment rate manufactured to order
STINC	standard inventory cost
TASHI	time to adjust shipments from inventory
TBLAD	time for backlog adjustment

TFLCH	time for labor change
TRMAD	time for raw material adjustment
VDELM	variable delay in manufacturing

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