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A Dynamic Model of a Small Manufacturing Company

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A DYNAMIC MODEL OF A SMALL MANUFACTURING COMPANY

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Typed by Katherine Shepherd

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CHAPTER I

INTRODUCTION

Dynamic Model

A manufacturing company typically has the objective of maximizing the long-term value of its common stock while satisfying its customers. To achieve this, the company might increase the quantity and improve the quality of production. Since the company is operating in a dynamic environment, its policies should be dynamic also, to achieve its objective.

In order to formulate dynamic policies, an understanding of how the company would perform under alternate courses of action is necessary. A Dynamic Model of the company shows how the company's performance varies over time for a given set of policies and actions. The Dynamic Model provides a basis for experimental investigation at less time and lower cost than trying actual changes in the company.

A company has several components such as raw material and finished goods inventories, production facilities, capital reserve, policy decisions, and an information network. These components are made up of still smaller elements. The manner in which these components are interrelated is as important as the components themselves, in determining the performance of the company.

There are several factors which affect a company's performance, but are beyond the company's control, e.g., the national economy, the political and legal environment, and competition from other companies. However, the company's present policies, actions, and functions (purchasing, sales, production, and R and D work)--which are factors within the company's control--interact with the present environment to result in the future set of conditions (see Figure 1).

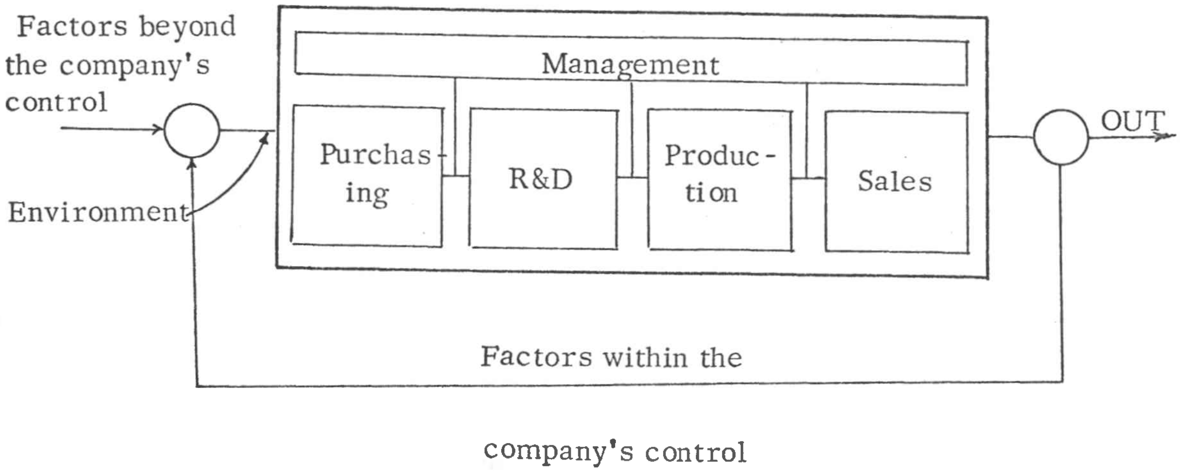

Fig. 1.--Interaction of the company's policies with the environment.

In this study, the policy decisions, actions, and their interrelationships are expressed by a set of mathematical equations. These relationships may be appropriately Fortran-coded and simulated on a digital computer.

Some changes may be made in the company's policies and actions, such as increasing production capacity or starting a Research and Development Department. Variations brought about in the company's performance because of these changes may be studied.

A Small Manufacturing Company

The company taken for study is a small manufacturing concern. The company started its operations in 1967 and shipped its first product in June, 1967. The company has been growing rapidly since then. In the period between April, 1968, and October, 1969, the company increased its production by three and one-half times.

Will the company be able to do as well in the future as in the past? Will the company be able to do better if the production capacity is increased? Will some well-directed policy changes cause better performance? The answers to these questions may be explored by developing a model and exercising it. It was the purpose of this study to develop such a model. The response of the model may be used by management as an indicator of the result to be expected for a certain action. The limitations of the model should always be taken into account when the results are considered.

Perhaps more important than the direct answers to specific questions is the insight into the relationship between different facets of the company which the model gives.

CHAPTER II

DELAYS

Delays are inherent in sociological, economic, and physical systems. An understanding of the types of delays and their effect upon the system's performance is essential for the study of the dynamic behavior of the system.

A delay has one or more inputs and outputs separated from each other in time by the delay time. During the delay time the inputs are being converted to outputs. In the case of production, inputs are the raw materials, and outputs are the finished products. In shipping, inputs are products in one place and outputs are the products in some other place. In clerical processing, inputs are the information and data coming piecemeal, and outputs are the averaged value of the data and the relevant information that the management needs for decision making.

There are two types of delays pertinent to the study of the dynamic behavior of this company. These are shipping and smoothing delays.

Shipping Delays

Shipping delays are represented by exponential delays. The first and third order exponential delays are discussed and their relative merits are shown in Figure 6.[1]

A first order delay has a level (LEV) which absorbs the difference between the input (IN) and output (OUT). The OUT is the LEV divided by the delay time (DEL). The LEV is the accumulated difference between inflows and outflows (see Figure 2).[2]

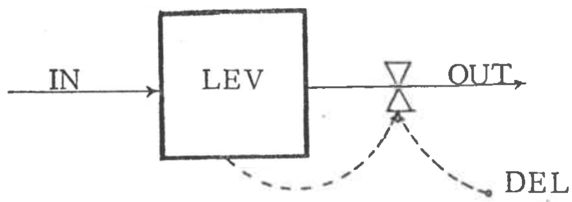

Fig. 2.--First order exponential delay

The level and rates (IN and OUT in Figure 2) are analogously shown as the quantity of fluid stored in a tank, and the inflow and outflow, respectively, in Figure 3.

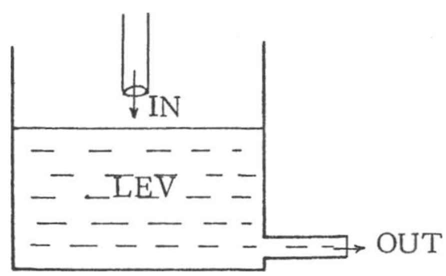

Fig. 3.--Level and rates

The effect of the inflow (IN) and outflow (OUT) on the level (LEV)

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[1] Jay W. Forrester, Industrial Dynamics (Cambridge, Massachusetts: The M. I. T. Press, 1969), p. 90, Figures 9-3 to 9-6.

[2] Forrester, p. 87, Figure 9-1.

during any time interval, DT, is to increase the level by

$$\triangle LEV = DT\ (IN - OUT)$$

where IN and OUT are the inflow and outflow, respectively, during the time interval DT (see Figure 4). LEV1 is the level at time 1 and LEV2 is the level at time 2. The LEV2 is given by

$$\begin{aligned} LEV2 &= LEV1 + \triangle LEV \\ &= LEV1 + DT\ (IN - OUT) \\ &= LEV1 + (IN - OUT)\ DT \end{aligned}$$

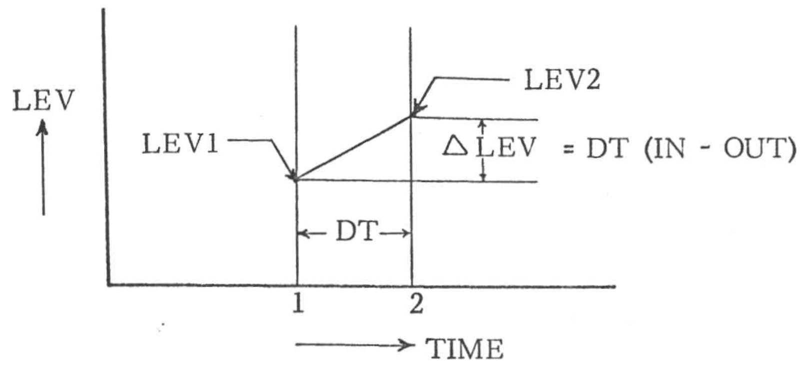


Fig. 4.--Evaluation of level

The outflow at time 1 (OUT1) is given by

$$OUT1 = LEV1/R$$

where R is the resistance offered to the outflow. R stands for the time delays in shipping delays.

The inflow can similarly be determined, from the level and delay on which it depends.

The equations below give the values of LEV and OUT at any time I. (I-1) and I are successive time-stages separated from each other by the time interval DT.

$$LEV (I) = LEV (I-1) + DT \cdot [IN (I-1) - OUT (I-1)]$$

$$OUT (I) = LEV (I-1) / DEL$$

A third order exponential delay is obtained by cascading three first order delays. This is schematically shown in Figure 5.[1]

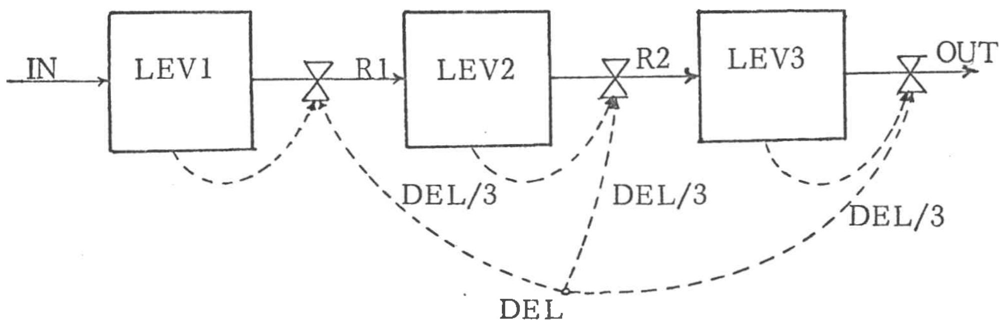


Fig. 5.--Third order exponential delay

The outflow of the first level becomes the inflow of the second level and the outflow of the second level becomes the inflow of the third level. The delay affecting each outflow is the total delay divided by three (see Figure 5).

The equations below give the values of levels and outflows at time I:

---

[1]Forrester, p. 88, Figure 9-2.

LEV1(I) = LEV1(I-1) + DT(IN(I-1) - R1(I-1))

R1(I) = LEV1(I-1)/(DEL/3)

LEV2(I) = LEV2(I-1) + DT(R1(I-1) - R2(I-1))

R2(I) = LEV2(I-1)/(DEL/3)

LEV3(I) = LEV3(I-1) + DT(R2(I-1) - OUT(I-1))

OUT(I) = LEV3(I-1)/(DEL/3)

The responses of first, third, and infinite order delays to a step input are diagrammed in Figure 6.

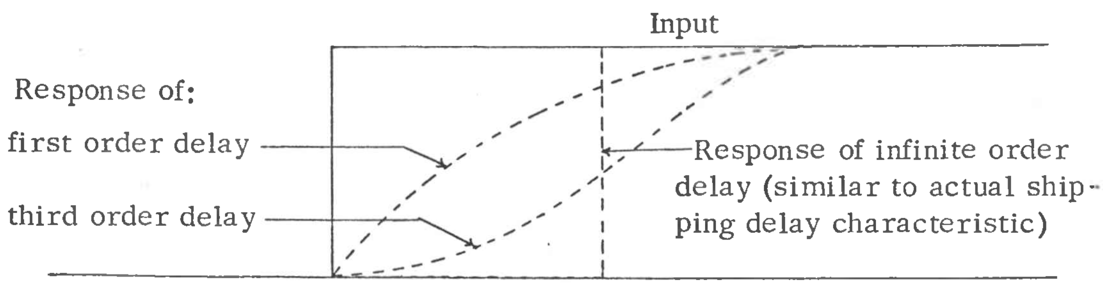


Fig. 6.--Responses of different order delays to a step input

The infinite order delay represents the actual shipping delay. But it is inconvenient to represent an infinite order delay, as it involves infinite cascadings and infinite level and rate evaluations at each time stage. A third order delay is closer to the infinite order delay in its response than the first order one and is simple enough; hence, a third order delay is taken to represent the shipping delays.

Smoothing Delays

A smoothing delay is the type of delay encountered in averaging incoming orders or deciding the production rate, etc. This delay helps to even out the momentary fluctuations in demand, production, etc., experienced by a business. The function of the smoothing delay is depicted in Figure 7.

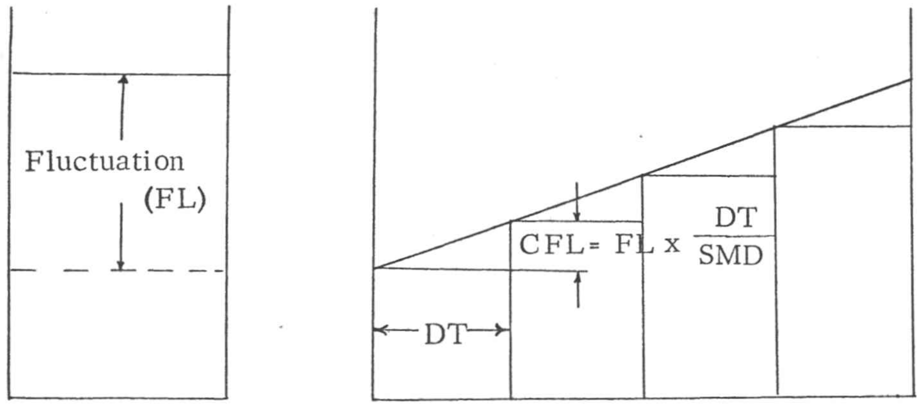


Fig. 7.--Smoothing delay

The fluctuation (FL) is adjusted during the smoothing delay (SMD). The contribution of the fluctuation at any solution interval (CFL) is given by

$$CFL = FL \cdot \frac{DT}{SMD}$$

CHAPTER III

MODEL DESCRIPTION

The model is a set of mathematical equations, representing the main activities (purchasing, production, inspection, sales, etc.), policy decisions, and their interrelationships. The main components of the company are identified and a gross flow diagram developed showing the flow of orders, goods, and information. The flow diagram is given in Figure 9.

The parameters are evaluated at each time stage from the known values of the parameters at the previous time stage. Figure 8 shows the values of parameters against time. (I-1), I, and I+1 are time stages separated from each other by solution interval DT.

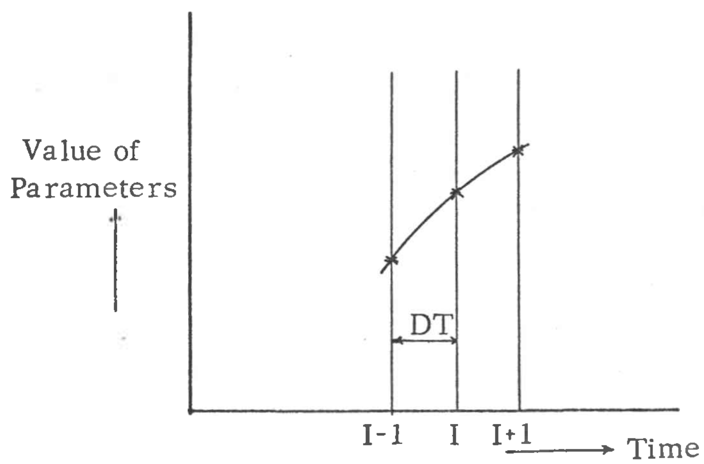


Fig. 8.--Evaluation of parameters

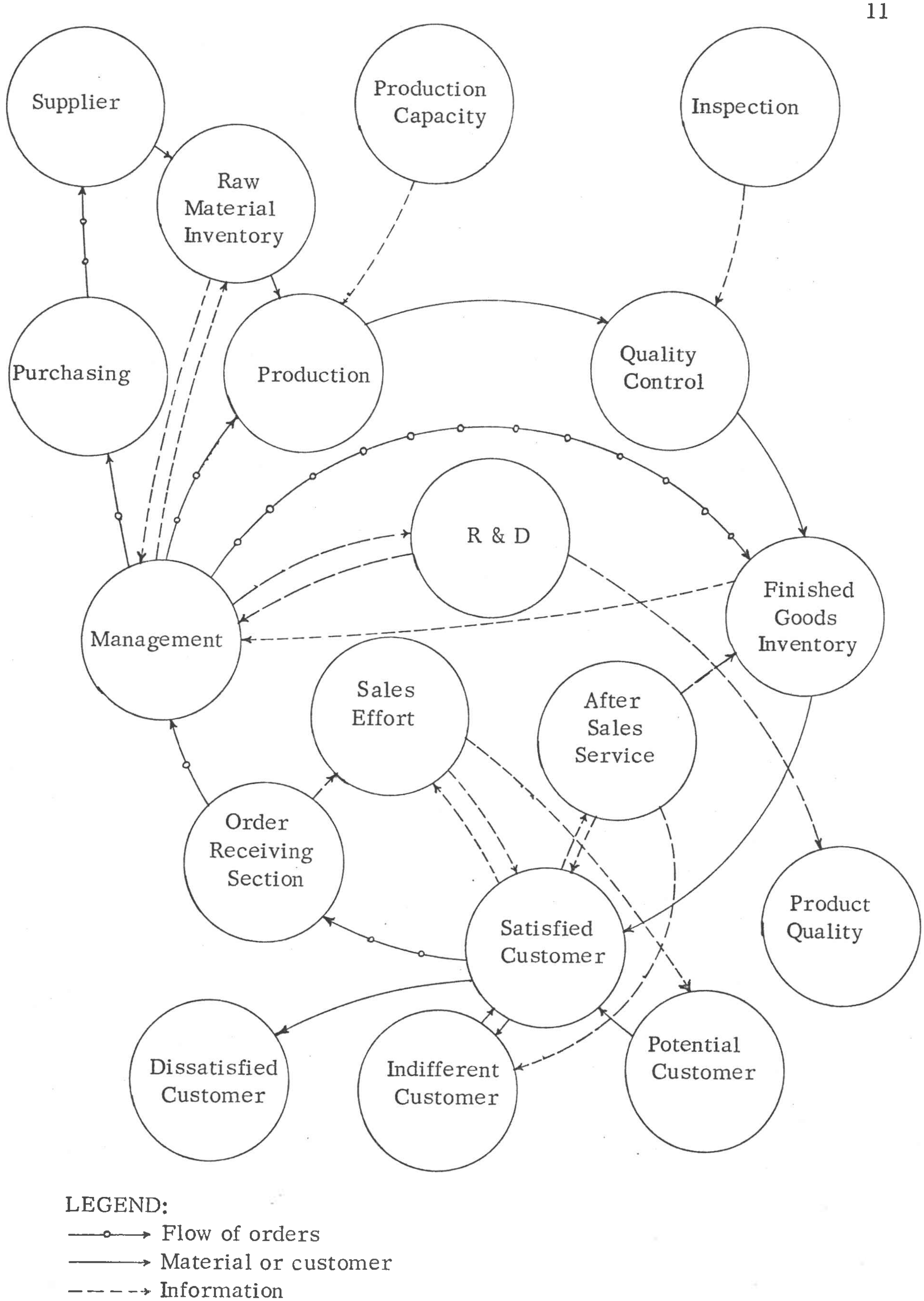


Fig. 9.--Gross model flow diagram

Market

The market consists of the:

1. Satisfied customer.

2. Indifferent customer.

3. Dissatisfied customer.

4. Potential customer.

The satisfied customer is the customer who places an order with the company. He knows other companies which make the same product. He continues to place orders with the company as long as the quality of the product, delivery time, and after-sales service are within acceptable limits.

For convenient mathematical model formulation, the satisfied customer is categorized into two types:

1. Permanently satisfied customer.

2. Temporarily satisfied customer.

The permanently satisfied customer is the customer who has placed orders in the past and continues to place orders in the future.

The temporarily satisfied customer has not placed orders in the past, but he is influenced by either the sales effort or the company's good name or both; therefore he is willing to place a sample order. He becomes a permanently satisfied customer if the product quality and delivery time are within the desired limits.

The indifferent customer knows about the company and its product, and has bought the product at least once in the past, but is rather reluctant to place more orders because of either the poor product quality or delayed delivery. However, he can be persuaded to buy more by proper follow-up.

The dissatisfied customer is the customer who has bought the company's product in the past, but is unhappy with either the product quality or delivery time and he decides not to place orders with the company in the future.

The potential customer is the one who needs the company's product, but has not known the company well enough in the past to place an order. The company can persuade him to buy the product by vigorous sales effort.

Demand for the product is directly proportional to the permanently satisfied customer and to the temporarily satisfied customer.

$$DMD(I) = DM1 \times (PSFC(I-1)) + DM2 \times (TSFC(I-1))$$

DMD Demand (units/week)

DM1 Demand Multiplier for permanently satisfied customer (units/week)

DM2 Demand Multiplier for temporarily satisfied customer (units/week)

PSFC Permanently Satisfied Customer (constant)

TSFC Temporarily Satisfied Customer (constant)

The multipliers DM1 and DM2 are the average weekly order quantities demanded by the permanently satisfied customer (PSFC) and the temporarily satisfied customer (TSFC), respectively.

The temporarily satisfied customer's order is placed on a trial basis only. This order is much smaller than the one placed by the permanently satisfied customer. Therefore,

$$DM2 < DM1$$

The number of temporarily satisfied customers (TSFC) who decide to place orders with the company in the future depends upon the product quality ratio (PQR), delivery time ratio (DTR), and after-sales service (AFS). A premium is put on quality, although weight is also placed on delivery time.

When the product quality of the company (PQC) is the same as the average product quality in the market (PQM), the permanently satisfied customers (PSFC) remain at the level of the previous time stage. When the PQC is higher than PQM, some of the TSFC decide to place orders with the company in the future, thereby increasing the number of the PSFC.

When the PQC goes below the PQM, the number of the PSFC is reduced.

The logarithmic function is taken to represent the effect of the product quality ratio (PQR)--the ratio of PQC to PQM--on the PSFC. The function is characterized by:

positive values for

$$PQR > \text{unity}$$

zero value for

$$PQR = \text{unity}$$

negative values for

$$PQR < \text{unity}$$

These characteristics of the logarithmic function are shown in Figure 10.

The effect of the delivery time ratio (DTR)--the ratio of required delivery time (RDT) to the actual delivery time (ADT)--is similar to that of the PQR.

$$PSFC(I) = PSFC(I-1) + TSFC(I-1) \cdot SMP \cdot [WTQ \cdot LOG \cdot PQR(I-1) + WTD \cdot LOG\ DTR(I-1)]$$

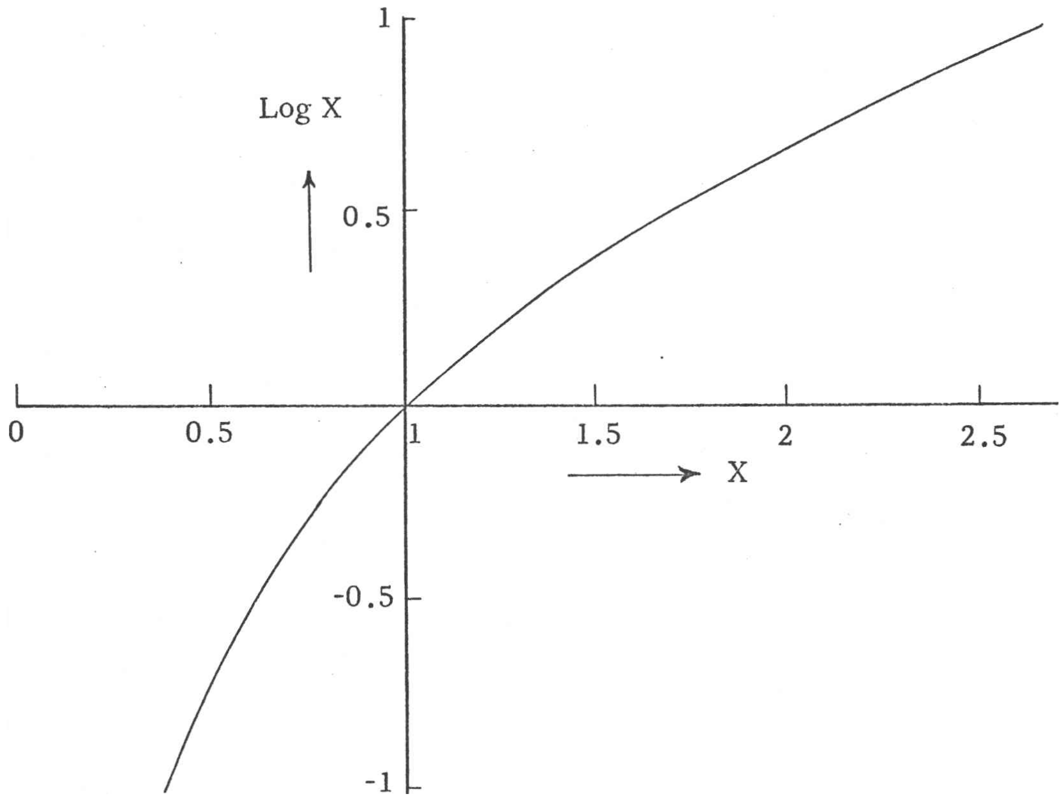
PSFC Permanently satisfied customer (non-dimensional)

TSFC Temporarily satisfied customer (non-dimensional)

SMP Sales multiplier (constant)

WTQ Weight on the product quality ratio (constant)

WTD weight on delivery time ratio (constant)



x	log x
0.5	-0.69
0.75	-0.286
1.0	0.0
1.25	0.223
1.50	0.405
1.75	0.56
2.0	0.695
2.25	0.81
2.5	0.915
2.75	1.01

Fig. 10.--Behavior of log function

PQR Product quality ratio

DTR Delivery time ratio

PQR(I) = PQC(I-1)/PQM(I-1)

PQR Product quality ratio (constant)

PQC Product quality of the company (constant)

PQM Average product quality in the market (constant)

DTR(I) = RDT(I-1)/ADT(I-1)

DTR Delivery time ratio (constant)

RDT Required delivery time (time in weeks)

ADT Actual delivery time (time in weeks)

The number of the potential customers (PCR) who place orders on a trial basis is a measure of the sales effort (SFT). The number of indifferent customers who decide to place orders on a trial basis is a measure of the SFT and after-sales service (AFS) combined.

$$TSFC(I) = SM1 \cdot PCR(I-1) \cdot SFT(I-1) + SM2 \cdot ICR(I-1)\left[SFT(I-1) + AFS(I-1)\right]$$

TSFC Temporarily satisfied customer (non-dimensional)

SM1 Sales multiplier for potential customer (constant)

SM2 Sales multiplier for indifferent customer (constant)

PCR	Potential customer (non-dimensional)
ICR	Indifferent customer (non-dimensional)
SFT	Sales effort (non-dimensional)
AFS	After-sales service (non-dimensional)

The product quality ratio (PQR) is the ratio of the quality of the company's product to the average quality of like products in the market. Product quality is a direct measure of the company's research and development work. If the company has no special R and D work, then its product quality might be expected to remain at the present level.

Technology is growing at a fast rate. Due to the efforts of public authorities on pollution control and due to the growing demand from customers for noiseless valves, research in the production and operation of control valves is anticipated to increase in the coming years. The R and D in this field is, therefore, expected to take an exponential growth curve (see Figure 11).

The company's product quality initially is much higher than the average product quality in the market. This is because of the technical know-how acquired by the company's two executives, while they were working with a leading company making control valves, and also because of some of the good designs patented by the company.

The product quality ratio is shown to be initially high, but drops gradually down if the product quality remains constant (see Figure 11).

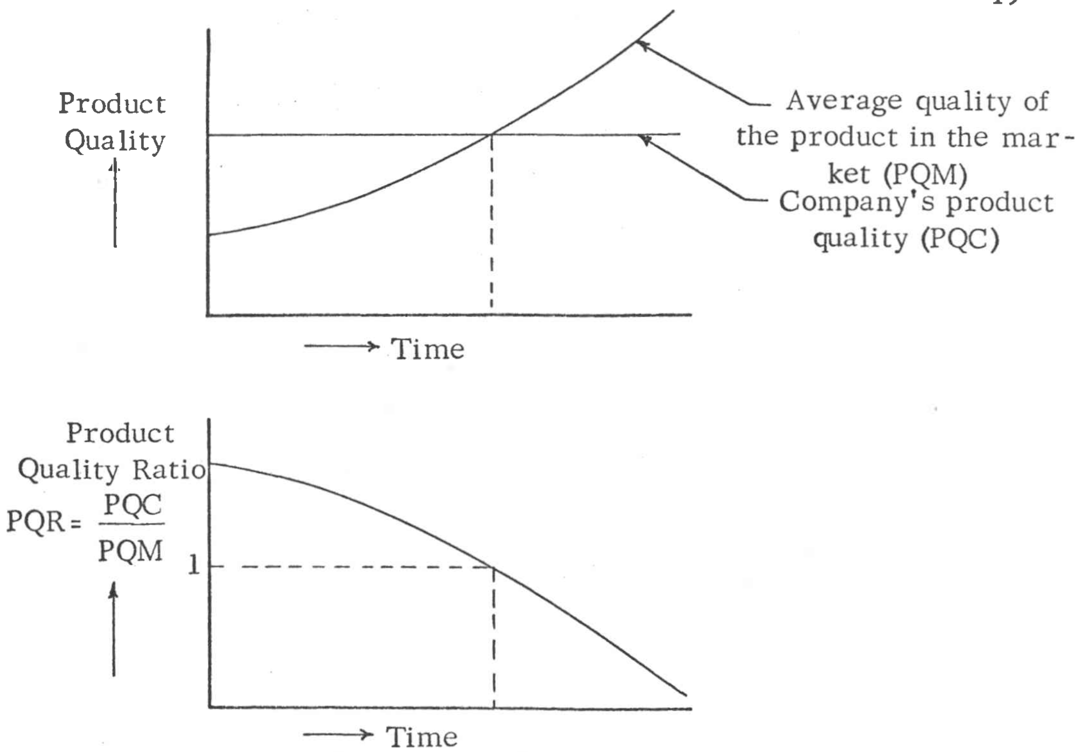


Fig. 11.--Product quality

$$PQC(I) = \text{Constant}$$

$$PQM(I) = \text{Constant} \times e^{(I/\text{Constant})}$$

The delivery time ratio (DTR) is the ratio of required delivery time (RDT) to actual delivery time (ADT). RDT is taken at an average of one month.

Actual Delivery Time (ADT)

A valve is assembled only after an order is procured. If all the parts are in finished goods inventory, the total delay consists of the mailing delay, assembling delay, and shipping delay. This total delay is called the minimum delay.

If the required parts are not in the finished goods inventory, total delay will be equal to the sum of the minimum delay, the production delay, and inspection delay, provided enough raw material is available.

If enough raw material is not available, then the total delay is the sum of the minimum, inspection, production, and procuring delays. These delays are represented in Figure 12.

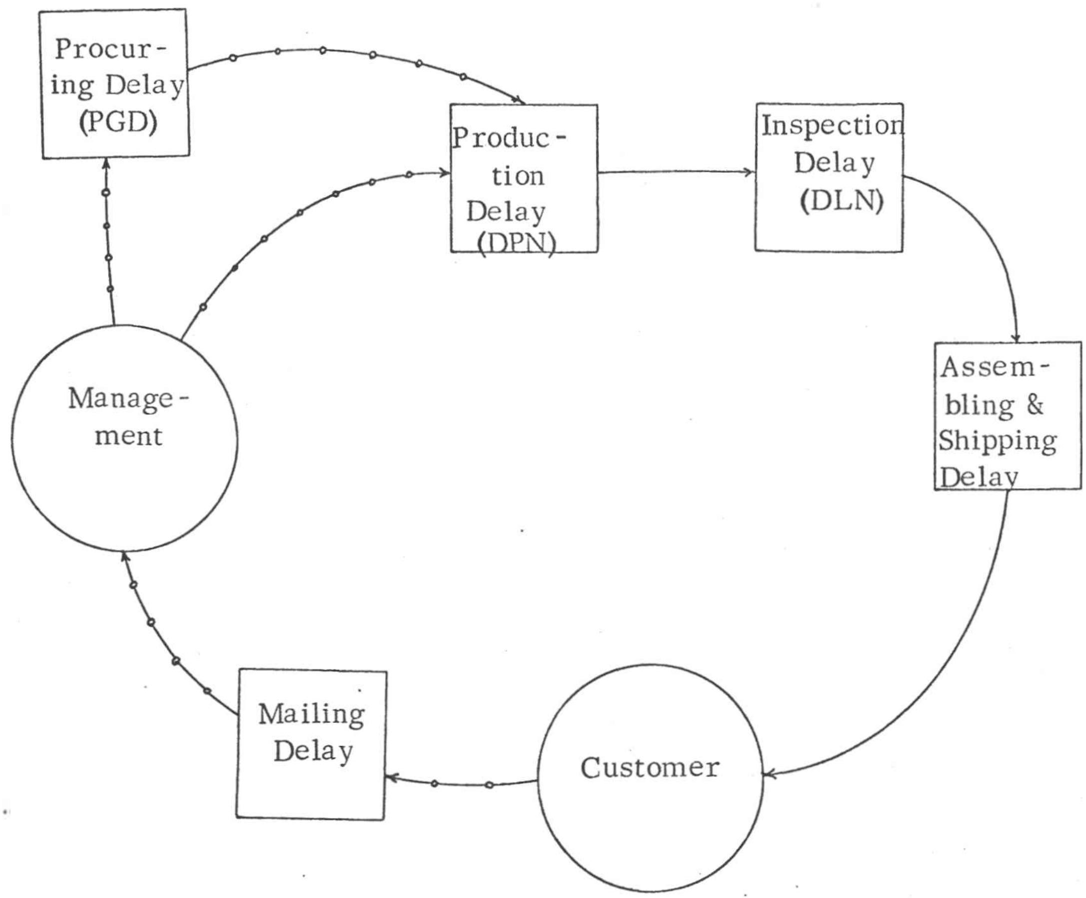


Fig. 12.--Actual delays

At normal inventory level, there will be a few parts which are out of stock. The company will take some time (DUD) in procuring and producing these parts. Thus the total delay at normal inventory level is the sum of the delay due to out-of-stock items (DUD) and minimum delay time (see Figure 13).

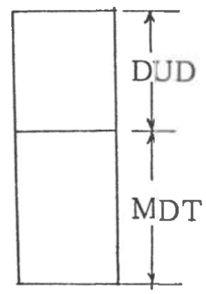


Fig. 13.--Total delay at normal inventory

When the inventory level increases, the ability to fill orders increases and the total delay decreases. When the inventory level decreases, the ability to fill orders decreases and the total delay increases. Thus, the total delay consists of the minimum delay time and a variable delay, caused by either production delay (DPN) or procuring delay (PGD) or both. The variable delay is modeled to be inversely proportional to the ability to fill orders.

$$\text{Variable delay} \propto \frac{1}{\text{Ability to fill orders}}$$

Ability to fill orders is directly proportional to the ratio of the finished goods inventory actual (FGI) to the finished goods desired (FGD):

$$\text{Ability to fill orders} \propto \frac{\text{FGI}}{\text{FGD}}$$

Thus the actual delivery time (ADT) is the sum of the minimum delay, and the variable delay, which varies inversely with the ratio FGI/FGD.

This is shown in Figure 14.[1] ADT is a customer decision parameter, and the customer continues to place orders if the ADT is within acceptable limits.

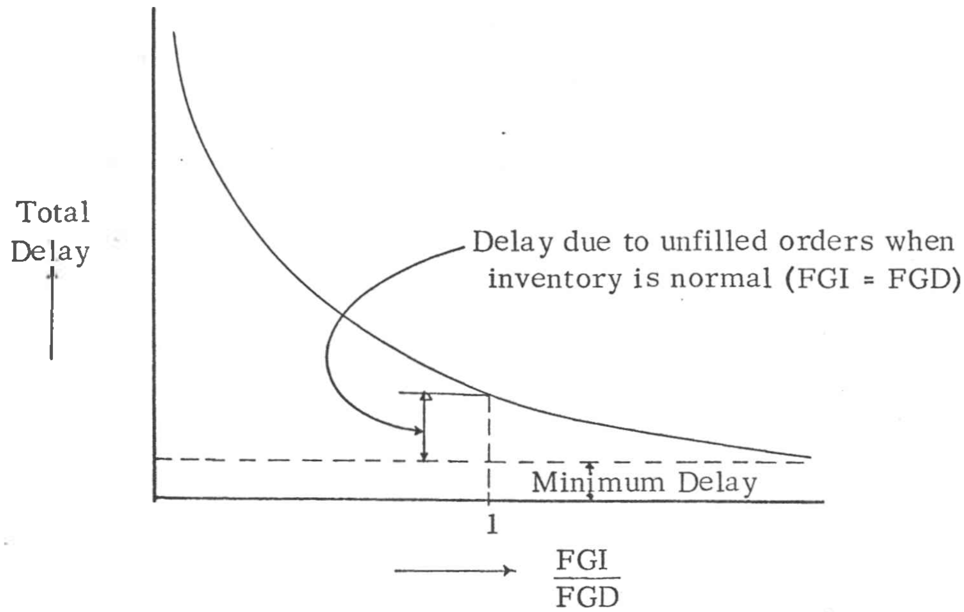


Fig. 14.--Actual delivery time

$$ADT(I) = MDT(I-1) + DUD \cdot \frac{FGD(I-1)}{FGI(I-1)}$$

ADT   Actual delivery time (time in weeks)

MDT   Minimum delay time (time in weeks)

DUD   Delay due to unfilled orders at normal inventory level (time in weeks)

FGD   Finished goods desired (units)

FGI   Finished goods inventory actual (units)

---

[1] Forrester, p. 147, Figure 15.9.

Sales Effort (SFT)

The company's sales effort consists of visiting the potential customers and indifferent customers to secure orders from them, participating in trade shows, and giving brochures.

Whenever the demand (DMD) is below the demand desired (DDD), sales effort is increased.

The incoming orders are clerically processed for the purpose of determining sales effort. This smoothing delay (SMD) is about a month.

$$SFT(I) = SFT(I-1) + \frac{DT}{SMD}(DDD(I-1) - DMD(I-1))$$

SFT Sales effort (units/week)

SMD Smoothing delay (time in weeks)

DDD Demand desired (units/week)

DMD Demand (units/week)

The demand desired (DDD) is the amount of orders that the company can meet at any time, which is the effective production capacity (EPC) available to new orders.

$$DDD(I) = EPC(I-1)$$

DDD Demand desired (units/week)

EPC Effective production capacity available to new orders

(units/week)

The After-Sales Service (AFS)

The company's AFS consists of replacing the defective items, if any, and effective follow-up after the product is supplied.

Due to lack of follow-up, customers might be lost at a rate of two to three a year. Since this is rather small, it is not incorporated in the model.

Finished Goods Desired (FGD)

The FGD is proportional to the demand accepted (DMDA). The constant CNSTI represents the number of weeks the FGD could meet the DMDA.

FGD(I) = CNSTI · DMDA (I-1)

FGD	Finished goods desired (units)
CNSTI	Number of weeks FGD could meet the DMDA (weeks)
DMDA	Demand accepted (units/week)

Finished Goods Inventory (FGI)

The company keeps a finished goods inventory consisting mostly of small parts. Only a few valve bodies are kept in finished condition, since the demand (DMD) for different size valves varies over time. The output of the inspection delay is shipments in (SIN) to the FGI. The FGI is the accumulated difference between SIN and the shipments sent from the factory (SSF). This is analogously shown as the storage of liquid in a tank in Figure 15.

Fig. 15.--Finished goods inventory

FGI(I) = FGI(I-1) + DT (SIN(I-1) - SSF(I-1))

FGI	Finished goods inventory (units)
SIN	Shipments into the FGI (SIN)
SSF	Shipments sent from the factory (SSF)

Inspection

Inspection is schematically shown in Figure 15. The input to inspection is the finished products (FPR) from the factory. Inspection is represented by a third order exponential delay. Therefore the SIN is the third order delay response of the inspection delay to FPR.

SIN(I) = DELAY3 (FPR(I-1), DLN)

SIN	Shipments into the FGI (units/week)

FPR Finished products (units/week)

DLN Delay in inspection

DELAY3
Response of a third order exponential delay of duration DLN to an input FPR

Production

Production has manufacturing orders as the input and factory production as the output. Production is also represented by a third order exponential delay (Figure 16).

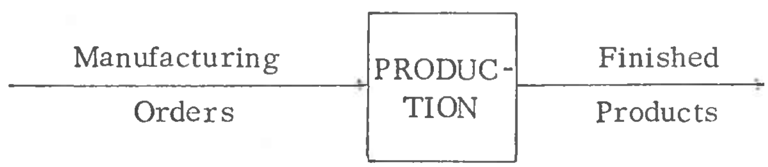


Fig. 16.--Production

FPR(I) = DELAY3 (MNO(I-1), DPN)

FPR Finished products (units/week)

MNO Manufacturing orders (units/week)

DPN Delay in production (weeks)

Manufacturing Orders (MNO)

The manufacturing order (MNO) is decided by either:

1. Manufacturing orders wanted.

2. Production capacity.

3. Available raw material that can be used for production. This is taken to be a fraction of the total raw material inventory.

The MNO is restricted by the least of the above three items.

MNO(I) = MNW(I-1) if MNW(I-1) < CA x (RMI(I-1)) and PNC(I-1)

= PNC(I-1) if PNC (I-1) < CA x (RMI(I-1)) and MNW(I-1)

= RMI(I-1) x CA if CA·RMI(I-1) < MNW(I-1) and PNC(I-1)

MNO	Manufacturing orders (units/week)
MNW	Manufacturing orders wanted (units/week)
PNC	Production capacity (units/week)
RMI	Raw material inventory (units)
CA	Constant --fraction of the RMI that can be used in production per week (1/week)

Manufacturing Orders Wanted (MNW)

Manufacturing has to:

1. Meet the demand accepted.

2. Replace inventory.

3. Adjust the excess backlog of orders.

4. Adjust the level in the pipeline.

$$MNW(I) = DMDA(I-1) + \frac{1}{IDL}\left[FGD(I-1) - FGI(I-1) + LDF(I-1) - LAF(I-1) + UDF(I-1) - UNF(I-1)\right]$$

MNW	Manufacturing orders wanted (units/week)
DMDA	Demand accepted (units/week)
IDL	Inventory adjusting delay (weeks)
FGD	Finished goods inventory desired (units)
FGI	Finished goods inventory actual (units)
LDF	Pipe-line orders desired at factory (units)
LAF	Pipe-line orders actually at factory (units)
UOF	Unfilled orders at factory (units)
UNF	Unfilled orders normal at factory (units)

Corresponding to the demand accepted (DMDA), there is a certain level of orders desired in production and inspection. This is the level which can meet the DMDA for a time equal to the sum of production and inspection delays.

$$LDF(I) = DMDA(I-1)\left[DPN + DLN\right]$$

LDF Pipe-line orders desired at factory (units)

DMDA Demand accepted (units/week)

DPN Delay in production (weeks)

DLN Delay in inspection (weeks)

Actual level of orders in the pipe-line is the sum of orders in production and inspection.

LAF(I) = OPF(I-1) + ONF(I-1)

LAF Pipe-line orders actually at factory (units)

OPF Orders in production at factory (units)

ONF Orders in inspection at factory (units)

Orders in production are the accumulated difference between the manufacturing orders (MNO) and factory production (FPR) (see Figure 17).

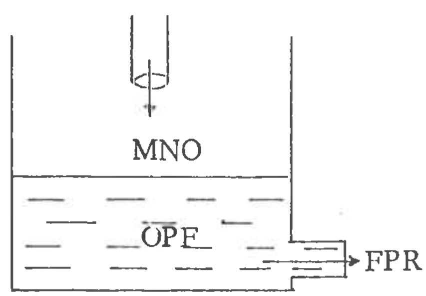


Fig. 17.--Order level in production

OPF(I) = OPF(I-1) - DT (MNO(I-1) - FPR(I-1))

OPF Orders in production at factory (units)

MNO Manufacturing orders (units/week)

FPR Factory Production (units/week)

Orders in inspection (ONF) are similarly the accumulated difference between the factory production (FPR) and the inflow into the finished goods inventory (SIN)

ONF(I) = ONF(I-1) - DT FPR (I-1) - SIN(I-1)

ONF Orders in inspection at factory (units)

FPR Factory production (units/week)

SIN Shipments coming into the finished goods inventory (units/week)

Unfilled Orders (UOF)

Unfilled orders (UOF) are the backlog of orders. This is a level, and it has as its input the demand accepted, and as its output the shipments sent from the factory.

UOF(I) = UOF(I-1) - DT DMDA(I-1) - SSF(I-1)

UOF Unfilled orders at factory (units)

DMDA Demand accepted (units/week)

SSF Shipment sent from the factory (units)

There is a permissible level of backlog of orders. This corresponds to the unfilled orders at normal inventory at the factory.

UNF(I) = DMDA(I-1) [MDT + DUD]

UNF Unfilled orders at normal inventory at factory (units)

DMDA Demand accepted (units/week)

MDT Minimum delay time (weeks)

DUD Delay due to unfilled orders at normal inventory level (weeks)

Shipments Sent from Factory (SSF)

There is a certain shipping rate desired which aims at filling up all the unfilled orders in the actual delivery time. This shipping rate desired (SRD) is given by the unfilled orders divided by the actual delivery time.

However, there is a maximum rate of shipping possible, which depends upon the finished goods inventory level. This maximum shipping rate possible (NIF) is given by the finished goods inventory divided by DT--the solution interval.

$$SSF(I) = SRD(I-1) \text{ if } SRD(I-1) < NIF(I-1)$$

$$= NIF(I-1) \text{ if } NIF(I-1) < SRD(I-1)$$

$$SRD(I) = \frac{UOF(I-1)}{ADT(I-1)}$$

$$NIF(I) = \frac{FGI(I-1)}{DT}$$

SSF Shipments sent from factory (units/week)

SRD Shipping rate desired (units/week)

NIF Negative inventory limit at factory (units/week)

UOF Unfilled orders at factory (units)

ADT Actual delivery time (weeks)

Demand Accepted (DMDA)

The demand placed on the company is clerically processed, and the plausibility of meeting the demand requirements is checked before accepting an order.

$$DMDA(I) = DSF(I-1) \text{ if } DSF(I-1) < EPC(I-1)$$

$$= EPC(I-1) \text{ if } EPC(I-1) < DSF(I-1)$$

DMDA Demand accepted (units/week)

DSF Demand smoothed at factory (units/week)

EPC Effective production capacity (units/week)

$$DSF(I) = DSF(I-1) + \frac{DT}{DSD}\left[DMD(I-1) - DSF(I-1)\right]$$

DSF Demand smoothed at factory (units/week)

DSD Delay in smoothing demand (weeks)

DMD Demand (units/week)

A certain percentage of the production capacity is reserved for filling the excess of backlog of orders (the difference between the unfilled orders actual--UOF--and the unfilled orders normal--UNF). The excess backlog has to be filled in the required delivery time (RDT). Therefore, the production capacity to be reserved for this is given by the excess backlog of orders divided by the required delivery time.

The effective production capacity available to new orders is the difference between the production capacity (PNC) and the capacity reserved for filling the excess backlog of orders. This is shown in Figure 18.

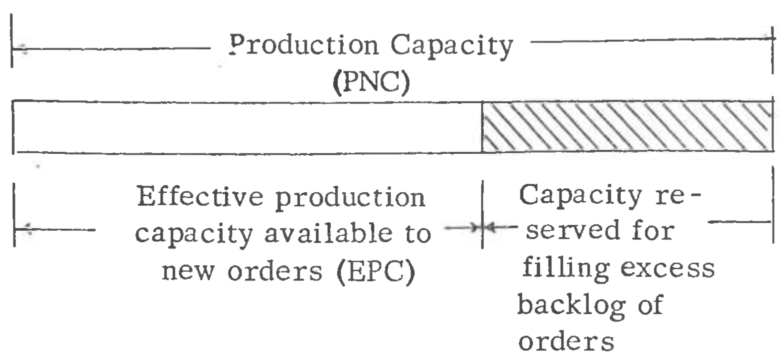


Fig. 18.--The effective production capacity available to new orders

$$EPC(I-1) = PNC(I-1) - [UOF(I-1) - UNF(I-1)] / RDT$$

EPC Effective production capacity (units/week)

PNC Production capacity (units/week)

UOF Unfilled orders at factory (units)

UNF Unfilled orders normal at factory (units)

RDT Required delivery time (weeks)

Raw Material Inventory (RMI)

Raw material inventory is a level which has its input as shipments from the supplier (RIN) and output as shipments going to production (ROT) (see Figure 19).

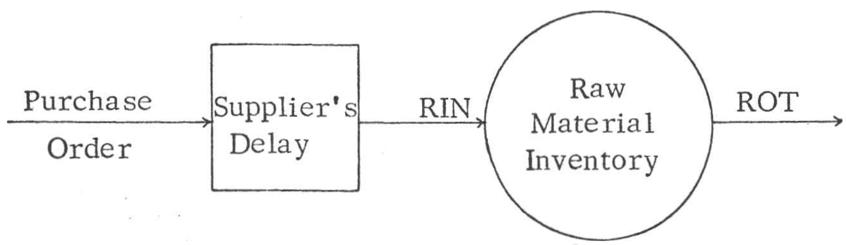


Fig. 19.--Raw material inventory

$$RMI(I) = RMI(I-1) + DT \cdot (RIN(I-1) - ROT(I-1))$$

RMI Raw material inventory (units)

RIN Raw material input (units/week)

ROT Raw material output (units/week)

The shipments out of the raw material inventory (ROT) are directly proportional to the manufacturing orders.

ROT(I) = CA · MNO(I-1)

ROT	Shipments out of raw material inventory (units/week)
MNO	Manufacturing orders (units/week)
CA	Constant

Suppliers' delay (SDL) is represented by a third order exponential delay. The input to the raw material inventory is the response of this delay to the purchase order (PDR).

RIN(I) = DELAY3 (PDR(I-1), SDL)

PDR	Purchase order (units/week)
RIN	Raw material input (units/week)
SDL	Supplier's delay (weeks)
DELAY3	Third order exponential delay

Purchase Order (PDR)

The company places a purchase order (PDR) so that it can meet the manufacturing rate wanted (MNW) and also can adjust the difference between the raw material inventory desired (RMD) and the raw material actual (RMI) as well as the difference between raw material in pipe-line desired (RLD) and raw material in pipe-line actual (RLA) in the smoothing delay time (SMD). The increment in purchase orders due to these differences is given by the sum of these differences divided by the smoothing delay.

This increment when added to a constant (CA times MNW) at the previous time stage gives the value of the purchase order (PDR) at the new time stage.

$$PDR(I) = CA \cdot MNW(I-1) + \frac{1}{SMD}\left[RMD(I-1) - RMI(I-1) + RLD(I-1) - RLA(I-1)\right]$$

MNW	Manufacturing wanted (units/week)
PDR	Purchase order (units/week)
SMD	Smoothing delay (weeks)
RMD	Raw material inventory desired (units)
RMI	Raw material inventory actual (units)
RLD	Raw material in Pipe-line desired (units)
CA	Constant

Raw material desired is proportional to the demand accepted (DMDA).

$RMD(I) = CNSTP \cdot DMDA(I-1)$

RMD Raw material desired (units)

CNSTP Number of weeks that the desired raw material could meet the demand accepted (weeks)

The raw material in pipe-line desired (RLD) is equal to the purchase order (PDR) multiplied by the supplier's delay (SDL).

$RLD(I) = SDL \cdot PDR(I-1)$

RLD Raw material in pipe-line desired (units)

SDL Supplier's delay (weeks)

PDR Purchase order (units/week)

The raw material in pipe-line actual is a level. It has the purchase order (PDR) as its input and the raw material input (RIN) as its output.

$RLA(I) = RLA(I-1) + DT \cdot (PDR(I-1) - RIN(I-1))$

RLA Raw material in pipe-line actual (units)

PDR Purchase order (units/week)

RIN Raw material input (units/week)

CHAPTER IV

SIMULATION AND RESULTS

The equations in Chapter 3 were Fortran-coded and a computer program was developed.[1]

The various parameters of the model were adjusted to represent the company's performance from April, 1968, to October, 1969. The values of the parameters given by the company accounts are shown by the asterisk mark in Figure 20. The model then is presumed to represent the company, and is used to predict the performance in the future (about two and one-half years). Admittedly, this is not a very long time over which to verify model performance, nor is the agreement precise. However, it gives a qualitative assurance that parameters are in the right order of magnitude.

The performance of the model is limited by production capacity (PNC). Increasing the PNC is suggested as a remedy. The model is used to study the changes that might be brought about in the model's performance as a result of the increased PNC.

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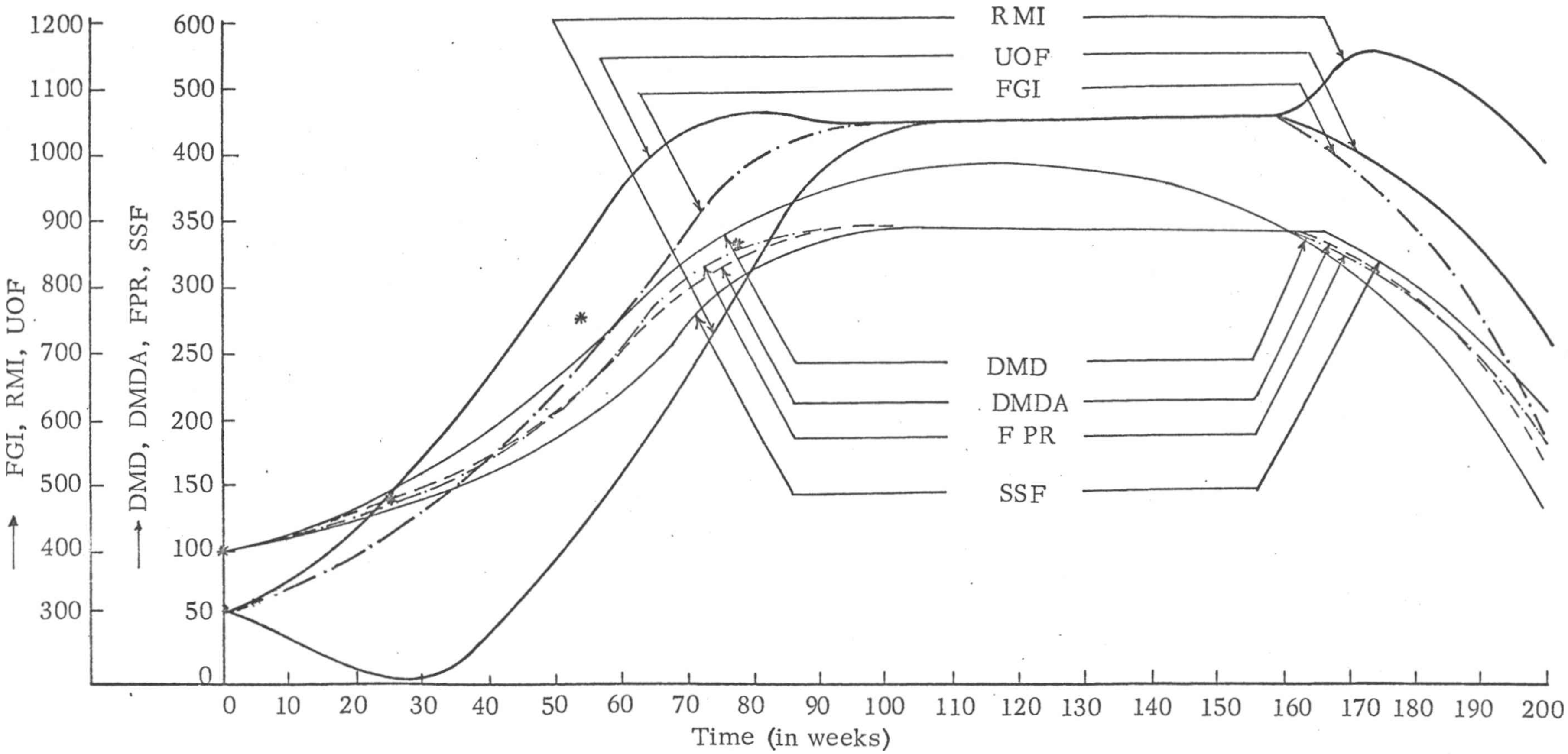
[1]The program is not appended with the thesis. It is available in the Mechanical Engineering Department, Brigham Young University, Provo, Utah.



DMD - Demand DMDA - Demand accepted FPR - Factory production SSF - Shipments sent from factory
FGI - Finished goods inventory RMI - Raw material inventory UOF - Unfilled orders at factory
*Actual performance figures (FPR)

Fig. 20.-- Model's performance with the present PNC and steadily falling PQR

The model shows that though the installed capacity of the company is doubled, the sales may not increase unless proper attention is paid to improve the product quality of the company (PQC). Research and development may improve the PQC. The model is used to predict the improvement made in performance because of the research and development work (RDW).

Prediction of the Model's Performance

The model is used to predict the performance during the next 122 weeks (about two and one-half years). The simulated results are shown in Figure 20.

The demand (DMD) increases and reaches its peak (400 per cent) during the 120th week, and then gradually drops to 155 percent during the 200th week. The DMD falls below the production capacity (PNC) during the period from the 160th to 200th weeks. The fall in the DMD is due to the PQR resulting from a steadily growing average product quality in the market (PQM) and a rather stagnant PQC.

The demand accepted (DMDA) is about the same as the DMD, but for the period between the 80th and 100th weeks, when the DMD exceeds the DNC. During this period the DMDA is about the same as the PNC.

The production, in this case, is limited by PNC. Therefore, in accordance with the policy of accepting only the orders which can be met, the model limits the DMDA to its PNC.

The factory production (FPR) and the shipments sent from the factory (SSF) almost closely follow the DMDA, since these are the responses of the latter.

The finished goods inventory (FGI) adjusts slowly to the increase in DMD. It reaches its peak during the 100th week and remains at this level until the 160th week, when it begins to drop.

The FGI increases when the FPR increases with respect to SSF and vice versa, since the input of the FGI is the response to the FPR and the output of the FGI is SSF. During the period between the 100th and 160th weeks the FPR and the SSF are equal, resulting in a constant level of the FGI.

The raw material inventory (RMI) initially drops to 66 per cent, due to the increased factory production (FPR). It then increases gradually, as a result of the purchasing orders placed on suppliers, to a maximum during the 120th week. The RMI continues to increase even when the DMDA drops, because of the reduction in the FPR, while the raw material input continues at the previous rate, as a result of past purchase orders. Thus it attains a peak (387 per cent) during the 170th week and then drops very rapidly.

The unfilled orders at the factory (UOF) increases as the DMDA increases, and attains its maximum value during the 80th week, and remains at this level until the 160th week. Thereafter, it falls rapidly to reach 140 per cent of its initial value during the 200th week.

The UOF is the accumulated difference between the DMDA and the SSF. When the DMDA increases relative to the SSF, UOF increases, and it decreases when the DMDA decreases with respect to the SSF. Initially the DMDA increases faster than the SSF; hence, the UOF increases. Between the 80th and 160th weeks the DMDA and the SSF are equal, resulting in a constant level of the UOF. After the 160th week, the DMDA falls faster than the SSF and the UOF decreases rapidly after the 160th week.

Model's Performance When the Production Capacity Is Doubled

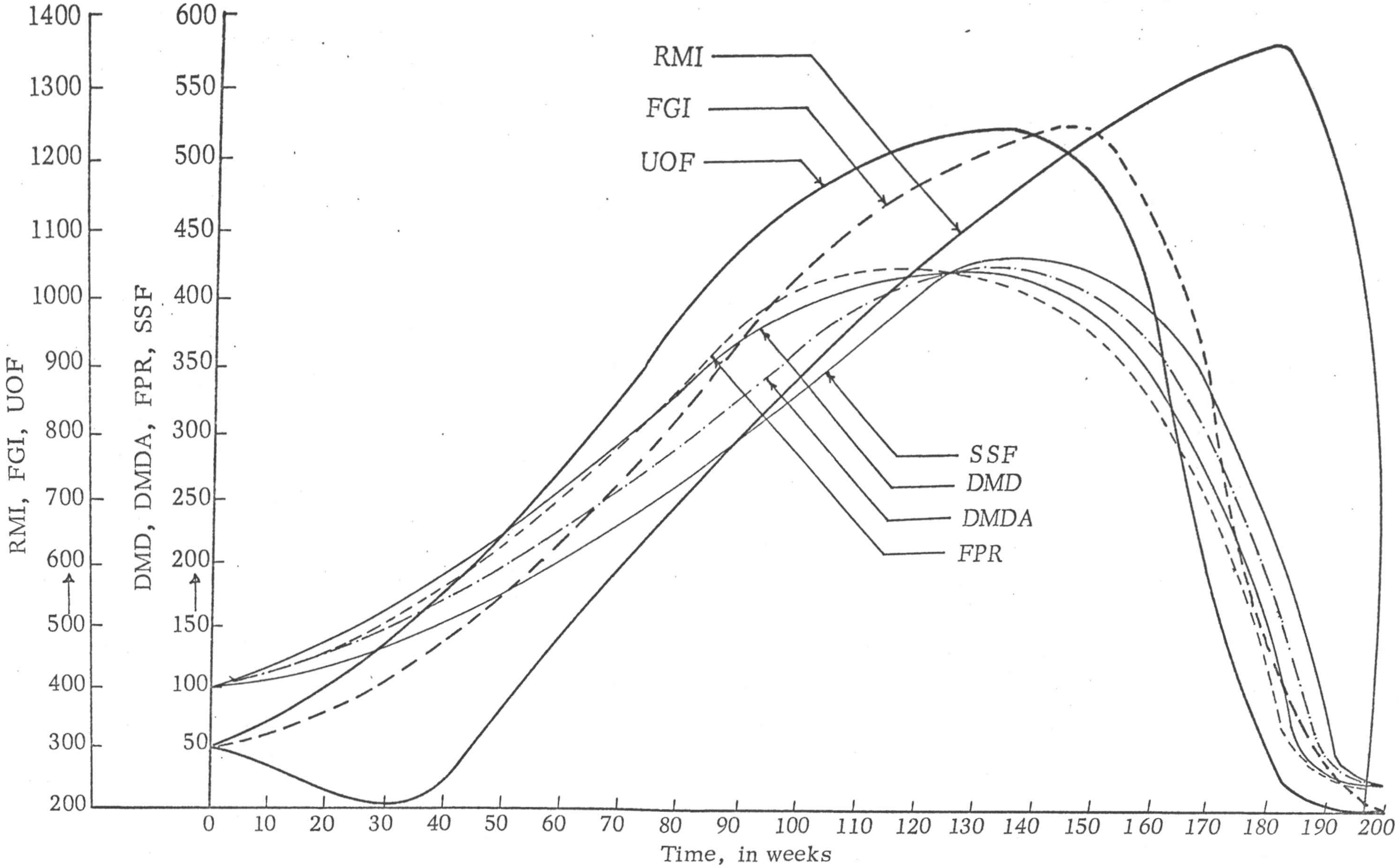
The results of the simulation when the production capacity (PNC) is doubled are shown in Figure 21.

The model's performance in this case is similar to the one when there is no change in the PNC, except that the model's performance is not levelling off during the period between the 80th and 160th weeks in this case. When the PNC is doubled, the demand accepted (DMDA) is no longer limited by the PNC as it is when the PNC remains at the old rate. In this case, the model is able to meet all the orders placed on it. Thus the DMDA is equal to the demand (DMD).

The shipments sent from the factory (SSF) and the factory production (FPR) follow the DMD, as they are the responses to the DMDA.

The finished goods inventory (FGI) increases as the FPR increases and reaches its peak during the 120th week. It then drops in response to the decline in DMD.

The raw material inventory (RMI) drops initially to 66 per cent during the 20th week, as a result of the increased FPR. As the DMD continues



RMI - Raw material inventory FGI - Finished goods inventory UOF - Unfilled orders at factory
DMD - Demand DMDA - Demand accepted FPR - Factory production SSF - Shipments sent from factory

Fig. 21.-- Model's performance with doubled production capacity and steadily falling PQR

to increase, the RMI builds up because of the increased purchase of raw materials. The RMI continues to increase even when the DMD falls, because of the continued raw material input (RIN) at the old rate as a result of the past purchase orders, while the FPR decreases. After the 134th week the RMI drops because of the decreased purchasing.

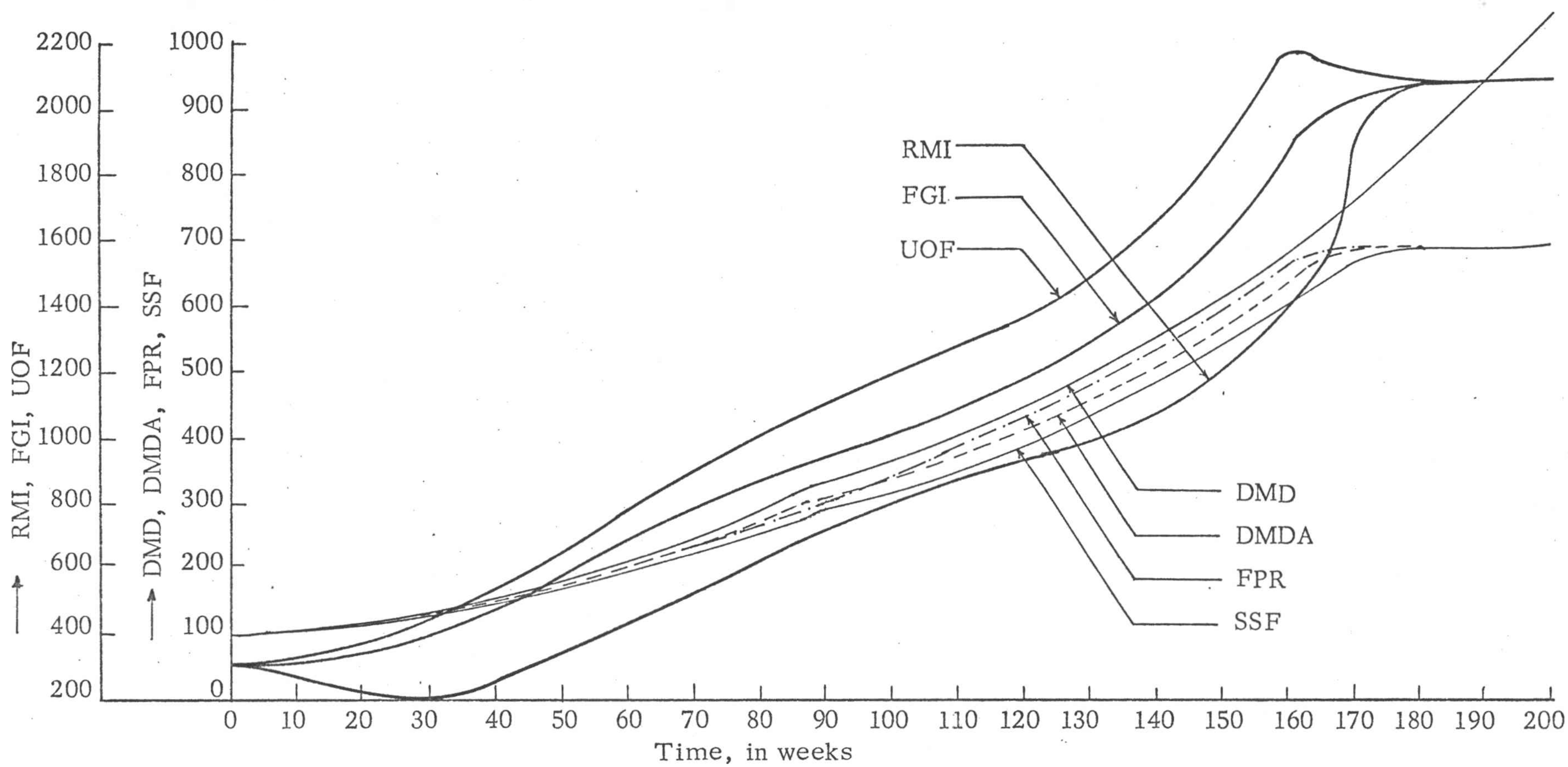
The unfilled orders (UOF) increases as the DMD increases with respect to the shipments sent from the factory (SSF) and then decreases rapidly because the DMD decreases with respect to the SSF.

Effect of Research and Development Work

As evidenced by the discussion in the previous section, and Figure 21, the model's performance is not commensurate with the increased production capacity (PNC). The model's performance declines after the 134th week because the company's product quality (PQC) is less than the average product quality of the market (PQM). Research and development work is suggested as a measure to improve the product quality of the company (PQC).

The model is used to predict the effect of the research and development work (RDW) on performance.

The PQC is assumed to vary exponentially with the quality index (QIX), which is taken to be a third order exponential delay response to the RDW. The RDW is taken to be done at a rate of 10 per cent of the sales.



RMI - Raw material inventory
FGI - Finished goods inventory
UOF - Unfilled orders at factory

DMD - Demand
DMDA - Demand accepted
FPR - Factory production
SSF - Shipments sent from factory

Fig. 22.-- Model's performance with research and development added to the doubled production capacity

PQC(I) = EXP (QIX(I-1))

QIX(I) = DELAY 3 (RDW(I-1), DLR)

RDW(I) = (0.1 SSF) / CA

PQC	Product quality of the company (non-dimensional)
QIX	Quality index (non-dimensional)
RDW	Research and development work (units/week)
SSF	Shipments sent from factory (units/week)
DLR	Delay for research and development (weeks)
CA	RDW necessary to make QIX = 1 (units/week)

The effect of RDW on the model's performance is shown in Figure 22.

The RDW improves the PQC in time. This increased PQC keeps more customers satisfied. Thus the level of the permanently satisfied customers (PSFC) increases, which in turn results in more demand (DMD).

The DMD increases steadily to reach the PNC during the 160th week. Though the DMD still increases thereafter, the model is not able to accept all the orders due to the limited PNC. Therefore, after the 160th week the demand accepted (DMDA) remains at the steady state of the PNC, which is equal to 700 units/week.

The factory production (FPR) and the shipments sent from the factory (SSF) follow the DMDA.

The raw material and the finished goods inventories build up to meet the increased DMDA and retain constant levels as the DMDA attains the steady state.

The unfilled orders at the factory (UOF) increases initially as the DMDA increases with respect to the SSF and then retains a constant value as the SSF becomes equal to the DMDA.

Comments

The first and second simulations are plagued by the relatively stagnant product quality of the company (PQC), compared to the steadily growing average product quality in the market (PQM). In the third simulation the research and development work starts during the 78th week. Its effect is brought to bear on the product quality of the company (PQC) only during the 110th week, because of the natural delay that the RDW takes to bring forth any fruitful results.

In the second simulation the fall in the model's performance is faster than that in the first. The model's production capacity (PNC) is double that of the first simulation. Consequently, the model has more customers, and the model's performance is more sensitive to the drop in the PQR. Therefore, the company should be more careful in guarding itself against major pitfalls, as it grows in size.

A policy of improving the product quality of the company (PQC) along with increasing the production capacity would help the model achieve its objective of attaining steady growth.

CHAPTER V

CONCLUSIONS

The preceding analyses show how to build a model and design a set of policies based on model performance to achieve the desired growth of the company. The model shows that merely increasing the production capacity (PNC) does not help in attaining a steady growth. Research and development work (RDW) coupled with the PNC would result in more production and better quality, which triggers more demand (DMD).

The dynamic model sheds light on the working of the company. It gives insight into the effect of the management policies. Man can intuitively see things which are very near only, when a limited number (one or two) of parameters change. But business is an interplay of numerous parameters, which, when they interact, produce results which are beyond human judging power. The model is used to predict the changes in the company's performance brought about by the parameter changes.

As time goes on, the predicted performance can be compared with the actual performance. The closeness of the predicted behavior to the actual behavior is a measure of the validity of the model.

The deviation between the predicted and actual performances should be critically analyzed, and parameters adjusted to close the gap.

This procedure would help to evolve a model which would represent the company more and more closely as time passes on.

The author attempted to incorporate all the major facets of this business. An extensive study could not be devoted to any one sector without producing a model of unreasonable size. Now that the preliminary work for the overall case is done, future investigations can be concentrated on a particular sector with a better understanding of the dynamic interaction with the external factors.

The cash flow is not incorporated in the model since sufficient data are not available. However, this is an important factor, and investing money in some areas would affect the company's operations in other areas. Hence, a more realistic model should take the cash flow into account. The general procedure of model building can, however, be extended to incorporate this link.

Some gross approximations have been made about the market. For better representation, more detailed data are necessary which at present are not available. The market is quite complex and deserves study in itself.

Time lags and other constants are not exact, but depict the general nature of the parameters.

One of the most powerful tools in solving managerial optimization problems is linear - programming. This assumes that the effect of the changes in parameters is directly proportional to the changes in parameters themselves. However, this assumption is valid only for a few parameters.

Most of the parameters in business are characterized by non-linear behavior. Dynamic modelling, as is presented in this study, is an aid in the study of the non-linear behavior of the parameters of business enterprises.

A model is not a panacea to the ills of business enterprises. It is no better than the premises on which it is based.

A model is no substitute for efficient management. But it is a powerful tool which can help management in decision making.

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A DYNAMIC MODEL OF A SMALL MANUFACTURING COMPANY

Abraham John

Department of Mechanical Engineering

M. S. Degree, August 1970

ABSTRACT

A dynamic model of Valtek Incorporated, Provo, Utah, was developed. The dynamic model shows the time-varying performance of the company and was used as a basis for designing policy decisions.

A gross flow diagram of the company was developed in consultation with the company's management. A set of mathematical equations representing the company's policies, actions, and their interrelationships was developed, and these relationships were appropriately Fortran-coded and simulated on a digital computer. The effect of increasing the production capacity and starting research and development work was studied using the model.

The model showed that in order to achieve steady growth, while increasing the production capacity, proper attention should be paid to research and development.

COMMITTEE APPROVAL: