A DYNAMIC STUDY OF SELF-INDUCED SEASONAL CYCLES

by

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Signature of Author . . . .

School of Industrial Management

Certified by . . . .

Faculty Advisor of the Thesis

May 20, 1960

Professor Philip Franklin
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Professor Franklin:

In accordance with the requirement for graduation, I herewith submit a thesis entitled "A Dynamic Study of Self-Induced Seasonal Cycles."

I wish to take this opportunity to express my appreciation to the members of my thesis committee for their understanding and assistance. Professor Jay Forrester and Professor Caroll Wilson provided helpful criticism and stimulated many of my thoughts. I am also indebted to the MIT Computation Center for their assistance in processing the data required to research the problem.

Sincerely yours,

Philip K. Bates, Jr.

ABSTRACT

"A Dynamic Study Of Self-Induced Seasonal Cycles"

by Philip Knight Bates, Jr.

Submitted to the School of Industrial Management on May 20, 1960 in partial fulfillment of the requirements for the dgree of Master of Science.

Many industrial enterprises are subjected to fluctuations in the rate at which the market place will purchase their products. These extraneous factors cause the firm to experience highs and lows in its apparent demand schedule, which are reflected back into the operation of the factory. In an effort to alleviate the operational problems introduced by the vagaries of the consumers behavior, management will often formulate policies designed to control or offset these variations in activity level. These policies, by their very application, are suspected of adding to any natural tendency for the firms operation to assume a regular pattern during subsequent years.

There may be many areas wherin the management of a firm openly or inadvertantly creates a seasonal pattern in its sales through the use of advertising, price promotions, or annual model changes. Whether the major source of variation is thus created, or inherent in the nature of the product, the factory or producing sector is called upon to meet the demands of the market place. The hazards of having the production activity closely geared to the retail sales are many. Any variations which are transmitted to the production line will cause problems in keeping a stable work force, obtaining full equipment utilization, and having some measure of inventory control. As a firm is soon able to appraise the costs of less stable operation, it will attempt to recognize the character of the sales pattern. It is believed that if the normal variations of sales are understood, then the management will be able to formulate policies which will permit it to have both the variable sales pattern and a stable, more efficient productive capability.

The concern of this thesis is to examine the effects of three production rate decision policies which have been designed to control or offset the evils of fluctuating activity levels. The common vacation period and factory shut down is presented as an annual occurance which obviates many problems in factory operation. Where management attempts to recognize and then anticipate an annual pattern of sales, it is acting on the belief that it will smooth out operations and have higher plant utilization. Many firms will use long range forecasting as the basis for production planning and stabilization. These three decision policies are formulated and examined in a model of a typical production-distribution system. The Industrial Dynamics technique of model simulation of company interactions is utilized for the insight it provides into the responses of the various sectors to the input conditions. The utilization of a mathematical formulation of decisions and activities permits an examination of the dynamic behavior of these perimeters under various conditions of consumer behavior and operating policies over a number of years.

The major conclusions of the study are that where production decisions are designed to control a specific phenomena, they will contribute to operational stability only when that phenomena is the dominant characteristic of the system. Where this policy is applied to a 'non-pure' fluctuating behavior it will have the effect of aggravating the natural disturbance of the dynamic response. Each of the policies studied has a tendency to create an annual pattern in the factory operation. This pattern is transmitted to other components of the system and their reaction is such as to reinforce the pattern. Although the greatest self-generation of an annual pattern is in the use of sales promotion devices, the policies of factory operation are seen to contribute measureably to the pattern.

Thesis Supervisor: Dr. Jay W. Forrester
Title: Professor of Industrial Management

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CHAPTER I

PROBLEMS OF SEASONAL OPERATION

In the advanced industrial society of today, there is still one area where the management of an industrial firm can exercise little or no control. The consumer is at liberty to enter the market to purchase or not to purchase as he sees fit. As much as the management of many firms would like to be able to control all their operations, including sales, in order to achieve the optimal results, they are still dependent on the consumer for their continued existance. Many firms may attempt to influence the consumer's buying pattern through advertising, sales promotion efforts, or price manipulation, but even these activities do not control the consumer. The only positive control a firm may reasonably exercise is to not make its product available for sale.

The pattern by which the consumer purchases the product may be completely random (no pattern) or it may have a regularity in its timing. The combined pattern of all consumers may accentuate the single consumer's pattern, if all have the same timing, or it may simply even out the total sales pattern. "Seasonal cycles" as discussed herein, shall refer to any pattern of events which appear to have a greater concentration of activity at a particular time or times of the year. The familiar sine wave, if describing the level of operations or sales, is a typical illustration of a seasonal characteristic, if the period is one year, or a whole fraction of a year. The frequency may be more than one cycle per year, but where peaks of activity are followed by periods of depressed activity, at the same time of year, every year, we attribute the definition "seasonal" to the activity. Much attention has been directed to the problems introduced into a firm's operations when the firm believes that it is faced with seasonal characteristics. The firm may feel that it has a natural seasonal pattern in the supply of its raw material, or in the disposition of its product.

In the interests of "stability", management will often direct its efforts to the correction or alleviation of the effects of a cyclical pattern in its operations or sales. It is the author's hypothesis that whether or not the firm is truly subjected to an exogenous annual cyclical influence, the policies which it imposes to "control" these fluctuations will tend to create and amplify any disturbance in its operations. If the firm has a known seasonal cycle, the policies it evolves which are an attempt to offset the cycle are very likely to accentuate the difficulty. It is further hypothesized that where only a random pattern of operation exists, that the policies of management designed to prevent the hazards of seasonality, will create an annual pattern in the operation of the firm.

Whether the initiation of the "seasonality" is with the supply of the raw material, or in the distribution of the end product, the problems of the cycle are concentrated in the manufacturing or processing element. The processing firm is expected to adapt itself to meet the requirements of those who deal with it. As the consumer will purchase only when he needs or wants to, the firm must adapt to the seasonal requirements of the market place, if there are any. With many raw materials, they become available only during certain periods of the year and again the firm must adapt to this condition if it is to have the product.

Seasonality can thus be seen to arise from either the producer's or consumer's environment, and to have its impact centered in the processing or adapting operation. It is this large middle area of industrial enterprise which is beset with problems, and attempts to alleviate them as thoroughly as possible. Among the problems created by a cyclical acitivity are those dealing with the stability of the work force, the size and capacity of physical facilities, and the cost and availability of capital.

Due to many pressures, the employer of today is seeking to have a stable (no cut-back) work force throughout the year. An employer, it seems, must be more careful to secure the good will and cooperation of the citizenry and work force of its home town. The cause for "social good" and the labor unions have strengthened the desire for annual employment, security, stability, etc. Economically, the best interests of the firm are also achieved through a stable work force. The cost of hiring and training additional work force for short periods is very often prohibitive. The "experience rating" for assesment of compensation taxes also has a considerable influence towards stability. Where-as some occupations are assumed to be unquestionably seasonal, most factory workers consider that their work can and should continue on without interruption during the entire year.

The size and economic utilization of the physical equipment is another problem associated with seasonality. Where the entire production for the year is accomplished in one month, with the consumption spread out evenly over the year, there is, among others, a tremendous storage problem. In this instance we would find a structure sized to hold the maximum needs for one year, but which is "full" only once a year. Again, the machinery involved in the processing of the goods must be sized for the peak capacity, and will very likely be under-utilized for the majority of the year.

A third problem inherent in seasonal productivity is that of the availability of capital. In an operation which is regularly producing and selling its product the firm need seldom run into money problems for ordinary expenses. In a seasonal operation however, the firm must be a heavy user of financial credit or unreasonably tie up its own funds. There is either a long costly production cycle prior to sale, or a large inventory tied up, either of which will absorb large amounts of capital. It is also generally agreed that if at all possible, the firm should avoid large fluctuations in its rate of productivity, as these swings only create more expensive operating conditions, thus reducing the margin on the product.

It is indeed difficult to avoid seasonal problems, as they may be imposed by the market, or by nature. Although most industrial managers are aware of the inconvenience and costs of cyclical operations, many of their actions are directed, either intentionally or unwillingly, towards the creation and strengthening of seasonal patterns. It is the author's hypothesis that there are some of the policies of industrial managers which are directed at the control or balancing of seasonal patterns, which by their very application, contradict their purpose. There is little point in discussing the case where management attempts to create a seasonal pattern, as management should be reasonably aware of the resultant problems it is creating, but it is thought worthwhile to determine the extent to which the "control" policies contribute to the creation of the problems.

Management decisions. -- Of those policies that create seasonality, perhaps the most obvious is the use of advertising. Many examples could be cited where the product is of equal utility throughout the year, is produced equally well throughout the year, but is advertised only at certain periods of the year. Although the effects of advertising are very difficult to quantify, it has been suggested that advertising will tend to concentrate (or speed up) the sales which would have occured anyway over a longer period of time. Thus, advertising may have created a seasonality which is not inherent in the nature of the product.

Other devices for the stimulation of seasonality are the use of "style changes" or "annual models". This innovation in the design or utility of a product focusses attention on the consumer's"need to be current", and at the turn-around date will bring a greater concentration of sales , and hence factory productive effort.

Some manufacturers further concentrate their consumer's and distributor's purchases by offering the sales group bonuses for special sales efforts. "Prize months" or "Year end goals" will stimulate a greater effort to sell, and may even induce the stalling of orders until this period. When activity is low, some manufacturers will offer discounts or price reductions to increase the sales rate, which again will help to "bunch" the subsequent production.

Through the manipulation of these policies, the sales results are frequently achieved, but at the expense of the production sector. The use of annual budgeting, fiscal years, etc., tend also to focus attention on an annual period, whereas the natural cycle of the firm's activities may not be fully compatible with an annual cycle.

In the area of these management policies which are designed to offset or control the annual pattern in a firm's operation, we find that the use of the summer shut-down vacation, seasonal recognition forecasting, and long-range planning are prominent devices. It is to these policies that this thesis is directed, in an attempt to explore the ramifications of the application of these policies on a typical production situation. One of the reasons behind the use of the shut-down vacation is "to obviate the hiring of extra workers for short period substitutions".[1] The implication is that the hiring of temporary help to replace vacationing employees is an expensive proposition for the company. The expense arises from the unproductive training period, lowered productivity on the new worker, and increased tax burden to the firm. What ever the motivation, the deicison to completely shut down operations for vacations is thought to induce a repetitious, annual pattern into the companies' operations.

Given the supposition that a stable work force and "even" production rate are approaches to optimizing the long term best interests of the firm, many managements design policy decisions around these objectives. For the firm which is accepted as having a seasonal pattern of sales, management will attempt to minimize the impact of this pattern on its productivity sector. It will assume that once it has recognized the seasonal pattern it can act so as to alleviate the

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[1]Employment Regularization, a survey by the National Association of Manufacturers, 1940, p.17

usual effects of cyclical operation. Even the firm with nothing more than random variations from an average sales rate will attempt to discover a pattern so as to better understand and hence, to control its operations. Very often the methods of data accumulation and reporting to management will group information so as to make each period's activity appear to be different and unique from the remainder of the year.

For many firms, the use of long-range planning is expected to introduce enough certainty of future sales that production can be stabilized, and the effects of seasonality reduced. Perhaps the most valid utility of long-range planning is in the determination of how much capital expansion will be needed by a certain date, if the firm is to achieve a pre-set goal. In this capacity, forecasting assists the firm in leading its competitors in expansion and achieving maximum potential sales. There is, however, more risk attached with producing goods before the orders are placed, but perhaps the stability achieved more than balances the added risk. With the use of a forecast in the establishment of production levels, it is also necessary to have a periodic adjustment to "more current economic conditions", which will tend to introduce a cyclical pattern under most circumstances.

Investigation. -- The investigation of the ramification of these mangement policies will be conducted using a mathematical model to simulate the activities of the firm. The advent of the high speed computer now permits the use of mathematical model studies to assist in tracing the dynamic behavior of a firm over many years. These studies can be accomplished in relatively short order and at minor expense for most firms. The field of Industrial Dynamics as developed by Dr. Jay W. Forrester[2] is an approach to better understanding of the problems affecting corporate life. Industrial Dynamics has been defined as

> "The analysis of the time-varying interactions between the flows of information, orders, materials, capital equipment, money, and manpower in a company, an industry, or a national economy."[3]

The utility of the Industrial Dynamics approach to problem understanding comes from the insight it provides into the benefits and dangers which would result from changing system parameters or policies. With the mathematical model, and the computer, any proposed change in the organization or in operational policies may be formulated, a few years operations simulated and the effects analyzed in a period of a few hours. Although it may be some time before this approach is accepted by management, as a control device for daily operations, rather than as simply a guide for management decision, the art of Industrial Dynamics currently proves to be a valuable tool for the understanding and guidance of corporate behavior.

As currently developed, the mathematical formulation in the models is a true representation of the actual behavior as it is seen to exist, or as it is altered for analysis. All operations are assumed to be carried out in the same manner for the entire length of the experiment. In a business situation, there is some degree of "learning from experience" which may assist the firm in correcting (or so it believes)

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[2] Industrial Dynamics, A Major Breakthrough for Decision Makers, by J. W. Forrester, Harvard Business Review, Vol. 36, July-August 1958.

[3] Memorandum D-59 by J. W. Forrester, School of Industrial Management, December 2, 1959.

the poor operating policies of early years. In the use of long time period investigations with consistent policies and interaction patterns, it must be recognized that there is no learning feedback in the model, which will distinguish it from a business experience. The experimental method also assumes "everything else equal" unless all possible forces are introduced into the model. The evaluation of simulation studies must allow for the effect of the many factors which may not be "equal" outside the model situation.

The management decision policies which are used as the basis of the study are derived from an examination of the literature relating to these problems. Examples are compounded from the actions of various firms in the consumer durable goods industry which have developed the policies for their own use. The reader is cautioned against generalizing the results of the investigation to too great an extent. It is pointed out that whereas the general philosophy of the decisions studied and the interactions portrayed is common-place and well accepted as a usual method of operation, the specific results apply only to the specific conditions introduced. The benefit derived from the responses observed will only be to demonstrate what might be expected to happen if the same general policies were utilized in a business situation.

CHAPTER II

SIMULATION MODEL

In a going industrial system it is very difficult to experiment with different management philosophies with any degree of accuracy. The use of a model of an industrial system permits the researcher to vary the system parameters, change decision rules, etc., without affecting the real situation. In the real world, a five year experimentation could be disasterous if the wrong policies were chosen, and the experimental conditons could not be readily duplicated for the next trial period. The researcher derives great benefit from having a mathematical tool which can be utilized to experiment with different management techniques.

When a mathematical model is built which fairly represents the actual situation, this model can then be subjected to the whims of the researcher with no damage to any "real world" business, and with the ability to apply consistent experimental conditions. With this tool, valuable information, without the effects of various actions, can be obtained over a short space of time. In building the model, the researcher must be careful in his selection of what factors to include, and how much detail is necessary. Some experience is helpful in determining what factors are likely to cause dynamic movements within the system. The researcher is torn between exactly specifying all factors pertinent to the system's behavior (and consequently a large model), or reducing the complexity by simplification and elimination of many of less important factors.

For the purpose of this investigation, it is desired to use a model which portrays a typical manufacturing operation with its destributor and retail sectors. This structure could be assumed to be representative of most consumer goods operations. As the behavior of most firms in the consumer goods industry is determined by their activity in the market place, it is thought beneficial to study the various management policies within a system where the major 'cause' stimulus is essentially beyond the management control. It is intended that the model demonstrate the effects of various decision rules when they are applied to the factory sector, and the model is subjected to the vagaries of the market place. As an evaluating guide, or criteria of benefit to management, the manufacturing rate will serve as the major factor, with inventories and backlogs assisting in the measurements. In the model under study, the manufacturing rate is a good indication of the number of employees necessary to produce the goods, and the capital equipment necessary for peak productions. It would be possible to portray the number of workers, their productivity under varying work load conditions, and the hiring and firing activities, but this would only serve to introduce confusion into the fluctuations observed.

The system under study is an adaptation of one presented by Dr. Jay Forrester on March 10, 1959 in "Equations for Production-Distribution System -- A Section of Industrial Dynamics Class Notes."[1]

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[1]Forrester, J. W. Memorandum: D-34: Equations for Production-Distribution System -- A Section of Industrial Dynamics Class Notes (an unpublished paper), Industrial Dynamics Group, School of Industrial Management, Massachusetts Institute of Technology, Cambridge, March 10, 1959.

The reader is referred to this work for a more complete treatment of the construction of the model, as only the changes will be explicitly treated here.

<u>General Model</u>. -- There are three inter-related sectors of the model; the factory, the distributor, and the retailer. Each sector is treated as an information and material processing center.

The activities which are included are those which will directly relate to the study of management decisions as they affect factory employment, and production rates. Each sector will be only generally described, as many functions such as billing, advertising, etc., are not necessary for the situation under study.

In the retail sector, shown in Figure 1, the major exogenous factor is the behavior of customers in placing orders. As orders are placed, they build up a backlog of unfilled orders. These orders will be filled in due course from inventory, and the backlog then reduced. The level of orders in the backlog at each moment of time is given below.

UOR.K = UOR.J + DT(RRR.JK - SSR.JK) Eq. 1, L

UOR--Unfilled Orders at Retail, (measured in units of goods on order)
RRR--Requisitions (orders) Received at Retail, (units/week)
SSR--Shipments Sent from Retail, (units/week)
DT--Delta Time (weeks) = the time interval between solutions of the equations.

The level of goods in the inventory is also a difference between those received from the distributors and those sent to the customers.

IAR.K = IAR.J + DT(SRR.JK - SSR.JK) Eq. 2, L

IAR--Inventory Actual at Retail, (units)
SRR--Shipments Received at Retail, (units/week)
SRR--Shipments Sent from Retail, (units/week)

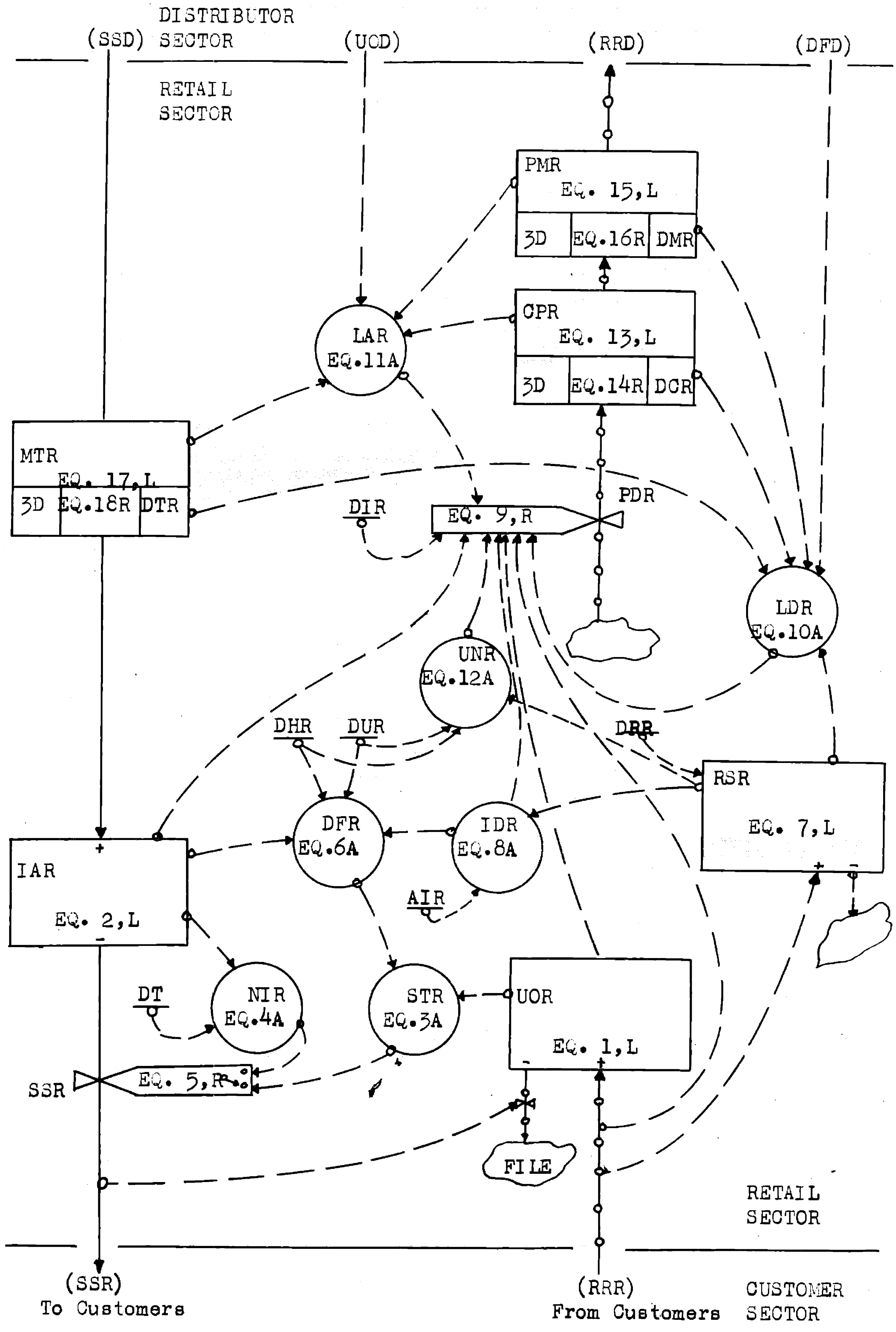

FIGURE 1 MODEL OF RETAIL SECTOR

In determining the rate at which goods will be sent from inventory, we assume a fairly typical industrial reaction. Of course, the shipment must be limited by the available goods, but it is otherwise directly related to the level of unfilled orders, and the average delay in processing orders.

$$STR.K = \frac{UOR.K}{DFR.K} \qquad \text{Eq. 3, A}$$

$$NIR.K = \frac{IAR.K}{DT} \qquad \text{Eq. 4, A}$$

$$SSR.KL = STR.K, \text{ if } STR.K \geqslant NIR.K \qquad \text{Eq. 5, R}$$
$$= NIR.K, \text{ if } STR.K < NIR.K$$

SSR--Shipments Sent from Retail, (units/week)
NIR--Negative Inventory limit rate at Retail, (units/week)
STR--Shipping rate to be Tried at Retail, (units/week)

STR--Shipping rate to be Tried at Retail, (units/week)
UOR--Unfilled Orders at Retail, (units)
DFR--Delay in Filling orders at Retail, (weeks)

IAR--Inventory Actual at Retail, (units)
DT--Solution Time interval, (week)

This processing delay is assumed to be the combination of a constant delay, and a delay which is proportional to the number of goods in the inventory.

$$DFR.K = DHR + DUR\ \frac{IDR.K}{IAR.K} \qquad \text{Eq. 6, A}$$

DFR--Delay in Filling orders at Retail, (weeks)

DHR--Delay due to minimum Handling time required at Retail, (weeks)

DUR--average Delay in Unfilled orders at Retail caused by out-of-stock items when inventory is "normal", (weeks)
IDR--Inventory Desired at Retail, (units)
IAR--Inventory Actual at Retail, (units)

The day by day activity is seldom used as a basis for major adjustment, and so we utilized a "smoothed" figure which is more stable than, but a bit delayed from, the actual current rate. First order exponential smoothing is used as a more current and accurate reflection of what is taking place than straight averaging. Smoothed orders are given below.

$$RSR.K = RSR.J + (DT) \frac{1}{DRR} (RRR.JK - RSR.J) \qquad \text{Eq. 7, L}$$

RSR--Requisitions Smoothed at Retail, (units/week)
RRR--Requisitions Received at Retail, present sales rate, (units/week)
DRR--Delay in smoothing Requisitions at Retail, the smoothing time constant, (week)

As a basis of comparison for determining action, the concept of "desired" conditions is utilized. Managers frequently use 'rules of thumb', or factors learned from experience as their guide posts for action, and the utilization of the "desired" concept reflects this behavior.

These "desired" levels should be based on aggregate amounts, monthly totals, or an average figure; otherwise, they would be unduly violent in fluctuations. The desired level of inventory is shown below.

$$IDR.K = (AIR)(RSR.K) \qquad \text{Eq. 8, A}$$

IDR--Inventory Desired at Retail, (units)
AIR--proportionAlity constant between Inventory and average sales at Retail, (weeks)
RSR--Requisitions Smoothed at Retail, i.e., average sales, (units/week).

The decision to replenish stock, is presented in equation 9. The retailer must replace those goods which were recently sold, and will therefore adjust his inventory over a period of time, to accomodate shifts in the general level of business. When adding up his inventory, the retailer will consider also the number of goods which he has previously ordered and are currently in shipment to him. He must also act to keep his order backlog at a reasonable level, otherwise customers may be discouraged from purchase by excessive waiting periods. The retailer's impression of his goods in transit is shown in equation 11, as the content of the pipeline. The desired content of the pipeline is shown in equation 10. A normal level of orders unfilled is shown in equation 12.

$$PDR.KL = RRR.JK + \frac{1}{DIR}(IDR.K - IAR.K) + (LDR.K - LAR.K) + (UOR.K - UNR.K) \qquad \text{Eq. 9, R}$$

$$LDR.K = (RSR.K)(DCR+DMR+DFD.K+DTR) \qquad \text{Eq. 10, A}$$

$$LAR.K = CPR.K + PMR.K + UOD.K + MTR.K \qquad \text{Eq. 11, A}$$

$$UNR.K = (RSR.K)\ DHR + DUR \qquad \text{Eq. 12, A}$$

PDR--Purchasing rate Decision at Retail, (units/week)
RRR--Requisitions Received at Retail, (units/week)
DIR--Delay in Inventory (and pipeline) adjustment at Retail, (week)
IDR--Inventory Desired at Retail, (units)
IAR--Inventory Actual at Retail, (units)
LDR--pipeLine orders Desired (necessary) in transit to supply Retail, (units)
LAR--pipeLine orders Actual from Retail, (units)
UOR--Unfilled Orders at Retail, (units)
UNR--Unfilled orders, Normal, at Retail, (units)
RSR--Requisitions Smoothed at Retail, average sales, (units/week)
DHR--Delay in Handling time at Retail, (weeks)
DUR--Delay in Unfilled orders at Retail from stock-outs at normal inventory, (weeks).
CPR--Clerical in Process orders at Retail, (units)
PMR--Purchase orders in Mail from Retail, (units)
UOD--Unfilled Orders at Distributor, (units)
MTR--Material in Transit to Retail, (units)
DMR--Delay in Mail from Retail to distributor (weeks)
DCR--Delay in Clerical processing of orders at Retail, (weeks)
DFD--Delay in Filling orders at Distributor, (delivery delay), (weeks)
DTR--Delay in Transportation of goods to Retail, (weeks)

Once the decision to order has been made, there are delays in filling out and mailing orders, which delays are most fairly represented by third order delays. Equation 13, 14, 15, 16 define the output from these delays, as well as the content of the delay itself.

CPR.K = CPR.J + (DT)(PDR.JK - PSR.JK) Eq. 13, L

PSR.KL = Delay 3 (PDR.JK, DCR) Eq. 14, R

PMR.K = PMR.J + (DT)(PSR.JK - RRD.JK) Eq. 15, L

RRD.KL = Delay 3 (PMR.K, DMR) Eq. 16, R

PMR--Purchase orders in Mail from Retail, (units)
PSR--Purchase orders Sent from Retail, (units/week)
RRD--Requisitions (orders) Received at Distributor, (units/week)
DMR--Delay in Mail from Retail to distributor, (weeks)
DELAY 3--specifies third-order delay equations.
CPR--Clerical in Process purchase orders at Retail, (units)
PDR--Purchase order Decision at Retail, (units/week)

There will also be goods in transit from distributors which are "delayed" from when they left the distributor to when they arrived at the retailer. Equation 17 and 18 explain the level and output of this third order delay.

MTR.K = MTR.J + (DT)(SSD.JK - SRR.JK) Eq. 17, L

SRR.KL = DELAY3(MTR.K, DTR) Eq. 18, R

MTR--Material in Transit to Retail, (units)
SSD--Shipments Sent from Distributor inventory, (units/week)
SRR--Shipments Received at Retail inventory, (units/week)
DTR--Delay in Transportation of goods to Retail, (weeks).
DELAY3--specifies third-order delay equations.

The activities at the distributor sector are very similar to the retail sector, and identical equations will be used in the model. The general flow of the system is highly comparable, by many of the time constants and "desired" ratios are different, to reflect the difference in operations. With this model we can use identical equation forms, and yet have different patterns of action, by changing the time to adjust inventories, the desired levels of inventories, or orders unfilled, etc. The equations for Figure 2 will simply be listed without full discussion. (Equations 19 to 37).

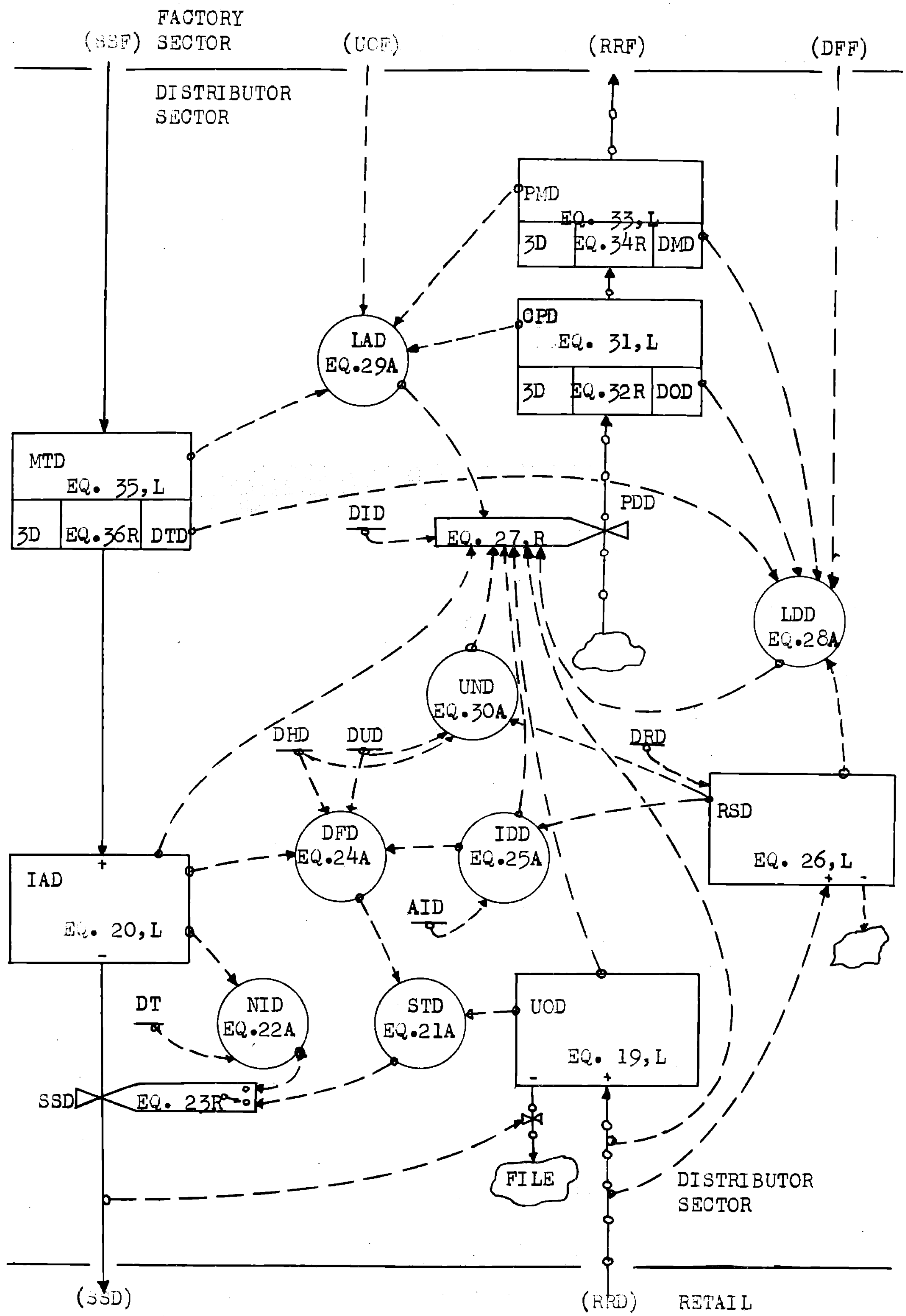

FIGURE 2 MODEL OF DISTRIBUTOR SECTOR

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UOD.K = UOD.J + (DT) (RRD.JK  - SSD.JK)              Eq. 19, R
IAD.K = IAD.J + (DT) (SRD.JK  - SSD.JK)              Eq. 20, L
STD.K = UOD.K/DFD.K                                  Eq. 21, L
NID.K = IAD.K/DT                                     Eq. 22, A
SSD.KL = STD.K, if NID.K≥STD.K                       Eq. 23, A
       = NID.K, if NIDK<STD.K
DFD.K = (DUD)(IDD.K)/IAD.K + DHD                     Eq. 24, R
IDD.K = (AID) (RSD.K)                                Eq. 25, A
RSD.K = RSD.J + (DT) (1/DRD)(RRD.JK - RSD.J)         Eq. 26, A
PDD.KL = RRD.JK+(1/DID)(IDD.K-IAD.K+LDD.K -          Eq. 27, A
         LAD.K+UOD.K - UND.K)
LDD.K = (RSD.K)(DCD)+(RSD.K)(DMD)+(RSD.K)            Eq. 28, L
        (DFF.K)+(RSD.K)(DTD)
LAD.K = CPD.K+PMD.K+UOF.K+MTD.K                      Eq. 29, R
UND.K = (RSD.K)(DHD+DUD)                             Eq. 30, A
CPD.K = CPD.J+(DT)(PDD.JK - PSD.JK)                  Eq. 31, A
PSD.KL = DELAY3(PDD.JK,DCD)                          Eq. 32. A
PMD.K = PMD.J+(DT)(PSD.JK - RRF.JK)                  Eq. 33, L
RRF.KL = DELAY3(PSD.JK,DMD)                          Eq. 34, R
MTD.K = MTD.J+(DT)(SSF.JK - SRD.JK)                  Eq. 35, L
SRD.KL = DELAY3(SSF.JK,DTD)                          Eq. 36, L
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(Definitions of distributor variables are the same as for the retail sector, with the correction to Distributor).

The factory sector shown in Figure 3 will be modified in the following chapters to study the various decision rules. The sector will continue to have the same general characteristics, however, and will be modified only enough to permit the different ordering rules to be introduced. The basic model structure and equations will be presented here to complete the general description of the entire system.

In the factory, Figure 3, the unfilled orders and inventory are treated similarly to those levels at other sectors of the model.

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UOF.K = UOF.J + (DT)(RRF.JK - SSF.JK)                Eq. 37, L

IAF.K = IAF.J + (DT)(SRF.JK - SSF.JK)                Eq. 38, L
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UOF--Unfilled Orders at the Factory, (units)
RRF--Requisitions (orders) Received at Factory, (units/week)

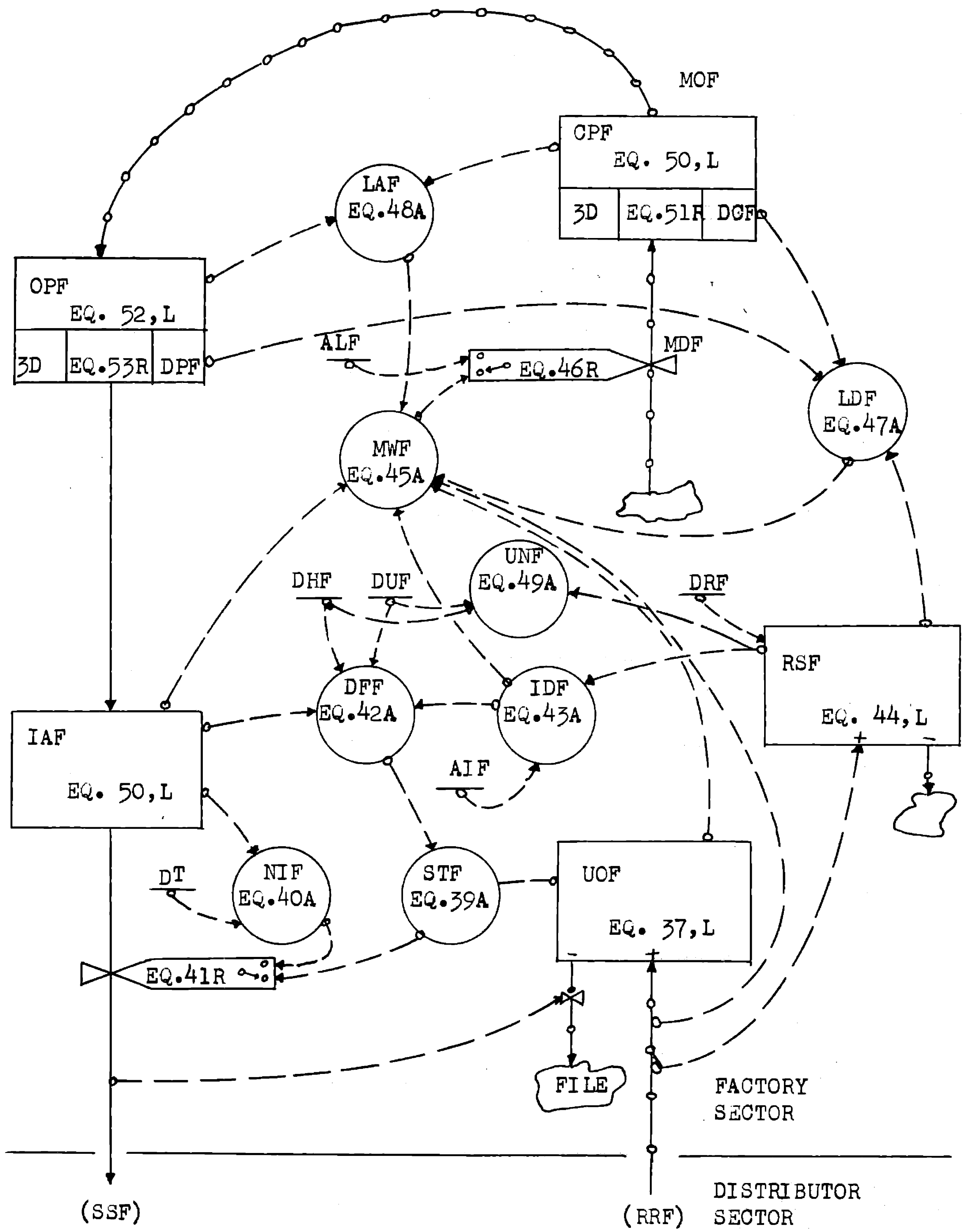

FIGURE 3 MODEL OF FACTORY SECTOR

SSF--Shipments Sent from Factory warehouse, (units/week)
IAF--Inventory Actual at Factory warehouse, (units)
SRF--Shipments Received at Factory warehouse, (manufacturing output), (units/week)

The shipping rate is represented by the following equations.

$$STF.K = \frac{UOF.K}{DFF.K} \qquad \text{Eq. 39, A}$$

$$NIF.K = \frac{IAF.K}{DT} \qquad \text{Eq. 40, A}$$

$$SSF.KL = STF.K, \text{ if } STF.K \geqslant NIF.K \qquad \text{Eq. 41, R}$$

$$= NIF.K, \text{ if } STF.K < NIF.K$$

STF--Shipping rate to be Tried at Factory, (units/week)
UOR--Unfilled Orders at the Factory, (units)
DFF--Delay (variable) in Filling orders at Factory, (weeks)
NIF--Negative Inventory limit rate at Factory, (units/week)
IAF--Inventory Actual at Factory, (units)
DT--solution time interval, Delta Time, (weeks)

The expressions for the delay in filling orders, the ideal inventory, and the smoothed sales rate can be of the same form as given in Equation 6, 7, and 8.

$$DFF.K = DHF + DUF \frac{IDF.K}{IAF.K} \qquad \text{Eq. 42, A}$$

$$IDF.K = (AIF)(RSF.K) \qquad \text{Eq. 43, A}$$

$$RSF.K = RSF.J + (DT) \frac{1}{DRF} (RRF.JK - RSF.J) \qquad \text{Eq. 44, L}$$

DFF--Delay (variable) in Filling orders at Factory, (weeks)
DHF--Delay due to minimum Handling time required at Factory, (weeks)
DUF--Delay, average, in Unfilled orders at Factory caused by out-of-stock items when inventory is "normal", (weeks)
IDF--Inventory Desired at Factory, (units)
IAF--Inventory Actual at Factory, (units)
AIF--Proportionality constAnt for Inventory at Factory, (weeks)
RSF--Requisitions Smoothed at Factory, (units/week)
DRF--Delay in smoothing Requisitions at Factory, (weeks)
RRF--Requisitions (orders) Received at Factory, (units/week)

The decision to manufacture goods is based on the "ideal" concept which is a generally acceptable expression of "real world" operations. There is no maximum production rate limit imposed in the study, as most industries have the ability to vary their production rate over a very large range. It is assumed that the upper limit, which would be set by limitations of capital and equipment and man hours is adequately foreseen and does not enter into the deliberations at this point. Both of these factors have been assumed to be 'available' in order to study more basic considerations.

$$MWF.K = RRF.JK + \left(\frac{1}{DIF}\right)(IDF.K - IAF.K + LDF.K - LAF.K + UOF.K - UNF.K) \qquad \text{Eq. 45, A}$$

MWF--Manufacturing rate Wanted at Factory, (units/week)
RRF--Requisitions (orders) Received at Factory (units/week)
DIF--Delay in Inventory (and pipeline) adjustment at Factory, (weeks)
IDF--Inventory Desired at Factory, (units)
IAF--Inventory Actual at Factory, (units)
LDF--pipeLine orders Desired (necessary) in transit to Factory, (units)
LAF--pipeLine orders Actual in transit to Factory, (units)
UOF--Unfilled Orders at the Factory, (units)
UNF--Unfilled orders, Normal, at Factory, (units)

Once the manufacturing decision is made, the manufacturing process is started, but as a desire to produce at "x" rate does not immediately become effective in the shop as the orders are subjected to a delay, as is the production operation. Goods will come out of production after these delays, and go to the factory inventory.

$$MDF.KL = MWF.K, \text{ if } MWF.K \geqslant ALF \qquad \text{Eq. 46, R}$$

$$= ALF, \text{ if } MWF.K < ALF$$

$$LDF.K = (RSF.K)(DCF + DPF) \qquad \text{Eq. 47, A}$$

$$LAF.K = (CPF.K + OPF.K) \qquad \text{Eq. 48, A}$$

UNF.K = (RSF.K)(DHF + DUF) Eq. 49, A

CPF.K = CPF.J+(DT)(MDF.JK-MOF.JK) Eq. 50, L

MOF.KL = DELAY3(MDF.JK, DCF) Eq. 51, R

OPF.K = OPF.J+(DT)(MOF.JK-SSF.JK) Eq. 52, L

SSF.KL = DELAY3(MOF.JK, DPF) Eq. 53, R

MDF--Manufacturing rate Decision at Factory, (units/week)
MWF--Manufacturing rate Wanted at Factory, (units/week)
ALF--constAnt specifying manufacturing capacity Limit at Factory, (units/week)
LDF--pipeLine orders Desired (necessary in transit through Factory, (units)
RSF--Requisitions (orders) Smoothed at Factory, (units/week)
DCF--Delay in Clerical processing of manufacturing orders at Factory, (weeks)
DPF--Delay in Production lead time at Factory, (weeks)
LAF--pipeLine orders Actual in transit through Factory, (units)
CPF--Clerical in Process manufacturing orders at Factory, (units)
OPF--Orders in Production at the Factory, (units)
UNF--Unfilled orders, Normal, at Factory, (units)
DHF--Delay due to minimum Handling time required at Factory, (weeks)
DUF--Delay, average, in Unfilled orders at Factory caused by out-of-stock items when inventory is "normal", (weeks).
MOF--Manufacturing Order sent to productive sector of Factory, (units/week)
SSF--Shipments of goods Sent from Factory to inventory, (units/week).

The complete listing of equations including initial conditions, constants, etc., as prepared for machine computation is presented in Appendix A.

This basic model as stipulated, is what might be known as a "follower" model, rather than a "leader" model. There is no inclusion of forward thinking or planning in the model as stated. All the ordering rules, for instance, are designed to re-establish a desired relationship with the current real world situation, after a disturbance or an unbalance is seen to exist. The benefits of planning have not been realized, whereas most industrial firms practice a considerable degree of planning. Although not used as widely as possible, the manager of today will nearly always plan ahead to some degree.

It is the writer's suggestion that this "follower" situation is not illustrative of most of our industrial economy. Many firms do attempt, in one manner or another, to pre-determine what their operations will be like for a coming period and then direct their efforts towards achieving this goal, rather than directing operations to regain a desired relationship. All the firms who predict must in some way adjust for unforeseen circumstances, but in the most part, their managements feel that they are able to exercise more control over their activities than otherwise possible. By planning ahead for some period of time, it is possible to establish constant, efficient levels of work, rather than to be continuously making minor adjustments. Many of the delays which create amplification in the system are shortened or eliminated through proper planning.

In the subsequent chapters, three decision methods, which are attempts by management to better control their work environment, are explored. It is generally expected that the periodic, repetitious nature of their efforts will produce annual variations which would not otherwise be presented.

CHAPTER III

COMMON VACATION SHUT DOWN

Vacation shut down. -- With the introduction of extensive vacation priviledges for many workers, there have come many problems associated with maintaining the continuity of sales and productivity. When given free reign, the workers would tend to bunch their vacation together at more favorable (for them) times, to take advantage of the hunting season, school vacation periods, weather conditions, etc. If these factors were spread evenly over the year there would be fewer problems, but they tend to occur so as to create peaks and valleys in the desirability preference for vacations throughout the year.

As much as management attempts to maintain good employee relations, it must also act in a manner which will assure its continuity of profitability. In some continuous process industries, the vacations must be spread fairly evenly over the year, but many manufacturing operations are amenable to moderate peaks and valleys in their productive work load, and can afford the bunching of vacations.

In an increasing number of cases, management is finding it better to concentrate all vacations in a given two week period of the year. Many firms which feel they are beset with a seasonal sales pattern will attempt to concentrate vacations during the slack periods. This practice obviously could not take place in some industries (fresh food, oil, steel) where continuity of operation is of the highest importance. However, where the goods produced are non-perishable, and amenable to inventorying, we find considerable application of the practice.

The advantages listed for this practice include, among others:

1) Stable employment, through avoidance of hiring short term temporary workers,

2) Avoiding running the factory with the work force below efficient levels with production also hampered by the unavailability of key men,

3) Preventing turmoil in the arrangement of vacations, and

4) Permitting the major maintenance or re-tooling of shop machines with a minimum of lost production time.

Some of these reasons are given added emphasis where there is annual change-over expected, or a strong seasonal or style preference by the consumer. There are,in addition, many companies which hold the vacation during that period of the year when most (or simply key) employees want to vacation, regardless of market conditions.

It is readily admitted that companies who produce yearly model changes are creating seasonability for themselves by their own actions. For those industries where the change-over is not prevelent, but the annual "common" vacation is practiced, it is suggested that this practice induces fluctuation over and above any natural conditions of the market. In order for a firm to cease operations entirely (except possibly for maintenance) for the period of two weeks, it is usually necessary to loose efficient productive time during the preceeding and succeeding weeks also. There is less worker productivity, and less efficiency as certain operations or jobs have to be finished prior to the full shutdown.

Starting up is again a slower process than normal operation. These effects combine to give 3 to 4 weeks of low productivity or lost time at the factory.

These shutdowns can take on greater significance as more and more firms adopt roughly the same time of year for their shutdowns. As suppliers and industrial customers shut down, one's operations are further hampered by the inability to get prompt responses to the normal demands of business.

For the purpose of looking at the implications of this practice in a production-distribution system,the general model described earlier was altered to permit the shut-down of the factory sector. In the study, the distributor and retailer are assumed to know of the factory policy to shut down, but will react only by following their normal policies. Thus, the distributor will start to deplete his inventory and then his regular ordering rule will restore the inventory to its desired level after the shut-down. The distributor also will see a longer delivery delay time from the factory, and will react accordingly. By using this distributor philosophy, we eliminate the considerations the distributors ordering ahead and instead, give him the opportunity to clean out the warehouse, realign stocks, etc.

Other approaches have been suggested in an attempt to offset the repercussions of the two-week shut-down vacation. One idea is that as this period of inactivity approaches, goods could be produced in excess of current demand so that those called for during the vacation would be already on hand. With this approach it is necessary for management to determine how far in advance it desires to start this extra production. If we assume that the customer ordering rate remains constant, it would be necessary to raise production by 4% for the entire year in order to have sufficient goods on hand by downtime. If we "prepared" for a month in advance, we would require a 50% increase in production during that month, or if for three months, a 16% increase. These figures could, of course, be reduced if the customers activity level during the vacation period were reduced.

With this policy of building up inventories in advance, it becomes necessary to have increased warehouse capacity, and additional capital to accomodate the extra goods. The management at various levels must also exercise cation to see that this 'shut-down' inventory is not included in its usual ordering rule computations.

As a general rule, it seems wiser and more accepted to let the inventory be drawn down during and after the shut-down. The lower inventories permit greater ease in stock taking and a chance to rebuild stock in selected lines. The firm may also benefit from a lower basis for property tax assesment if the fiscal year is set properly. Further advantage results from the sure knowledge that, in the event that sales do not materialize as anticipated, there will not be large excess inventories on hand. The absolute impact of each of these factors will vary between firms, but their net effect will usually point to the advantages of using a manufacturing rule which reacts to correct the deficiencies after the disturbance has occured, for this situation.

Model Changes. -- In order to shut down the factory sector, it is necessary to introduce 'zero' rates into all factory operations.

Factory model, as changed, is shown in Figure 4. A factor was derived for this purpose, which starts the shut-down at week five, and permits the selection of any length of vacation.

With these equations it is possible to multiply the desired parameters by "0" for the two or three week shut-down period, and still permit them to have their normal value and effect during the remainder of the year.

SUMSD.K = VPD.K if SMSD*1.K $\geq$ 5.0 Eq. 54, A
= 1.0 if SMSD*1.K < 5.0

VPD.K = 1.0 if SMSD*1.K $\geq$ EOV Eq. 55, A

0.0 if SMSD*1.K < EOV

SUMSD--SUMmer Shut-Down factor
VPD--- end of Vacation Period Determinant for shut-down factor
SMSD-- Summing Method for Shut-Down timing, (weeks)
EOV--- End Of Vacation, (weeks)

In order to permit the repeated occurance of the shut-down, a time keeping boxcar train was utilized. This boxcar counts time up until week 52, when it starts over again.

SMSD = BOXLIN (1, 52) Eq. 56, B

SMSD*1.K = SMSD*1.J + DT Eq. 57, L

SMSD--Summins Method for Shut-Down timing, (weeks)

This factor was introduced into the desired manufacturing rate by changing ALF to ALFM, and using this new parameter in the decision.

ALFM.K = (ALF)(SUMSD.K) Eq. 58, A

MDF.KL = MWF.K if ALFM.K $\geq$ MWF.K Eq. 59, R
= ALFM.K if ALFM.K < MWF.K

MDF--Manufacturing rate Decision at Factory, (units/week)
MWF--Manufacturing rate Wanted at Factory, (units/week)

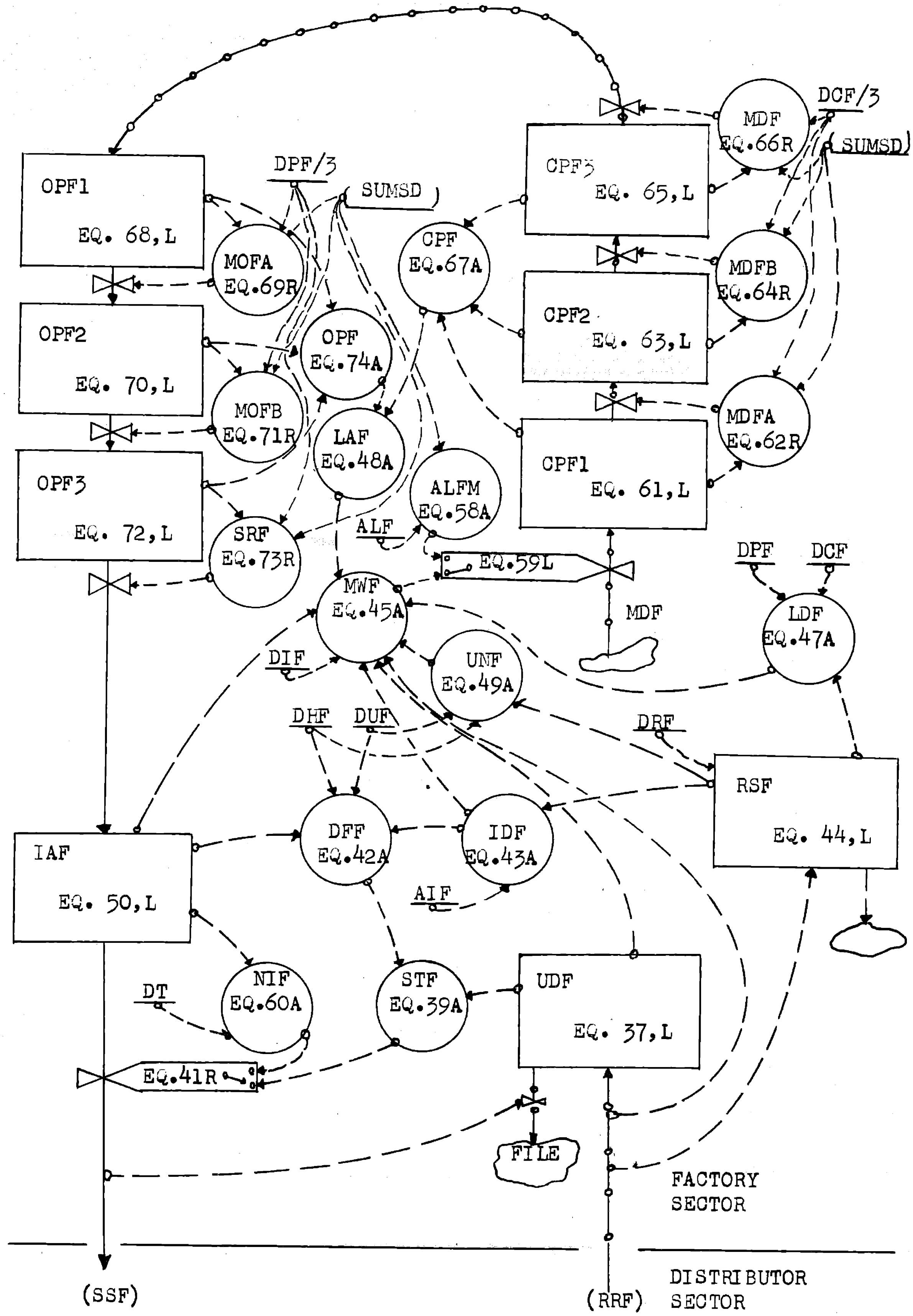

FIGURE 4 FACTORY SECTOR- FOR VACATION SHUT DOWN

ALFM--constAnt specifying manufacturing capacity Limit at Factory, Modified, (units/week)
ALF--constAnt specifying manufacturing capacity Limit at Factory, (units/week)
SUMSD--SUMmer Shut-Down factor

The shipping rate was modified to permit shut-down by changing the NIF equation.

$$NIF.K = \frac{IAF.K}{DT} (SUMSD.K) \qquad \text{Eq. 60, A}$$

NIF-- Negative Inventory limit rate at Factory, (units, week)
IAF-- Inventory Actual at Factory, (units)
SUMSD--SUMmer Shut-Down factor

The clerical delay and production delay both were reduced to three first order delays each so that these rates also could be stopped. When the factor SUMSD is zero (weeks 5,6). All these factors are zero also.

CLERICAL DELAY

$$CPF1.K = CPF1.J+(DT)(MDF.JK-MDFA.JK) \qquad \text{Eq. 61, L}$$

$$MDFA.KL = \frac{CPF1}{DCF/3} (SUMSD.K) \qquad \text{Eq. 62, R}$$

$$CPF2.K = CPF2.J+(DT)(MDFA.JK-MDFB.JK) \qquad \text{Eq. 63, L}$$

$$MDFB.KL = \frac{CPF2}{DCF/3} (SUMSD.K) \qquad \text{Eq. 64, R}$$

$$CPF3.K = CPF3.J+(DT)(MDFB.JK-MOF.JK) \qquad \text{Eq. 65, L}$$

$$MOF.KL = \frac{CPF3}{DCF/3} (SUMSD.K) \qquad \text{Eq. 66, R}$$

$$CPF.K = CPF1.K+CPF2.K+CPF3.K \qquad \text{Eq. 67, A}$$

CPF1--Clerical in P ocess manufacturing orders at Factory, level #1, (units)
MDF--Manufacturing rate Decision at Factory, (units/week)
MDFA--Manufacturing rate Decision at Factory from level #1, (A), (units/week)
CPF2--Clerical in Process manufacturing orders at Factory, level #2, (units)
MDFB--Manufacturing rate Decision at Factory from level #2 (B), (units/week)

CPF3--Clerical in Process manufacturing orders at Factory, level #3, (units)
MOF--Manufacturing Orders into Factory (units/week)
SUMSD--SUMmer Shut-Down factor
DCF --Delay in Clerical Processing of manufacturing orders at the Factory (weeks)
CPF--Clerical in Process manufacturing orders at Factor, total, (units)

PRODUCTION DELAY

CPF1.K = OPF1.J+(DT)MOF.JK-MOFA.JK) Eq. 68, L

$$MOFA.KL = \frac{OPF1.K}{DPF/3} (SUMSD.K)$$ Eq. 69, R

OPF2.K = OPF2.J+(DT)(MOFA.JK-MOFB.JK) Eq. 70, L

$$MOFB.KL = \frac{OPF2}{DPF/3} (SUMSD.K)$$ Eq. 71, R

OPF3.K = OPF3.J+(DT)(MOFB.JK-SRF.JK) Eq. 72, L

$$SRF.KL = \frac{OPF3}{DPF/3} (SUMSD.K)$$ Eq. 73, R

OPF.K = OPF1.K+OPF2.K+OPF3.K Eq. 74, A

OPF1 --Orders in Production in Factory, level #1 (units)
MOF --Manufacturing Orders into Factory, (units/week)
MOFA --Manufacturing Orders into Factory from level #1 (A) (units/week)
SUMSD--SUMmer Shut-Down factor
DPF --Delay in Production lead time at Factory, (weeks)
OPF2 --Orders in Production in Factory, level #2, (units)
MOFB --Manufacturing Orders into Factory, from level #2 (B), (units/week)
OPF3 --Orders in Production in Factory, level #3, (units)
SRF --Shipments Received into Factory inventory, (units/week)
OPF --Orders in Production in Factory, total, (units)

Effect of Shut-Down under steady-state conditions. -- In considering the effect of a two week complete shut-down, it is desirable to examine what reactions will occur in an otherwise stable situation. In the general model, the flows and levels of all sectors remain constant unless the model is disturbed by a change in the only external variable (customer ordering rate), or by a change in the equation format of the model. In this study, by keeping the customer's ordering rate constant, any changes observed in the rates and levels of the model, can be attributed solely to the disturbance of the shut-down.

In examining the impact of the shut-down on a steady state situation, it will be beneficial to explore the resultant changes when shut down for two weeks, and for three weeks. Also, various values of the delay used in correcting the necessary inventory (and pipeline) adjustments, should be examined to determine if the effects of the change are the same as when the system is otherwise disturbed.

The effects of this disturbance can be appraised by a comparison with the effects of alternate source disturbances, and by comparison with the same source but different parameters in the model. General criteria for the extent of impact on the system are the amplification of the disturbance at the various sectors, the duration of any resultant imbalance, and the magnitude of the changes in the various parameters.

When the shut-down occurs, all operations in the factory cease, and we find that the customers orders must be filled from the retailer's and distributor's inventory. The depletion will be primarily in the distributor sector, as the retailer has goods coming from the distributor to replenish his stock whereas the distributor's stock is not refilled.

As inventories fall, the re-order policies will carry a corrective component, and thus the factory will get an increase in orders which is greater than the customers ordering rate which is set at 1000 units/week. During the shut-down the distributor was continuing to place orders with the factory, and therefore the factory backlog increased markedly. The increased backlog led to greater factory activity, which then persisted until the model had regained steady state.

In Figure 5, are illustrated the manufacturing and inventory responses to the shut-down in a steady state system. Each curve illustrates a different delay in the correction of inventory, but all have the same basic formulation and model. With the delay in adjusting inventory set at four weeks, Curve A, the stock depletions at these other levels will lead to demands for increased activity in the factory, at a level which will attempt to correct the discrepancies in four weeks. For this case we find a +40% increase in productivity (to 1400 units/week) shortly after the shut-down, with the unfilled orders nearly doubled (from 2000 units to 3900 units, or a 90% increase). This sharp increase in activity following the shut-down subsequently fell off somewhat (to 1200 units/week)and then persisted at a rate above the average ordering rate for nearly 15 weeks. The distributors inventory experienced a depletion of about 1200 units (20%), while the retailer only lost 120 units (less than 2%). Following the shut-down the factory inventory fell to 2760 units from its normal 4000 units (a 30% drop) while the system was returning to normal. During the periods of lower inventory these sectors also percieved longer delivery delays. This delay, in combination with the need to adjust inventories, caused the lower levels to order more than their current sales requirements. The distributor increased his orders to a maximum rate of 1100 units/week

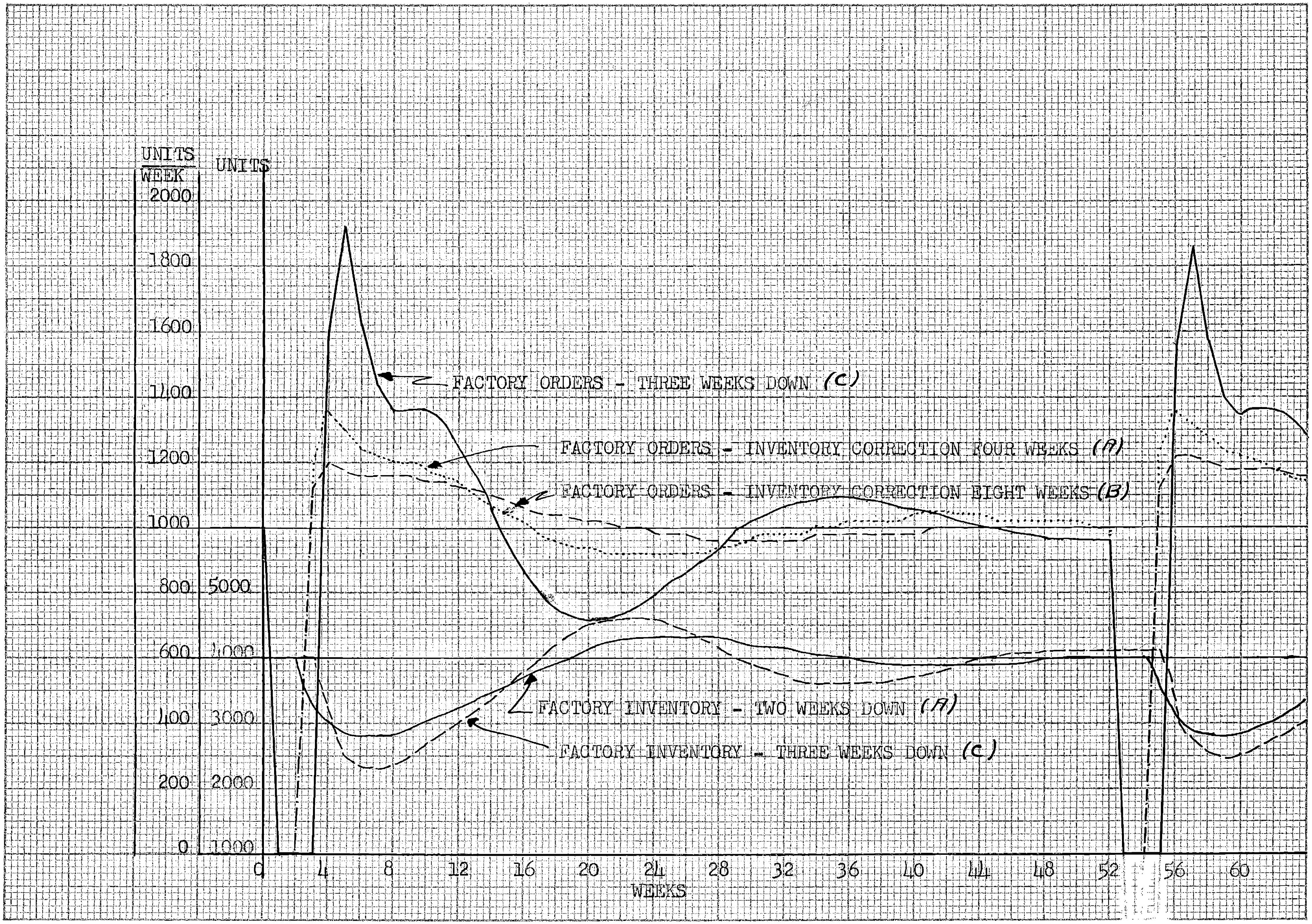

FIGURE 5 VACATION SHUT DOWN IN STEADY STATE BUSINESS

(+10%) in the seventh week after the disturbance, while the retailers orders to the distributor increased to 1020 units/week (+2%).

The imbalance died off after 14 weeks but overshot to below the average for a period of roughly 18 weeks. The low point in the manufacturing rate was some 920 units/week (-8%) or 80 units/week below the actual sales rate. The recovery from this low level caused a subsequent overshoot of around 40 units/week (+4%) in the manufacturing rate, which finally reached equilibrium at year's end. All disturbances caused by the shut-down have persisted in the model for a full year, at which time they have closely regained the steady state condition.

The general model is known to have a natural period of approximately thirty-eight weeks, and any disturbances will persist in the dynamic effects at this period until damped out, unless the system explodes. In this case we observe that the second peak in the orders to the manufacturing sector is thirty-eight weeks removed from the initial surge, after the shut-down. This may be a reflection of the natural period, but it is not a dominant characteristic in this case.

With the system nearly at steady state equilibrium when subsequently disturbed, we find that there is no amplification from year to year. The same dynamic response is observed year after year. There is no tendency for the system to explode from this disturbance alone.

Longer adjustment period. -- If the time to correct inventory deficiencies is lengthened to eight weeks we would expect that the responses would not be as extreme, and would not persist for as long a time before reaching equilibrium. These conditions would result from the lower correction applied to the imbalances, and would also reduce the overshoot of subsequent corrections.

From Figure 5, Curve B, we observe that the manufacturing rate rose to only 1220 units/week (+22%), but that it persisted at a positive imbalance for twenty weeks, as against the fourteen weeks in the previous case. The overshoot amounted to only -4% and the system reached a state of near equilibrium forty weeks after the disturbance. There was no appreciable rebound overshoot.

The responses in most other sectors (inventory, delivery delay, etc.) at the factory were similar to the previous curve, with the exclusion of the incoming orders from the distributor. Incoming orders reached only +6% above average (1060 units/week) rather than the 10% in the former case. The smaller reaction on the part of the retailer and distributor is due to the use of the longer adjustment period for the correction of inventories. The disturbance has had the same initial impact, but the reaction is more sluggish. In this case the amount of the correction applied to the manufacturing rate in the adjustment of unbalanced inventories was small, so that there was only one overshoot while the system was regaining stability. The full correction lasted only forty weeks.

Three weeks shut-down. -- If the shut-down itself were to last for three weeks, or if we were to assume that three weeks was a more reasonable approximation of the time lost due to the vacations, we can expect responses with more extreme fluctuations than the previous case. When the system has experienced this longer period of inactivity, we can reasonably expect the management to be more apprehensive about the imbalances which result. They might, therefore, attempt to correct inventories to desired levels as quickly as possible, so this investigation uses a correction time for inventories of two weeks. From other studies we have seen that shortening the delay from four weeks to two weeks increased the corrective response by some 20% (from a +40% increase to +48%).[1]

From Figure 5, Curve C it is seen that the combined effects have had a profound absolute impact on the manufacturing rate, which reached a maximum of 1920 units/week (+92%) and then dropped off rather sharply to near 1400 units/week. This peak shows the influence of the extended shut-down, as the disturbance added around 2880 units to the unfilled order backlog. By way of comparison, the response we might have expected from a two weeks shut-down with this adjustment delay would be a maximum ordering rate of approximately 1450 units/week (20% more than the 38% disturbance previously seen). The peak cycle is shorter and the overshoot greater than in the previous case. The system oscillation persisted through the second peak and its rebound was not quite stabilized at years end.

The purchase orders coming from the distributor reached a maximum of 1200 units/week (double the case in Curve A) and the orders from retail also were higher. This is the normal result of the greater depletion of inventories. The factory inventory fell to

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[1]Forrester, J. W., Memorandum D-42, "Additional Information on the Illustrations in the July 1958 Harvard Business Review Article -- A Section of Industrial Dynamics Class Notes", (an unpublishedpaper), Industrial Dynamics Research Group, School of Industrial Management, Massachusetts Institute of Technology, Cambridge, October 27, 1959.

2280 units, as against 2760 in Curve A, and distributors inventory dropped to 4080 units, where it had only fallen to 4800 units in the former case. Inventories continued to oscillate throughout the year. Again the pattern induced by this disturbance has no major effect on the subsequent years activities, but some imbalance was carried forward. Since the value of the parameters were then in an opposite relationship to the response to the disturbance, the subsequent fluctuations were slightly lower in the later years.

The annual shut-down does certainly generate a response pattern which is repititious, and could possibly be later treated by management as an inherent characteristic. This pattern could then be further amplified by the adoption of different management ordering policies.

Shut-down in a seasonal industry. -- One of the factors which may lead a great many firms to adopt the 'common vacation period', is the belief that their sales have a well defined seasonal pattern. If this pattern is evident, then it is believed to be much easier to close down operation. As operations would be at a low ebb, the discontinuities introduced would be minor, and the effect on the rest of the system slight.

From previous studies[2], which will be used as a reference for comparison, it has been shown that a sinusoidal disturbance in the customer's ordering behavior will be reflected directly into the operation of the firm. All sectors will take on a sinusoidal behavior pattern of the same frequency as the stimulating input. In Figure 6, Curve A we have the same general model as before, with the

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[2] Industrial Dynamics Research Group, Run No. 0077

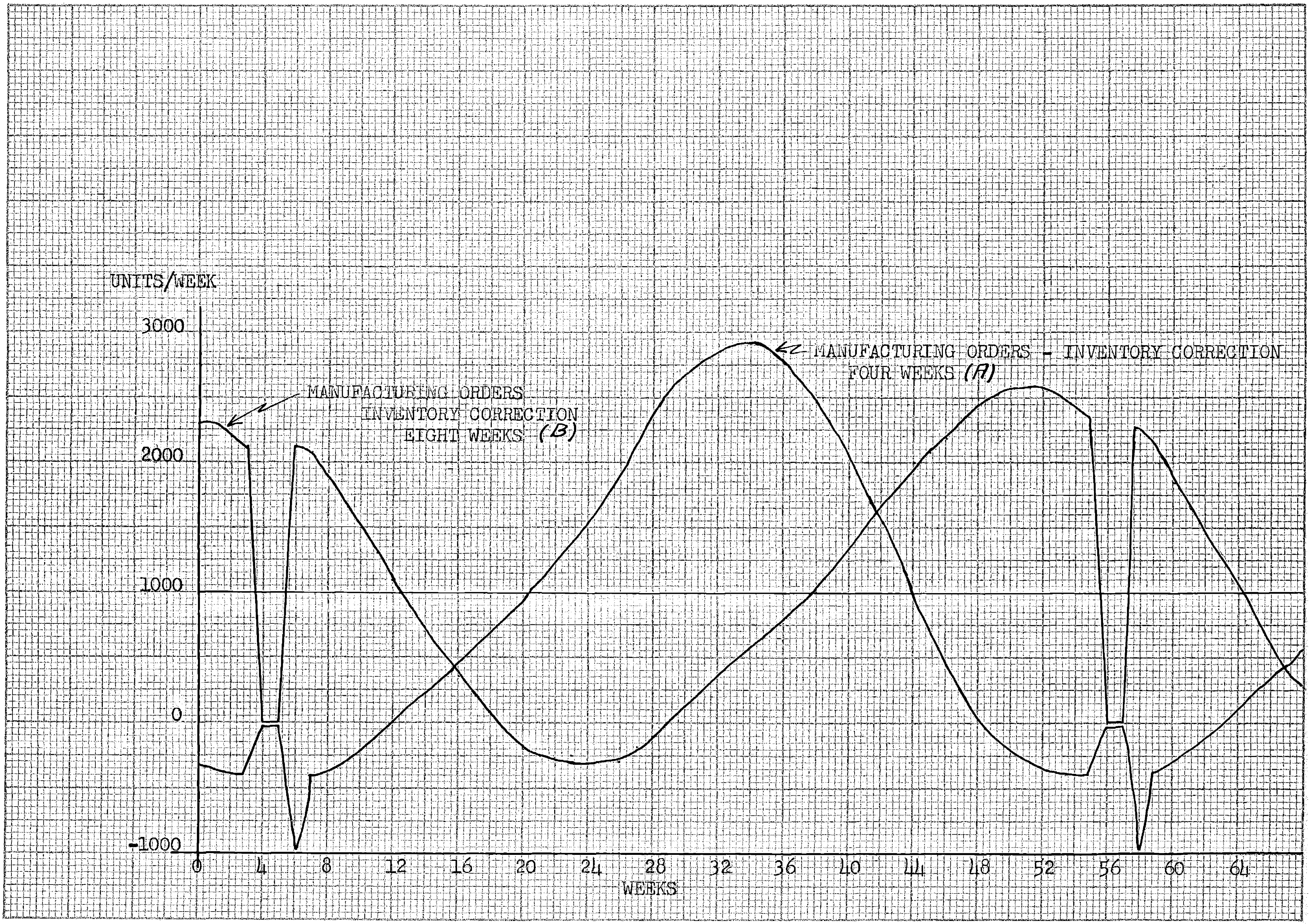


FIGURE 6 VACATION SHUT DOWN IN SEASONAL BUSINESS

customer's ordering rate varying from 800 units/week to 1200 units/week in a continuous manner with a one year period. This ±20% input variation induces the other sectors to depart from the average sales rate as follows:

	Maximum Amplification	Maximum Increase	Minimum Amplification	Minimum Decrease
M	9.7 : 1	195%	7 : 1	-140%
F	6.2 : 1	125%	3.7 : 1	- 75%
D	3.0 : 1	60%	2 : 1	- 40%
R	1 : 1	20%	1 : 1	- 20%

The above table shows the amplification observed in each sector, and the percentage increase or decrease from the average sales rate. Comparison of this amplification with that shown in previous studies, shown below, points up the fact that this situation has a greater impact in the system behavior than the normal sinusoidal disturbing input.

	Maximum Amplification	Minimum Amplification
M	8.1 : 1	6.5 : 1
F	4.8 : 1	3.8 : 1
D	2.2 : 1	2.0 : 1
R	1.0 : 1	1.0 : 1

The factory inventory is at its maximum when the shut-down occurs, and had reached a value 172% above average sales, rather than 62% as in the reference case. This reflects an amplification of 8.6:1 as against 6.2:1 in the reference situation. The amplification at the minimum is not quite as great in the case under study; 3.7:1 as in the reference 4.5:1.

With the inventory fluctuations of this magnitude, it is reasonable to expect the delay in filling orders at the factory to have a greater swing. The delay was lowest during the shut-down (when inventories were high) at 1.25 weeks, and reached 5 weeks at the maximum. Average delay is still 2.5 weeks, but in the reference, the swing was from 1.5 to 3 weeks.

In this seasonal situation, the immediate consequences of the shut-down do not loom as large as in the constant ordering rate situation. The shut-down has an appreciable effect on the manufacturing rate for 3 or 4 weeks, but the residual corrections serve only to flatten the growth of the rate as dictated by the input condition. It thus appears that with the system in motion, the discrepancies from normal operation are less apparent than when there is no outside (customer) disturbances. With the shut-down occuring when the inventories are at a maximum, the effect is to create a less drastic imbalance, and therefore lower the extent of adjustment necessary.

As there may be cases where the vacation period is not determined by the activity level of sales, Figure 6, Curve B is presented to show what can be expected if the shut-down occurs at or near the peak of the business cycle. In this example, the delay in adjusting inventories was taken as eight weeks, and no direct comparison run without the shut-down was made. As was expected, the amplification was not as great as in Curve A. As all adjustments were adverse to the trend of change at that time, the system showed greater discontinuities than in the previous case. The whole behavior pattern was similar, in that the sinusoidal reproduction of the input curve was not materially altered. If the variance of the input had not been as high, we could expect that the disturbance would show up more forceably, but the effects of the shut-down are still very apparent.

Random variation in sales. -- As any industrial situation cannot truly be characterized by such smooth operations as described in the earlier figures, it is well to look at the effects of the shut-down when introduced into a "noisy" environment. The customer ordering rate was therefore given a different value each week, which value varied around the average with a normal distribution. The effect of the shut-down on the manufacturing order rate, as shown in Figure 7, was roughly what would have been expected from the previous examples. The rate increased for 12 to 14 weeks after the shut-down, and then assumed to approximate values of the normal noisy situation. With the inventory corrections constantly trying to adjust to a new level of activity, the impact of the correction for shut-down depletion is felt only in the early weeks following the shut-down. The disturbance of the noise seems to dominate the manufacturing decision permitting only a small influence from the shut-down.

General impact. -- From the previous illustrations it is evident that the two weeks shut-down vacation has definite repercussions in plant operations. As both the retailer and distributor feel the effects of this action by the factory, their reaction will cause additional hardship on the factory. The amplification of their ordering decisions gives the appearance of prosperity for several months after shut-down, and has a fairly negligible effect for the

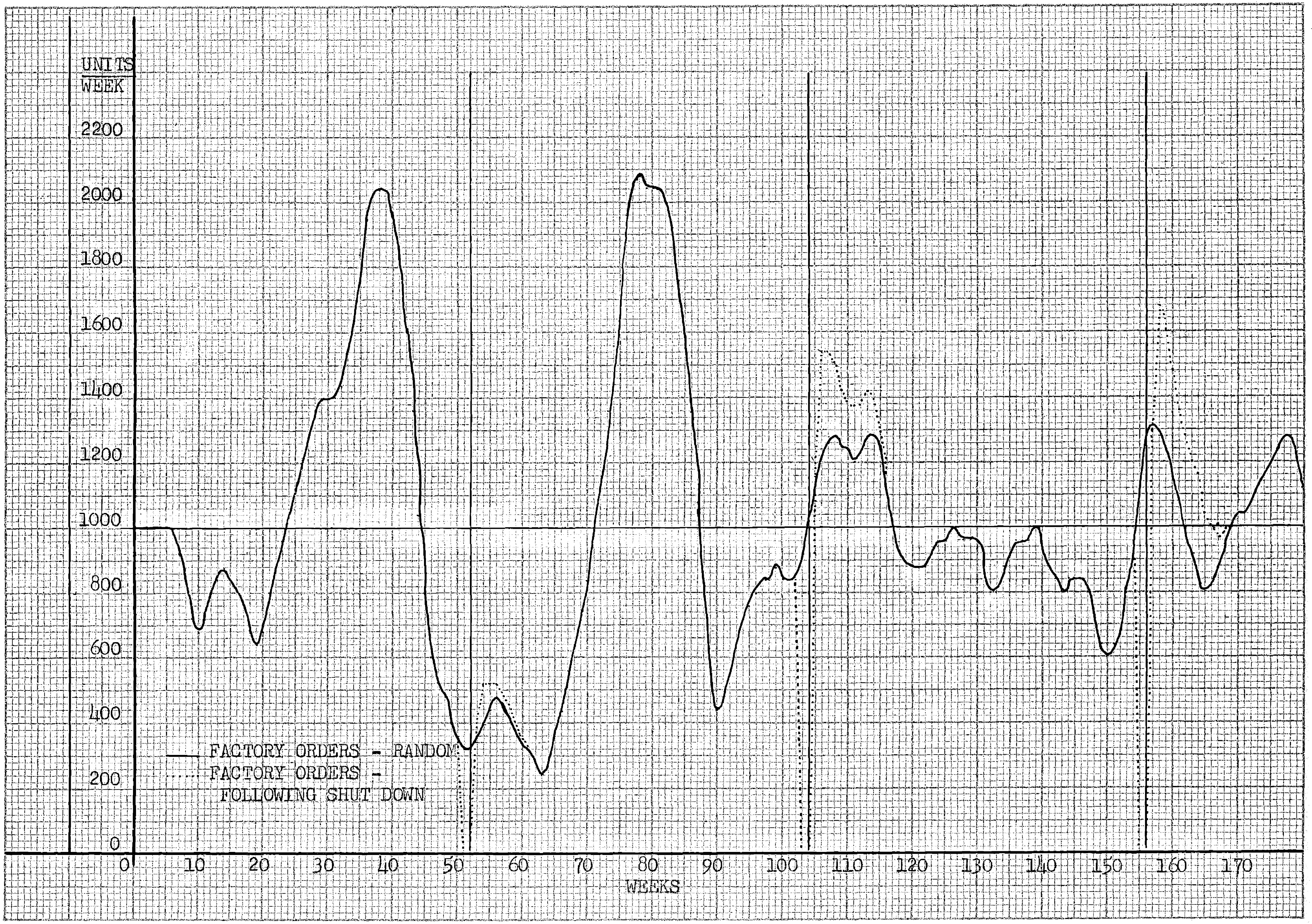


FIGURE 7 VACATION SHUT DOWN IN RANDOM ORDERS SITUATION

remainder of the year. The cost of this disturbance can not be assessed with this model, but the extremes in production rate certainly do not have benficial consequences.. One of the dangers of this approach to handling the two week shut-down, is that this post-shut-down period of prosperity could be mistaken for a market place phenomenan. If, after some years the management comes to believe that this increase in activity is a seasonal pattern in consumer buying habits, they may attempt to concentrate more sales at this time through the use of advertising, price discounts, etc. These devices could then become a major driving force in the model, and not simply a reflection of the disturbance of a common vacation period.

CHAPTER IV

SEASONAL ANTICIPATION FORECASTING

To the management of an industrial firm, the market place for its product will be the most important factor in many of its decisions. Their success as a firm depends on the continued consumer acceptance of their product. Management may attempt to influence the sale of its product through advertising, discounts, and other devices, but the consumer can not be controlled by the company. Most firms will have some well defined goals (sales) in mind which will serve as a guide to their operations.

For most of its life, any product will have copies and substitutes competing with it for the consumers purchase. While the firm has a monopolistic position, as during the introduction of a new product, the firm need not be as concerned with its operating costs and efficiencies, as when the market becomes competitive. During its initial growth, the firm can probably sell all it can produce, and would not have major problems of backlogs, inventories, etc. When the market becomes competitive, or sales drop for other reasons, the situation of the firm changes markedly. The firm must now become more responsive to the vagaries of the market place, and soon learns that it can not always sell all of the goods it can produce at the time they are produced.

It may be the affect of consumer preferences, the season of the year, or the weather conditions, but it seldom happens that a producer experiences an even rate of sales throughout the year. These variations in sales must be handled in some manner, so that the firm is in a position to sell as much of its product as possible, at the time it is wanted. It frequently happens that customers who don't see the item they want on the shelf, and are asked to wait for delivery, will find a substitute product which is an adequate replacement.

In many firms, where the production time is shorter than the acceptable waiting period, the firm can simply work on those orders which it has received. This is something of a 'job shop' situation, and the manufacturer may later find himself in a serious dilema, through simply following the demands of his customers. If business picks up, he must add more hands to the work force in order to keep the delay period short, and then he would need to reduce the work force later on if business falls off. This instability and fluctuation of work load can have a deleterious effect on firm profits, and on its employee's morale.

Where each item need not be "tailor made", the manager soon learns the desirability of making use of a finished goods inventory, to assist him in keeping a steadier work force, and still meeting the consumer's demands. Inventories, however, do cost quite a bit in space occupied, and capital tied up, so that there is a hesitency by management to store too many items in inventory.

In an attempt to keep his inventories under control, the manager will try to understand his market situation better. He may reason that if there are marked regularities in the market behavior for his product, he may use these cycles as a guide to his own actions. When he understands what the sales pattern will be like, he can anticipate future sales and thus utilize a "leading" factor in his production decision rather than to "lag" the market variations as he previously has done.

If the manager feels that June sales have been 20% higher than May sales for a number of years, he may set his production so as to have these extra goods readily available in June.

The manager will also try and keep his delivery delay to the distributor at a constant low value, as he has in the past felt the repercussions of a high delivery delay. As the delay increases, the retailer and distributor feel that they need to order further in advance, so that they will not run out of goods while the new order is being processed. This additional increase of orders creates a feeling of "fictitious well being" in that it does not reflect any increase in final sales to customers. The factory manager is apt to misinterpret the higher rate of orders, and cause further disturbance to the system. The manager who has been through this expansion period can never be sure if the next repitition is due to 'real' sales, or simply additional ordering ahead. By keeping the delivery delay as consistent as possible, the manager can eliminate the adverse effects of this volatile factor.

It is the belief of many managers that if they can understand the vagaries of the market place, they are then better able to maintain control over inventories, delays, employment, and costs. One of the first approaches to understanding sales, is to reconstruct the historical pattern of actual sales. With this in mind, the manager then attempts to "explain" sales, either from a seasonal pattern, or from a long term relationship with some other factor, or from major economic disturbances.

In this chapter the study is directed to the effects of management decision policies which are designed to accomodate and adjust for the seasonal variations. It is hypothesised that these practices, by their application, create in the system a persistent annual pattern which is not inherent in the 'natural' condition of the market.

The most immediate benefit to the firm will presumably come from a recognition of, and explanation of, any seasonal pattern which may be present. If it is possible to recognize and isolate a seasonal pattern, then managers feel that it should be an easy matter to utilize this pattern in achieving the the goals of stability and control. If the length of the production cycle is known within certain close limits, then it is thought possible by management to adjust the current rate of production in order that the goods which can reasonably be expected to be ordered in the future (at the end of the production delay) will in fact have already been produced. If the length of the production delay, and the advance time used to make the adjustment are closely identical, it is expected that inventories should remain more stable (giving the possibility of lower absolute amount) and that the delivery delay would be at a more even value.

Where sales will fluctuate around some median value, the use of a forecasting ratio will permit the current level of sales to be adjusted to the level which is expected to occur a short time hence. The manager, to make use of this device, must first, however, have some reasonable understanding of his sales picture.

Management will generally examine its past sales record to ascertain if there are fluctuations which can be isolated and seen to persist. Typically as a starter, the data from each January for the past five years will be analyzed, to see what percentage of each year's sales it was. Again, this history for each month will be averaged, or if a more sophisticated approach is desired, it may be smoothed by use of a first order exponential averaging, and then compared to the yearly total. The accumulation of data in this manner will then lead to the acceptance of these figures as the 'norm' for the various months and their subsequent use for seasonal adjustment computations.

With the month's sales subject to many exogenous variables, such as the weather, school holidays, the spacing of weeks in the month, etc., the sales pattern of one year can not reasonably be expected to reflect accurately the pattern which will be produced in subsequent years. Many firms, however, do use the past pattern as a guide in their planning for the future. As an initial approach to control over operations, some plan is better than none - but it is the writer's hypothesis that the use of this ratio (seasonal anticipation) forecasting will aggravate the fluctuations over and above those disturbances which are inherent in the system. Once the year has been compartmentalized, and treated as though the observed variations were inherent in the system, the management is locking in a seasonal pattern which will thereafter affect its own operations.

<u>Model formulation</u>. -- In order to gain insight into the effects of such management behavior on a production-distribution system, some modifications were made to the basic model described earlier. These changes were all centered within the factory sector, where it is assumed that the initial attempt at stabilization and control is made. The major area of change is in the manufacturing decision formulation. As we have seen from the general model, a

typical ordering rule is designed so as to replace what is currently being ordered, and to adjust the inventory, etc., to a more desired level for the current level of sales. The usual rule is:

MWF.K = RRF.JK+ (1/DIF)(IDF.K-IAF.K+LDF.K-LAF.K+UOF.K-UNF.K)

MWF--Manufacturing rate Wanted at the Factory, (units/week)
RRF--Requisitions Received at Factory, (units/week)
DIF--Delay in Inventory (and pipeline) adjustment at Factory, (weeks)
IDF--Iventory Desired at Factory, (units)
IAF--Inventory Actual at Factory, (units)
LDF--pipeLine orders Desired in transit through Factory, (units)
LAF--pipeLine orders Actual in transit through Factory, (units)
UOF--Unfilled Orders at the Factory, (units)
UNF--Unfilled orders, Normal, at Factory, (units)

This same concept shall be used, but it is necessary to make the appropriate corrections, so that sales of the future will be anticipated. Our model is set up so that at steady state conditions there is approximately an eight-week delay from the time a decision is made, to when the goods are sent from inventory to the distributors. With this in mind, we shall arrange to order now, the goods we think will be ordered (by the distributor) eight weeks hence. By using our concept of the historical pattern of the sales, we can adjust the current ordering decision to reflect our expectations.

In adjusting our ordering rule, the appropriate correction would be to apply a ratio, found from the historical pattern, of the sales in the month two months ahead, to the sales in the current month, in our current decision.

$$\text{Forecast Multiplier Ratio} = \frac{\text{Historical Sales in Month, T+2 (July)}}{\text{Historical Sales this Month, T, (May)}}$$

Assuming the persistence of the historical pattern of sales, this equation gives us a factor, which when applied to the current sales level, is the expected sales of the second month hence.

$$\text{Expected Sales (July 60)} = \text{Current Sales (May 60)} \frac{\text{Hist. Sales (July)}}{\text{Hist. Sales (May)}}$$

In order for this factor to have effect on the factory it must be applied to one of the components of the ordering rule. If the factor is applied to (multiplied by) the current rate of sales, the anticipated rate will enter the decision formulation. Even though the factor is also in the next time computation, its effect will be negated at this subsequent time computation, since it will then also appear in the pipeline term. This has only the effect of a bump in the ordering rate, and not a persistent element.

To apply the factor to the sum total of adjustments (inventory etc.) is the same as changing the inventory correction delay smoothing factor (DIF) - again without the desired results on the system, as there is no need for adjustment until the disturbance occurs. Even in a dynamic system the correction would be very small.

The third and best approach is to use the factor to change the "desired" levels of the inventory, pipeline, and unfilled orders. By forecasting the desired levels, the effect will persist until the projected increase occurs and will in effect, get the desired levels on hand at the time we anticipate the change in orders. Any abrupt changes in manufacturing rate which might be the change in value introduced by the factor from period to period, are damped somewhat by the delay in inventory adjustment (DIF), again helping to smooth out production.

For the sake of convience, the year is divided into thirteen 4-week periods, and data is gathered for these periods. It seems unnecessary to anticipate the fluctuations of sales at any greater frequency than every 4 weeks,and at any greater length of data accumlation period, the year would begin to loose any cyclical characteristics. Any wide movements in the sales figure which might occur within this 4-week period are accentuated or damped, depending on ratio values and direction of change, as the same factor will apply to all computations over this period.

Data accumulation. -- To accumulate the historical data for use in forecasting, many approaches could be used. For this study two methods are utilized: the five year moving average, and first order exponential averaging (smoothing) over a five year period. It is felt that the most frequently applied approach would be the moving average, while the latter is the more advanced technique. To collect the historical data for averaging, the following system was utilized. A series of 14 car boxcar trains was arranged so that the total rate of sales for each month would be stored in the first car of the first train during that month, and then this figure was shifted back through the chain by the following equations. (Figure 8)

CYPT = BOXLIN(13,4) Eq. 75, B

PY1PT = BOXLIN(14,4) Eq. 76, B

PY2PT = BOXLIN(14,4) Eq. 77, B

PY3PT = BOXLIN(14,4) Eq. 78, B

PY4PT = BOXLIN(14,4) Eq. 79, B

PY5PT = BOXLIN(14,4) Eq. 80, B

CYPT*1.K = CYPT*1.J+(DT)(RRF.JK+0) Eq. 81, L

PY1PT*1.K = CYPT*13.K Eq. 82, A

PY2PT*1.K = PY1PT*14.K Eq. 83, A

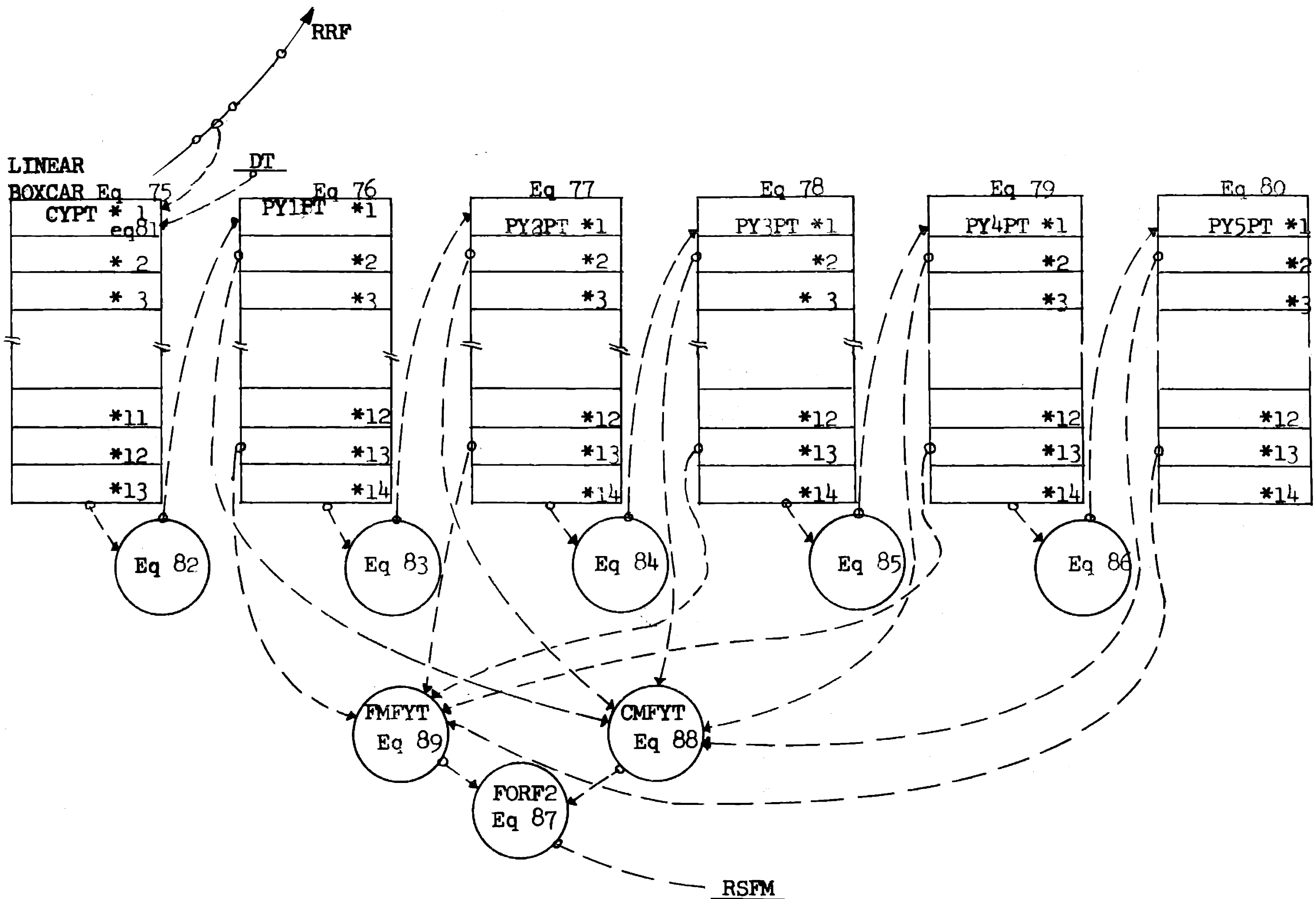


FIGURE 8 RATIO FORECASTING - DATA ACCUMULATION - AVERAGING

PY3PT*1.K = PY2PT*14.K   Eq. 84, A

PY4PT*1.K = PY3PT*14.K   Eq. 85, A

PY5PT*1.K = PY4PT*14.K   Eq. 86, A

CYPT--Current Year orders for this Period, Total, (units)
PY1PY--Past Year 1, Period Total, (units)
PY2PT--Past Year 2, Period Total, (units)
PY3PT--Past Year 3, Period Total, (units)
PY4PT--Past Year 4, Peridd Total, (units)
PY5PT--Past Year 5, Period Total, (units)
RRF--Requisitions Received at the Factory, (units/week)

The forecasting factor for the averaged data was easily obtained by summing the contents of car two and car thirteen in each of the past five years. The current year was not used, as its data content was not yet complete.

FORF2.K = FMFYT.K/CMFYT.K   Eq. 87, A

CMFYT.K = PY1PT*2.K+PY2PT*2.K+PY3PT*2.K+PY4PT*2.K+
PY5PT*2.K   Eq. 88, A

FMFYT.K= PY1PT*13.K+PY2PT*13.K+PY3PT*13.K+PY4PT*13.K+
PY5PT*13.K   Eq. 89, A

FORF2--FORcasting Factor #2
FMFYT--Forecast Month Five Year Total, (units)
CMFYT--Current Month Five Year Total, (units)
PY1PT--Past Year 1 Period Total, (units)
PY2PT--Past Year 2, Period Total, (units)
PY3PT--Past Year 3, Period Total, (units)
PY4PT--Past Year 4, Period Total, (units)
PY5PT--Past Year 5, Period Total, (units)

In accumulating the smoothed historical data, a single 13 car boxcar train was used, and cycled every four weeks. Each period the current sales would be smoothed into the history for that period, with this latest history indexed at the period's end. (Figure 9)

SFOP = BOXCYC(13.4)   Eq. 90, B

$$SFOP*1.K = SFOP*1.J + \frac{(DT)}{SDY}(RRF.JK - SFOP*1.J) \quad \text{Eq. 91, L}$$

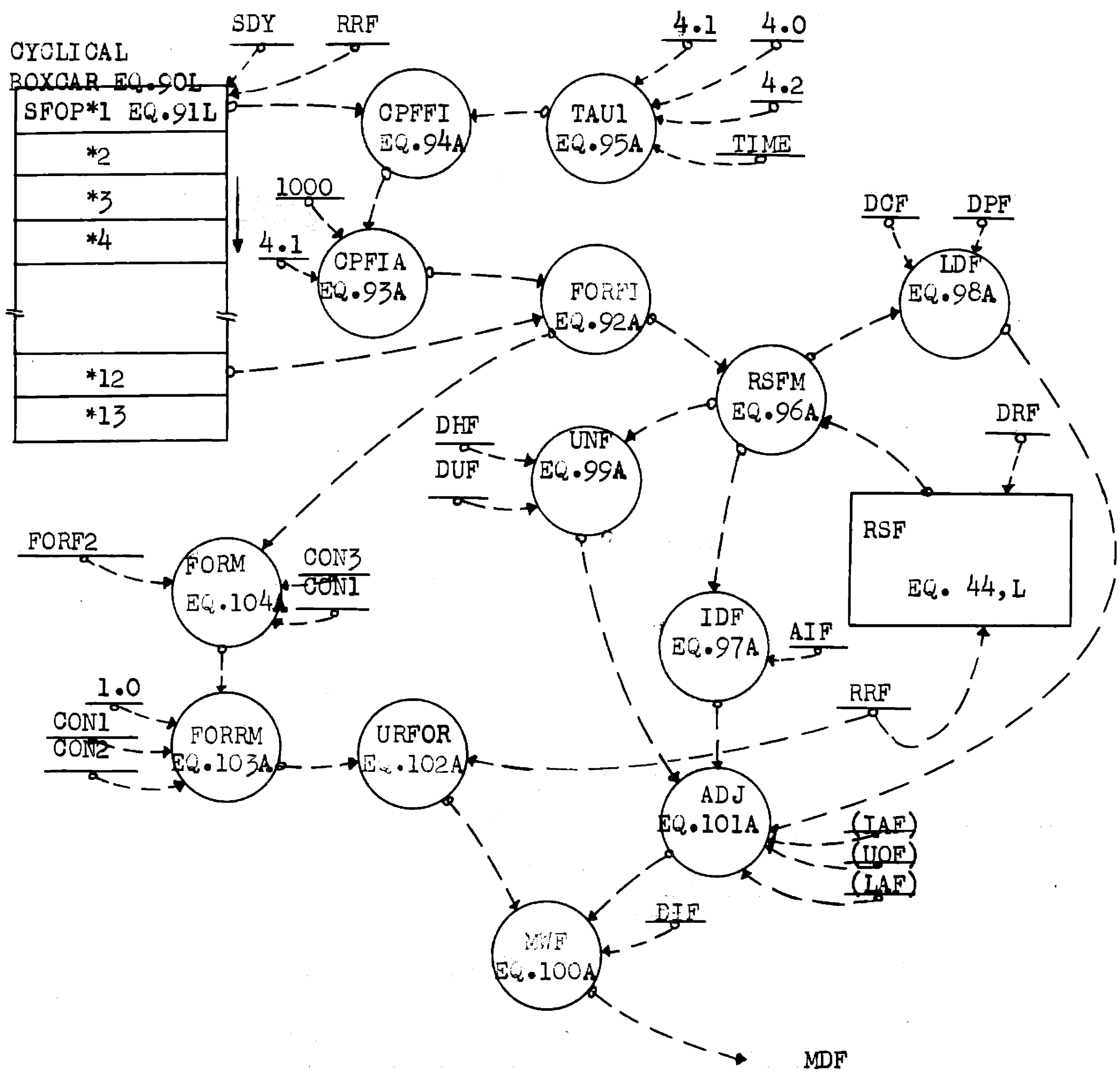


FIGURE 9 RATIO FORECASTING- DATA ACCUMULATION- SMOOTHING AND MANUFACTURING DECISION CHANGES

SFOP*1-- Smoothed orders at Factory Over Period, car 1, (units/week)
SDY-- Smoothing Delay, (weeks)
RRF--Requisitions Received at Factory, (units/week)

The forecasting factor for the smoothed data was simply the ratio of the contents of car 12 to car 1. As car 1 is being constantly added to, its value is sampled just after cycling and then held constant throughout the period, so as to avoid having a changing factor.

FORF1.K = SFOP*12.K / CPF1A.K Eq. 92, A

CPF1A.K = CPFF1.K if TIME.K > 4.1 Eq. 93, A

= 1000 if TIME.K < 4.1

CPFF1.K = SFOP*1.K sampled every TAU1.K Eq. 94, A

where
TAU1.K = 4.0 if Time.K ≥ 4.2 Eq. 95, A

= 4.1 if Time.K < 4.2

FORF1 = Forecasting Factor #1
SFOP*12--Smoothed Orders at Factory Over Period, car 12, (units)
CPF1A--Current Period Forecasting factor #1, Alternate, used for getting initial values at proper magnitute, (units)
CPFF1--Current Period Forecasting Factor #1, (units)

<u>Change in general model</u>.-- The forecasting factor desired was introduced into the general model by modifying the equation for Requisitions Smoothed at the Factory, and the desired level equations:

RSFM.K = (RSF.K) (FORM.K) Eq. 96, A

IDF.K = (AIF) (RSFM.K) Eq. 97, A

LDF.K = (RSFM.K) (DCF+DPF) Eq. 98, A

UNF.K = (RSFM.K) (DHF+DUF) Eq. 99, A

RSFM--Requisitions Smoothed at Factory, Modified, (units/week)
RAS--Requistions Smoothed at Factory, (units/week)
FORM--FORcast Multiplier
IDF--Inventory Desired at Factory, (units)
AIF--proportionality constAnt for Inventory adjustment at Factory, (weeks)

LDF--pipeLine orders Desired in transit through Factory, (units)
DCF--Delay in Clerical processing of manufacturing orders at Factory, (weeks)
DPF--Delay in Production lead time at Factory, (weeks)
UNF--Unfilled orders, Normal, at Factory, (units)
DHF--Delay due to minimum Handling time required at Factory, (weeks)
DUF--Delay, average, in Unfilled orders at Factory caused by out-of-stock items when inventory is "normal", (weeks)

The manufacturing order decision was modified to permit the testing of the model by forecasting the current rate as well as the desired levels. All these possibilities of vatious changes in order rules are handled by using constants of value 1 or 0.

MWF.K = (ADJ.K/DIF)+URFOR.K Eq. 100, A

ADJ.K = IDF.K-IAF.K+LDF.K-LAF.K+UOF.K-UNF.K Eq. 101, A

URFOR.K = (RRF.JK)(FORRM.K) Eq. 102, A

MULTIPLE RUN FACTORS for experimental runs

FORRM.K = (1)(CON1)+(FORM.K)(CON2) Eq. 103, A

FORM.K = (CON3)(FORF1.K)+(CON4)(FORF2.K) Eq. 104, A

MWF--Manufacturing rate Wanted at Factory, (units/week)
ADJ--ADJustments in order rate for inventory, pipeline, and backlog, (units)
DIF--Delay in Inventory (and pipeline) adjustment at Factory, (week)
URFOR--Usage Rate FORcast multiplier
FORRM--FORcast Rate Multiplier
IDF--Inventory Desired at Factory, (units)
IAF--Inventory Actual at Factory, (units)
LDF--pipeLine orders Desired in transit through Factory, (units)
LAF--pipeLine orders Actual in transit through Factory, (units)
UOF--Unfilled Orders at the Factory, (units)
UNF--Unfilled Orders, Normal, at Factory, (units)
RRF--Requisitions Received at Factory, (units/week)

Evaluation. -- To evaluate the benefits of seasonal recognition forecasting, there are two important aspects of the system to investigate. First, does the accumulation of data in this fashion, and its subsequent application to the control of production, change a random pattern of sales into a repeticious seasonal behavior? Will a preconceived notion that sales are seasonal create a "locked-in " behavior pattern? A second area of concern is whether the application of ratio forecasting to the manufacturing operation will assist in the stabilization of its activities? In addition, the use of alternate methods of data accumulation, and ratio application will be examined.

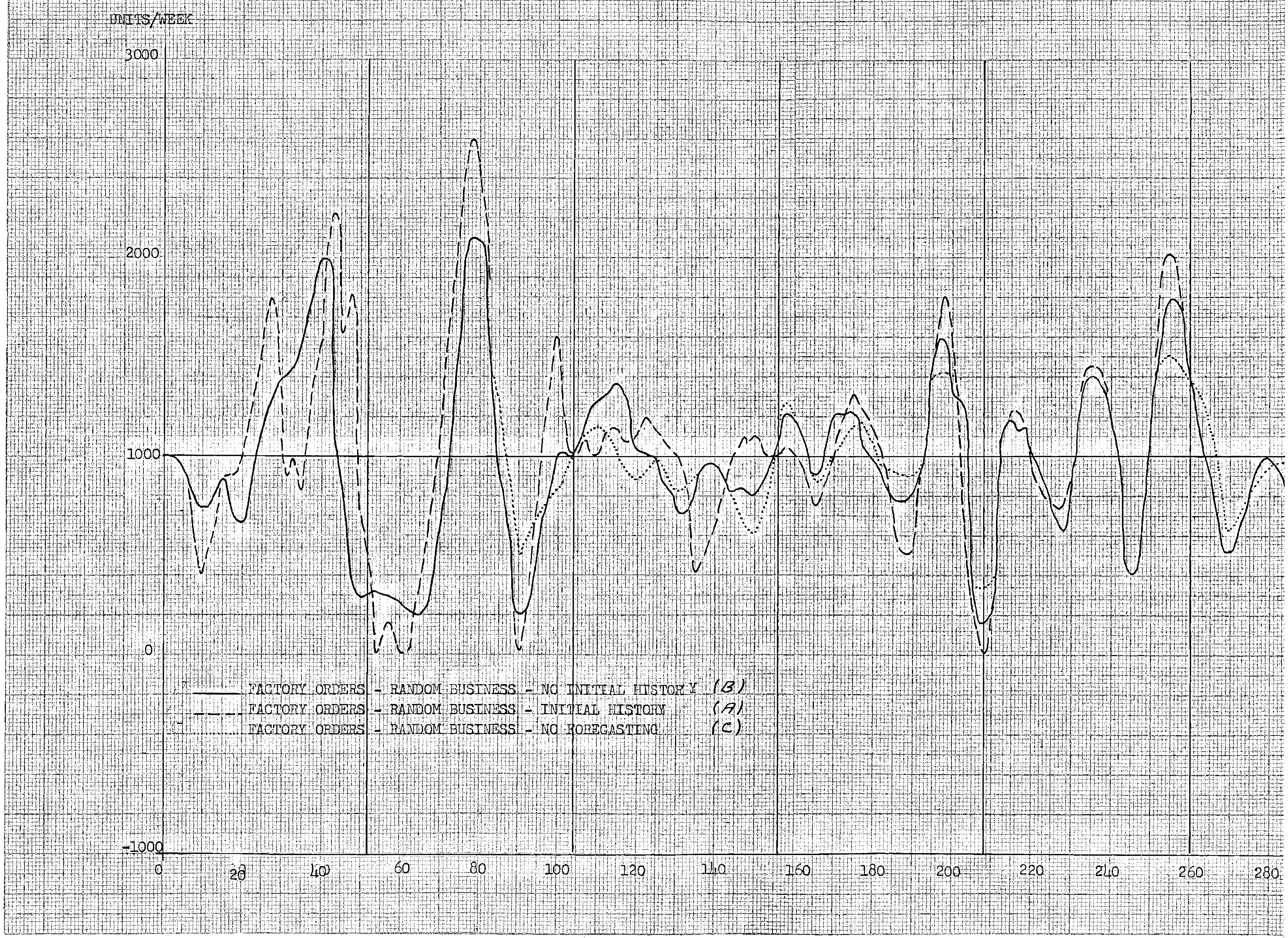
Random pattern of retail sales. -- In the examination of the effect of periodic data handling, a random variation is added to the average customer's ordering rate, in order to simulate more closely the true occurance of retail sales. This random disturbance is propagated throughout the model in the ordering rules of the various sectors. To be sure, when the factory receives its orders from the distributor, the disturbance has been considerably evened out, but it will be subject to larger oscillations than at retail, due to the amplification introduced by the various sectors in their desire to adjust inventory. As the orders received at the factory are increasing, the adjustment needed to maintain the desired relationship in inventory and unfilled order backlog will also increase. This amplification continues throughout the delay in fabricating the goods. When the shipments from the factory start to pick up and thus offset the adjustment, the orders to fabricate will taper off. From what is nominally a ±20% random disturbance in the customer's ordering behavior, the model will generate manufacturing rates as high as 108%

above of the average rate, and as much as -76% below. These large swings are not common, however, and result from a customer's ordering rate which happens to be consistently on one side of the average for a number of weeks. More usual fluctuations are from +80% above to -50% below average sales.

Stability. -- The appraisal of the benefits of various manufacturing rate policies is made by comparing their responses with the responses of the policies of the general model, or other experimental runs. Figure 10 is a composite illustration of three different runs, all using 20% random variation input, and an inventory adjustment delay of four weeks. All parameters are the same except for the manufacturing decision, and the use of historical data.

In Curve A, a history of semi-annual seasonal peaks was present at the start of the run. Curve B generates and uses its own history as time progresses, but had no initial sales history pattern. As a basis of comparison Curve C is the response to a random input where no forecasting is used. In evaluating these various policies, the extent of fluctuations in the manufacturing rate is used as the basis of comparison. As there is no financial accounting included in the model, the attempt to stabilize the fluctuations in the various rates and levels of the factory is taken as the desired objective for management.

As there is no history of seasonality in Curve B, it and Curve C are identical in the first year. Study of the later years shows that the policy which collected, recognized, and used the historical data for a forecast, experienced more extreme movements in the manufacturing rate. The non-forecast run is approximately 1/3 to 1/5



UNITS/WEEK
3000
2000
1000
0
-1000
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
FACTORY ORDERS - RANDOM BUSINESS - NO INITIAL HISTORY (B)
FACTORY ORDERS - RANDOM BUSINESS - INITIAL HISTORY (A)
FACTORY ORDERS - RANDOM BUSINESS - NO FORECASTING (C)

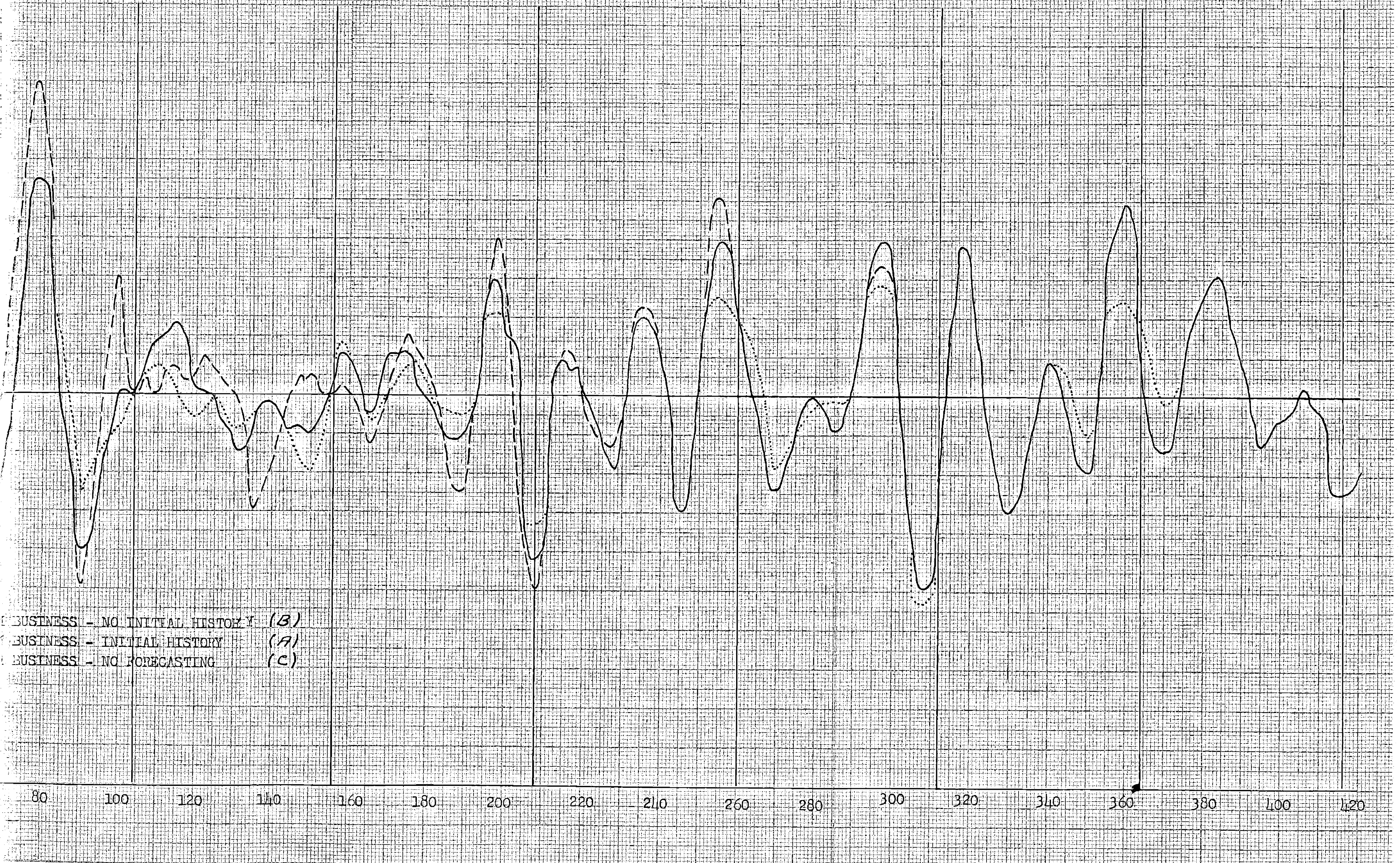


FIGURE 10 SEASONAL ANTICIPATION FORECASTING WITH RANDOM BUSINESS

lower in the peaks than in the case where the ratio is used. This indicates that the use of forecasting in a noisy situation, with no persistent historical pattern, causes instability rather than to correct or compensate for it. When the ratio is used in the manufacturing decision there is no appreciable improvement in the stability of inventory or backlog. There also seemed to be no improvement in the delay in delivering goods to the distributor.

Pattern creation and consistency. -- In the case where there was an initial history, Curve A, it served to accentuate the peaks in the ordering rate in the early years. The values of the various ratios derived from the historical pattern,were of sufficient magnitude to cause a repetition of the annual pattern in some subsequent years. Where the incoming order rate varied only slightly from average, the ratios caused greater amplification than might be expected, and repeated the historical pattern. However, where orders were appreciably different from the average, or 'out of phase' with the pattern, the manufacturing rate was not altered sufficiently to be considered as 'following the pattern.'

With the pre-set history, the ratio had values of from 0.7 to 1.4 at the start, and this was smoothed through the years to 0.85 and 1.18 as the extreme values. Where the history was generated by the model it reached extreme values of between 0.9 and 1.1. The pattern of peaks and valleys in the ratio values as generated by the model is the same in all respects, except magnitude as the pattern which resulted from the initial pattern and subsequent modification through the years.

The large randomness of the customer's ordering rate does not permit the successful use of the ratio forecasting technique to create a definite pattern of annual sales. As the model has a "natural frequency" of about 38 weeks, the ratio is not usually applied to the comparable level of incoming orders in the same period of all subsequent years. In some years, the random nature of customer orders caused the factory orders to be declining in the last period, so that the multiplication by a ratio greater than 1 still did not give a definite positive value to the manufacturing rate. In other years, when the incoming orders to the factory were increasing during this same period, a ratio which is greater than 1 would accentuate the increase, and result in a manufacturing rate which is greater than the non-forecast case. This inconsistency in the base for the application of the ratio negated any tendency for the model to become seasonal. A smaller variation in the base may have been more susceptible to pattern creation by the ordering rule. The introduction of the monthly pattern into the system through the ordering rate did not change the natural period characteristics of the basic model, indicating that any changes which were introduced into the manufacturing rate (through forecasting) were not sufficiently large in this case to alter the feedback of information to the distributor.

The data accumulation process did bring about a consistency in the magnitudes of the "historical ordering rates" for the various periods throughout the year. With no history at the outset, the fluctuations of the first and second year set the pattern of the historical sales for the subsequent years. When the data for any following year is smoothed into past history, the resultant value of the "historical rate" will not change materially, unless the spread between the past and the current values of the ordering rate is very great. With this relative stability in the historical data for each period, the ratios formulated for each period also have reasonably consistent values through the years.

Known periodic cycle in retail sales. -- The occurance of a consistent customer ordering policy permits the factory to have the use of a more stable historical pattern for its forecasting base. Once the pattern is recognized, its use leads to the reduction in amplitude of the manufacturing rate. The effect of the ratio is to move the manufacturing rate back in its phase relationship to the incoming orders to the factory. With the period of amplitude equal to 26 weeks, the eight weeks cycle anticipation factor is roughly 1/4 of a cycle "out of phase". This will lead us to anticipate the higher sales of the upswing when at the bottom of one cycle, and the lower rate coming when at the peak. This is in effect at this period a contra-cyclical adjustment, and therefore serves to dampen the manufacturing rate. When the incoming order rate is high, it normally creates an even higher manufacturing rate through the added orders thought necessary to adjust inventories to this current higher rate of sales. Through the forecast ratio, these adjustments are accomodated in the manufacturing rate prior to their being actually called for, and we thus have reduced much of the amplification at the peak ordering rate.

Stability of operations. -- If there is a strong periodic cycle in the customer's ordering rate, we have a different end result when forecasting is used in the manufacturing decision. In Figure 11 there are shown the results of the introduction of a 10% sinusoidal fluctu-


UNITS/WEEK
2000
1500
1000
500
0
0
20
40
60
80
100
120
140
160
180
200
210
220
240
260
WEEKS
INCOMING ORDERS TO FACTORY
MANUFACTURING ORDERS

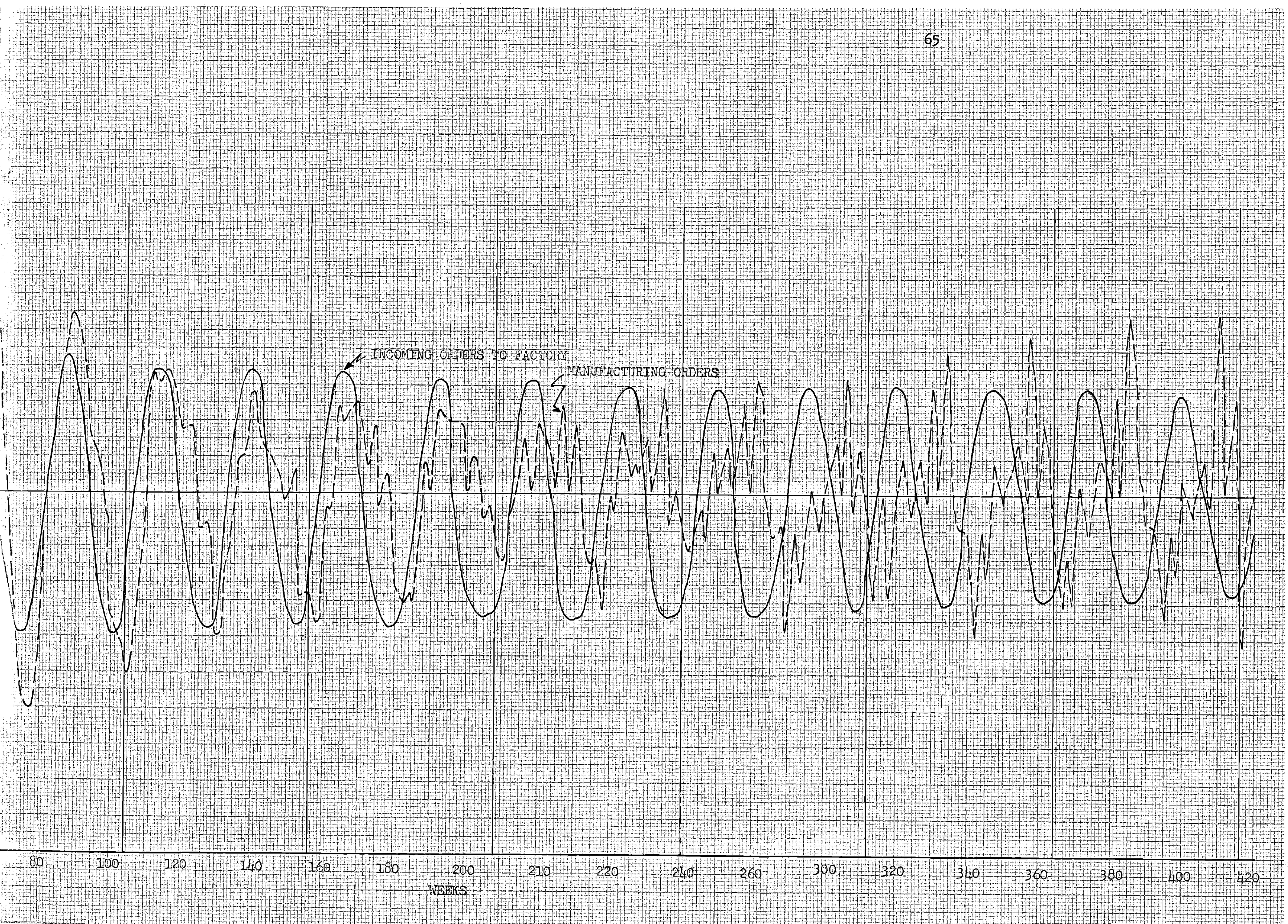


FIGURE 11 SEASONAL ANTICIPATION FORECASTING WITH SEASONAL BUSINESS

ation of customers ordering rate with a 26 week period, into the modified model. From previous studies with the general model[1], it is shown that with this input into the retail sector, the manufacturing rate duplicated the input characteristics, but with a greater amplitude. After the transient period, all subsequent years followed similar patterns, and the amplitudes were the same year after year. With the use of forecasting we find that the manufacturing fluctuations are markedly reduced in subsequent years. The initial response is a manufacturing rate which is 78% above average, and later cycles have peaks of 50%, 40%, 36%, 8%, and 26%.

The use of a constant ratio for four weeks creates a minor problem of discontinuities in the manufacturing rate decisions. The sometimes large jump in the value of the ratio, when multiplied by nearly equal values for the incoming order rate and adjustments desired, has created sharp movements in the rate of production orders. It would improve the stability of the model if the ratio were to be changed more frequently, as this would lessen some of the sharp variations in the manufacturing rate.

As time progresses, the final smoothed values of the historical data for each period will get larger and larger, due to the consistent amplitude and period of the input. As the historical values get larger the ratios also become larger in their difference from 1, so that in the later years the production rate is multiplied by factors of from 0.66 to 1.52 and therefore has been raised to a high value

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[1]Forrester, J. W., Memorandum D-42, "Additional Information on the Illustrations in the July 1958 Harvard Business Review--A Section of Industrial Dynamics Class Notes" (an unpublished paper), Industrial Dynamics Research Group, School of Industrial Management, Massachusetts Institute of Technology, Cambridge, October 27, 1959

when the incoming orders are low, and lowered when the orders are high. This higher value for the ratio is causing the amplitude of the manufacturing rate to become greater again, in the later years.

The backlog of orders still fluctuates but with amplitude very much reduced in the later years. Early swings were from 80% above to 50% below average, whereas the later years fluctuated between 24% above and 20% below. This decrease has come about through the shifting of the manufacturing rate out of phase with the incoming order rate. Initially, the inventories were high when orders were low, but in later years the inventory was high 13 weeks after the orders were low. The amplitude of inventory variation decreased by about 25% throughout the run, as it was some 3120 units in spread in year eight, and 4180 units in year two.

The swing in the rate of distributors orders to the factory, which reflects his unchanged orders from the retailer and his opinion of the factory response delay, have narrowed some 31% throughout the run. Variation was about 780 units/week at the start, and 600 units/week at the end of eight years. This reduction is due to the beneficial effects of leveling out the production rate. Where there is a regularized pattern of input sales, the use of forecasting can be of material benefit in stabilizing the operations of the firm. The forecast has the effect of removing the impact of a large inventory adjustment which had previously been timed to coincide with the peak of the incoming order rate. In the un-forecast model, the peak ordering rate is accentuated because of large inventory deficits which occur at the same time. By pre-producing the anticipated adjustment we have reduced the amplification of this factor. The exploration of the effects of forecasting indicate that where there is any appreciable "noise" in the customer's ordering rate, the use of seasonal anticipation forecasting does not bring stability or regularity to the operation of the firm. If regularity is inherent in the sales pattern, then some benefit is derived from this planning device.

Forecasting desired levels and orders. -- To test the presumption that forecasting the anticipated desired level of inventory, etc., is the more stabilizing approach when using ratio forecasting, some runs were made with the noise input in which the forecasting factor was also multiplied by the current sales rate to determine the manufacturing rate.[2] In the case where the orders also are multiplied by the ratio we find that the manufacturing rate, and factory inventory, have a greater amplitude in their swings, than when only the desired levels are forecast. In the general model it is shown that the "levels" adjustment connections factor is largest when the ordering rate is large. Thus, when we multiply a ratio factor by both orders and adjustments, we are doubling the impact of the factor. When an increase in orders is expected, forecasting both orders and levels will obviously produce a larger manufacturing rate than if only one were forecast. Considering this factor alone, the ordering rule which is based on anticipating desired levels does not amplify the external disturbances as much as the combined forecast, and is therefore a more stable ordering rule.

Smoothed or averaged data. -- For the accumulation of the historical data two approaches were utilized. In one instance the straight five-year moving average was used, and for the other, a first order

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[2]Industrial Dynamics Research Group, Runs 0735, 0736.

order exponential smoothing. From an examination of two model runs, not illustrated, there is no apparent persistent affect on the system which would distinguish one from the other. The ratios computed from the two histories did not vary more than 1% from each other, for any given time period. This difference was not enough to make itself apparent in the output of the model.

CHAPTER V

LONG RANGE FORECASTING

In the industrial society of today, most firms anticipate to remain in business for some time, and this implies their continued growth and development. There must be some member of each firm who is thinking about the day after tomorrow, and the year after next year. In order to stay competitive, if not to grow in your market share, a firm must engage in "leadership" activities. If a firm does not plan ahead, it is left to meet the crisis and necessities of day-to-day activity, and is utterly dependent on its surroundings. With the use of planning, the firm regains control over itself and much of its environment. Planning is usually practiced in two parts, long-range planning and short-term planning.

Long-range planning should cover the entire scope of the business, inlcuding its customers and suppliers, as well as the firm's own men, material, and money. This planning is usually centered around a forecast of one or more of the critical parameters of business operations, most frequently the sales estimate.

There are many different methods of generating a sales estimate for future years ranging from the intuitive assumptions of practitioners to statistical extrapolation of a past time series, correlation with some leading series, or an opinion poll of the public. The most relevant approach for any firm should be that which can demonstrably include the most logical assumptions concerning the determinates of sales. If these causative forces can be identified, and also be presumed to persits, then estimates can be made with some high degree of accuracy. However generated, the sales estimate can be an important tool in the progress of the firm within its industry.

Once established, the planning figures can be evaluated for plant capacity, manpower and inventory requirements, capital budgeting, etc. As these areas typically need a longer period in which to make a change, the further ahead the ~~the~~ plans can be accurately foreseen, the more the firm is apt to be current with its environment. If additional plant capacity, which takes two years to build, is started two years before its need is current, the firm will then be able to meet its current requirements at all times.

After an evaluation of the raw materials availability, profit and loss potential, and probability of accuracy, the forecast becomes a guide for the actual production activity of the firm. If the company has expanded its capacity in anticipation of future increased activities, it is able to produce as many items as the customer desires. The management will then attempt to detail the production levels for the year ahead, using the forecast as a planning base. This plan is developed so as to help the company obtain 1) controlled inventories, 2) level labor employment, 3) full machine utilization, and 4) reduced manufacturing costs.

Usually the firm is primarily interested in keeping a stable employment level, and then giving these other areas of concern priority only when they are excessively out of line. The use of "experience ratings" in the assessment of compensation taxes has been a tremendous stimulus to maintaining a stable work force. If the work force is

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pg. 72 is not missing - only mis-numbering error.

held constant, it is less painful to step up the factory output by using overtime when needed, than to hire and fire. In many cases in durable goods production, there is a minimum tempo, or production rate, which is economically feasible. Many of the automatic machine tools which are an intregral part of current manufacturing practice, have a nearly "fixed rate" output. They are so expensive to shut down and start up again that their use dictates a minimum feasible output rate. The firm's management will plan production rates so as to achieve lowest total cost in meeting the expected customer requirements. With the production rate established primarily by other considerations, the inventory is used to balance the peaks and valleys in field sales. Due to the unpredictable nature of our economy, the forecast is usually compared with reality each month, or more likely each quarter.

A sales forecast which is low will establish low spending at the factory, and not support the sales which are available, resulting in lost sales (and lost profits). If, however, the sales estimate is high, the factory's spending is not supportable by sales, and profits again are lost as costs cut the margin. With these hazards in mind, the periodic review of actual events is made so that plans can be shifted as necessary to meet the current conditions. If this adjusting were done more frequently, it would approach the dependent situation which exists in the absence of planning, and thus quarterly or monthly revision of expected levels of activity is generally thought to be adequate. With the general acceptance of the need for planning and smooth operations, it seems possible that this management philosophy will create a pattern of regularity in the operations which is not inherent in the customer's behavior. Not only does management think in terms of discrete years, but the production is controlled by an arbitrarily established time pattern. In an attempt to understand the effects of a regularized (time-wise) behavior response to the random movements of the customer, it is worthwhile to study this activity in the context of the model, to see if it will introduce a regularity and repititions bias into the firm's operation. This policy could easily become a fixation of management which, because of its very nature, repeats and grows on itself until an annual pattern is imposed on what is a otherwise random occurance of events.

Forecasting included in model. -- The examination of the production distribution system in which forecasting is used will provide an insight into the nature of the disturbances this management practice will create. In this instance we are more interested in the effects of the planning for future activity and growth, than in the planning treatment associated with the variations within a single year. Most attempts to explain the historical occurance of events and to fit them to a recognizable pattern, are based on the knowledge that many factors will have been responsible for the observed events. Perhaps the two most persistent factors are the long-term growth and the seasonal (annual) cycle. Then major events, such as wars and depressions, are used to explain further remaining deviations in the pattern. In the planning of most industrial firms, however, the long-term growth of the firm, and an annual pattern are the major basis for analysis and projection.

In this chapter, we shall consider the reactions of the system to those policies which are directed at maintaining a strong consistent growth pattern for the firm. With the technology of industry at very advanced levels, most firms find it necessary to increase their activities every year. As a matter of fact, a firm will not stay strong and competitvie long, if it does not at least keep up with the growth of the economy. The majority of our industrial leaders, in fact, have definite expectations of growing at a faster rate than the economy as a whole.

Other policies have been examined which were primarily directed towards the recognition of and compensation for seasonal patterns in the ratail sales of the firm. This section will neglect the seasonal pattern as such, and be concerned with those management decisions which are concerned with the growth of the company.

In the interest of stable employment along with maximum sales, many firms will formulate an estimate of sales for the coming year, and then use this estimate as a guide for scheduling production. Depending on the nature of the product, the firm may or may not desire to maintain an inventory which could sustain sales for a certain length of time. To many firms the practice of holding a large finished goods inventory at the factory is offensive. Management sees little capital recovery from the items stored at the factory and may fear losses through obsolescence and excessive warehousing costs.[1] On the other hand, other firms would rather maintain a comparatively large inventory, so that they will not experience excessive delays in filling orders, etc.

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[1]Minnesota American Legion Foundation, Employment Stabilization Service, "To Make Jobs More Steady, and To Make More Steady Jobs", Case #53, St. Paul, 1942.

No inventory correction applied. -- The management would first set out to establish their sales forecast. In this model the sales forecast is a simple extrapolation of the past activities, with particular emphasis given to the most recent past. This approach assumes that the firm is attempting to maintain the consistency of its past expansion pattern, and is not concerned with additional exogenous influences. Understanding that there may be seasonal and other fluctuations in the firm's business, we have taken the rate of factory orders smoothed over a long period (1 or 2 years) as the true picture of the firm's long term growth trend.

The determination of the long term slope of the trend line necessitates that we provide the model with a memory of what the 'current' value was at some time in the past, for comparison with the present value. This 'memory' is provided by a third order delay, whose output will now reflect what the input was some time in the past (at the start of the delay). The slope is therefore easily generated by the model by the following equations, (Figure 12)

Current value of long term smoothed requisitions is given by:

$$RSFE.K = RSFE.J + \frac{DT}{LTSM}(RRF.JK - RSFE.J) \qquad \text{Eq. 105, L}$$

The current value of this 'trend line' at a prior time is

$$RSFL.KL = DELAY3(RSFE.K, PEROS) \qquad \text{Eq. 106, R}$$

where PEROS is arbitrarily set as one or two years.

To get the slope of the line, we simply examine the change in ordinate value over the change in time.

$$SLPFL.K = (1/PEROS)(RSFE.K - RSFL.JK) \qquad \text{Eq. 107, A}$$

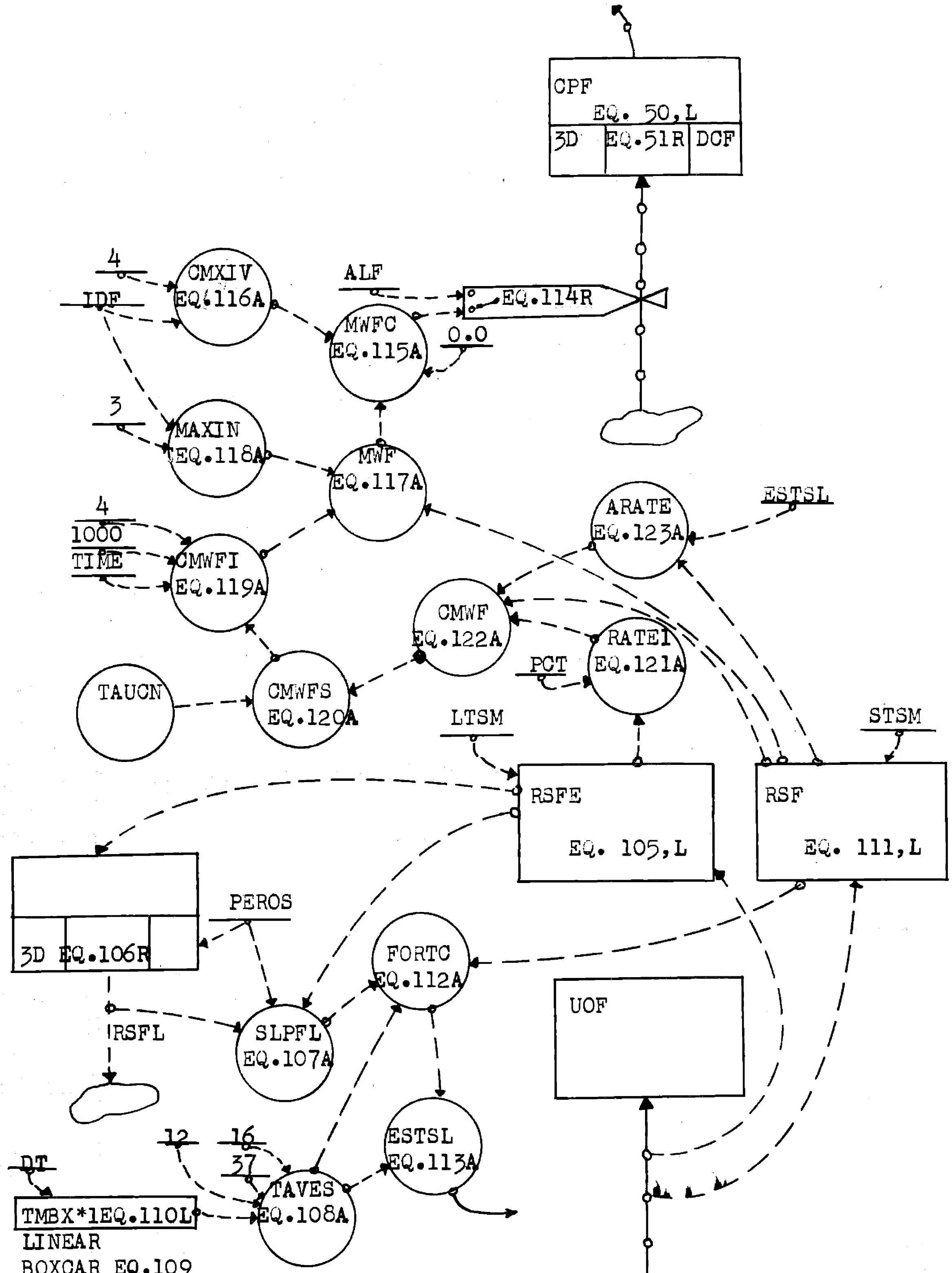

FIGURE 12 FACTORY SECTOR- LONG RANGE FORECASTING WITHOUT INVENTORY ADJUSTMENT

RSFE--Requisitions Smoothed at Factory, for Estimating, (units/week)
LTSM--constant for Long Term SMoothing, (weeks)
RRF--Requisitions Received at Factory, (units/week)
RSFL--Requisitions Smoothed at Factory for estimating, Lagged, (units/week)
PEROS--constant for fixing the PERiod Of Smoothing, (weeks)
SLPFL--SLoPe of the Forecast Line, (units/week)

The use of forward forecasting is beneficial only if we don't loose sight of reality. The firm which relies solely on its estimate for the planning of production, can end in serious trouble. It is generally practiced that the forecast be examined in light of current events every quarter, if not every month. This examination gives management the opportunity to adjust its operations up or down depending on the then current business outlook. In terms of our model, the smoothed sales is the figure which most truly reflects the 'trend' of the firm's business in the short term. It is reasonable, therefore, to establish an 'adjusted' estimate of sales for the coming quarter, by basing an extrapolation on the short term smoothed sales value. The forecast then is an extension of the current slope of the 'trend line' over the coming quarter. The estimate of sales is given by the following equations.

For conveniences in matching estimate changes and manufacturing rate changes, the estimates were made every 12 or 16 weeks, rather than for an even quarter of 13 weeks. The use of full weeks, 4 -week months (periods) etc., is becoming more popular with business leaders, as they realize the difficulties inherent in matching months, weeks, etc.,for accounting purposes.

The year is therefore divided as shown for estimating purposes by these equations.

0 12 24 36 52 weeks

$$TAUES.K = 16 \quad \text{if } TMBX*1.K \geq 37 \qquad \text{Eq. 108, A}$$

$$= 12 \quad \text{if } TMBX*1.K < 37$$

$$TMBX=BOXLIN(1,52) \qquad \text{Eq. 109, B}$$

$$TMBX*1.K = TMBX*1.J+(DT)(1+0) \qquad \text{Eq. 110, L}$$

TAUES--Time Adjustment for Estimating Sales, (weeks)
TMBX--TiMe keeping BoX car train; to allow repetition of the annual pattern

The forecast value for the next quarter is given by --

$$RSF.K = RSF.J+ \frac{DT}{STSM} (RRF.JK-RSF.J) \qquad \text{Eq. 111, L}$$

$$FORCT.K = RSF.K+ (RAUES.K)(SLPFL.K) \qquad \text{Eq. 112, A}$$

FORCT--FORecast value of sales, (units/week)
RSF--Requisitions Smoothed at Factory, (units/week)
TAUES--Time AdjUstment for Estimating Sales, (weeks)
SLPFL--SLoPe of Forecast Line, (units/week)
STSM--constant for Short Term SMoothing, (weeks)
RRF--Requisitions Received at Factory, (units/week)

The sales estimate is determined every 12 or 16 weeks (as the value of the forecast at that time) and is held constant throughout the coming time period --

$$ESTSL.K = SAMPLE\ (FORCT.K,\ TAUES.K) \qquad \text{Eq. 113, A}$$

ESTSL--ESTimated SaLes, (units/week)
FORCT--FOReCasT value of sales, (units/week)
TAUES--Time AdjUstment for Estimating Sales, (weeks)

Once the estimate is made for the coming quarter the manufacturing rate decision is made. As the firm is interested in stable employment, and desires to maintain no large inventory on hand, we can assume that they will produce as many items as they feel they can reasonably expect to sell.

In the interests of uniformity the rate of desired production is determined, and then held constant for a period of two or four weeks. The use of a constant rate permits more accurate manpower planning, greater efficiency and higher productivity through long runs. In this model, the rate as determined, is held constant unless the limits of the system are exceeded. There is some physical capacity limit to the rate of manufacture which is set by the current capacity and the number of hours in the day. We shall assume that this limitation poses no problem, as production can be stepped up considerably through the occasional use of overtime, or a second shift. Management may also have some limitations in the number of goods it will put into inventory. If there is an inventory accumulation of considerable size, management will drop operations to a minimal figure, or even cease operation entirely. The capacity and inventory limits can thus take precedence over the manufacturing rate desired by other criteria.

$$\text{MDF.KL} = \text{MWFC.K} \quad \text{if ALF} \geq \text{MWFC.K} \qquad \text{Eq. 114, R}$$
$$= \text{ALF} \quad \text{if ALF} < \text{MWFC.K}$$

$$\text{MWFC.K} = 0.0 \quad \text{if IAF.K} \geq \text{CMXIV.K} \qquad \text{Eq. 115, A}$$
$$= \text{MWF.K} \quad \text{if IAF.K} < \text{CMXIV.K}$$

$$\text{CMXIV.K} = (4)(\text{IDF.K}) \qquad \text{Eq. 116, A}$$

$$\text{MWF.K} = \text{RSF.K} \quad \text{if IAF.K} \geq \text{MAXIN.K} \qquad \text{Eq. 117, A}$$
$$= \text{CMWFI.K} \quad \text{if IAF.K} < \text{MAXIN.K}$$

$$\text{MAXIN} = (3)(\text{IDF.K}) \qquad \text{Eq. 118, A}$$

MDF--Manufacturing Desired at Factory

MDF--Manufacturing rate Decision at Factory, (units/week)
MWFC--Manufacturing rate Wanted at Factory, under Critical inventory situation, (units/week)
ALF--constAnt production Limit at Factory, (units/week)
IAF--Inventory Actual at Factory, (units)
CMXIV--Critical upper limit on MaXimum InVentory at factory, (units)
IDF--Inventory Desired at Factory, (units/week)
RSF--Requisitions Smoothed at Factory, (units/week)
MAXIN--MAXimum INventory at factory, limit, (units)

The sampling function in the formulation is such that an initial value is needed prior to the first sample time.

$$CMWFI.K = CMWFS.K \quad \text{if } TIME.K \geq 4 \qquad \text{Eq. 119, A}$$

$$= 1000 \quad \text{if } TIME.K < 4$$

$$CMWFS.K = SAMPLE\ (CMWF.K,\ TAUCN) \qquad \text{Eq. 120, A}$$

CMWFI--foreCast Manufacturing rate Wanted at Factory, Initial, (units/week)
CMWFS--foreCast Manufacturing rate Wanted at Factory, Sampled, (units/week)
TAUCN--Time AdjUstment factor for holding manufacturing rate CoNstant at factory, (weeks)
TIME--TIME counting sequence

In establishing a desired manufacturing rate, the management is presumed to be motivated to maintain fairly stable employment, and to be conservative in any increases in productivity. The day by day sales will very likely vary rather widely, and therefore the smoothed average sales is a more stable representation of the level of current activity. When sales are increasing, the smoothed average will lag behind the sales, and if sales then fall, the smoothed sales will also reflect this change, but in a less extreme manner. This smoothed average would seem therefore to present a conservative picture of the current sales. Management then can use either the estimate for the level of activity expected in the coming quarter, or the smoothed average to establish the production rate for each month. Each time the rate is to be changed (every 2 or 4 weeks), the decision maker should examine the current ordering rate, to see if it exceeds the estimated order rate for the quarter. One illustration of the myriad possible rules incorporating forecasting into the production order decisions is used here to test the implications of this decision. If the current rate is the greater, the desire to meet these increased sales prospects dictates that the production rate be set at the higher level of the smoothed average. If the estimated sales are higher than the current smoothed average sales, continuity of operations suggests that we produce so as to be prepared to meet the estimated sales. If the current smoothed sales were to fall below a level which is felt to be representative of long run minimum expected sales, then production should continue at the minimum rate. If the production rate followed the sales rate down, there would undoubtedly be unnecessary lay-offs. Many firms will utilize this downswing to build up inventory, while keeping production going at, say, 80% of capacity. When sales are constantly increasing, this set of rules indicates that the factory will be producing at the smoothed rate which is lower than the rate of incoming orders to the factory and consequently, we would have a low factory inventory. If, however, the factory orders fell off, we would continue to produce at a rate to meet our estimated sales, and start to build up the inventories, until the orders fell below our percentage of expectations.

If experience had shown that sales would typically vary 20% from average, we would be justified in continuing to produce at 80% of the long term smoothed average, even though the short run average fell below this figure. The inventory which is built up during this period will be drawn down again if sales pick up, but if they stay low, we will cease operation when the inventory exceeds a maximum, which is felt to reflect the limit of practical disposability.

The selection of the manufacturing rate is made through the following formulation --

RATE1.K = (PERCT)(RSFE.K) Eq. 121, A

CMWF.K = ARATE.K if RSF.K $\geq$ RATE1.K Eq. 122, A

= RATE1.K if RSF.K $<$ RATE1.K

ARATE.K = RSF.K if RSF.K $\geq$ ESTSL.K Eq. 123, A

= ESTSL.K if RSF.K < ESTSL.K

CMWF--foreCast Manufacturing rate Wanted at Factory, (units/week)
ARATE--mAximum RATE of manufacturing of factory, (units/week)
RSF--Requisitions Smoothed at Factory, (units/week)
ESTSL--ESTimated SaLes at factory, (units/week)
RATE1--alternate RATE, for minimal level #1 production, (units/week)
PERCT--PERCenTage constant for minimum production -
RSFE--Requisitions Smoothed at Factory for Estimating, (units/week)

Maintaining a desired inventory. -- In the case of the manufacturers who desire to maintain an adequate "on hand" inventory, the stability of the manufacturing rate may have to be sacrificed somewhat. In the previous discussion, little attention was paid to the inventory, as it was considered that the production would be held at more stable levels and any minor business fluctuations would be absorbed by the inventory. In this instance, the maintainance of a desired level of inventory may transfer the need for flexibility to the productive sector. We would expect that management would prepare its sales estimate in a similar manner, and again hold the desired manufacturing rate constant for two or four weeks.

Even with the attempt to keep operations in a certain prescribed relationship with the 'normal' level of activity, management may prefer not to continuously make minor adjustments in the manufacturing rate. If inventories, etc., are roughly in balance, the production rate will be estiablished as in the previous case, at the higher value of smoothed average sales, or estimated sales. For the sake of allowing only limited discontinuity, however, the manufacturing rate will be modified to include the necessary adjustments, when those adjustments are greater than a given percentage of the current factory output. With the ordering rule, the factory will not be subject to continuous adjustment, and will only be concerned with production rate changes when system imbalances are greater than 5% or 10% (as established by management) of current output.

Only when the imbalances reach a considerable proportion of current output will they be included in the manufacturing decision. With the adjustments included, the danger of excessive inventory variations seems to be alleviated, due to the occasional adjustment to desired levels, and so the only limitations in the factory are the capacity limit and the saturation of the system inventories.

To carry out the desired policy, the following equations are utilized: (Figure 13)

$$\begin{aligned} MDF.K &= MWF.K \quad \text{if } ALF \geqslant MWF.K & \text{Eq. 124, A} \\ &= ALF \quad \text{if } ALF < MWF.K & \end{aligned}$$

$$\begin{aligned} MWF.K &= 0.0 \quad \text{if } TIS.K \geqslant MXINV.K & \text{Eq. 125, A} \\ &= CMWFI.K \text{ if } TIS.K < MXINV.K & \end{aligned}$$

$$MXINV.K = (AXIS)(IDF.K + IDD.K + IDR.K) \qquad \text{Eq. 126, A}$$

$$TIS.K = IAR.K + IAD.K + IAF.K \qquad \text{Eq. 127, A}$$

MDF--Manufacturing rate Decision at Factory, (units/week)
MWF--Manufacturing rate Wanted at Factory, (units/week)
ALF--constAnt production Limit at Factory, (units/week)
TIS--Total Inventory in the System (units)
MXINV--MaXimum INVentory permitted in system, (saturation) (units)
AXIS--constAnt to determine maXimum Inventory in System
IDF--Inventory Desired at the Factory, (units)
IDD--Inventory Desired at Distributor, (units)
IDR--Inventory Desired at Retail, (units)
CMWFI--foreCast Manufacturing rate Wanted at Factory, Initial, (units/week)

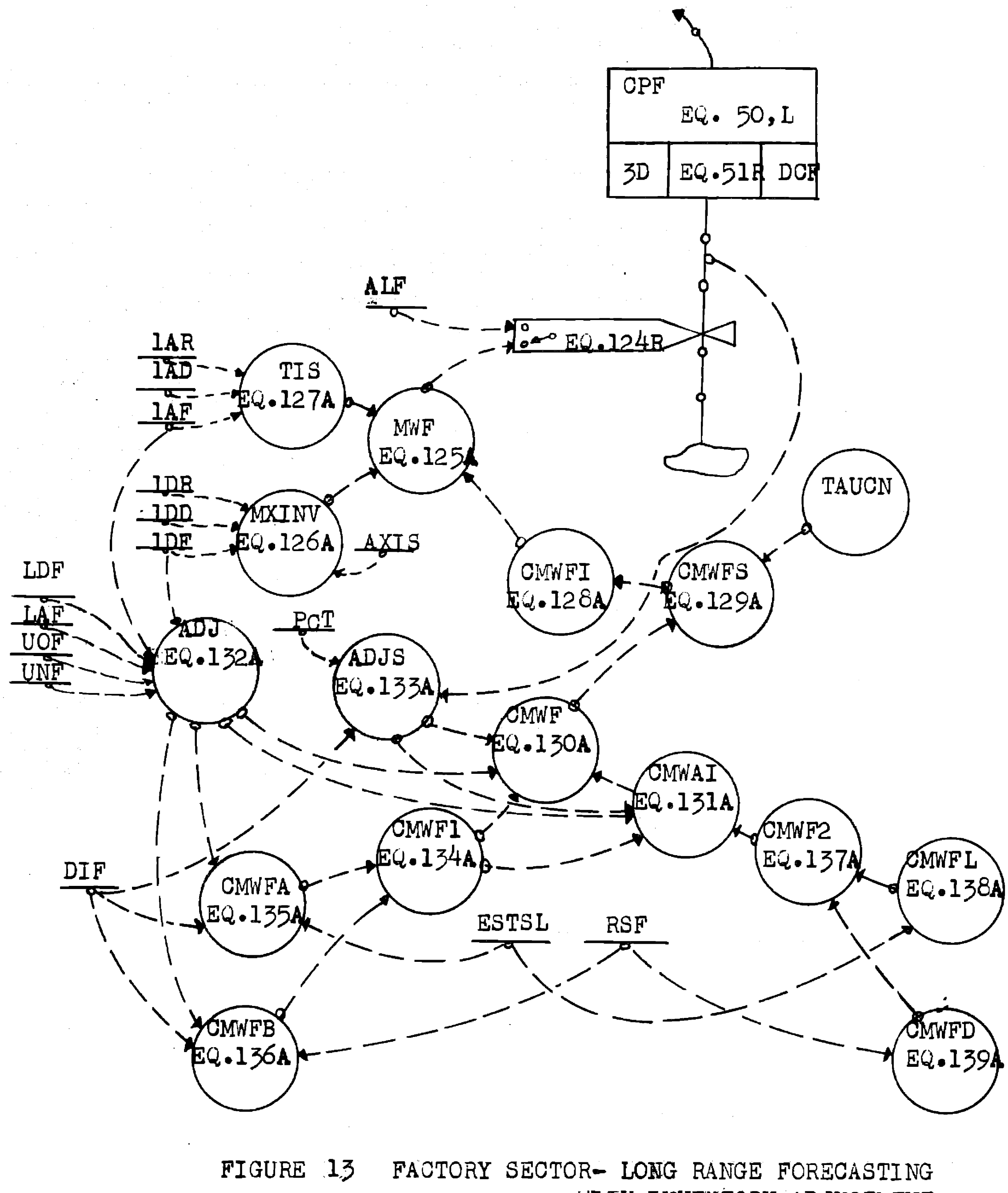

FIGURE 13 FACTORY SECTOR- LONG RANGE FORECASTING WITH INVENTORY ADJUSTMENT

Again it is necessary to provide a manufacturing rate until the first sample can be taken.

$$CMWFI.K = CMWFS.K \quad \text{if} \quad TIME.K \geq 4 \qquad \text{Eq. 128, A}$$

$$= 1000 \quad \text{if} \quad TIME.K < 4$$

$$CMWFS.K = SAMPLE\ (CMWF.K\ ,\ TAUCN) \qquad \text{Eq. 129, A}$$

CMWFI--foreCast Manufacturing rate Wanted at Factory, Initial, (units/weeks)
CMWFS--foreCast Manufacturing rate Wanted at Factory, Sampled, (units/week)
TIME--TIME computation value (weeks)
CMWF--foreCast Manufacturing rate Wanted at Factory, (units/week)
TAUCN--Time AdjUstment factor for holding manufacturing rate CoNstant, (weeks)

The extent of adjustments required is then compared with the output rate to see if adjustments should be introduced to the manufacturing decision. The increment to be added or taken away from the order rate at any time is given by Increment = (1/DIF) (Adjustment). If management decides that the increment added or substracted is to be not less than 5% of current output, ($INC \geq 5\% \cdot MOF$), then the comparison of the gross adjustment should be made against (5%)(MOF)(DIF).

$$CMWF.K = CMWF1.K \quad \text{if } ADJ.K \geq ADJS.K \qquad \text{Eq. 130, A}$$

$$= CMWA1.K \quad \text{if } ADJ.K < ADJS.K$$

$$CMWA1.K = CMWF2.K \quad \text{if } ADJ.K \geq -ADJS.K \qquad \text{Eq. 131, A}$$

$$= CMWF1.K \quad \text{if } ADJ.K < -ADJS.K$$

$$ADJ.K = IDF.K - IAF.K + LDF.K - LAF.K + UOF.K - UNF.K \qquad \text{Eq. 132, A}$$

$$ADJS.K = (PCT)(MOF.JK)(DIF) \qquad \text{Eq. 133, A}$$

CMWF--foreCast Manufacturing rate Wanted at Factory, (units/week)
CMWF1--foreCast Manufacturing rate Wanted at Factory, condition 1, (units/week)
CMWF2--foreCast Manufacturing rate Wanted at Factory, condition 2, (units/week)
CMWA1--foreCast Manufacturing rate Wanted at factory, alternate 1, (units/week)

ADJ--summation of ADJustments to bring inventory pipeline and backlog to desired levels, (units)
ADJS--value of ADJustments which will Start their inclusion in the manufacturing rate computation, (units)
IDF--Inventory Desired at Factory, (units)
IAF--Inventory Actual at Factory, (units)
LDF--pipeLine Desired at Factory, (units)
LAF-pipeLine Actual at Factory, (units)
UOF--Unfilled Orders at Factory, (units)
UNF--Unfilled orders, Normal, at Factory, (units)
PCT--PerCenT of current output at which adjustments will be started
MOF--Manufacturing Output of the Factory, (units/week)
DIF--Delay in Inventory adjustment at Factory, (week)

The management in its optimism will then choose the rate of production which is the largest to be reasonably anticipated. The higher rate of production will assure that there are sufficient goods available at all times, and the adjustments will not permit the stock to become excessive.

Where the inventory is to be adjusted, the choice is between

$$\text{CMWF1.K} = \text{CMWFA.K} \quad \text{if} \quad \text{CMWFA.K} \geqslant \text{CMWFB.K} \qquad \text{Eq. 134, A}$$

$$= \text{CMWFB.K} \quad \text{if} \quad \text{CMWFA.K} < \text{CMWFB.K}$$

$$\text{CMWFA.K} = \text{RSF.K} + \frac{1}{\text{DIF}} (\text{ADJ.K}) \qquad \text{Eq. 135, A}$$

$$\text{CMWFB.K} = \text{ESTSL.K} + \frac{1}{\text{DIF}} (\text{ADJ.K}) \qquad \text{Eq. 136, A}$$

CMWF1--foreCast Manufacturing rate Wanted at Factory, condition 1, (units/week)
CMWFA--foreCast Manufacturing rate Wanted at Factory, choice A, (units/week)
CMWFB--foreCast Manufacturing rate Wanted at Factory, choice B, (units/week)
RSF--Requisitions Smoothed at Factory, (units/week)
ESTSL--ESTimated SaLes for the coming quarter, (units/week)
DIF--Delay in Inventory adjustment at Factory, (weeks)
ADJ--value of AdJustments to bring inventory, etc., to desired levels, (units)

Where no inventory adjustment is called for, the choice is as follows:

$$\text{CMWF2.K} = \text{CMWFC.K} \quad \text{if} \quad \text{CMWFC.K} \geqslant \text{CMWFD.K} \qquad \text{Eq. 137, A}$$

$$= \text{CMWFD.K} \quad \text{if} \quad \text{CMWFC.K} < \text{CMWFD.K}$$

CMWFC.K = RSF.K Eq. 138, A

CMWFD.K = ESTSL.K Eq. 139, A

CMWF2--foreCast Manufacturing rate Wanted at Factory, condition 2, (units/week)
CMWFC--foreCast Manufacturing rate Wanted at Factory, choice C, (units/week)
CMWFD--foreCast Manufacturing rate Wanted at Factory, choice D, (units/week)
RSF--Requisitions Smoothed at Factory, (units/week)
ESTSL--ESTimated SaLes for coming quarter, (units/week)

Long term forecasting with Inventory Adjustment

Random variations. -- The response of the model to a system which includes long term forecasting and inventory adjustment, when random customer ordering rate were impressed on the input, indicated that the expected fluctuations were accentuated. As the rate of incoming orders varies quite rapidly, the constant production period of four weeks causes the adjustments to become more extreme when applied. If the correction were permitted continuously, (as in the general model) the magnitude of the inventory, etc., corrections necessary would not be as great, and then the production rate would not fluctuate to such wide values. Comparison with a general model run, Figure 10 , Curve C , shows that where forecasting is used, Figure 15 the amplification is close to half again as much as the regular run, Curve C . Typical values were:

Amplification Factor	1st Peak	1st Low	2nd Peak
Regular Run	5.2 : 1	1.6 : 1	5.2 : 1
Forecast Run	7.2 : 1	2.6 : 1	9.0 : 1

Probably the major impetus for the additional amplifications came from the constant production rate. We could expect some periodic inventory adjustment with the basic ordering rule even without holding production constant, but this act will cause exageration of the de-

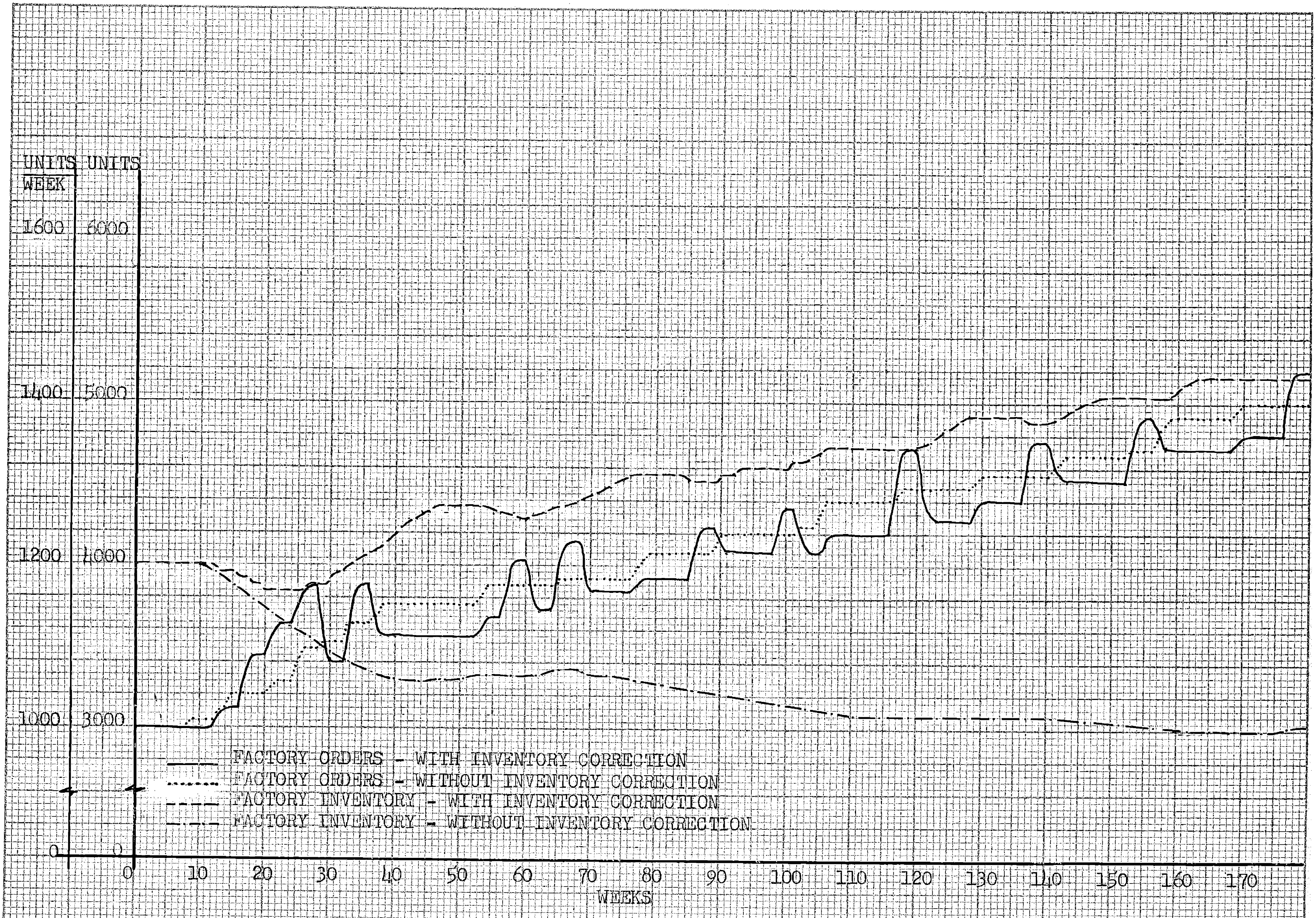

FIGURE 14 LONG RANGE FORECASTING IN A GROWTH BUSINESS

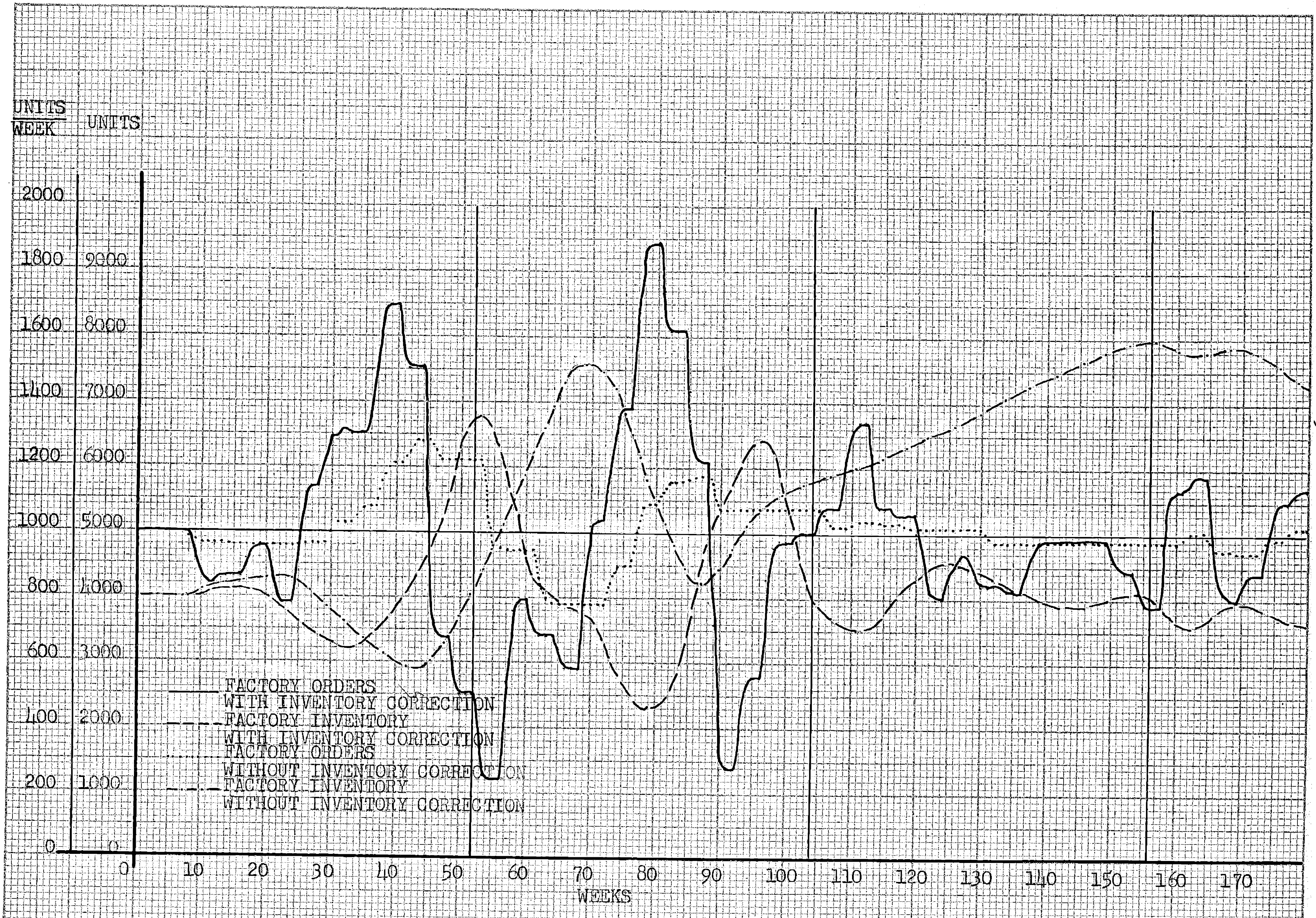

FIGURE 15 LONG RANGE FORECASTING IN A VARIABLE BUSINESS

ficiencies. Even in years (three and four) of relative stability in consumer ordering the variations in production range 250 units/week (2.5:1 amplification) where in the straight run the range was around 200 units/week (1.0:1 amplification). During this period, however, there is less use of the inventory adjustment factor, as the factory output was more closely related to incoming orders, or less effect from the production delay.

The combinations of the desired effects of the policy as formulated, seem not to be achieved. Where "stability" is expected, the model shows greater amplification and what would appear to be poorer operating conditions. Even with the forecast tied to the "smoother" base in the long term smoothed current sales (RSFE), the amplifications were almost as great. We can not trace any major effect, which the decision policy may have on creating an annual pattern, but as was expected, the randomness of the consumer was rather an over powering factor in the decision policy.

Growth circumstances. -- The first year was subject to some transient conditions, inpassing from "level" activity to the continuous growth. The standard effects of the management policies to produce at a constant rate for four weeks, and to adjust inventories only when they will require a five (or better) percent change incurrent production will be observed in the second and subsequent years. The production sector is seen to produce for many weeks at a constant rate, and then every few months, the factory must step up production temporarily to bring the adjustments back into line. The production rate selected is usually the estimated sales for the coming period, which is above the incoming order rate. As the estimate is based on the smoothed sales, which is again below current incoming sales, if the estimate is held for a long period, the production falls below the incoming orders. The imbalances in the adjustment factor are accelerated in the final portion of the quarter, as the inventory becomes depleted.

This response tends to concentrate many of the production jumps in the final weeks of each quarter, although each period will be different. Some quarters start with higher adjustments necessary than others. No completely regular response pattern is observed, but there seems to be a tendency for "extra" production to occur every 20 to 26 weeks.

This decision policy has produced quite a more irregular pattern than where no forecasting was used.[2] The stability of this situation must, however, be evaluated in the light of each firm's specific requirement. If it is assumed that the production rate can be changed in gradual amounts, continuously over time, then the general model responses are acceptable as a good approach to stable operation. There are many circumstances, however, where it is preferable to operate at constant rates and use overtime to supply the occasional bumps in productivity that may be needed. If this were the case for a firm, then its best approach from those studied would be to utilize forecasting as much as possible to establish the production rates.

No Inventory Adjustment Rule

Growth. -- The responses to a manufacturing rule which utilized long range forecasting but took no cognizance of a minimum inventory level, are shown in Figure 14 . In a growth situation the manufacturing rate was a rather smooth series of steps. The rate was held constant

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[2]Industrial Dynamics Research Group, Run 0396

for twelve to sixteen weeks during most of the run, usually at the estimated sales rate. The rate at the beginning of each quarter was the same 16 to 30 units/week above the incoming order rate, but usually was below the order rate at the end of the quarter. With this averaging across the quarter, inventory at the factory remained quite stable. Once past the initial transient period, the inventory varied some 60 to 100 units around a base of 3000 units.

By not keeping a desired level of inventory, in the manufacturing rule, the delivery delay as determined by the ratio $\frac{IDF}{IAC} + C$ continues to increase. The delay, however, only increased from 2.0 weeks to 2.9 weeks over the four year period, which is not an alarming increase.

This policy certainly tended to make manufacturing pattern follow the regularity of the quarters. This year is now portrayed by a few plateaus of activity. For certain types of production activity, this "plateau production" is a very plausible and beneficial operational objective. It will, however, cause an action pattern which is closely related to the calendar, and may invite an annual look-in of action.

Random customer orders. -- Where subject to a random customers ordering rate, the manufacturing rate was much more stable, than under alternate ordering rules. The facts that there is no inventory correction factor included in the rate, and that manufacturing is generally based on the smoothed order rate (which is below actual in an upswing) combined to give this more appreciable stability to the activity of the factory sector.

As was expected, the inventory was forced to absorb the majority of system fluctuations. Starting with 4000 units in inventory, the stock fell below 3000 units during the heavy customer ordering period, and varied over a large range while the orders were moving over large ranges. When the ordering pattern became more stable, the inventory increased to around 8500 units, as the manufacturing rate (based on estimated sales) was usually above the ordering rate. This build-up was still within the maximum limitations set by management.

Again the constant period of production accentuated the regularity of the planning period, but did not create an over balancing feedback sufficient to regularize the customer's behavior to an annual pattern.

CHAPTER VI

CONCLUSIONS

The analysis of these management decision policies to determine their impact on the model response must necessarily be viewed in a restrictive manner. As the model did not include all of the factors which might have some bearing on an actual industrial situation, the results can not be immediately transferred to practice. For the purpose of understanding the basic behavior interrelationships, the investigation was carried out in a management atmosphere which will not exist in such a limited way in industry. The policies formulated were prepared by the writer and represent no single firms mode of operation, but rather are an agglomeration of some of the methods generally used by firms in the durable consumers goods industry.

The investigation has been helpful in providing insight into the operations of a firm when different planning and stabilizing characteristics were employed in the establishment of manufacturing rates. The point of view of the production sector was assumed during the analysis, thus limiting the value of the conclusions to the benefits or hazards of this group. The impact of this section's policies on the sales group, or other company operations would be a valuable extention of these results. Much of the causative reactions which would help to reinforce the seasonality of the policies discussed have been by-passed with the elimination of the consumers reaction to company actions. This elimination is beneficial in the preliminary stages of any investigation, in that it enables a basic understanding of the factory responds to its own decision policies, uncomplicated by the variable reactions of the consumer.

The policies as they were formulated assumed that the input of the consumer would be of a certain characteristic, and hence the pattern could be recognized and then adapted to, in order to provide smoother operations. That there may be feedback from the factory to the consumer was not overlooked, but considered as extraneous to the primary ramifications of the policies. Consumer response to factory operation is as hard to specifically enumerate, as is the consumer response to advertising or other non-price competition devices. From the point of view of the production manager, he must act so as to optimize his benefit to overall company operation. This 'sub-optimization' will generally create some hardships for the other sectors of the company, but an appreciation of how he can optimize his own activity is an essential first step to the overall improvement of the companies position.

Perhaps the major lesson to be brought out in the study, is that where a policy is designed to alleviate the ill effects of a certain condition, it will be of little value when the actual situation deviates from that assumed condition. This should lead management to be very cautious in the rigid application of corrective policies where there is an uncertainity about the nature of the pattern. In practice, management may assume that it has a seasonal fluctuations, and may act to offset the usual ramifications of these fulctuations to the factory, but unless the pattern is dominant and day to day variations are small, the application of the correction will be of little or no benefit. From the illustrations of the earlier sections, we can see the attempt at seasonal recognition and correction will have some impact in creating a repetitious pattern in factory operations when the incoming orders are random, but will amplify the factory response to this type of normal input disturbances. Where the input pattern is regular, however, the utilization of the policy is materially beneficial in achieving stabilization of factory activity.

Where long range forecasting is utilized as a guide to the establishment of constant production levels, the need felt by some manufacturers to maintain a certain desired level of inventory on hand will create problems not present when day to day adjustments are made. Even the benefits of stable production rates will not be fully realized, as inventory corrections, when considered necessary, will cause some amplification of the input variations. Where production continued at determined levels with no regard for the size of inventory we find the most stable operation, but the danger of building an excessive inventory. This, in practice, can be harmful if the industry reacts with price competition to eliminate the excess, but the policy as formulated could be modified with a long term correction to alleviate the excess problem. Both of these situations brought about a regular pattern of operation in the factory which although not cyclical, would induce the recognition of the calander as a determining force for operations rather simply following the natural course of events.

The model reactions to the summer shut down were somewhat severe in some cases, as judged by actual practice. It served to show, however, what the application of a rigid policy could do to the system when subjected to arbitrary forces. The irrationality of doubling production for two weeks immediately following the shut down is evident, but it is the natural end result of the model. We can at least expect that the firm will be overloaded by roughly 20% for a period of many months as a result of the inactivity. The problem of hhe shut down may be further aggravated by the consumers reaction to the shut down. If the consumer anticipates the coming of vacations, he may heap his orders shortly prior the expected down time, and thus aggravate the apparent level of customer activity.

The absolue amount of self-induced seasonality as evidenced by these investigations is not as considerable as could be expected when including some manner of customer reaction. However, the presence of some feedback in the application of these policies indicates that the behavior of the firm in determining its own operation does have a marked impact on the rest of the chain. That the production manager has this power to upset the remainder of the system is not usually recognized by many managers, and therefore, policies of 'sub-optimization' for various departments may often create more disturbance in factory operations than does the customers variations. The presence of adverse effects for these corrective policies should serve notice to management as to the dangers inherent in too rigidly defining its operational policies, since the circumstances of application cannot always be accurately foreseen.

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Appendix A

DATA FOR GRAPHS

Calculations by MIT Computation Center

		Industrial Dynamics Group, Run, Number
Figure 5,	Curve A, Factory Orders - Inventory Correction Four Weeks Factory Inventory - Two Weeks	0768PB
	Curve B, Factory Orders - Inventory Correction Eight Weeks	0770PB
	Curve C, Factory Orders- Three Weeks Down Factory Inventory - Three Weeks Down	0769PB
Figure 6,	Manufacturing Orders - Inventory Correction Eight Weeks	0774PB
	Manufacturing Orders - Inventory Correction Four Weeks	0773PB
Figure 7,	Factory Orders - Random	0666PB
	Factory Orders - Following Shut Down	0667PB
Figure 10	Factory Orders - Random Business - No Initial History	0739 PB
	Factory Orders - Random Business - Initial History	0735PB
	Factory Orders - Random Business - No Forecasting	0739AB
Figure 11	Manufacturing Orders Incoming Orders to Factory	0740PB
Figure 14	Factory Orders - With Inventory Correction Factory Inventory - With Inventory Correction	0892PB
	Factory Orders - Without Inventory Correction Factory Inventory - Without Inventory Correction	0894PB
Figure 15	Factory Orders - With Inventory Correction Factory Inventory - With Inventory Correction	0890PB
	Factory Orders - Without Inventory Correction Factory Inventory - Without Inventory Correction	0893PB