DYNAMICS OF PRODUCT GROWTH
IN A COMPETITIVE MARKET

by

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Signature of Author

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Certified by

Faculty Advisor of the Thesis
June 12, 1963

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

Dear Professor Franklin:

In accordance with the requirements for graduation, I herewith submit a thesis entitled "Dynamics of Product Growth in a Competitive Market."

I should like to take this opportunity to express my gratitude to Professor Jay W. Forrester for his assistance throughout this study. His suggestions, comments, and observations were most stimulating.

The work done in this thesis is based in part upon several previous studies by Ole C. Nord and Carl V. Swanson. Their work and their suggestions have been most valuable in the preparation of this document.

To Mrs. Jean Lewellen, Miss Joan Surprenant, and Miss Virginia Chapin, I wish to express my thanks for the typing of the final manuscript.

This work was done in part at the Massachusetts Institute of Technology Computation Center.

Sincerely yours,

Richard F. Miller, Jr.
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Richard Fowler Miller, Jr.

Submitted to the School of Industrial Management on June 12, 1963, in partial fulfillment of the requirements for the degree of Master of Science.

ABSTRACT

This study is concerned with certain problems of the growth of new products, and it suggests possible solutions for them. Very often when a new product is introduced and gains rapid acceptance, the firm which first brought out the product is unable to retain a dominant share of the market. This occurs even when the quality and price of the innovative firm's product are equal, or superior, to the quality and price of the competition. Throughout this period of loss of market share, the innovative firm finds the accuracy of demand forecasts excellent, but the accuracy of the forecasts suddenly deteriorates near the end of the growth phase. Overcapacity and price crashes are frequent occurrences as growth ceases.

The first phase of the study involves the formulation of a hypothesis of the system structure which causes this over-all behavior. In the second phase, this hypothesis is translated into a precise mathematical description of the relationships between the variables. Simulations of this mathematical model are analyzed in the third phase. The way in which the system structure and policies of the competing firms interact to cause the previously mentioned problems is discussed, and the effects of certain changes in system parameters are described. The fourth and final phase of the study involves the design and testing of new policies for eliminating many of the undesirable elements of behavior.

The growth of new products tends to be exponential until the demand is very close to saturation because an increase in the order rate leads to increases in marketing effort and the number of customers available to mention the product to still other customers. Firms frequently fail to keep up with demand in the early stages of
growth, and the delivery time goes up. The poor deliveries cause some customers to find substitute products; and because the production capacity is purchased on the basis of observed demand, too little is ordered to satisfy the entire market. Forecasts will tend to be self-justifying. If orders start to increase above production capacity, delivery delay increases further and discourages enough customers to bring the order rate back in line with capacity; if orders fall below capacity, delivery delay falls, and some customers who had been buying elsewhere shift back to the innovative firm. Meanwhile, the high delivery delay serves as an indication to competition that there is room in the market, and competitors begin to offer the product. It is easy for competition to gain customers by offering more rapid delivery, and they may also be willing to cut price to gain business. Finally, as the market approaches saturation, the firms extrapolate the exponential growth rate too far and suddenly find themselves with overcapacity. Overcapacity creates strong pressures to lower price, and this often snowballs into a price crash.

Some of the results of the study indicate that the innovative firm can increase its chances of success by explicitly considering the effects of delivery delay in deciding on the amount of production capacity to be ordered. Behavior is also improved, again from the viewpoint of the innovator, if price is used to keep orders in line with capacity instead of allowing delivery delay to serve this function.

Thesis Advisor: Jay W. Forrester
Title: Professor of Industrial Management
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CHAPTER 1

Introduction

This chapter presents some of the questions which make product growth an interesting and important area of study. The history of the efforts preceding this study is related, and the techniques used—industrial dynamics and DYNAMO—are described briefly.

1.1 Problems of Product Growth

Each year thousands of new products are introduced to the market. Some are never accepted and are withdrawn after a period of disappointing and unprofitable sales. Others are accepted and follow a multitude of growth patterns. The demand for some products grows slowly and steadily for many years; other products grow at tremendous rates, sometimes remaining popular for years after reaching saturation and sometimes disappearing as rapidly as they grew.

This study deals with products which grow successfully and exhibit a period of stable demand after reaching maturity. It treats only the growth phase of the product life cycle—growth, maturity, and decline. The product is a hypothetical one of the general class of industrial components. The system structure should be valid for the majority of products which are small components in larger systems, but because parameter values must be chosen for the model, it is convenient to think of a more specific class of products. Electronic components, such as diodes, transistors, capacitors, and inductors, have been chosen. Some of the system structure and parameter values
are based loosely upon the solid tantalum capacitor market, but this market served only as a source of ideas. No attempt was made to model it exactly.

The factors which affect product growth are not well understood. For example, one can read many arguments for and against various pricing policies for new products. The arguments are often well thought out and clearly stated, but there is a limit to insight which human understanding and the presently available analytic tools can give in large, complex, nonlinear systems of the type surrounding product growth. The arguments nearly always fail to even try to explain why the growth of some products is marked by great stability of price, while others show extremely erratic behavior, and still others are hit with dramatic and damaging price crashes upon the entry into maturity.

Occasionally, a firm will introduce a product as the sole supplier and will retain this position throughout a long and profitable product life. More often, the success of the product seems to draw many competitors, and the innovative firm retains only a small share of the market at maturity, even though the firm may have expanded its sales many times during the growth period. These differences in behavior can sometimes be attributed to patent protection in the first case, but are usually attributed to some sort of technological monopoly. It is questionable, however, if any technological monopoly could long exist if potential competitors saw real profits to be gained from breaking it.

These are several of the questions regarding product growth for
which adequate explanations do not exist. The hypothesis taken in this study is that these different modes of behavior are the result of the interactions between the policies, both explicit and implicit, of the firms in the market and the characteristics of the market. A dynamic model has been constructed which exhibits these different kinds of behavior and makes possible an understanding of their causes.

1.2 History and Relation to Other Work

Industrial dynamics research on product growth was initiated in a graduate student research seminar at the M.I.T. School of Industrial Management in the spring term of 1961. This seminar was led by Professor Jay W. Forrester.

Since that time, research in the area has continued at M.I.T. in the Industrial Dynamics Group. Ole C. Nord has written a Master of Science thesis\(^1\) considering product growth from the position of the aggregate industry, and Nord and Carl V. Swanson wrote an internal memorandum\(^2\) describing a simplified version of the same system and devising improved policies for the system. A research monograph\(^3\)


combining the results of both of these works is in the process of publication by Nord and should be available in 1963.

Much of the basic structure of the system described in the following chapters evolved from this previous work. The first of the two improved policies discussed in Section 4.3 was developed to a state of partial completion in the memorandum by Nord and Swanson⁴, and was further improved to the form used in this document by Nord for the research monograph on capacity acquisition policies.⁵

The contribution of this document beyond that of the preceding work is the investigation of the effects of price and competition on growth behavior. Price was not treated as a variable in the studies mentioned, and the industry was treated in an aggregated form with all firms using the same policies and behaving in the same way.⁶ Price and competition add new dimensions to the understanding of the growth process.

1.3 Industrial Dynamics and DYNAMO

The approach taken in this study is that of industrial dynamics.⁷ Industrial dynamics is both a philosophy and a methodology for analyzing

⁴Nord and Swanson, op. cit.

⁵Nord, Growth of a New Product—Effects of Capacity Acquisition Policies, op. cit.

⁶Alternatively, the studies could be viewed as being of a single firm facing competition which never changes in size or behavior.

industrial problems and improving the managerial policies of industrial and economic enterprises. It views the policies and decisions of management as parts of an information-feedback system involving the enterprise and its environment. The structure of the system, of which these policies and decisions are elements, determines the behavior of the system variables and therefore determines the success of the enterprise in meeting its objectives. Because the actions of management are linked by the information-feedback characteristics of the system, they are not independent of each other and their interaction must be considered. The approach usually involves the building of a model which establishes precise mathematical relationships between the variables and simulating real world behavior with the model through the use of high-speed digital computers.

DYNAMO[^] is a computer program which provides a convenient means of preparing the model for simulation on the computer. Equations are written in a simple form which can be quickly learned even by one with no experience in the use of computers. The program takes these equations and puts them in a form usable in the computer. It checks the model for errors and finally produces data in convenient tabular and plotted form.

To explain in detail industrial dynamics or the DYNAMO program would involve far more space than could reasonably be allotted here. It will be assumed that the reader is already familiar with the

approach and techniques. If this familiarity does not exist, the reader is advised to go to the references in footnotes 7 and 8 for more detail. However, only Chapter 3 of this thesis requires great familiarity with the details of the techniques, and the remaining chapters should be readable without it.
CHAPTER 2

A Hypothesis of the Dynamic Behavior of the System

Presented in this chapter is a general description of product growth and a discussion of certain factors which influence growth behavior. The manner in which corporate policies concerning price and the acquisition of production capacity influence produce growth and how these policies can influence the entry of competition and the success of the innovative firm in maintaining its market share\(^1\) are also examined. This will be done first by tracing through a time history which might be typical of many products, and later by examining the most important feedback loops in the system to determine how the characteristics of these loops influence the behavior.

This chapter introduces the feedback nature of growth -- the system of cause-and-effect relationships interacting to control the pattern of behavior of the market and producing firms. It serves an additional function, also, for some hypothesis of the variables and relationships which are important determinants of the behavior is necessary in order to proceed to the building of a model. Without such a hypothesis, important and unimportant variables cannot be distinguished; and the risk of excluding key factors or of building needless, confusing complexity into the model is great.

\(^1\)This is not to imply that it is always to a firm's best interests to seek the largest possible share. Overemphasis of market share can prove detrimental to a firm's position, in both the long and the short run.
2.1 A Time-History of Product Growth

Figure 2-1 indicates the relationships between the important concepts for a simple system surrounding product growth.

![Diagram showing the cycle of potential customers, awareness of market to product, customers using product, observed use of product, orders, and other influences (price, delivery).]

Figure 2-1. Concepts Involved in Simple System Surrounding Product Growth
The inherent quality and usefulness of a product determine the number of potential customers. Introductory marketing effort\(^2\) by the innovator carries information to the market, and brings some of the potential customers to an awareness of the product. A few of the more perceptive customers recognize its potential and begin to develop uses within their organizations. After a delay for developing such uses\(^3\), orders are placed and subsequently filled. At this point, knowledge of the product may begin to spread by direct observation of its use, by word of mouth, or through trade journals, etc. The orders would also be expected to stimulate increased marketing efforts on the part of the innovator. These parallel flows to information further increase the awareness of the product, more of the potential customers begin to develop uses, and growth continues.

Simplifying the process by neglecting for a moment the other influences on orders, we can explain the common pattern of product growth sketched in Figure 2-2. In Region A, few firms are aware of the product. Those who are aware of it are learning to use it and making preparations for future use, and it is not yet being used so that its qualities can be readily observed by potential customers. Region B is frequently characterized by exponential growth

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\(^2\)This may consist of nothing more than allowing information that the product exists to leak out to the market, or it may involve a major promotional campaign. The only assumption made here is that the amount is small compared to the amount that would be required to make the entire market aware of the product.

\(^3\)This delay could be very different for different products, and might be quite long if the product is a major innovation.
The inherent quality and usefulness of a product determine the number of potential customers. Introductory marketing effort\textsuperscript{2} by the innovator carries information to the market, and brings some of the potential customers to an awareness of the product. A few of the more perceptive customers recognize its potential and begin to develop uses within their organizations. After a delay for developing such uses\textsuperscript{3}, orders are placed and subsequently filled. At this point, knowledge of the product may begin to spread by direct observation of its use, by word of mouth, or through trade journals, etc. The orders would also be expected to stimulate increased marketing efforts on the part of the innovator. These parallel flows to information further increase the awareness of the product, more of the potential customers begin to develop uses, and growth continues.

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\textsuperscript{3}This delay could be very different for different products, and might be quite long if the product is a major innovation.
rates. Orders and use stimulate market development efforts and offer wider exposure for the product; the resulting increases in orders create a situation of positive feedback. By the beginning of Region C, the number of potential customers not yet using the product has diminished to a small fraction of the original and becomes the controlling factor as saturation is reached.

Figure 2-3 is a sketch of the important interactions in the complete system under study. Included are the price, delivery delay, capacity acquisition, and competition entry loops. These loops affect the "ideal" growth pattern (Figure 2-2) characteristic of the simple loop.

As the order rate increases, the average order rate follows, and the order backlog begins to grow. As long as the production rate can remain abreast of the order rate, the delivery delay de-
Figure 2-3. The Important Loops in the System under Investigation
pends only upon the delays in processing, handling, and shipping an order, but should the order rate increase more rapidly than the production capacity is expanded, the production rate becomes limited by the available capacity. Under such circumstances the backlog of unfilled orders grows rapidly, and the delivery delay increases.

This is a result of the delay for receiving capacity and the policies commonly found in capacity expansion. The delay between ordering new production capacity and the completion of its installation\(^4\) is often quite long, and in the new technology areas might well be measured in years. This requires that the decision relating to the necessary capacity be made far in advance of the time it is needed, and thus some type of forecast is required. A common type of forecast would be a simple linear extrapolation\(^5\) of the average order rate, and such a forecast would be consistently low during the exponential growth phase. In addition, delays exist in the averaging of orders and in making a decision and actually placing the orders after the forecast has been made. It should not be surprising if the order rate for the product exceeds production capacity for at least part of the growth phase.

Price is function of extent to which the production capacity is being utilized, the unit profit, and the competitors' prices. When the firm is operating near full capacity, there will be little ten-

\(^4\)This includes not only the time to set up the machinery, but also the time to train new personnel, make equivalent increases in quality control capacity, etc.

\(^5\)It would seem that an exponential forecast would be called for, but such a forecast is more aggressive, and increases the chances of greatly overestimating as saturation is approached. Managers seem to fear overcapacity far more than undercapacity.
dency to change price, but if, for example, they were caught with a great deal of idle capacity, the pressures would be strong to reduce price in hopes of increasing volume and spreading the costs. Firms also typically have some concept of a "fair", or "normal", unit profit. There would be a strong desire to increase price if the markup was much below such a value (or range), and the notion of a "fair" price, or the fear of antagonizing customers or attracting competition, will create pressures to reduce it if it is above. Firms vary widely in their sensitivity to the prices of their competitors' products, but in general, competing prices play a significant role in setting price.

The entry of competition can be the result of many factors, but all such factors would seem to be based on the expectation by the potential competitors that they can profitably compete with the innovative firm. Some of these factors might be:

1) the apparent existence of very high margins, encouraging the belief that it would be possible to enter with a lower price and capture a share of the market during a period of price competition,

2) the belief that it would be possible to make the product either more cheaply or with higher quality, or

3) some indications that the demand is growing more rapidly than the innovator is expanding his capability to supply, and that a new entrant could gain a share of the market simply by being able to supply the product.

This study is based primarily upon the third factor, even though certain elements of price competition will be considered. Joel Dean makes reference to the importance of this aspect of competition in an article on pricing policies for new products.
"In many industries ... the important potential competitor is a large, multiple-product firm operating as well in other fields than that represented by the product in question. For such a firm, the most important consideration for entry is not existing margins, but the prospect of large and growing volume of sales. Present margins over costs are not the dominant consideration because such firms are normally confident that they can get their costs down as low as competitors' costs if the volume of production is large.\textsuperscript{6}

The hypothesis taken in this study is that the observed delivery delay often serves as an indication that the innovator is unable to satisfy the demand for the product. If the innovator were always able to make off-the-shelf deliveries in the minimum handling time, this would seem to discourage potential competitors even if the market seemed to be steadily expanding. Conversely, if the firm or firms presently servicing the market were exhibiting delivery times far in excess of the normal handling times for products in the class, this would indicate to potential competitors that if they could only supply a comparable product they might gain a significant share of the present and future customers seeking better delivery. It has been assumed that potential competitors will base their decisions regarding entry on their estimate of the unfilled market, the estimate being based on the observed growth of demand and the delivery delays of the earlier producers.

A typical pattern of growth might then involve an initial period of increase in the order rate controlled by the delays in

loop A alone, similar to behavior described in the simple system of Figure 2-1. As orders begin to increase more rapidly, the delays in the capacity expansion loop (loop C) might result in production capacity falling behind orders. As the order rate exceeds the production rate, the order backlog will climb, and delivery delay will increase. The increasing delivery delay will discourage some customers and slow the growth rate (loop B) while at the same time causing competitors to recognize the existence of an opportunity to capture some of the unfilled market (loop D). During this time both the innovator and competitors are taking steps to acquire more capacity. As the new capacity begins to arrive, the innovator begins to work off his backlog while the competitors take advantage of their faster deliveries (and possibly lower prices) to secure a fraction of the market. The increase in industry capacity and general improvement of deliveries now reduces the brake put on market growth by the delivery delay, and the growth rate increases again toward that dictated by loop A. This increase in growth rate causes revisions in the forecasts of future orders, may lead to another increase in delivery delay, and induces another round of capacity expansion. This process can repeat itself a number of times during the growth period. As described here, behavior has as yet been little influenced by price, but as the market approaches

---

7 Because the innovator is at this point operating at full capacity, receiving all the orders he can handle, he might be little inclined to meet a price differential.

8 In Chapters 4 and 5 the implications of various price policies on this stage of growth will be examined in more detail.
saturation the forecasting techniques can lead to overexpansion, and
the excess capacity can lead to the drastic price-cutting often ob-
served shortly after a market reaches saturation.9

The preceding description is one possible mode of behavior
which might occur in this system. The following section will de-
scribe how other modes of behavior might occur.

2.2 Other Possible Modes of Behavior

Different delays and varying sensitivities of the loops iden-
tified in Figure 2-3 can lead to very different patterns of growth.
Three such patterns and the conditions which create them are de-
scribed below.

1) If the delays in loop A are very long relative to the
decision delays and time required to increase capacity in
loop C, the pattern of behavior will be controlled almost
entirely by loop A. Such a situation would exist if it took
a long time to learn the potentialities of the product and
to learn to use it, and if the customers were not greatly
affected by marketing efforts and required a long observation
of the use of the product to be convinced of its value. The
order rate would then increase very slowly, and a short delay
in receiving and installing capacity would permit the innova-
tor to control his backlogs and delivery even if his forecast-
ing was not particularly optimistic. Because the innovator
was always able to satisfy the demands of the market, there
would be little inducement for competitors to enter, and
price would also exhibit great stability.

2) If the market is highly sensitive to delivery delay,
loop B can interact with loop C to control the growth rate.
If orders become slightly higher than production, backlog
increases slightly, and the increased delivery delay dis-
courages further orders. The order rate is then controlled
by the expansion of capacity, for an increase in capacity,

9The price crash in the transistor industry is a recent example.
permitting the working off of some of the backlog, will be followed by increased orders until they once again exceed capacity. It might appear to the firm that their forecasts were extremely accurate, since throughout the entire growth period they always had capacity almost exactly matching the order rate.

3) Short delays in loop A, reflecting a product very rapidly accepted by the market, if coupled with very long delays in obtaining production capacity, can lead to the capturing of a major share of the market by competition, and price crashes during or after the growth period. If the order rate increases extremely rapidly, the innovator may take steps to expand his capacity, but delivery delay can climb to very high values before the new capacity is received. The high delivery delay encourages the entry of competitors, and when the new production capacity is received much later, delivery delay falls rapidly and growth rate again increases. The ordering of production capacity is likely to fluctuate widely, and order rate for the product might also exhibit cyclic behavior. The very long delay in receiving capacity necessitates forecasting far into the future, the probable outcome being a large excess of industry capacity upon saturation and possible periods of temporary excess even during the growth phase. Prices may be quite volatile in this situation.

These are but a few of the possible modes of behavior, but they serve to indicate the variety which can exist. The situations described here, and others, will be examined in more detail in Chapter 4.
CHAPTER 3

The Formulation of the Model

This chapter presents the detailed equations\(^1\) necessary for computer simulation of the system described in Chapter 2. The system has been divided into seven sectors, and the sectors and the flows between them are shown in Figure 3-1. The division into sectors is simply for convenience and could have been done in different ways or not at all. The circles represent entire sectors, and the arrows show all flows between them. Each flow is identified by its name, and the mnemonic symbol and equation number for each variable are given in the parenthesis.

Price, delivery delay, and awareness generated by marketing effort and observed sales interact to determine the industry demand, through time, for the product and to determine the market shares of the innovator and the aggregate competition.

The market development sector generates awareness to the product through a flow of market development effort to the market. The introductory marketing effort is the result of a prior decision by the innovator and is independent of the behavior of the model variables,

\(^1\)As mentioned in Chapter 1, the reader is assumed to be familiar with industrial dynamics and the DYNAMO compiler. If this familiarity does not exist, references 2 and 9 of the bibliography are recommended. It would not be feasible to attempt to furnish the necessary background here.
but all following efforts are based upon the dollar volume of sales, as determined by price and units shipped. The competitive sector differs slightly; their introductory efforts are based upon their estimate of the unfilled market. Entering into production after the market has begun to exhibit acceptance of the product, they have this additional information useful in choosing a reasonable level of introductory effort.

On receipt of orders the production and capacity acquisition sectors produce units, make shipments, forecast demand, and order and install production capacity. The state of the backlog relative to capacity determines the delivery delay, and the extent to which the capacity is being utilized is a principal determinant of price. The acquisition of production capacity calls for some type of forecast of demand. The innovator makes this forecast on the basis of the present and past order rate and trends in the incoming orders. The competition is an aggregate of many competitors and those who have begun production forecast in the same way as does the innovator. The potential competitors -- the ones deciding whether or not to enter the market -- base their forecast on the sales and aggregate delivery delay of the existing suppliers. A delivery delay higher than normal for the product type indicates that an unfilled market exists, since the present suppliers are unable to produce at the rate the market is demanding the product.

The pricing sectors consist of the decision functions which determine prices. Both the innovator and the competition take into
account the same factors in making this determination, although they may take account of them in different ways and attach different degrees of importance to them. The factors considered are the competitive prices, the costs of making the product, the markup or unit profit, and the extent to which capacity is being utilized.

The equations and detailed flow diagrams for each of these sectors are presented in the following sections.

3.1 The Market Sector (Figure 3-2)

The first knowledge which the market has of the product is transmitted by the market development efforts of the producers. Some time is required for marketing efforts to have their full effect on the potential customers. Awareness builds up rapidly at first, but at a decreasing rate as saturation is approached. At least one study has produced data backing up this assumption. Such a relationship is obtained from a first-order exponential delay.

\[
\text{OMDEI}\_K=\text{OMDEI}\_J+(\text{DT})(1/\text{TOMDE})(\text{AMDEI}\_JK-\text{OMDEI}\_J) \quad 1, L^3
\]

\[
\text{OMDEI}=0 \quad 2, N
\]


3The number 1 means that this is the first equation described. The equations will be numbered consecutively through the chapter. The letter L refers to the fact that this is a level equation. Other symbols are N for initial values, A for auxiliary equations, and R for rate equations.
Figure 3-2. Flow Diagram of the Market Sector
OMDEC.K = OMDEC.J + (DT)(1/TOMDE)(AMDEC.JK - OMDEC.J)  

OMDEC = 0

OMDEI = Observed Market Development Effort of the Innovator (dollars/month)
TOMDE = Time to Observe Market Development Effort (months)
AMDEI = Actual Market Development Effort of the Innovator (dollars/month)
OMDEC = Observed Market Development Effort of the Competition (dollars/month)
AMDEC = Actual Market Development Effort of the Competition (dollars/month)

The initial conditions for OMDEI and OMDEC are set at zero because the system will be started with no past history of activity. The units of both of these variables are given as dollars per week. An examination of the effects of different methods of market development would make it necessary to relate the dollars spent to the effectiveness of the methods, but for simplicity it will be assumed that a given dollar amount has a certain effectiveness.

As mentioned previously, this study deals not with a specific product, but with a hypothetical one. This permits the taking of certain liberties in the selection of parameters, with the restrictions being only that the individual values are plausible and the entire group consistent. For a new product, market development must do more than convince people to buy this product and buy it now; it must teach them what is is and how it might be useful. Six months seems to be a reasonable time for the effort to take effect.

TOMDE = 6

C, 1, 3

4The C denotes that this is a constant, and the numbers indicate the equations in which it is a parameter.
TOMDE--Time to Observe Market Development Efforts (months)

Those customers who are unaware of the product can learn of it from two sources -- the producers or the market. Information from the producers comes in the form of market development efforts, while information from the market consists of seeing the product in use, hearing of it by word of mouth, etc. Just as in the build-up of awareness to marketing, there is a delay in recognizing the use of a product. It takes time for word-of-mouth information to travel, and a product of the component type does not go into use, where it can be seen, immediately after purchase. Since this type of information is not specifically directed at the customer, it will require a longer time to take effect.

\[ \text{OUPI}.K = \text{OUPI}.J + (DT)(1/\text{TEOU})(\text{SSI}.JK - \text{OUPI}.J) \]
\[ \text{OUPI} = 0 \]
\[ \text{TEOU} = 12 \]
\[ \text{OUPC}.K = \text{OUPC}.J + (DT)(1/\text{TEOU})(\text{SSC}.JK - \text{OUPC}.J) \]
\[ \text{OUPC} = 0 \]

\[ 5, L \]
\[ 6, N \]
\[ 0; 5, 7 \]
\[ 7, L \]
\[ 8, N \]

OUPI--Observed Use of the Product of the Innovator (units/month)
OUPC--Observed Use of the Product of the Competition (units/month)
TEOU--Time for Effect of Observed Use (months)
SSI--Shipments Sent by the Innovator (units/month)
SSC--Shipments Sent by the Competition (units/month)

The awareness of the market to the product is a function of the observed market development effort and the observed use. The exact relationship could be the subject of a great deal of discussion and might vary considerably for different products. It will be assumed...
for the purposes of this study that some level of awareness is generated by market development and some by the observed use of the product. One study of the growth of new consumer products obtained results indicating that about 80 percent of the information is derived from marketing efforts and 20 percent from observation of use. There were indications that the relative weights of these factors varied slightly over the period of growth, but the system is not particularly sensitive to these parameters, and they will be taken as constant in the interests of simplicity. However, industrial buyers are likely to be less sensitive to promotion and more convinced by actual use, and for this reason the values selected attribute only 60 percent of the awareness to marketing and 40 percent to observed use.

Awareness is most meaningful in a relative sense. The dimensional units attached to it are simply units of awareness. The parameters have been selected so that if the innovator and competition equally share the market at maturity, and each allocates 10 percent of sales (with price at one dollar per unit) to market development, the awareness to their respective products will be unity, and total awareness of the market to the product will be two units of awareness.

\[
\text{AMPI}.K = (\text{IOUA}).(\text{OUPI}.K) + (\text{IMDA}).(\text{OMDEI}.K)
\]

\[
\text{AMPC}.K = (\text{IOUA}).(\text{OUPC}.K) + (\text{IMDA}).(\text{OMDEC}.K)
\]

---

IOUA=8E-7  
IMDA=12E-6

AMPI--Awareness of the Market to the Product sold by the Innovator (units of awareness)  
AMPC--Awareness of the Market to the Product sold by Competition (units of awareness)  
IOUA--Influence of Observed Use on Awareness (units of awareness/unit/month)  
OUPI--Observed Use of the Product of the Innovator (units/month)  
OUPC--Observed Use of the Product of Competition (units/month)  
IMDA--Influence of Market Development on Awareness (units of awareness/dollar/month)  
OMDEI--Observed Market Development Effort of the Innovator (dollars/month)  
OMDEC--Observed Market Development Effort of Competition (dollars/month)

The awareness of the market to the product is the total of the awareness to the innovator's product and the competitors' product.  

AMP.K=AMPI.K+AMPC.K

AMP--Awareness of Market to the Product (units of awareness)  
AMPI--Awareness of Market to the Product sold by the Innovator (units of awareness)  
AMPC--Awareness of Market to the Product sold by Competition (units of awareness)

As the awareness of the market to the product increases, so does the fraction of the potential customers becoming aware of it each month. This fraction will grow very slowly at first, begin to increase rapidly as a very noticeable volume of information becomes available.

68E-7 equals 8 \times 10^{-7}, or 0.0000008. It is written in this form for convenience of use in the DYNAMO program.

7Awareness to firm and product are being treated as synonymous.
available, and then level off to approach some maximum. This saturation would occur as the point was reached where more than enough information was available and the limiting factor became the time necessary for the information to be accepted. Figure 3-3 shows a reasonable estimate of values for such a relationship.

![Graph showing the relationship between FBAP and AMP (Awareness of Market to Product)](image)

**Figure 3-3. Fraction Becoming Aware of the Product versus Awareness of Market to Product**

A value from the preceding figure is obtained by the following table interpolation equation.

\[ \text{FBAP} = \text{TABHL}(\text{TFBAP}, \text{AMP} \cdot \text{K}, 0.2, 0.0, 0.2) \]

TFBAP* = 0, 0.015, 0.04, 0.1, 0.21, 0.3, 0.36, 0.39, 0.4, 0.4, 0.4

FBAP--Fraction Becoming Aware of the Product (1/months)
TFBAP--Table for Fraction Becoming Aware of the Product
AMP--Awareness of Market to the Product (units of awareness)

The fraction per month becoming aware of the product and the
number of customers not yet aware of it determine the rate at which they become aware.

\[ \text{CBAP.KL} = (\text{FBAP.K})(\text{PCUP.K}) \]

**CBAP**—Customers Becoming Aware of the Product (customers/month)

**FBAP**—Fraction Becoming Aware of the Product \((1/\text{months})\)

**PCUP**—Potential Customers Unaware of the Product (customers)

As customers become aware of the product, the number still unaware of it decreases. This can be represented by a level equation which computes the present number as the number one time period in the past minus the number which has become aware during the preceding period. The number which has become aware is equal to the rate at which customers are becoming aware times the length of the time period.

\[ \text{PCUP.K} = \text{PCUP.J} - (\text{DT})(\text{CBAP.JK}) \]

**PCUP**—Potential Customers Unaware of the Product (customers)

**DT**—Delta Time, the computation interval (months)

**CBAP**—Customers Becoming Aware of the Product (customers/month)

The assumption has been made that no changes will occur in the physical characteristics of the product. Therefore, the inherent quality of the product determines the number of potential customers who might, at some time, use the product. This number will determine the initial value for the potential customers unaware of the product PCUP. A number of 500 has been selected.

\[ \text{PCUP} = 500 \]

**PCUP**—Potential Customers Unaware of the Product (customers)
Customers do not begin to use a product immediately after becoming aware of it. They require some time to learn to use the product, do any design work necessary to incorporate it into their production, and complete any other preparation for its adoption. This time will vary for different customers and different uses, and it might reasonably have a distribution similar to a third-order delay. Eighteen months is a plausible average for this process. The number of customers developing uses will be a level with an inflow of customers becoming aware of the product CBAP and an outflow of customers becoming active users. Initially, there would be no customers developing uses.

\[
\text{CDUP}_K = \text{CDUP}_J + (DT)(\text{CBAP}_JK - \text{CBAU}_JK) \\
\text{CDUP} = 0 \\
\text{CBAU}_KL = \text{DELAY}_3(\text{CBAP}_JK, \text{DLUP}) \\
\text{DLUP} = 18
\]

CDUP---Customers Developing Uses for the Product (customers)
CBAP---Customers Becoming Aware of the Product (customers/month)
CBAU---Customers Becoming Active Users (customers/month)
DLUP---Delay in Learning to Use the Product (months)

As customers complete this process of learning and preparation, they become active users, ready to order the product if price and delivery delay are satisfactory. There are no active users when the product is first introduced.

\[
\text{CAUP}_K = \text{CAUP}_J + (DT)(\text{CBAU}_JK) \\
\text{CAUP} = 0
\]
CAUP--Customers Actively Using the Product (customers)
CBAU--Customers Becoming Active Users (customers/month)

At any time, a fraction of the market will be placing their orders with the innovator, and the remainder will be ordering from the competition. These market shares change as changing prices and delivery delays lead customers to re-evaluate the relative merits of these producers and their products. There are many ways to formulate such a situation. Here levels will represent the fractional market shares; and later, in order to determine the order rates, they will be multiplied by the total number of active customers CAUP to determine the number of customers ordering from the two sources of supply. Initially, the innovator, being first in the market, controls it entirely.

\[
\begin{align*}
\text{FPOI}_K &= \text{FPOI}_J + (DT)(\text{FCIC}_J - \text{FCIC}_K) \\
\text{FPOI} &= 1.0 \\
\text{FPOC}_K &= \text{FPOC}_J + (DT)(\text{FCIC}_K - \text{FCIC}_J) \\
\text{FPOC} &= 1.0 - \text{FPOI}
\end{align*}
\]

FPOI--Fraction of market Placing Orders with the Innovator (dimensionless fraction)
FPOC--Fraction of market Placing Orders with Competition (dimensionless fraction)
FCIC--Fraction Changing from the Innovator to the Competition (fraction/month)
FCCI--Fraction Changing from the Competition to the Innovator (fraction/month)

Customers will be continually switching their ordering from the innovator to the competition, or vice versa. The rate at which they switch is a function of the number who might possibly switch and relative prices and delivery delays of the alternate sources of supply.
FCIC.KL=PFCC.K(FCCP.K+FCCD.K)

FCCI--Fraction Changing from the Competition to the Innovator (fraction/month)
FCIC--Fraction Changing from the Innovator to the Competition (fraction/month)
PFCC--Potential Fraction Changing to the Innovator (dimensionless fraction)
PFCC--Potential Fraction Changing to the Competition (dimensionless fraction)
FCIP--Fraction Changing to the Innovator because of Price (fraction/month)
FCCP--Fraction Changing to the Competition because of Price (fraction/month)
FCID--Fraction Changing to the Innovator because of Deliveries (fraction/month)
FCCD--Fraction Changing to the Competition because of Deliveries (fraction/month)

Some fraction of the customers buying from one source of supply will be influenced by the marketing efforts of the other supplier. It is this fraction which is amenable to changing suppliers.

8This formulation has certain defects which become obvious when the situation which could occur at the extreme limits is considered. If both of the fractions, FCIP and FCID, are small, the probability is high that the customers who are changing because of price are not the same customers who are dissatisfied with delivery delay. In this case the fractions are independent, and the sum very closely approximates the theoretical total. If, however, the fractions are large, the probability is quite high that at least some of the customers dissatisfied with the price are also dissatisfied with the delivery delay, and the sum of the two fractions no longer accurately produces the total flow. For example, if 50 percent found the relative prices sufficient to warrant a change, and 50 percent felt the same about delivery, there would be considerable overlap, and the total fraction changing within a month might be closer to 75 percent than 100 percent. The formulation does not invalidate the results, however, because in none of the model runs did the maximum fractions reach values when overlap would create a real problem.
PFCL.K=(FIMI.K)(FPOC.K)
PFCC.K=(FIMC.K)(FPOI.K)

PFCL--Potential Fraction Changing to the Innovator
  (dimensionless fraction)
PFCC--Potential Fraction Changing to the Competition
  (dimensionless fraction)
FIMI--Fraction Influenced by Marketing of the Innovator
  (dimensionless fraction)
FIMC--Fraction Influenced by Marketing of the Competition
  (dimensionless fraction)
FPOI--Fraction of market Placing Orders with the
  Innovator (dimensionless fraction)
FPOC--Fraction of market Placing Orders with the
  Competition (dimensionless fraction)

As the observed market development effort of a firm increases,
the fraction of the market which is sufficiently informed to consider
it as a potential supplier increases. The fraction increases rapidly
for small amounts of market development for two reasons:

(1) It is likely that firms can be more directive with
small amounts of effort, achieving efficiency through
  careful selection of prospects.

(2) There are always some customers willing to change
    solely for the sake of change, and a minimum of effort
    attracts these customers.

The effort becomes less efficient as its magnitude increases, as
shown in Figure 3-4, as directivity becomes less feasible and as
the remaining customers become those more closely attached to their
present supplier. The relationship would be a characteristic of the
market and would therefore be the same for the innovator and the
competition.
Figure 3-4. Fraction Influenced by Marketing of the Innovator versus Market Development Saturation by the Innovator

\[
\begin{align*}
FIMI.K &= TABHI(TFIMI, MDSI.K, 0.1, 2, 0.2) \\
TFIMI* &= 0/0.3/0.57/0.80/0.95/1.0/1.0 \\
FIMC.K &= TABHL(TFIMC, MDS.C.K, 0, 1, 2, 0.2) \\
TFIMC* &= 0/0.3/0.57/0.80/0.95/1.0/1.0
\end{align*}
\]

FIMI--Fraction Influenced by Marketing of the Innovator (dimensionless fraction)
FIMC--Fraction Influenced by Marketing of the Competition (dimensionless fraction)
TFIMI--Table of Fraction Influenced by Marketing of the Innovator
TFIMC--Table of Fraction Influenced by Marketing of the Competition
MDSI—Market Development Saturation by the Innovator  
(dimensionless fraction)  
MDSC—Market Development Saturation by the Competition  
(dimensionless fraction)  

The market development saturation is the ratio of the marketing 
effort observed by the market to the amount which would be necessary 
to completely saturate the market.

\[
\text{MDSI}_K = \frac{\text{OMDEI}_K}{\text{ERS}_K} \\
\text{MDSC}_K = \frac{\text{OMDEC}_K}{\text{ERS}_K}
\]

31, A  
32, A  

MDSI—Market Development Saturation by the Innovator  
(dimensionless fraction)  
MDSC—Market Development Saturation by the Competition  
(dimensionless fraction)  
OMDEI—Observed Market Development Effort of the  
Innovator (dollars/month)  
OMDEC—Observed Market Development Effort of the  
Competition (dollars/month)  
ERS—Effort Required for Saturation (dollars/month)  

The amount of marketing effort required to saturate the market 
increases as the number of customers using the product increases.  
It takes more money to convince two hundred people to consider a  
product than it does to convince two. It takes less than one hundred 
times as much, however, for some forms of effort, such as advertising, 
are visible to a widely varying number of people at a single price. 
This increasing efficiency per dollar is reflected in Figure 3-5.  

It should be noted that the curve does not go through the (0,0)  
point. This is because a minimum amount of effort is required to  
convince anyone. Amounts which are too small are just lost in the 
mass of promotional effort to which people are subjected.
Figure 3-5. Effort Required for Saturation versus Customers Actively Using the Product

In equation form:

ERS.K = TABLE(TERS, CAUP.K, 0, 500, 50) 33, A

TERS* = 500/6000/10500/14000/17000/19500/22000/23500/
        24500/25000/25000  C, 33

ERS--Effort Required for Saturation (dollars/month)
TERS--Table of Effort Required for Saturation
CAUP--Customer Actively Using the Product (customers)

The values of TERS were selected as plausible based upon the values for IONS (C,9,10) and IMDA (C,9,10).

The other factors determining the fraction changing are the relative prices and delivery delays. The price effects will be examined first.
As the price charged by the innovator decreases relative to that charged by the competition, more customers will shift their orders to the innovator. People are not always completely rational, however, and Figure 3-6 reflects the fact that a small fraction of the customers will be changing to the innovator even when price there is higher. At the other extreme, when the innovator's price is far less than the competitive prices, the fraction shifting does not increase indefinitely because price alone can generate only a limited amount of pressure to change suppliers. For very great price differences other factors (the time required to make purchasing decisions, special commitments to one supplier, etc.) limit the rate at which customers can and will shift.

In Figure 3-6 the fraction changing to the innovator because of price is plotted against the logarithm to the base 2 of the price ratio. The logarithmic plot is used only for convenience in constructing the graph and has no effect on the substance of the model. The actual ratio is indicated beneath the logarithm.

The fraction changing to the competition is the mirror image of this relationship, as shown in Figure 3-7.
Figure 3-6. Fraction Changing to Innovator because of Price versus Log to the Base 2 of the Price Ratio

Figure 3-7. Fraction Changing to the Competition because of Price versus Log to the Base 2 of the Price Ratio
The relationships are represented by the following equations:

\[
\begin{align*}
FCIP.K = & \text{TABHL(TFCIP, L2PR.K, -2.0, 1.5, 0.5)} \quad 34, A \\
TFCIP* = & 0.25/0.225/0.15/0.075/0.001/0.0005/ \\
& 0.0005/0.0005 \quad C, 34 \\
FCCP.K = & \text{TABHL(TFCCP, L2PR.K, -1.5, 2.0, 0.5)} \quad 35, A \\
TFCCP* = & 0.0005/0.0005/0.0005/0.001/0.075/0.15/ \\
& 0.225/0.25 \quad C, 35 \\
\end{align*}
\]

FCIP--Fraction Changing to the Innovator because of Price (dimensionless fraction/month)
FCCP--Fraction Changing to the Competition because of Price (dimensionless fraction/month)
TFCIP--Table for Fraction Changing to the Innovator because of Price
TFCCP--Table for Fraction Changing to the Competition because of Price
L2PR--Log to the base 2 of the Price Ratio (dimensionless)

The price ratio PR is simply the ratio of the price being charged by the innovator to that charged by the competition. The DYNAMO compiler has available a function which will take the natural logarithm of a number, and this is multiplied by 1.4426 to obtain the logarithm to the base 2.

\[
\begin{align*}
L2PR.K = & (1.4426) \text{LOGN(PR.K)} \quad 36, A \\
PR.K = & \text{PRII.K/PRIC.K} \quad 37, A \\
\end{align*}
\]

L2PR--Log to the base 2 of the Price Ratio (dimensionless)
PR--Price Ratio (dimensionless)
PRII--Price at the Innovator (dollars/unit)
PRIC--Price at the Competition (dollars/unit)

The fraction changing because of deliveries follows a similar pattern, except that the market is assumed to be somewhat less sensitive to delivery delay than it is to price. For example, if the
innovator's price is twice that of the competition, 15 percent of the customers at the innovator will shift to the competition each month. If, on the other hand, the delivery delay is twice as high, only 5 percent will shift each month. Figure 3-8 shows the fraction changing to the innovator as a function of the delivery delays. The relationship for the competition is the mirror image, just as it was for prices. The equations for both follow the figure.

Figure 3-8. Fraction Changing to the Innovator because of Delivery Delay versus Log to the Base 2 of the Delivery Ratio

FCID.K=TABHL(TFCID,L2DR,K,- 4.0, 3.0, 1.0) 38, A
TFCID*=0.15/0.135/0.10/0.05/0.0001/0.0005/0.0005/0.0005 C, 38
FCCD.K=TABHL(TFCCD,L2DR,K,- 3.0, 4.0, 1.0) 39, A
TFCCD*=0.0005/0.0005/0.0005/0.001/0.05/0.10/0.135/0.15 C, 39
FCID -- Fraction Changing to the Innovator because of Deliveries (dimensionless fraction/month)
FCCD -- Fraction Changing to the Competition because of Deliveries (dimensionless fraction/month)
TFCID -- Table for Fraction Changing to the Innovator because of Deliveries
TFCCD -- Table for Fraction Changing to the Competition because of Deliveries
L2DR -- Log to the base 2 of the Delivery Ratio (dimensionless)

The log of the delivery ratio is found in the same way as was the log of the price ratio.

\[ L2DR.K = (1.4426) \log N(DR.K) \]

L2DR -- Log to the base 2 of the Delivery Ratio (dimensionless)
DR -- Delivery Ratio (dimensionless)

Delivery delay is a variable which is not so readily observed as is price. On the aggregate level, even if the suppliers quote accurately their best estimate of what the delivery delay is, it may change before the orders in backlog are filled. Even if it does not change during a given period of time, all firms do not get quotations at the same time. All of these conditions contribute to a situation in which the recognized delay is an average of delays for some time in the past. The delivery ratio is therefore formulated as a ratio of the observed delivery delays.

\[ DR.K = ODDI.K / ODDC.K \]

DR -- Delivery Ratio (dimensionless)
ODDI -- Observed Delivery Delay at the Innovator (months)
ODDC -- Observed Delivery Delay at the Competition (months)

The delivery delay observed and acted upon by the customers is represented as a first-order exponential average of the quoted delivery
delay. The first-order exponential average reflects the delays for the market to become aware of changes in the delivery delay, as discussed in the preceding chapter.

\[
\text{ODDI}_K = \text{ODDI}_J + (DT)(1/TODD)(\text{DDQI}_J - \text{ODDI}_J)
\]

\[
\text{ODDI} = \text{DDQI}
\]

\[
\text{TODD} = 3
\]

\[
\text{ODDC}_K = \text{ODDC}_J + (DT)(1/TODD)(\text{DDQC}_J - \text{ODDC}_J)
\]

\[
\text{ODDC} = \text{DDQC}
\]

ODDI—Observed Delivery Delay at the Innovator (months)  
ODDC—Observed Delivery Delay at the Competition (months)  
TODD—Time to Observe Delivery Delay (months)  
DDQI—Delivery Delay Quoted by the Innovator (months)  
DDQC—Delivery Delay Quoted by the Competition (months)

It is assumed that initially all the customers will accept the quoted delay as the actual delay. Three months is selected as a reasonable time over which to smooth the delivery delay.

The sales of any product are sensitive to its price; while the price elasticity may be very low for certain products within the normal range of prices, great changes in price will always affect sales. Since the product considered is a hypothetical product, a demand curve can be selected which seems plausible for an electronic component. Figure 3-9 is drawn as a curve of the price multiplier versus the price. This multiplier has a value of one at a price of one dollar per unit. The normal order rate, to be discussed later, becomes then the actual order rate if the price is one dollar, while the actual order rate will be higher or lower, as shown by the curve, if the price is at some other value. Notice that the multiplier
Figure 3-9. Price Multiplier of Average Orders at the Innovator versus Price at the Innovator
differs from the demand curves commonly found in economics texts in that the demand does not become infinite as the price goes to zero. This reflects the real-world constraint that there is some limit to the use of a product even if it is free.

The curve for the competition will be identical, since the curve applies to the product and not to a particular supplier.

\[ \text{PMAOI.K} = \text{TABLE}(\text{TPM}, \text{PRII.K}, 0, 4.00, 0.20) \]

\[ \text{TPM*} = 3/2.45/1.98/1.58/1.27/1/0.8/0.66/0.55/0.47/0.41/
  0.36/0.325/0.296/0.27/0.25/0.23/0.215/0.2/
  0.187/0.175 \]

46, A 46, 47
Delivery delays also have an effect on the aggregate orders for the product. Customers may substitute another product for the one in question if the time required to get this product becomes so long that it causes, or might be expected to cause, a disruption in the production of those products of which it is a component. Even in cases where there are no satisfactory substitutes, extremely long delivery delays are likely to cause a reduction in orders, as customers delay the introduction of new systems which would use the component. This leads to a delivery delay multiplier of normal orders, as shown in Figure 3-10. If the delivery delay remains near a value considered normal for this class of products, it will not affect orders. As the delay increases, however, more and more customers find substitutes or delay the introduction of new systems, and the fraction of normal orders declines.

The delivery multiplier, like the demand curve, is the same for both the innovator and the competition.

---

9 This assumes a constant stream of new systems being introduced by customers, going through their life cycles and becoming obsolete. At a given time, orders are being placed for components to be used in systems being produced, but if the delivery delay is long, as these systems become obsolete, the introduction of their replacements is delayed.
Figure 3-10. Delivery Multiplier of Average Orders at the Innovator versus Observed Delivery Delay of the Innovator

DMAOI.K = TABHL(TDM,ODDI.K,0,12,1)  
TDM* = 1/0.98/0.9/0.8/0.67/0.5/0.35/0.25/0.15/  
0.1/0.07/0.05  C, 48, 49

DMAOC.K = TABHL(TDM,ODDC.K,0,12,1)  

DMAOI--Delivery Multiplier of Average Orders to the Innovator (dimensionless)  
DMAOC--Delivery Multiplier of Average Orders to the Competition (dimensionless)  
TDM--Table for Delivery Multiplier  
ODDI--Observed Delivery Delay at the Innovator (months)  
ODDC--Observed Delivery Delay at the Competition (months)

The average order rate per customer per month is multiplied by the number of customers actively using the product CAUP to determine the industry order rate, which may then be multiplied by the fraction placing orders at the respective suppliers to give their normal incoming.
order rate. The average order rate per customers CAOR is defined for a price of one dollar per unit and a delivery delay satisfactory to all customers; therefore, the price multipliers PMAOI and PMAOC and the delivery multipliers DMAOI and DMAOC must also be included in the formulation of the actual order rates.

\[ \text{ORI.KL} = (\text{CAOR})(\text{CAUP.K})(\text{FPOI.K})(\text{PMAOI.K})(\text{DMAOI.K}) \]

CAOR=2000

\[ \text{ORC.KL} = (\text{CAOR})(\text{CAUP.K})(\text{FPOC.K})(\text{PMAOC.K})(\text{DMAOC.K}) \]

ORI--Order Rate to the Innovator (units/month)
ORC--Order Rate to the Competition (units/month)
CAOR--Customers' Average Order Rate (units/customer-month)
CAUP--Customers Actively Using the Product (customers)
FPOI--Fraction Placing Order with the Innovator (dimensionless)
FPOC--Fraction Placing Order with the Competition (dimensionless)
PMAOI--Price Multiplier of Average Orders to the Innovator (dimensionless)
PMAOC--Price Multiplier of Average Orders to the Competition (dimensionless)
DMAOI--Delivery Multiplier of Average Orders to the Innovator (dimensionless)
DMAOC--Delivery Multiplier of Average Orders to the Competition (dimensionless)

The customer average order rate is selected as 2000 units/customer-month. With the value of 500 potential customers, at a normal price of one dollar per unit, industry sales in the fully saturated market would then be twelve million dollars a year, a plausible figure for an electronic component.

3.2 The Market Development Sector for the Innovator (Figure 3-11)

It is a common policy in the business world to base market development effort and promotion on sales. In a mature product line,
Figure 3-11. Flow Diagram of the Market Development Sectors for the Innovator
marketing budgets are determined simply by taking a fixed percentage of the previous year's sales. During the growth period, it is reasonable that a firm would be somewhat more aggressive. One approach might be to have a more flexible budget, revising it on the basis of recent sales.\(^{10}\) An exponential average of sales over the past six months is used here as a basis for the decision. The dollar sales are equal to the price times the units shipped.

\[
\begin{align*}
\text{SALEI}.K &= (\text{PRII}.K)(\text{SSI}.K) \\
\text{ASALI}.K &= \text{ASALI}.J + (\text{DT})(1/\text{TASI})(\text{SALEI}.J - \text{ASALI}.J) \\
\text{ASALI} &= 0 \\
\text{TASI} &= 6
\end{align*}
\]

\(^{52, A}\)

\(^{53, L}\)

\(^{54, N}\)

\(^{C, 53}\)

\text{SALEI} -- \text{SALEs at the Innovator (dollars/month)}
\text{PRII} -- \text{PRIce of product as sold by the Innovator (dollars/unit)}
\text{SSI} -- \text{Shipments Sent by the Innovator (units/month)}
\text{ASALI} -- \text{Average SALES at the Innovator (dollars/month)}
\text{TASI} -- \text{Time to Average Sales at the Innovator (months)}

Average sales are initially zero as there is no sales history.

One component of the funds allocated to market development is a percentage of average sales. A reasonable figure is 10 percent.\(^{11}\)

An additional component independent of sales is expected for the purposes of introducing the product. This component will be taken as constant, and a figure of 5000 dollars per month seems consistent with the size of the market.

\(^{10}\) Another approach might be to use some kind of forecast of sales. The simpler case will be used here, however.

\(^{11}\) The sensitivity of system behavior to this parameter is investigated in Chapter 4.
AFMDI.KL=IMEI+(FSMDI)(ASALI.K)  55, R
IMEI=5000
FSMDI=0.10  C, 55

AFMDI -- Allocated Funds to Market Development by the Innovator (dollars/month)
IMEI -- Introductory Marketing Efforts by the Innovator (dollars/month)
FSMDI -- Fraction of Sales to Market Development at the Innovator (dimensionless)
ASALI -- Average SALES at the Innovator (dollars/month)

Funds are not spent immediately upon allocation. Campaigns must be planned, sales engineers must be hired and/or trained, etc. The funds allocated begin to produce marketing effort and promotion only after some delay.

AMDEI.K=AMDEI.J+(DT)(1/DAMDI)(AFMDI.JK-AMDEI.J)  56, L
AMDEI=IMEI
DAMDI=6

AMDEI -- Actual Market Development Effort by the Innovator (dollars/month)
DAMDI -- Delay for Actual Market Development by the Innovator (months)
AFMDI -- Allocated Funds to Market Development by the Innovator (dollars/month)

The point of initial observation is the time at which the innovator has just begun to reach the market with the initial effort. For this reason the actual effort AMDEI will initially be equal to the introductory effort IMEI.

3.3 The Production and Capacity Acquisition Sector for the Innovator (Figure 3-12)

Orders received by the innovator accumulate in an unfilled order backlog and remain there until the units are shipped.
Figure 3-12. Flow Diagram of the Production and Capacity Acquisition Sector for the Innovator
\[ \text{BLI}.K = \text{BLI}.J + (\text{DT})(\text{ORI}.JK - \text{SSI}.JK) \]

\[ \text{BLI} = 0 \]

**BLI**—BackLog at the Innovator (units)

**ORI**—Order Rate to the Innovator (units/month)

**SSI**—Shipments Sent by the Innovator (units/month)

Initially, the innovator will have received no orders and the backlog will be zero.

The shipment rate is determined by the firm's production capacity and the extent to which it is being used.

\[ \text{SSI}.KL = (\text{LPCI}.K)(\text{PCI}.K) \]

**SSI**—Shipments Sent by the Innovator (units/month)

**LPCI**—Loading of the Production Capacity at the Innovator (dimensionless)

**PCI**—Production Capacity of the Innovator (units/month)

A firm's output is determined by its utilization of its production capacity. If half of a firm's production capacity is in use, its production will be very close to half as great as if all the capacity were in operation. Also, a firm's production capacity is never a rigidly fixed quantity. By using more overtime or just exerting more pressure for production, for example, it is usually possible to squeeze out more production than would normally be considered full capacity. Production capacity is used here in the sense of a minimum cost point. The loading of the production capacity, shown in Figure 3-13, reflects the fact that output is a function of the desired shipment rate, varying from zero when no output is desired to a value 20 percent above nominal capacity when the pressures for production are great.
Figure 3-13. Loading of Production Capacity at the Innovator versus the Ratio of Shipments Desired to Capacity at the Innovator

\[ \text{LPCI}.K = \text{TABHL} (\text{TLPC}, \text{RSDCI}.K, 0, 2.0, 0.25) \]

\[ \text{TLPC} = 0/0.25/0.5/0.75/1.0/1.125/1.18/1.2/1.2 \]

LPCI--Loading of Production Capacity at the Innovator (dimensionless)
TLPC--Table for Loading of Production Capacity
RSDCI--Ratio of Shipments Desired to Capacity at the Innovator (dimensionless)

The ratio of shipments desired to capacity is adequately explained by its name.

\[ \text{RSDCI}.K = \frac{\text{SRDI}.K}{\text{PCI}.K} \]

RSDCI--Ratio of Shipments Desired to Capacity at the Innovator (dimensionless)
SRDI--Shipment Rate Desired by the Innovator (units/month)
PCI--Production Capacity of the Innovator (units/month)
It is assumed that the innovator will consider one month as a reasonable time for filling orders, from receipt to shipment. The shipment rate desired will be the backlog divided by the months of sales desired in backlog.

\[ SRDI.K = BLI.K / MSDBI \]

\[ MSDBI = 1 \]

Production capacity is the aggregate of all factors necessary for production. It includes such things as quality control and other support facilities, and manpower, as well as capital equipment. The level of production capacity is the sum of all the capacity added. As mentioned previously, it is not a fixed quantity, in the sense of being an upper limit on production, but a measure of the production possible with minimum cost.

\[ PCI.K = PCI.J + (DT)(PCIRI.JK) \]

\[ PCI = PCII \]

\[ PCII = 1000 \]

The firm has some production capacity at the time it introduces the product. This initial production capacity is chosen as 1000 units per month. It is defined as a constant so that it may
be varied more easily for different simulations, to test the effects of different initial capability.

There is a considerable delay between the time capacity is ordered and the time it is received. A time of twenty-four months is selected as a reasonable average for such varied activities as adding another work bench, training another foreman, devising quality control schemes, and building an additional plant. A third-order exponential delay is used, reflecting the fact that there is considerable variability around the average delay. The production capacity on order is a level increased by new orders for capacity and decreased as capacity is installed.

PCIRI.KL=DELAY3(PCORI.JK,DRPC) 66, R
DRPC=24 C, 66, 79, 115, 128
PCOOI,K=PCOOI,J+(DT)(PCORI.JK-PCIRI.JK) 67, L
PCOOI=0 68, N

PCIRI--Production Capacity Installation Rate at the Innovator (units/month^2)
PCORI--Production Capacity Order Rate by the Innovator (units/month^2)
DRPC--Delay for Receipt of Production Capacity (months)
PCOOI--Production Capacity On Order by Innovator (units/month)

The initial production capacity on order is zero.

The existence of a deficit in the production capacity creates a desire to order more capacity. Depending upon the apparent magnitude of the deficit, however, the firm may wish to correct none, part, or all of it. The ordering of production capacity does not take place immediately upon recognition of a deficit, but only after
sufficient time for management to become convinced that more capacity is needed and time for the necessary decisions regarding the equipment needed, which may involve such things as contacts with suppliers, acceptance and evaluation of bids, etc. A time of six months is selected for this delay.

\[ \text{PCORI}.KL = (\text{FDCI}.K)(\text{DPCI}.K)/\text{TOPCI} \]

\[ \text{TOPCI} = 6 \]

\[ \text{PCORI} -- \text{Production Capacity Order Rate by the Innovator (units/month}^2) \]
\[ \text{FDCI} -- \text{Fraction of Deficit Corrected by the Innovator (dimensionless)} \]
\[ \text{DPCI} -- \text{Deficit in Production Capacity at the Innovator (units/month)} \]
\[ \text{TOPCI} -- \text{Time for Ordering Production Capacity by the Innovator (months)} \]

If the fractional deficit between the production capacity desired and the actual capacity is very slight, it is unlikely that a firm would order more capacity. The conservatism inherent in most organizations would cause them to overload their capacity slightly, thus operating above minimum cost, rather than act upon a small deficit which might easily disappear. As the deficit becomes substantial, the fear of being unable to give reasonable customer service combines with recognition of the heavy costs of operating far above capacity to induce a greater relative correction of the deficit. This behavior is reflected in Figure 3-14.
Figure 3-14. Fraction of Deficit Corrected by the Innovator versus Fractional Capacity Deficit at the Innovator

\[ FDCI.K = TABHL(TFDCI,FCDI.K,0,0.10,0.01) \]

\[ TFDCI* = 0/0/0.05/0.15/0.35/0.6/0.8/0.93/0.98/1.0/1.0 \]

\[ FCDI.K = DPCI.K/PCI.K \]

FDCI--Fraction of Deficit Corrected by the Innovator (dimensionless)
TFDCI--Table for Fraction of Deficit Corrected by the Innovator
FCDI--Fractional Capacity Deficit at the Innovator (dimensionless)
DPCI--Deficit in Production Capacity at the Innovator (units/month)
PCI--Production Capacity of the Innovator (units/month)

The deficit in production capacity is equal to the desired capacity less both actual installed capacity and the capacity on order, which will be installed later.

\[ DPCI.K = PCDI.K-PCI.K-PCOOL.K \]
DPCI—Deficit in Production Capacity at the Innovator (units/month)
PCDI—Production Capacity Desired by the Innovator (units/month)
PCI—Production Capacity of the Innovator (units/month)
PCO01—Production Capacity On Order by the Innovator (units/month)

The production capacity desired at the present is not the capacity which the firm wishes to have at this time; it is the amount which it believes that it will need at a time in the future at which it would receive capacity ordered now. The production capacity desired is made up of two terms, the future expected order rate and the capacity desired for backlog adjustment. The firm will wish to bring its backlog into line with its concept of a normal backlog. The rapidity with which it wishes to do so, after the necessary capacity has been received, determines the increment to capacity orders thus created. It is assumed that the innovator will wish to make the adjustment over a twelve-month period.

\[
PCDI \cdot K = EORI \cdot K \cdot (1/TDBAI) \cdot (BLI \cdot K - NBLI \cdot K)
\]

\[
TDBAI = 12
\]

PCDI—Production Capacity Desired by the Innovator (units/month)
EORI—Expected Order Rate to the Innovator (units/month)
TDBAI—Time for Desired Backlog Adjustment at the Innovator (months)
BLI—Backlog at the Innovator (units)
NBLI—Normal Backlog at the Innovator (units)

The normal backlog is equal to the months of sales desired in backlog times the average order rate.

\[
NBLI \cdot K = (MSDBI) \cdot (AORI \cdot K)
\]

NBLI—Normal Backlog at the Innovator (units)
MSDBI--Months of Sales Desired in Backlog by the Innovator (months)
AORI--Average Order Rate to the Innovator (units/month)

The average order rate will be taken as a four-month, first-order exponential smoothing of the order rate. Initially, it will be zero.

\[
AORI.K = AORI.J + (DT)(1/TAOI)(ORI.JK-AORI.J)
\]

75, L

\[
AORI=0
\]

76, N

\[
TAOI=4
\]

0, 75

AORI--Average Order Rate to the Innovator (units/month)
TAOI--Time to Average Orders at the Innovator (months)
ORI--Order Rate to the Innovator (units/month)

For the present it will be assumed that the expected order rate is based on a linear extrapolation of orders. In Chapter 4 the effects of different forecasting techniques will be examined.

Figure 3-15 explains the formulation of the forecasting procedures. If it is assumed that the order rate has been increasing linearly through time, the present is represented by point A. The average order rate, point B, is equal to the order rate TAOI (C, 75) months in the past. If the average order rate is smoothed for DAOFI (C, 78, 80) months, a value is obtained for point C. The difference between the average order rate AORI and the past average order rate PAORI is the change in the order rate during a period DAOFI. The change CHORI is divided by DAOFI to determine the average increase (or decrease) in the order rate each month, and this average change is multiplied by the forecast time FTI to arrive at the expected change in the order rate during the period of the forecast. This change ECORI, added to the average order rate AORI, gives the expected
Figure 3-15. Technique for Forecast
order rate at a time FTI in the future. \(^{12}\)

\[
\begin{align*}
\text{EORI}.K &= \text{AORI}.K + \text{ECORI}.K \\
\text{ECORI}.K &= (\text{FTI})(\text{CHORI}.K)/\text{DAOFI} \\
\text{FTI} &= \text{DRPC} \\
\text{DAOFI} &= 18 \\
\text{CHORI}.K &= \text{AORI}.K - \text{PAORI}.K \\
\text{PAORI}.K &= \text{PAORI}.J + (\text{DT})(1/\text{DAOFI})(\text{AORI}.J - \text{PAORI}.J) \\
\text{PAORI} &= 0
\end{align*}
\]

\(77, A\) \(78, A\) \(79, N\) \(C, 76, 81\) \(80, A\) \(81, L\) \(82, N\)

EORI—Expected Order Rate to the Innovator (units/month)
AORI—Average Order Rate to the Innovator (units/month)
ECORI—Expected Change in Order Rate to the Innovator (units/month)
FTI—Forecast Time at the Innovator (months)
CHORI—Change in Order Rate at the Innovator (units/month)
DAOFI—Delay in Averaging Orders for Forecast at the Innovator (months)
DRPC—Delay in Receipt of Production Capacity (months)
PAORI—Past Average Order Rate to the Innovator (units/month)

The forecast time FTI is equal to the delay in receiving production capacity DRPC because it is this delay which determines how far into the future the firm must look. DAOFI is selected as eighteen months because this seems a reasonable time to permit an examination of the long-term trend, relatively uncluttered by short-term fluctua-

\(^{12}\) As the diagram shows, the forecast is for FTI months from point B, so it is actually only (FTI - TAOI) months in the future. The firm, however, sees the average order rate AORI as the apparent state of affairs and would therefore believe that the forecast was actually for FTI months in the future.
tions, in the type of market studied. The initial past average order rate is zero, since there is no sales history.

If backlog is at its normal value, the delivery delay quoted will equal the months of sales desired in backlog MSDBI (C, 63, 74, 83). One month of sales in backlog means that it is taking one month, on the average, to fill an order. If the backlog is different from normal, there will be an additional increment, which may be positive or negative, reflecting the time necessary to work off the present excess backlog with the production capacity available. The increment is equal to the excess backlog divided by the production capacity. 13

\[ \text{DDQI}_K = \text{MSDBI} + \left( \frac{1}{\text{PCI}_K} \right) (\text{BLI}_K - \text{NBLI}_K) \]

83, A

\begin{align*}
\text{DDQI} & \quad \text{Delivery Delay Quoted by the Innovator (months)} \\
\text{MSDBI} & \quad \text{Months of Sales Desired in Backlog by the Innovator (months)} \\
\text{PCI} & \quad \text{Production Capacity of the Innovator (units/month)} \\
\text{BLI} & \quad \text{BackLog at the Innovator (units)} \\
\text{NBLI} & \quad \text{Normal BackLog at the Innovator (units)}
\end{align*}

\[\text{---}\]

13 It should be noted that although it is possible to operate at more than nominal capacity, the quotation is framed in terms of the nominal value.
3.4. The Pricing Sector of the Innovator (Figure 3-16)

Price will be treated as a continuously variable quantity. Two reasons justify the continuous treatment. First, and most important, price changes are not as discontinuous as they might at first appear. While catalog prices may follow a pattern of discrete jumps, very frequently discounts, extensions, or reductions of payment terms, variations in services offered, etc., cause the actual net price to vary in a much more continuous fashion than is obvious from looking at price lists. Second, even though some real discontinuities may exist, they will have no significant effect on the behavior of the system. The continuous value will closely approximate the alternative discontinuous one.

It will be assumed that management will at all times have a concept of a price which they feel is indicated for the product, considering the conditions which affect price. The actual price will be gradually adjusted to this indicated price if it is different. The formulation is accomplished by making the actual price a first-order, exponentially smoothed version of the indicated price. The smoothing time is twelve months, reflecting management's desire to avoid short-term, erratic variations in price.

PRII.K=PRII.J+(DT)(1/TFPCI)(IPRII.J-PRII.J) 84, L
TFPCI=12 84, C

PRII --PRICE at the Innovator (dollars/unit)
TFPCI--Time For Price Change at +he Innovator (months)
IPRII--Indicated Price at the Innovator (dollars/unit)
Figure 3-16. Flow Diagram of the Pricing Sector of the Innovator
There are many different theories about establishing an introductory price. For the basic system model, a practice apparently quite common in the electronics industry will be followed -- that of introducing a product at a price which is well above the price expected in the mature market. Two dollars per unit is selected for the basic system, but it is defined by means of a constant so that it can be easily varied and the effects of different initial prices tested.

PRII=IPI 85, N
IPI=2.00 C, 85

PRII--PRIce at the Innovator (dollars/unit)
IPI --Initial Price at the Innovator (dollars/unit)

The present price of a product is a strong determinant of the future price. The same conditions of product cost, fraction of capacity at which the firm is operating, and price of the competitors' products would indicate to most managers a different price change if the present price is one dollar per unit than it would if the present price were ten dollars per unit. The indicated price is therefore formulated as a fraction (which may be more or less than unity) of the present price.

IPRII,K=(PRII,K)(1+FCPII,K) 86, A

IPRII--Indicated PRIce at the Innovator (dollars/unit)
FCPII--Fractional Change in Price Indicated at the Innovator (dimensionless)
PRII --PRIce at the Innovator (dollars/unit)

When a firm first introduces a new product, unit costs are typically quite high, and there is a considerable amount of ex-
cess capacity. At a later stage in the growth phase, such conditions would very likely lead to price changes, but until sales have developed to a point where market reaction is meaningful, a firm will tend to stick with this initially established price. This is done here by modifying the ratio of indicated price to present price by an allowance for market growth.

FCPII.K = (AIMGI.K)(RIPPI.K-1) 87, A

FCPII—Fractional Change in Price Indicated at the Innovator (dimensionless)
AIMGI—Allowance for Initial Market Growth at the Innovator (dimensionless)
RIPPI—Ratio of Indicated to Present Price at the Innovator (dimensionless)

The ratio of the average order rate AORI (75, L) to the initial production capacity PCI (C, 65, 89) will be taken as a measure of the market growth. When the average order rate is low relative to the firm's initial capacity, the firm will be relatively insensitive to the pressures of cost and excess capacity, expecting that these problems will be alleviated as the market becomes more aware of the product and begins to accept it. As the orders increase, the firm will begin to accept their conditions as being more indicative of a continuing state of affairs, and less indicative of the problems of introducing a product. By the time that their average order rate has increased to several times the initial capacity, the initial price will no longer be sacred, and changes will be based almost entirely upon present conditions. This relationship is shown in Figure 3-17.
Figure 3-17. Allowance for Initial Market Growth at the Innovator versus Fraction of Initial Production Capacity at the Innovator

In equation form:

\[ \text{AIMGI}.K = \text{TABHL}(\text{TAMG}, \text{FIPCI}.K, 0, 4.0, 0.5) \quad 88, A \]
\[ \text{TAMG} = 0/0/0.1/0.25/0.60/0.85/0.95/1.0/1.0 \quad C, 88, 150 \]
\[ \text{FIPCI}.K = \text{AORI}.K/\text{PCII} \quad 89, A \]

AIMGI -- Allowance for Initial Market Growth at the Innovator (dimensionless)
TAMG -- Table of Allowance for Market Growth
FIPCI -- Fraction of Initial Production Capacity at the Innovator (dimensionless)
AORI -- Average Order Rate to the Innovator (units/month)
PCII -- Production Capacity, Initial, of the Innovator (units/month)

Three factors are dominant in the decision to change price.

These are:

1) the price difference between a firm and its competition,
2) the amount of over or under-capacity at the firm, and
3) the markup over cost, or profit margin.
There are other factors which may, from time to time, cause price changes, but those mentioned are probably the most important. Almost all price changes are the result of one or more of these, although in some cases the effect may be indirect, and the model is limited to the consideration of these factors only.

The ratio of indicated to present price RIPPI is a product of the multiplicative effects of these factors.

\[ \text{RIPPI}_K = (\text{PMVI}_K)(\text{PMCI}_K)(\text{PMMCI}_K) \]

\( \text{RIPPI} \) -- Ratio of Indicated to Present Price at the Innovator (dimensionless)
\( \text{PMVI} \) -- Price Multiplier due to Volume at the Innovator (dimensionless)
\( \text{PMCI} \) -- Price Multiplier due to Competition at the Innovator (dimensionless)
\( \text{PMMCI} \) -- Price Multiplier due to Markup over Cost at the Innovator (dimensionless)

The existence of excess capacity will generate strong pressures to cut price. Figure 3-18 shows a plausible relationship between the fraction of the present price to which management expects to adjust price and the extent of capacity utilization. The figure as sketched shows that they are just satisfied with the present price when operating at full capacity. This would vary from one firm to another. An aggressive firm might wish to reduce price even at full capacity, expecting to expand the capacity if there is an increase in orders. A conservative firm might prefer to bear 20 to 30 percent unused capacity before cutting price. The relationship saturates at both extremes, since at any given price management views the possible range of prices as being in a band around the present price. If the present price is $1.00 per unit, no co-
ditions can be sufficiently extreme to indicate a rapid change to $100 or $0.01 per unit. The curve as drawn is assymetrical, reflecting the greater ease of reducing prices than of raising them. The fraction of full capacity at which the innovator is operating is given by the ratio of the average order rate AORI (75, L) to the production capacity PCI (64, L).

Figure 3-18. Price Multiplier due to Volume at the Innovator versus Fraction of Full Capacity at the Innovator

PMVI.K=TABHL(TPMVI, FFCI.K, 0, 1.5, 0.125) 91, A

TPMVI*=0.25/0.25/0.27/0.3/0.4/0.65/0.85/0.95/1.0/
1.05/1.075/1.075/1.075 91, C
Almost every firm considers the prices being changed by their competition an important determinant of the price which they will change. Firms vary greatly, however, in their sensitivity to the competitors' prices. The relationship assumed here, and sketched in Figure 3-19, represents a firm quite sensitive to small or moderate price decreases, meeting them exactly, but becoming more independent if the price decreases are very large. A price gap can create only so much excitement, and the firm will be cautious about following drastic price cuts. On the increase side, the firm is assumed to be only mildly inclined to follow. The two dotted lines in the figure represent two commonly discussed extremes -- the pure leader and the pure follower. The pure leader is completely insensitive to the prices being changed by other firms, and sets his prices entirely upon the situation at his own factory. The follower,

14 A better formulation here would be an average of the ratio of the shipment rate desired SRDI (63, A) to the production capacity. The formulation as given neglects the fact that a high backlog may keep the firm operating at full capacity for a time after capacity exceeds the average order rate. A simulation was performed with the alternate formulation, with the result that the price rose to a higher value and fell more slowly.
on the other hand, will meet any price change exactly.

Figure 3-19. Price Multiplier due to Competition, at the Innovator versus Ratio of Prices at the Innovator

PMCI.K = TABHL(TPMCI, RPI.K, 0, 1, 2, 0.1)  
TPMCI* = 0.4/0.4/0.4/0.425/0.45/0.525/0.6/0.7/0.8/0.9/  
1.0/1.0375/1.05  
RPI.K = PRIC.K/PRII.K  

PMCI -- Price Multiplier due to Competition, at the Innovator (dimensionless)  
TPMCI -- Table for Price Multiplier due to Competition, at the Innovator  
RPI -- Ratio of Prices at the Innovator (dimensionless)  
PRIC -- Price at the Competition (dollars/unit)  
PRII -- Price at the Innovator (dollars/unit)

The third factor determining the indicated price is the effect of the markup over cost. Most firms have some strong feeling about
the markup appropriate for their products. In fact, it is traditional in many industries to have profit margins within a certain limited range. If the price of a product results in a margin close to this normal figure, there is little pressure to change price. If, however, the markup is low, strong pressures are typically generated for a price increase, if this is at all feasible. On the other hand, a markup greater than the traditional one will create pressure for a price cut. This pressure arises from fears of alienating customers by overcharging them, or from attracting competition, or simply from traditions. Traditions are powerful forces, and it is not too unusual to find prices being cut simply because they are "too high". The pressure for a price cut does not, however, become as great as does the pressure for a price increase, as shown in Figure 3-20. A markup of 50 percent is taken as the value for which there is complete indifference to a price change.

The fractional markup is the profit margin in dollars per unit -- the price less the cost -- divided by the cost per unit.

\[
PMMCI.K = \text{TABHL}(TPMMI, FMCI.K, -0.25, 0.75, 0.125) \quad 95, A
\]

\[
TPMMI* = 1.5/1.35/1.2/1.12/1.07/1.03/1.0/0.97/0.95 C, 95
\]

\[
FMCI.K = (PRII.K - UCI.K)/UCI.K \quad 96, A
\]

\[
PMMCI -- \text{Price Multiplier due to Markup over Cost at the Innovator (dimensionless)}
\]

\[
TPMMI -- \text{Table for Price Multiplier due to Markup at the Innovator...}
\]

\[
FMCI -- \text{Fractional Markup over Cost at the Innovator (dimensionless)}
\]

\[
PRII -- \text{Price at the Innovator (dollars/unit)}
\]

\[
UCI -- \text{Unit Cost at the Innovator (dollars/unit)}
\]
Figure 3-20. Price Multiplier due to Markup over Cost at the Innovator versus Fractional Markup over Cost at the Innovator

Unit cost as defined here is somewhat different than that which would normally be arrived at by an accountant. For the purposes of making a price decision, it is assumed that the product in question is the sole output of the firm. All costs of doing business -- overhead, labor, materials, marketing, etc. -- are summed and divided among the units produced. The formulation is simplified still further by aggregating all costs into the headings of market development, labor, and overhead (which includes everything else), and defining a normal value for these
costs which would exist when the firm is operating at full capacity. This neglects the fact that some costs are dependent upon things other than capacity utilization, but the relationship should be sufficiently accurate for the purposes of price setting.

A policy of budgeting market development effort as a percent of dollar sales was assumed earlier, so the marketing costs per unit can be found as the product of the fraction of sales to market development FSMDI (C,55,97) and the price PRII (84, L). The labor cost per unit is equal to the minimum labor cost modified by the efficiency multiplier for labor content. Likewise, the unit overhead cost is given by the minimum overhead cost per unit and the efficiency multiplier of overhead content.

\[ UCI.K = (FSMDI)(PRII.K) + (ELCI.K)(MLC) + (EOCI.K)(MOC) \]

\( UCI \) -- Unit Cost at the Innovator (dollars/unit)
\( FSMDI \) -- Fraction of Sales to Market Development at the Innovator (dimensionless)
\( PRII \) -- Price at the Innovator (dollars/unit)
\( ELCI \) -- Efficiency multiplier for Labor Content at the Innovator (dimensionless)
\( MLC \) -- Minimum Labor Cost (dollars/unit)
\( EOCI \) -- Efficiency multiplier for Overhead Cost at the Innovator (dimensionless)
\( MOC \) -- Minimum Overhead Cost (dollars/unit)

The minimum labor cost MLC and minimum overhead cost MOC are chosen to be consistent with previously established parameters. MLC is selected as $0.40 per unit and MOC as $0.30 per unit. At a price of $2.00 per unit, the initial price, marketing costs are $0.20 per unit, for a total cost of $0.90.
MLC = 0.40
MOC = 0.30

MLC--Minimum Labor Cost (dollars/unit)
MOC--Minimum Overhead Cost (dollars/unit)

At very low capacity utilization, labor costs will be somewhat above the minimum, because of the indivisibility of certain kinds of jobs and the low efficiency of production when there is little pressure for it. As activity approaches a reasonable level, labor costs fall to the minimum or very close to it. This is under the assumption that labor can be obtained or released quickly. As production begins to exceed nominal capacity, however, wage premiums and inefficiencies due to overcrowding, inadequate supervision, rush orders, etc., rapidly drive the costs upward. Figure 3-21 shows the relationship.

ELCI.K = TABLE(TELC, LPCI.K, 0, 1.2, 0.1) 98, A

TELC* = 1.1/1.05/1.025/1/1/1/1/1/1/1/1.1/1.4 C, 98, 160

ELCI--Efficiency multiplier of Labor Content at the Innovator (dimensionless)
TELC--Table for Efficiency of Labor Content
LPCI--Loading of the Production Capacity at the Innovator (dimensionless)

Unit overhead costs are at a maximum when very few units are being produced, for overhead, as defined here, is made up of costs which are either fixed, or very nearly so, for a given production capacity, or constant per unit of output, such as material costs. Since the fixed costs are spread over more and more units as production increases, the unit overhead cost will continually decline, as shown in Figure 3-22.
**Figure 3-21. Efficiency Multiplier of Labor Content at the Innovator versus Load on Production Capacity at the Innovator**

**Figure 3-22. Efficiency Multiplier of Overhead Content at the Innovator versus Loading of Production Capacity at the Innovator**
EOCI.K = TABLE(TEOC, LPCI.K, 0, 1.2, 0.1)

TEOC* = 3/2.6/2.3/2/1.8/1.6/1.4/1.25/1.15/1.05/1/0.97/0.95

EOCI--Efficiency multiplier of Overhead Content at the Innovator (dimensionless)
TEOC--Table for Efficiency of Overhead Content
LPCI--Loading of Production Capacity at the Innovator (dimensionless)

The combined effect of the preceding two curves is to cause the cost to be high when capacity is greatly underutilized, to fall to a minimum at nominal capacity, and rise again as production exceeds nominal capacity. This behavior fits very well a description of the process by Harlan, Christenson, and Vancil.

"The incremental cost of the very first units may be quite high as a result of the necessity to hire a minimum staff and provide certain facilities. Once the minimum staff and facilities are provided, incremental cost will be less than average cost and may, in fact, be nearly constant over a considerable range of output. With increasing output, however, incremental cost may begin to rise. To produce the higher output, it may be necessary to press less efficient facilities into service, hire inexperienced workers, and cope with the difficulties created by a crowded plant. When plant capacity is reached, additional output may require the payment of overtime or night shift premiums or of subcontract costs."  

The formulation is an essentially static one, because at a given loading of the production capacity the unit cost due to labor and overhead is fixed. This neglects some of the dynamics of cost, but serves as a simple, reasonably accurate, approximation.

3.5. The Market Development Sector for the Competition (Figure 3-23)

It will be assumed that the competition will follow the same general market development policy as does the innovator, budget-

---

Figure 3-23. Flow Diagram of the Market Development Sector for the Competition
ing marketing efforts as a percent of sales. The innovator, however, when first entering the market, had no real information upon which to base introductory marketing efforts; it was necessary to simply arrive at a single figure on the basis of past experience and intuition. The competition, entering the market at a time when there is an indication of its probable size and character, has some information which can be used to determine a reasonable introductory effort.

The funds allocated to market development by the competition will consist of one component calculated as a certain fraction of dollar sales, and a second, introductory component based upon a fraction of the estimated sales potential. It is reasonable for a late entrant into a market to use an estimate of the sales which might be attained in order to gauge the expenditure which is economically justified.

\[
AFMDC_{KL} = (FESMC)(ESPC_{K}) + (FSMDC)(ASALC_{K})
\]

C, 103

\[
FESMC = 0.05
\]

C, 103

\[
FSMDC = 0.10
\]

C, 103

AFMDC—Allocated Funds to Market Development at the Competition (dollars/month)
FESMC—Fraction of Estimated Sales to Market development at the Competition (dimensionless)
ESPC—Estimated Sales Potential by the Competition (dollars/month)
FSMDC—Fraction of Sales to Market Development at the Competition (dimensionless)
ASALC—Average SALEs at the Competition (dollars/month)

The fraction of sales allocated to market development FSMDC will be assumed equal at the innovator and competition, and in therefore taken as 0.10. It is reasonable that a firm will be less willing to allocate funds on the basis of potential sales than on actual
sales, since potential sales may never be realized, and a value of 0.05 is taken for the fraction of estimated sales FESMC.

To obtain the estimated sales, in dollars, it is necessary only to multiply the estimated unfilled market by the price.

\[ \text{ESPC}_K = (\text{PRIC}_K)(\text{EUMAC}_K) \]

3.6 The Production and Capacity Acquisition Sector of the Competition (Figure 3-24)

The most important difference between the innovator and the competition is the difference between their production capacity acquisition policies. The innovator must install some initial capacity on the faith that there will be a demand for the product. The competition, on the other hand, installs capacity only when a demand for the product has been observed and it appears that the innovator is unable to satisfy all the demand. As discussed in Chapter 2, the study is based on the hypothesis that a delivery delay higher than that which seems normal for the type of product is an indication to the potential competitors that an unsatisfied demand exists.

The expected order rate at the competition is equal to the sum of the average order rate, the expected change during the time it takes to get capacity, and an estimate of the unfilled market.

\[ \text{EORC}_K = \text{AORC}_K + \text{EORC}_K + \text{EUMAC}_K \]
Figure 3-24. Flow Diagram of the Production and Capacity Acquisition Sector for the Competition
ECORC--Expected Change in the Order Rate at the Competition (units/month)
EUMAC--Estimate of the Unfilled Market affecting Action at the Competition (units/month)

The first two terms of this formulation are identical to the formulation for the expected order rate at the innovator. These first two terms represent the expectations held by those competitors who have already entered the market. The competition sector is an aggregate of those competitors already in the market, and the potential competitors who are considering entry. It is reasonable that the competitors already committed to producing the product will make their expansion plans in the same way as does the innovator. The orders which a firm is receiving, and the trend of these orders, create strong pressures for the control of expansion. A firm not yet in the market must instead base the decision to enter upon an estimate of the remaining available market.

The inclusion of the entire estimate of the unfilled market might be subject to question. It might seem reasonable that the competition would expect to get only a part of the unfilled market, with some going to the innovator. On the other hand, some of the more aggressive competitors might expect to get not only the unfilled market, but also to capture part of the innovator's present share. It is therefore reasonable to take the exact estimate as a close measure of the expectations.

Entry into a new market is a major step for a firm to take. For this reason, it is unlikely that decisions will be based on an estimate of the unfilled market derived from the immediate conditions, but instead the actions would be based on a delayed value of
the estimate. In addition to the delay for becoming more sure of the conditions, there are numerous other delays between the making of an estimate and the taking of action. All of these delays are aggregated into the time for the decisions to take action on the estimate TDAEC. This is likely to be in the neighborhood of a year for new electronic products.

\[EUMAC\cdot K = EUMAC\cdot J + (DT)(1/TDAEC)(EUMC\cdot J - EUMAC\cdot J)\]

EUMAC = 0

TDAEC = 12

EUMAC -- Estimate of the Unfilled Market affecting Action at the Competition (units/month)
TDAEC -- Time for the Decisions to take Action on the Estimate at the Competition (months)
EUMC -- Estimate of the Unfilled Market at the Competition (units/month)

The competition has an idea of the size of the market at a given time, and an estimate of the unfilled market as a fraction of the present market. The concept of present market size is the total of the observed shipments of both the innovator and the competition already in production.

\[EUMC\cdot K = (EFMU\cdot K)(ASIOC\cdot K + ASCOC\cdot K)\]

EUMC -- Estimate of the Unfilled Market at the Competition (units/month)
EFMU -- Estimated Fraction of present Market Unfilled (dimensionless)
ASIOC -- Average Shipments by the Innovator as Observed by the Competition (units/month)
ASCOC -- Average Shipments by the Competition as Observed by the Competition (units/month)

It is not too difficult for a potential competitor to learn the sales of a product, but it does take time. Here the observed
shipments are taken as a six-month delayed version of the actual shipments.

\[
\text{ASIOC.K} = \text{ASIOC.J} + \left( \frac{1}{\text{TCOSI}} \right) \left( \text{SSI.JK-ASIOC.J} \right)
\]

\[
\text{ASIOC} = 0
\]

\[
\text{TCOSI} = 6
\]

\[
\text{ASIOC}\ --\text{Average Shipments by the Innovator as Observed by the Competition (units/month)}
\]

\[
\text{TCOSI}\ --\text{Time for Competition to Observe Shipments by the Innovator (months)}
\]

\[
\text{SSI} --\text{Shipments Sent by the Innovator (units/month)}
\]

At first, it might seem that the shipments by the competition could be observed more quickly by the competition, but it is quite evident that it takes just as long for a competitor considering entry into the market to observe the shipments of a competitor already producing as it does to observe the shipments of the innovator. To a potential competitor looking in from the outside, there is no difference between the innovator and the other competitors.

\[
\text{ASCOC.K} = \text{ASCOC.J} + \left( \frac{1}{\text{TCOSC}} \right) \left( \text{SSC.JK-ASCOC.J} \right)
\]

\[
\text{ASCOC} = 0
\]

\[
\text{TCOSC} = 6
\]

\[
\text{ASCOC}\ --\text{Average Shipments by Competition as Observed by the Competition (units/month)}
\]

\[
\text{TCOSC}\ --\text{Time for the Competition to Observe Shipments by the Competition (months)}
\]

\[
\text{SSC} --\text{Shipments Sent by the Competition (units/month)}
\]

If the delivery delay for the new product is quite short -- as short as or shorter than would be expected for a mature product in the industry -- the competition is unlikely to expect the existence of any unfilled market. As the delivery delay lengthens and it becomes more obvious that the innovator is failing to fill
orders in a normal period of time, the competitors recognize that all of the customers are not getting the service which they might expect. As the delivery delay becomes extremely high, it ceases to have much of an effect on the estimate, for delivery delay alone can generate only a limited amount of confidence in the existence of an untapped market. Figure 3-25 shows this relationship.

![Graph showing the relationship between RDDN (Ratio of Delivery Delay to Normal) and EFMU (Estimated Fraction of Present Market Unfilled (Dimensionless)).]

**Figure 3-25. Estimated Fraction of the present Market Unfilled versus Ratio of Delivery Delay to Normal**

This relationship is simply the reflection of an estimate of the delivery delay multiplier effect on orders. For example, the estimate of 2.0 for the fraction of the market unfilled when the ratio of the delivery delay to normal is ten is another way of saying that there are twice as many customers not buying because
of the delay as there are customers willing to accept the delay. In other words, the delivery delay multiplier is one-third. Figure 3-26 shows the implicit estimate and the actual relationship.

Figure 3-26. Fraction of Market Willing to Accept the Given Delay versus Delivery Delay (Actual and Estimated)

The implicit estimate first overestimates and then underestimates the effect of delivery delay. This is reasonable, because the competition will probably reason that some of the present customers are being discouraged and, in addition, if these customers started using the product still more customers would become interested. This would explain the overestimate, and the underestimate for very high delays is simply the result of failing to fully recognize how important delivery delay can be.
The equations for this estimate are:

\[ \text{EFMU}.K = \text{TABHL(TEFMU, RDDN}.K, 0, 10, 1) \]  
\[ \text{TEFMU} = 0/0/0.10/0.25/0.5/0.8/1.2/1.5/1.75/1.9/2.0 \]  
\[ \text{RDDN}.K = \text{DDOPC}.K / \text{DDN} \]

\[ \text{EFMU} -- \text{Estimated Fraction of the present Market Unfilled (dimensionless)} \]
\[ \text{TEFMU} -- \text{Table for Estimated Fraction of present Market Unfilled} \]
\[ \text{RDDN} -- \text{Ratio of Delivery Delay to Normal (dimensionless)} \]
\[ \text{DDOPC} -- \text{Delivery Delay Observed by Potential Competition (months)} \]
\[ \text{DDN} -- \text{Delivery Delay considered Normal (months)} \]

It would be reasonable for the competition to consider as a normal delay the number of months of sales which they would expect to carry in backlog.

\[ \text{DDN} = \text{MSDBC} \]

\[ \text{DDN} -- \text{Delivery Delay considered Normal (months)} \]
\[ \text{MSDBC} -- \text{Months of Sales Desired in Backlog by the Competition (months)} \]

The instantaneous value of delivery delay is no more available to the competition than it is to the market. Therefore, the delay acted upon will be an observed value, which is formulated as a first-order delayed version of the actual aggregate delay.

\[ \text{DDOPC}.K = \text{DDOPC}.J + (\text{DT})(1/\text{TPCOD})(\text{ADD}.J - \text{DDOPC}.J) \]  
\[ \text{DDOPC} = 0 \]  
\[ \text{TPCOD} = 6 \]

\[ \text{DDOPC} -- \text{Delivery Delay Observed by Potential Competition (months)} \]
\[ \text{TPCOD} -- \text{Time for Potential Competition to Observe Delay (months)} \]
\[ \text{ADD} -- \text{Aggregate Delivery Delay (months)} \]
The time for the potential competition to observe the delivery delay TPCOD is, at six months, somewhat longer than the time for the market to observe the delay TODD (C, 42, 44). This is to reflect the greater caution which the competitors are likely to use, considering the importance which this observation holds for them.

The aggregate delivery delay for all firms selling the product is the important influence on the potential competition. A weighted average can be found by multiplying the delivery delays of the innovator and the competition by their respective market shares.

\[
ADD.K = (FPOI.K)(DDQI.K) + (FPOC.K)(DDQC.K)
\]

ADD --Aggregate Delivery Delay (months)
FPOI--Fraction of market Placing Orders with the Innovator (dimensionless)
DDQI--Delivery Delay Quoted by the Innovator (months)
FPOC--Fraction of market Placing Orders with the Competition (dimensionless)
DDQC--Delivery Delay Quoted by the Competition (months)

3.7 The Pricing Sector of the Competition (Figure 3-27)

The pricing sectors of the innovator and the competition are nearly identical. The one difference is that the competition is sensitive to the price charged by the innovator even before their entry into the market. The price which the competition will charge at the time they enter the market will be dependent upon the price which the innovator is charging at the time. It is unlikely that the competition would introduce the product at $3.00 when the innovator was selling for $1.00, although the reverse of this might be possible.
Figure 3-27. Flow Diagram of the Pricing Sector of the Competition
The indicated price at the competition is equal to the present price times the price multiplier due to competitive prices and one plus the fractional change in price indicated.

\[
\text{IPRIC}.K = (\text{PRIC}.K)(\text{PMCC}.K)(1 + \text{FCPIC}.K)
\]

IPRIC -- Indicated Price at the Competition (dollars/unit)
PRIC -- Price at the Competition (dollars/unit)
PMCC -- Price Multiplier due to Competition, at the Competition (dimensionless)
FCPIC -- Fractional Change in Price Indicated at the Competition (dimensionless)

The fractional change in price indicated is formulated identically for the innovator and competition, while the ratio of indicated to present price differs only in the number of terms -- it does not include the multiplier from competitive prices which was included.

\[
\text{FCPIC}.K = (\text{AIMGC}.K)(\text{RIPPC}.K - 1)
\]

\[
\text{RIPPC}.K = (\text{PMVC}.K)(\text{PMMCC}.K)
\]

FCPIC -- Fractional Change in Price Indicated at the Competition (dimensionless)
AIMGC -- Allowance for Initial Market Growth at the Competition (dimensionless)
RIPPC -- Ratio of Indicated to Present Price at the Competition (dimensionless)
PMVC -- Price Multiplier due to Volume at the Competition (dimensionless)
PMMCC -- Price Multiplier due to Markup over Cost at the Competition (dimensionless)

By comparing the preceding three equations with the equivalent equations for the innovator (equations 86, A, 87, A, and 90, A), the reader can see that the net change consists simply of eliminating the effect of the allowance for initial market growth AIMGC on the multiplier due to competitive prices PMCC. Thus the competitors will adjust their price to meet that of the innovator even before they have received their first orders.
CHAPTER 4

The Behavior of the Model

The behavior of the model described in Chapter 3 is examined in this chapter. Section 4.1 describes the behavior of the basic model. Section 4.2 demonstrates the effects of various changes in parameters and structure on model behavior, and should isolate some of the more important determinants of behavior. In section 4.3 some of the managerial policies of the innovative firm will be changed in an attempt to improve its success in the market. These policies will be tested, and some of their limitations will be discussed.

4.1 The Behavior of the Basic System

Two simulations of the basic system will be described in this section. The model is a closed system and needs no exogenous input. The Chapter 3 formulation neglected, however, the fact that decisions are not always made in exactly the same way, or do not always give the same result, even if the conditions surrounding them are the same. In a real world system there are many elements of randomness. Decisions are not always made in the same way, delays are not constant, and some variables can take on only certain discrete values. Weather, illness, vacations, and numerous other factors are constantly disturbing the system. In addition to a noise-free run showing the underlying behavior which would be visible in the absence of random disturbances, a run showing the ef-
fects of this randomness is included.

The Basic Model (Figure 4-1)

This run exhibits behavior very similar to that described in Chapter 2 as a typical pattern of growth. The introductory marketing efforts to the innovator create some awareness of the product, and the innovator begins to receive a few orders. These orders quickly exceed the small initial production capacity at about month 17. Because of the delays for the recognition of the need for additional capacity, the time to place orders after the need is recognized, and the time to receive and install the new capacity, the production capacity does not even begin to increase for 9 months. Backlog begins to increase, and delivery delay climbs rapidly to a peak of over twelve months occurring at the twenty-eighth month. The oscillations which occur in the delivery delay are the result of the delays around loop B in Figure 4-2.1 There is a delay for the customers to recognize the actual delivery delay. During this time orders continue to flow into backlog, and the delay continues to climb. As the high delivery delay is recognized, customers reduce their ordering. Backlog and delivery delay start to fall. This time, however, the delay in observing the delivery delay causes the apparent value to exceed the actual value during the period over which the delay is falling, and the customers reduce

1 Figure 2-3 reproduced.
Figure 4-1. Behavior Without Noise
Figure 4-2. The Important Loops Controlling System Behavior
their ordering beyond the point where those continuing to order
would just be satisfied with the actual value. As the lower de-

delivery delay causes the order rate to increase once again, the
cycle repeats.

The increasing order rate and the high delivery delay lead to
an estimate by the competition that a substantial unfilled market
exists. There is a delay for the competition to take action on
the basis of the estimate, and this delay, plus the delays for
ordering, receiving, and installing production capacity, causes
an 18 month lag between the estimate and the capturing of a share
of the market by the competition. Between months 34 and 44 the
delivery delay of the competition increases rapidly. The high
delivery delays of the innovator make it very easy for the com-
petition to get orders, and the order rate increases faster than
capacity can be installed. Because the potential order rate to
the competition is less than the rate to the innovator during this
period, the competitors' delivery delay does not become as great
as does the innovator's.

Figure 4.3 shows the customers' awareness of the product as
a function of time. Over the first ten years the growth is very
nearby exponential, and the compound growth rate is approximately
40 percent per year. As discussed in Chapter 2, the exponential
growth is a result of the expansion of the information flow to
the market. A policy of budgeting promotion as a fraction of sales
means that an increase in sales leads to an increase in promotion
which then further increases sales. At the same time, as more cus-
tomers begin to use the product, the probability of a potential cus-
Figure 4-3. Potential Customers Aware of the Product as a function of Time
omer not yet aware of it either seeing it in use or hearing of it increases. The structure of the market thus creates strong positive feedback which will cause the growth to be exponential until saturation is approached. When saturation does occur, it comes rapidly. The constantly increasing awareness keeps the fraction of the customers becoming aware of the product increasing, and this causes the rate at which they are becoming aware to remain high until there are very few potential customers left. The rate then rapidly falls to zero as there are no potential customers left to interest. As a result, any forecasting method which involves an extrapolation of past data is very likely to result in excess capacity or a price reduction to increase volume to capacity. Whether the forecast is linear, exponential, or based on a more complex assumption, overshooting is almost a certainty if the time to get capacity, and therefore the length of the projection, is any significant fraction of the growth period.

When the competition first enters the market, the rate at which customers are captured is small, and it is almost independent of a price or delivery delay difference. There are always some customers willing to switch suppliers, for reasons either logical or illogical, and the factor limiting the number shifting is simply the awareness of the market to the existence of the alternate source of supply. The market share of the innovator falls slowly at first, but by month 60 the market is aware that the product is available from the competition and the delivery delay gap leads to a rapid attrition of the innovator's market share. The order rate
to the competition first exceeds the rate to the innovator at about month 93, even though the innovator has at this time a 70 percent share of the market. The much higher delivery delay at the innovator causes its customers to be more active in seeking and using substitute products.

The competitors' estimate of the unfilled market reaches a peak at about 118 months, long after delivery delay has begun to fall. The estimate is based not only upon delivery delay, but also upon industry sales, and the order rate must be large before the estimate becomes large. The production capacity order rate reaches a peak at 130 months, 12 months later, due to the delay between the estimate and the taking of action based upon it. At this point, the estimate accounts for 72 percent of the total capacity desired, with the expected order rate and the capacity desired for backlog adjustment accounting for the remaining 28 percent.

During the period in which delivery delay is high, from months 20 to 160, production capacity follows the order rates quite closely. This would seem to indicate that the forecasting was excellent, since the suppliers were able to have just the right amount of production capacity at just the time it was needed. This result is somewhat surprising as it does not seem likely that a linear forecast would be so accurate when the potential demand is

---

2 The order rates are very close to a constant 20 percent above nominal capacity. Because it is possible to produce at up to 20 percent above nominal capacity if the pressure for production is sufficiently great, the order rates and the maximum possible production are nearly identical.
growing exponentially, as shown in Figure 4-3. The fact that the competition was able to acquire 75 percent of the market indicates a weakness in such a superficial evaluation. Figure 4-4 shows the important factors relating to this situation. There are five feed-

Figure 4-4. Factors Determining the Relationship between the Forecast and the Order Rate

back loops in the above diagram, but the two loops marked are sufficient to explain the observed behavior. Looking first at loop 1, an increase in the order rate will lead to an increase in backlog, which in turn leads to an increase in delivery delay. The increased delivery delay causes the orders to decrease because it encourages substitution of other products and ordering from the competition. The mechanism which permits the order rate to grow is traced in loop 2. An increase in the order rate leads to a forecast for ad-
ditional increases, stimulating the ordering of more capacity. As the capacity becomes effective, the production rate can be increased, reducing backlog and delivery delay. This eliminates the restraining effect which the delay was having on the order rate, and the order rate can continue to grow.

Such a forecast will tend to be self-justifying. The first time a forecast leads to the ordering of less capacity than could actually be used, there will be, at some later time, insufficient capacity to handle the order rate. For a short time the order rate will exceed shipments and backlog and delivery delay will rise, causing the order rate to fall until it equals the production capacity. Once this balance has been reached, the order rate will equal the production capacity throughout the growth phase. If the order rate should get slightly above capacity, delivery delay will increase further and reduce orders; if order rate falls below capacity, delivery delay will fall and some of the customers who had been withholding their orders will place them, and the order rate will again rise to capacity. It is this structure which creates a situation in which the innovator, with a new and valuable product, can find its forecasts of demand extremely accurate during the period of growth, while at the same time most of the market is lost to competition.

Prices are increasing between months 24 and 110, and are generally falling after this time. The price rise is a result of the high volume of operation. A firm which is unable to produce the
quantity of goods demanded is much more likely to increase price than is a firm with a large amount of idle production capacity.\(^3\)

As mentioned in section 3.4, this may not show up as an increase in the publicly quoted price, but might show up in other ways, such as a reduction of generosity with discounts, the shifting of transportation costs to customers, or a reduction of customer services. Price is determined by a continually shifting balance of forces. Throughout this initial period of rising prices, there are pressures opposing a price increase, but they are simply not strong enough to outweigh the pressures in favor of the increase. Questions about the effect of increasing or exhorbitant prices on the long-term image of the firm held by the customers and fear of further encouraging competition are two factors which tend to discourage price increases even if it is possible to sell more at the present price than can yet be produced. By month 110 the extreme pressure on production capacity has begun to subside slightly, and the downward pressures on price start pulling it down. The fall is relatively slow at first, but as the potential customers are exhausted and growth no longer continues to be fed by falling delivery delay, about month 170, price begins to fall more rapidly.

\(^3\)This assumes, of course, that the firm believes that the demand for the product is relatively elastic. The steel industry is an example of the opposite situation. The industry apparently feels that demand will fall very little if price is increased, and total revenues will thus be increased.
From month 174 to month 208, the competition is saddled with a small amount (slightly over 3 percent) of excess capacity. The innovator's more conservative capacity ordering has prevented excess capacity and the competition thus becomes the leader in the price crash. The innovator follows to remain competitive. The falling price causes an expansion of demand which leads to full capacity once again at month 209. This continues until month 273 at which time the bottoming out of the price fall and the extrapolation of the trend in orders which the price reduction was causing combine to lead to overcapacity once again.

The overcapacity which occurs is slight, however, due to the elasticity of the demand curve. The market is saturated after approximately 180 months, to the extent that there are no more potential customers to take up use of the product, but the expansion of the order rate caused by falling price serves to utilize the excess capacity which would exist. Were the demand for the product much less elastic, price would fall faster and faster and the industry would still be left with a significant amount of unused capacity, as will be shown in section 4.2.

The model exhibits behavior similar to that observed in many product growth situations. The growth of the tantalum capacity market has followed much the same pattern, and transistors exhibited even more extreme behavior. At no time do any of the variables behave in a way which is implausible or contradictory. Since this study is not an attempt to duplicate a particular product growth
situation, but is trying only to examine some of the problems common to many of these situations, this general comparison is sufficient to establish the usefulness of the model. 4

The Basic Model with Noise (Figure 4-5)

The basic model was altered in this simulation so that the biweekly values of incoming order rate would be normally distributed about a varying mean. It might at first appear that the mean would be the order rate of the first basic model, but because this is a feedback control system, the mean is dependent upon the random variations during previous periods, and thus will not be identical to the order rate in Figure 4-1. The standard deviation is 20 percent 5 and a new random value is selected every one-half month.

Random variations occur many places other than in the order rate, and it might seem reasonable to permit variation at every place where it is likely to occur in the real system. This would be extremely laborious, however, and would not significantly change

4The previous acceptance of each of the individual equations as properly representing the cause and effect relationship between the variables was another form of validation. A model must not fail either of these tests.

5The absolute magnitude of the standard deviation therefore varies with the mean. The mean is the order rate which results from equations 50,R and 51,R.
Figure 4-5. Behavior With Noise
system behavior. The reason for stimulating the system with a random variation in the input is simply to test its sensitivity to high frequencies, insuring that the formulation does not react in an implausible manner to rapid variations of system variables. No such weakness is exposed.

The quantitative behavior of this run is very much like that of the noise-free run. The high frequencies are damped considerably by the long delays in the system. The most significant effect of the noise is the increase in industry overcapacity at saturation. While the noise-free run showed slightly more than 0.05 percent undercapacity for the industry at month 300, the noisy run showed approximately 11 percent overcapacity as an average for the months from 294 to 300. The overcapacity is caused by the combination of the forecasting and the irreversibility of the capacity expansion decision. When random variations cause the order rate to exceed the long-term mean for a period of time, extrapolation of the apparent trend causes capacity to be ordered in excess of that needed to handle the average order rate. As there is no compensating reduction when orders fall below capacity, excess capacity will exist in the long run.

This excess capacity creates a downward pressure on prices, and they fall further because of it. They are still falling very slowly at the end of both runs, but have almost reached steady-state values. Ending prices at the innovator are $1.278 per unit in the noise-free case and $1.147 in the noisy case, with the prices at
the competition about $0.008 lower in both cases. At the same time, costs per unit produced run slightly higher -- about one cent per unit -- due to the excess capacity. The lower prices have, of course, increased the demand, and dollar sales have changed very little.

The only other difference of any significance is in the behavior of the market shares. This run shows, at the end of the simulation, 30.6 percent of the market purchasing from the innovator as compared with a value for FPOI of only 25.1 percent in the noise-free run. This is a gain of 21.9 percent from the point of view of the innovator. The noise causes frequent variations in the prices and delivery delays after the end of the major growth phase. The alternating periods of advantage and disadvantage give, in the net, an opportunity for the innovator to regain some of the customers lost during the period of rapid growth. The innovator did not have this opportunity in the noise-free system because delivery delays were exactly equal after saturation, and price was always lower at the competition because of the greater excess capacity there.
4.2 Other Modes of System Behavior

The runs in this section fall into three categories. First, there is a group of runs in which major changes in a number of parameters cause behavior of a different character than that of the basic model. Included are runs exhibiting behavior similar to the possible modes described in Chapter 2. Second, certain parameter values which are of special interest are changed in a demonstration of system sensitivity. Finally, some parameter changes which lead to improved behavior are discussed.

Market Highly Sensitive to Delivery Delay (Figure 4-6)

This run shows the effect of a very high sensitivity to delivery delay at the market. Loop B (Figure 4-3) nearly dominates the behavior. Any increase in delivery delay causes a drastic reduction in orders. Such a situation might occur when prompt delivery of the end product using the components was essential and substitute products were very readily available. In addition, customers shift very rapidly to whichever supplier has the smallest delivery delay, and base this action on the most recent month's quote of the delay instead of an average service time exhibited over a period of several months.\(^6\)

\(^6\)The values in the basic run were:

\[
\begin{align*}
\text{TFCID}^* &= 0.15/0.135/0.10/0.05/0.001/0.0005/0.0005/0.0005 \\
\text{TFCCD}^* &= 0.0005/0.0005/0.0005/0.001/0.05/0.10/0.135/0.15 \\
\text{TODD} &= 3 \\
\text{TDM}^* &= 1/1/0.98/0.9/0.8/0.67/0.5/0.35/0.25/0.15/0.1/0.07/0.05
\end{align*}
\]

The changes were:

\[
\begin{align*}
\text{TFCID}^* &= 0.15/0.135/0.10/0.05/0.001/0.0005/0.0005/0.0005 \\
\text{TFCCD}^* &= 0.0005/0.0005/0.0005/0.001/0.05/0.10/0.135/0.15 \\
\text{TODD} &= 3 \\
\text{TDM}^* &= 1/1/0.98/0.9/0.8/0.67/0.5/0.35/0.25/0.15/0.1/0.07/0.05
\end{align*}
\]

(Footnote to be continued)
Figure 4-6. Behavior With Market Highly Sensitive to Delivery Delay
Growth is significantly slowed in this run, taking approximately 40 months (25 percent) longer to reach saturation. As the order rate first exceeds production capacity and causes delivery delay to rise, the greater sensitivity acts as a brake on further increases in the order rate. The amount of production capacity apparently necessary is therefore less, and less is ordered. Because the delivery delay cannot fall until production exceeds orders, it remains high, and order rate continues to be held down. In addition, the reduced sales rate results in less exposure of the product and a lower market development budget, reducing the growth of demand through loop A.

Forecasting appears to be excellent in this simulation. The order rate is controlled by the capacity available, just as it was in the basic run, but the high sensitivity to delivery delay tends to keep it even more closely in line. The delivery delay at the competition is remarkably constant from month 48 to month 140 as every increase in capacity is rapidly followed by an increase in the order rate, as the result of attracting customers away from either the innovator or substitute products.


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6 (Footnote continued from previous page)

TFCID* = 0.45/0.40/0.20/0.10/0.001/0.0005/0.0005/0.0005 C, 38

TFCCD* = 0.0005/0.0005/0.0005/0.0001/0.10/0.20/0.40/0.45 C, 39

TODD = 1 C, 42, 44

TDM* = 1.0/1.0/0.9/0.6/0.3/0.1/0.05/0.02/0.01/0.01/0.01/0.01/0.01 C, 48, 49

TFCID - Table for Fraction Changing to Innovator because of Delivery
TFCCD - Table for Fraction Changing to Competition because of Delivery
TODD - Time to Observe Delivery Delay (months)
TDM - Table for Delivery Multiplier
The final market shares are almost identical with those found in the basic run. This is a result of the approximate canceling out of several opposing factors. The lower average value of the delivery delays makes the market seem less attractive to competition and entry is less aggressive. Also, the slower growth rate improves the chances for the innovator to keep up with demand. On the other hand, the greater sensitivity to delivery delay means that the competition will gain more customers with a smaller delivery delay advantage, and the long period of high delivery delays prolongs the opportunity to do so.

**Slow Market Acceptance with Short Time to Get Capacity (Figure 4-7)**

Here is a situation in which capacity is no longer limiting the growth. The limiting factors are simply the time necessary for the potential customers to notice and to accept the market development efforts of the supplier, the time to take an interest in the product, and the time to learn how to use it and to develop uses for it.  

---

7The original values were:

TFBAP*=0.0/0.015/0.04/0.1/0.21/0.3/0.36/0.39/0.4/0.4  

C, 12

DLUP = 36  

C, 18

DRPC = 4  

C, 66, 79, 115, 128

The following changes in parameters were required:

TFBAP*= 0.0/0.0075/0.02/0.05/0.105/0.15/0.18/0.195/0.2/0.2  

C, 12

(Footnote to be continued)
Figure 4-7. Behavior With Slow Market Acceptance
and a Short Time to Get Capacity
The delivery delay at the innovator rises early in the growth phase, but not nearly as high as in the basic model, and it is brought under control much earlier. The innovator keeps a much larger share of the market because of this.

The competition overestimates the immediate potential for sales early in the growth phase (months 40 to 60) and orders a large excess of production capacity. Fearful of being stuck with useless investment, they drastically reduce prices both to increase industry demand and to capture a larger share of the orders going to the innovator. The innovator follows shortly, but the combination of continued market growth and at least partial success in creating additional demand leads to greater utilization of capacity, and prices begin to climb slowly for the remainder of the growth phase.

The estimate of the unfilled market EUMC contributes little to the ordering of production capacity in comparison with its contribution in the basic system. At its first peak (month 80), it accounts for 35 percent of the production capacity order rate (not shown) and at the second peak (month 194) the figure is only 2.3 percent. This compares with a maximum of 72 percent in the basic run.

In terms of what is occurring in the real world, this indicates that there will be far fewer competitors when the market growth

7 (Footnote 7 continued)

DLUP = 36

DRPC = 4

TFBAP - Table for Fraction Becoming Aware of the Product
DLUP - Delay for Learning to Use the Product (months)
DRPC - Delay for Receipt of Production Capacity (months)
is slow. Some competition enters early in the growth phase, but after that the gains by the competition occur as the early entrants expand these shares. In the basic run much of the market lost by the innovator went to new competitors entering relatively late in the growth phase.

The slow rate of market growth and the short forecasting period which the short delay in receiving capacity allows combine to produce no excess capacity upon the market saturation.

Rapid Market Acceptance with Long Time to Get Capacity (Figure 4-8)

The conditions for the simulation are exactly the opposite of the conditions for the previous examples. The delays around loop C (see Figure 4-2) are very long while those around loop A are quite short. Customers are very eager and ready to accept the product and will do so given a minimum of information about it. They can learn to use it and incorporate it into their production rapidly. On the other hand, the suppliers can expand their production capacity only very slowly, due to the long time required to receive and to install it. This might occur if the

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8 The values of these parameters in the basic run were:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TFBAP*</td>
<td>0.0/0.015/0.04/0.1/0.21/0.3/0.36/0.39/0.4/0.4/0.4</td>
</tr>
<tr>
<td>DLUP</td>
<td>18</td>
</tr>
<tr>
<td>TEOU</td>
<td>12</td>
</tr>
<tr>
<td>TOMDE</td>
<td>6</td>
</tr>
<tr>
<td>DRPC</td>
<td>24</td>
</tr>
</tbody>
</table>

The constants which are changed from the basic run are:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TFBAP*</td>
<td>0.05/0.15/0.3/0.45/0.55/0.6/0.63/0.65/0.65/0.65</td>
</tr>
<tr>
<td>DLUP</td>
<td>6</td>
</tr>
<tr>
<td>TEOU</td>
<td>3</td>
</tr>
<tr>
<td>TOMDE</td>
<td>3</td>
</tr>
<tr>
<td>DRPC</td>
<td>60</td>
</tr>
</tbody>
</table>

TFBAP* - Table for Fraction Becoming Aware of the Product
DLUP - Delay for Learning to Use the Product (months)

(Footnote to be continued)
Figure 4-8. Behavior With Rapid Market Acceptance and a Long Time to Get Capacity
limiting item of equipment had to be made to order, was highly complex and required a long time to debug, or if it required a very long time for the personnel to become proficient. The value selected, sixty months, is probably longer than would be expected for any light industrial product, but the use of such an extreme value serves to better emphasize the characteristics of behavior in this situation.

The most striking characteristic of this run is the difference between the growth in sales as observed by the supplier and the growth of potential sales at the market. By the month 125, 95 percent of the potential customers are aware of the product and ready to use it, but at this time the order rate is only 8.8 percent of its final value. The high prices and very high delivery delays combine to hold orders down. This in turn causes only a small amount of capacity to be ordered, and the situation improves very slowly.

The estimate of the unfilled market made by the competition reaches a value 2.9 times the maximum of the estimate in the basic run. This occurs because the delivery delays remain high long after all the potential customers are aware of the product, and therefore the estimated multiple of the industry order rate remains high even after the order rate is substantial. In the basic run the delivery delays had fallen to very low values by the time the order rate was nearing saturation.

8 (Footnote continued)

TEOU- Time for Effect of Observed Use (months)
TOMDE- Time to Observe Market Development Effort (months)
DRPC- Delay for Receipt of Production Capacity (months)

9 The reader should note that both delivery delay DDQI and the estimate of the unfilled market by the competition EUIMC go off the scale in Figure 4-8. This occurs because the scales were chosen to maintain comparability between most of the runs, and did not allow for the extreme variations found here. The peak value of DDQI is 29.2 months, occurring at month 46, and the peak of EUIMC is 189, 090 units per month, occurring at month 164.
The high estimate late in the growth period couples with the long forecast required to produce 9.4 percent overcapacity after saturation. This over-capacity causes in turn an 11.6 percent decline (to $1.13 per unit) in the steady state price, as compared with the basic run.

Demand Curve with Low Elasticity (Figure 4-9)

The elasticity of demand for the product was greatly reduced in this run. This largely eliminated the feedback control which the price loop (Loop E in Figure 4-2) had exerted on the order rates. The structure of the decision controlling prices remains unchanged. The behavior which this causes -- the reduction of prices when faced with overcapacity -- at first seems unreasonable. Managers would not be expected to do this if the income elasticity is less than unity, at least not if the elasticity is recognized. Examples contradicting this theory are readily available, however, with one of the most easily observed being gasoline service stations. Therefore, while there are examples, such as the steel industry, when pricing policies seem to reflect a recognition of, and reaction to, the income elasticity, it is not implausible to assume that an industry will react in the manner which the structure used here indicates.

Figure 4-10 shows the "demand curve" used in this simulation, and the curve from the basic run is repeated for comparison. 10

(Figure on following page)

---

10 The values for the old demand curve were:

\[ TFM^* = 3/2.45/1.98/1.58/1.27/1.0/0.8/0.66/0.55/0.47/0.41/0.36/0.325/0.296 \]

(Footnote continued on following page)
Figure 4-9. Behavior With Low Elasticity of Demand
Figure 4-10. Table for Price Multiplier

Because the price multiplier at the initial price is much higher in this run (see Figure 4-10), the order rate at any given value of delivery delay will be higher, and the delivery delay will rise.

\[10\] (Footnote continued)

TPM cont. 0.27/0.25/0.23/0.215/0.2/0.187/0.175/ \[C, 46, 47\]

The values for the less elastic demand curve are:

\[TPM^* = 2/1.65/1.4/1.21/1.1/0.95/0.91/0.87/0.84/0.84/0.82/C.79/0.77/0.76/0.75/0.74/0.73/0.72/0.71/0.705/0.7\] \[C, 46, 47\]
to a higher value before the order rate is sufficiently depressed to equal the production capacity. The delivery delay loop acts to take over some of the control previously offered by the price loop. The delivery delay rises proportionately at both the innovator and competition, however, and at month 140 the market shares are identical to the values in the basic run. During the relatively short time span of 20 months which follows, however, the competition gains 8.2 percent of the market, compared with only 4.8 percent in the basic run. In the basic run, the falling prices during the period caused a more gradual slowing of the growth. The break is seen to be very sharp here, as the inelasticity of demand greatly reduces the increase in orders which results from reducing prices. The loop in Figure 4-11 below is also causing a very high rate of growth during

![Diagram](image)

**Figure 4-11 Variables Creating Rapid Growth**

this period. The signs show the direction of the effects which each
variable has on the next. Since there are two negative effects, the gain of the total loop is positive, and the rate of growth will continue to increase until the delivery delay falls to a point where further decreases causes little or no increase in the order rate (see Figure 3-10). The delivery delays at both the innovator and competition fall very rapidly, therefore, but because the high estimate of the unfilled market by the competition peaks during this period and adds additional gain at the competition, delivery delay falls more rapidly there, and the competition gains the increased market share.

The loop in Figure 4-11 causes the growth of production capacity to be extremely rapid between months 120 and 160 and the capacity overshoots the demand by a substantial amount. In the basic run, the slower growth near saturation reduced the initial overshoot, and the increased demand produced by the falling prices filled the gap. The price loop contributes so little additional demand in this case, however, that the gap is never closed. Industry overcapacity stabilizes at 19.6 percent. Price is driven much lower—$1.04 at the innovator versus $1.28 in the basic run—but with little effect on the system.

Variations in the Initial Price

The price at which a product is introduced is usually felt to be of great importance, and many articles have been written on the subject of pricing for new products. Figure 4-12 shows the variation of the minimum value of the fraction placing orders at the innovator FPO1, the price at month 300 at the innovator, and the estimate of the unfilled market causing action at the competition EUMAC for a range in the initial prices.
Figure 4-12. Various Effects of Changing Initial Prices
IPI and IPC, from $1.00 to $3.00 per unit. In drawing conclusions about the behaviour, the assumptions upon which the model is based must always be kept in mind. The assumption with the most importance for analyzing this behaviour is that neither price nor any associated estimates of unit profits to the producers has any effect on the entry of competition. The competition looks upon all products as equally, or at least sufficiently, profitable, and are interested only in the prospect of a large sales volume and the apparent room for more producers. Still another assumption is that the competition will be no more likely to try to undercut the innovator's price.

Figure 4-12(a) shows that the higher initial prices lead to improvement in the innovator's market share, and to a substantial increase in the price at month 300. Because of the income elasticity is slightly less than unity over this range, revenues increase only 3.1 percent at the innovator, while market share increased 13.7 percent, because of the higher price. This result is due to the particular values of the demand curve, and no generality can be attached to it.

The decline in the peak values of the estimated unfilled market EUMAC shown in Figure 4-12(c) serves to explain the improved performance of the innovator. The higher prices reduce the order rate and the delivery delay, leading to a less optimistic estimate by the competition. Production capacity rises less rapidly, the difference in delivery delays is relatively less, and the competition gains a smaller fraction of the market. One can
conclude that if prices were kept sufficiently high, delivery delay would never rise to a point where it was attracting competition. This would probably work only in cases where the product was a sufficiently radical innovation that it would take many years for the potential competition to judge the costs. A product for which costs could be easily estimated would be attractive to competition if the observed markup was high and technology simple, because the competitors would expect to be able to undercut the innovator's price easily and still make a substantial profit. On the other hand, situations such as the one portrayed by this model are probably quite common.

**Variations in the Fraction of Sales to Market Development**

The fraction of industry sales going to market development effort affects the gain in loop A, Figure 4-2. This is a positive feedback loop. Increased marketing efforts lead to a greater awareness, an increase in the awareness leads to an increase in the number of customers aware of the product, the customers using the product, and the order rate, and this causes still another increase in the market development efforts. The fraction of sales going to market development determines the extent of changes in awareness that a given change in order rate\(^{11}\) can cause.

\(^{11}\)The sales figure used in budgeting for market development is actually based on shipments, not orders. Treating orders and shipments as synonymous simplifies the discussion without significantly affecting the conclusion.
The most noteworthy thing about the results of changing the fraction of sales going to market development is the small impact which the changes have on system behaviour. As shown in Figure 4-13(a), a change in the fraction from 0.05 to 0.15 causes the innovator's minimum market share to drop from 24.4 percent to 23.5 percent. The more aggressive marketing drives delivery delay slightly higher, more competition enters, and the innovator loses a little more of the market.

Figure 4-13(b) and (c) are a graphic demonstration of the extent to which the capacity acquisition policies control system behaviour. The threefold increase in the fraction of sales going to market development reduces the time required for 475 (95 percent) of the potential customers to become aware of the product from 158 months to 136 months, yet the time required for the industry order rate to reach 600,000 units per month falls only from 218 months to 215 months. The increased promotion has sped the growth of the potential orders, but delivery delay limited the actual order rate to the production capacity.

The behaviour would be very different if the time required to get production capacity was much shorter. Figure 4-7 showed an example of a situation in which the acceptance of the product by the market was limiting the growth rate. In a case such as this, a change in the fraction of sales going to market development would have a substantial effect on behaviour. The growth rate would be directly determined by market development efforts. The price loop could restrain the effect under some circumstances, however. The increased market development efforts would increase costs,
Figure 4-13. Various Effects of Changing Fraction of Sales Going to Market Development

(a) Minimum Value of FFDI (Dimensionless)

(b) Time for 45% Percent of the Potential Customers to Become Aware of the Product

(c) Time for Industry Order Rate to Reach 600,000 Units/Month
producing pressures to keep prices higher, and the higher prices would reduce demand.

*Reduced Time to Order Capacity at the Innovator* (Figure 4-13)

This run and the next show the dramatic improvements in behavior which result from changing certain parameters. In this run the time to order production capacity at the innovator is reduced from six to two months.\(^{12}\)

The effect of this change is to reduce the total delay between the existence of a need for additional capacity and the installation of this capacity. Capacity stays closer to the potential order rate, and delivery delay falls more rapidly. The delivery delay of the innovator stays closer to the delay of the competition, and fewer customers are lost. The aggregate delivery delay of the industry is reduced slightly, reducing the estimated unfilled market and capacity acquired by the competition. The minimum market share held by the innovator increases from 23.8 percent to 37.3 percent, or a 56.5 percent gain from the innovator's perspective.

This is just one situation from a continuum of behavior as the delay in the production capacity acquisition loop at the innovator

\(^{12}\)The original value was:

\[
\text{TOPCI} = 6
\]

In this run the value was changed to

\[
\text{TOPCI} = 2
\]
Figure 4-13: Behavior With Reduced Time to Order

Capacity at the Innovator
(loop C in Figure 4-2) ranges from zero to infinity. If production capacity miraculously appeared just before the moment it was needed, this would be equivalent to a delay of zero, and delivery delay would never rise above its minimum value; no competition would ever be attracted. On the other hand, if the delay was infinite, capacity would never increase above its initial value, and the innovator's final market share could be no greater than the percentage of the total market represented by his initial capacity. Any reduction of the delay around the loop will increase the innovator's market share.

In this run the time to order production capacity TOPCI was reduced. Reducing any of the following delays would also reduce the total delay around the loop:

- **DRPC** - Delay for Receipt of Production Capacity
  C, 66, 79, 115, 128

- **TDBAI** - Time for Desired Backlog Adjustment at the Innovator
  C, 73

- **TAOI** - Time to Average Orders at the Innovator
  C, 75

- **DAOFI** - Delay in Averaging Orders for Forecast at the Innovator
  C, 78, 81

The latter three delays are under the direct control of management, at least within broad limits. There may be some minimum to which they, and TOPCI, can be reduced because of fixed times such as the time to get bids, the time to process new employees, the communication delays which cannot be overcome, etc., but the major portions of the delays are set by choice, or perhaps failure to make a choice. The reduction of the delays is not without problems, however. Random
variations in the order rate will not be filtered out by short delays, and the value arrived at for the desired production capacity can fluctuate wildly. A decrease in the time for desired backlog adjustment TDBAI is likely to be the most detrimental, because its effect is slight during the early part of the growth, when it is most needed, while it adds greatly to the capacity order rate just before capacity exceeds the product order rate because this is the time of the backlog peak. The delay which is most desirable to decrease is the delay in receiving production capacity DRPC because it will never change the amount of capacity ordered but will get the capacity that is ordered into operation more rapidly. This delay would not seem to be under the control of the management at the innovator, but there are ways in which it might be affected. Increasing the pressure on suppliers to deliver, informing in advance the suppliers of specialized equipment that some certain item may be needed if demand continues to increase, keeping the personnel department informed about the types of people needed and the numbers that may be needed in the future under a number of different conditions-- these are but a few of the ways which might be found to reduce the delay.

**Increased Initial Production Capacity at the Innovator** (Figure 4-14)

If the innovator enters the market with substantially more production capacity, a longer time elapses before undercapacity becomes a problem. The initial production capacity at the innovator is increased to 50,000 units per month from the 1,000 units per month of the basic model.\(^{13}\) This is a large increase,

\(^{13}\)The basic run used: (Footnote to be continued)
Figure 4-14. Behavior With Increased Initial Production Capacity at the Innovator
but it leaves the initial capacity far short of the final industry
demand of 881,110 units per month. If the innovator had a slight
feeling for the potential size of the market, and had a natural
amount of faith in the usefulness of the product, the accumulation
of this much capacity is not unreasonable even without orders to
back it up. The most obvious reason that an innovative firm would
not install so much capacity initially is simply that most firms would
want to introduce the product as soon as they could produce it;
the fear of being beaten by a competitor would tend to prevent the
accumulation of a large amount of capacity before announcing the
product. The results of this run indicate, however, that possible benefits
of waiting are large, and should be weighed against the risks of not
being first in the market.

The larger initial production capacity delays the time at which
the order rate first exceeds capacity from month 17 to month 56.
Delivery delay at the innovator climbs rapidly after the capacity
is exceeded, but the peak is only 4.16 months. The peak in backlog
(not shown) is over 3.5 times as high as the maximum backlog at the
innovator in the basic run, but this is a much lower percentage
than the increase in production capacity at the same point in
time, and delivery delay is greatly reduced.

---

13 (Footnote continued)

PCII=1,000

In this run, the initial capacity was:

PCII= 50,000

0, 65, 89
During the early period of growth the market looks unattractive to competition and the entry is greatly delayed. Because the order rate, both to the innovator and to the industry in total, is much larger at the time delivery delay is high, the peak estimate of the unfilled market is increased, and the competition orders capacity aggressively when the demand is recognized. However, the innovator has become firmly established and a large part of the growth phase has passed them by, and the competition captures only 47 percent of the market, a substantial drop from the 75 percent share they captured in the basic run.

The delayed entry of the competition causes the fluctuations observed in Figure 4-14, and these fluctuations in turn cause the overcapacity occurring at saturation. At the time the competition entered the market in the basic run, the number of customers using the product was very small, and capturing even a substantial share of the total market did not involve a large volume of sales for the competition. In the present case, however, the number of customers using the product serves as an unlimited market compared to the small size of the competition immediately after their entry. In the basic run the competition was forced to grow along with the innovator; here they can grow very rapidly for a while at the innovator's expense. This rapid growth quickly brings the competition to full capacity, and because of the delay for the customers to recognize that the competition is unable to meet demand, the delivery delay climbs. The heavy demand causes a price rise; because the delays in the price loop are longer than those in the
delivery delay loop, price peaks about two months after delivery delay. The high price and delivery delay now begin to drive the order rate back down. Because of the delays in the recognition of the effects of price and delivery, the order rate falls below the point which would just stabilize the system, and the cycle begins again. Meanwhile, the growing order rate encouraged the competition to expand their production capacity, and now, with more capacity than at the beginning of the cycle, price falls farther than it rose, in an attempt to fully utilize the larger volume of capacity.

The behavior is actually even more complex than described above, however, as shown by the fluctuations in the fraction ordering from the innovator FPOI, and the order rates, ORI and ORC. This behavior is determined largely by the characteristics of loop D in Figure 4-2. When delivery delays and prices cause the competition to compare unfavorably with the innovator, customers shift to the innovator. Because they do not immediately recognize the time when the relative merits are reversed, too many shift before the changed situation is recognized. This loop amplifies the fluctuations characteristic of the other loops.

These fluctuations are the principal cause of the substantial amount of excess capacity. Between months 144 and 158, the order rate to the innovator is rising rapidly. Some of this increase is due to expansion of industry demand, but most of it is the direct result of capturing orders away from the competition because of the price and delivery delay advantage at this time. An extrapolation of this increase causes the innovator to estimate a capacity requirement two years hence at 541,590 units per month, and orders are placed
accordingly. The innovator did not, however, keep up with demand in
the short run and the order rate exceeded production capacity from
months 147 to 164. The resulting increase in backlog caused the
reversal of the price and delivery delay situation, and from month
156 to about month 172, the competition experiences a dramatic
rise in orders, largely at the expense of the innovator. Their
peak forecast is for a future demand of 473,360 units per month,
and they also place orders for the capacity. The industry has at this
point arrived at a combined estimate of future demand of 1,014,950
units per month. Final industry demand is 881,110 units per month;
the double-counting in the forecasts led to a substantial overestimation.

Even the problems of unstable demand and excess capacity do not
over shadow the great gains made by the innovator. The innovator's
market share is 211 percent of the basic run value. This result is a
strong case in favor of a careful evaluation of the danger of
losing the position of innovator versus the danger of attracting
competition by entering a market with minimal production capacity.
4.3 Improved Policies

The last two simulations in Section 4.2 showed the possibility for improving behavior by changing certain parameters of the system. This process could be continued and more parameters could be changed, resulting in still further improvement. There are limits, however, to the improvement that can be realized through such changes. Delays reach minimums and are often hard to control to exact values. Extreme parameter changes often make the system very sensitive to outside disturbances. The greatest potential for improvement lies in the area of improved policies—changing the structure of the system by changing the way in which decisions are made. This section shows two examples of how a change in the way a decision is made at the innovator can lead to greater success.

It might seem reasonable at this point to establish criteria against which improvement will be judged. Specific criteria do not prove necessary, however, because the improvements in behavior are sufficiently obvious that arguments are not likely to arise. If the possible measures of success moved in opposite directions so that it was necessary to give up something to gain something else, standards would be required for indicating how much of X will be given up in return for how much Y. Because all variables which would be considered as factors in judging success move in directions which would be considered desirable, the question of trade-off does not arise. Also, because industrial dynamics seeks to improve, not to optimize, the problem of whether the policies could do still more is not of direct concern.
The possible approaches to improving behavior are actually quite limited. The present scope of the system allows the innovative firm control of its price, its market development effort, and the decision to order production capacity. The quality of the product, for example, is not a potential means of control because its effect on the system is not treated. In fact, price and the production capacity ordered are the only variables whose manipulation may prove instructive; the treatment of market development effort is not sufficiently complete to justify any conclusions which might result from new policies in this area. Most obviously, the neglect of the possible effects of outstanding salesmanship or marketing programs in attracting customers from competitors would make any results in this area highly questionable.

The ideal production capacity acquisition decision would be one which always resulted in the installation of just enough capacity to meet the potential demand at each point in time. This calls, of course, for a perfect forecast. The model which has been developed is not really adapted to the study of forecasting methods involving such things as market research, leading indicators, etc., but is best used to evaluate the

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14 The problem is really more complex, because the potential demand is not an independent quantity. The firm's decisions regarding market development and price play a large role in determining the demand, even when delivery delay is kept sufficiently low that it is of no concern.
Usefulness of forecasts using the after-the-fact information available at the firm. A great deal of forecasting is done just this way. The first improved policy is a capacity acquisition decision based on improved recognition of potential market growth.

Very often a firm simply cannot grow, or does not wish to grow, as rapidly as does the potential market. If this is the case something must limit the order rate to the production capacity. Backlogs will not continue to grow indefinitely. In the basic model, delivery delay accomplishes this limiting, as a result of the failure of management to make an explicit decision regarding the problem. It seems far more reasonable to use price in this capacity, thus getting far more income from an identical physical volume of production. This is the nature of the second improved policy.

It seems reasonable to mention at this point a policy often advocated for pricing new products--the very low markup designed to discourage competition. Under the assumptions of this model, such a policy is doomed to failure. A lower price increases potential demand, and delivery delay must play a larger role in limiting orders. Delivery delay is driven higher, and more, not less, competition is attracted. While this model does indeed neglect the effects of estimated profit margin on the competitor's decisions to enter, the conclusions reached are valid up to the point where profits are so unattractive to the competition that they can hardly help but be less than desirable from the innovator's point of view.
Capacity Acquisition Policy Based on Estimate of Delivery Delay Multiplier

One of the most obvious faults of the policy by which the desired production capacity is determined is its neglect of the effects of delivery delay on the order rate. The average order rate observed by the firm and an extrapolation of the trend in this average are combined to arrive at an estimate for the order rate at some time in the future. Some recognition is made of the undercapacity, should it exist, in the additional increment to desired capacity for the purpose of backlog adjustment, but this is not necessarily related in magnitude or timing to the real effect of delivery delay.

By neglecting delivery delay, the firm is, through the greatest portion of the growth phase, underestimating the demand. Because the delivery delay loop (loop B in figure 4-2) prevents the actual order rate from exceeding the production capacity by more than a very slight amount, the firm never realizes their mistake. Meanwhile, the high delivery delay is attracting competition, and the innovator loses most of the market.

If the firm knew the exact relationship between the delivery delay and the fraction of the potential orders which are actually being placed, the potential orders\(^{15}\) could easily be determined. The determination of the actual order rate can be expressed as:

\(^{15}\) The potential order rate is simply the rate which would be given by equation 50, \(R\) if the delivery multiplier D MAOI were unity. It refers to the potential order rate at the particular moment of time only, not the maximum which may be attained in the future.
Actual Order Rate = (Potential Order Rate)(Delivery Delay Multiplier)

A rearrangement of this equation gives an expression for the potential order rate:

Potential Order Rate = Actual Order Rate /Delivery Delay Multiplier

It is unlikely that a firm could ever determine exactly the relationship between delivery delay and the delivery delay multiplier, but this relationship can be estimated, and in many cases the accuracy may be surprisingly good. Assuming that such an estimate can be made, a formulation for the estimated potential demand is easily obtained.

\[ EPDI.K = AORI.K / EDMOI.K \]

- **EPDI** - Estimate of Potential Demand at the Innovator (units/month)
- **AORI** - Average Order Rate to the Innovator (units/month)
- **EDMOI** - Estimate of the Delivery Multiplier of Orders at the Innovator (dimensionless)

Because it is impossible to know the actual order rate at any given moment of time, the average order rate AORI is used for the estimate.

The estimate for the relationship between the delay and the multiplier might be, to some extent, the result of talking to customers about the importance of deliveries. It is likely, however, that a carefully thought out judgement by management will be the principal determinant of the estimate. It should be obvious that for very short delivery delays, all of the potential orders will be received, while for extremely long delays, few, if any, will be received. Between these extremes the fraction will fall as
delivery delay increases. If an estimate for the delay at which some particular fraction, for example one-half, of the potential orders will be received, the curve is almost completely determined, and it should not require great effort to arrive at estimates for the intermediate delays. The result will be a curve such as those shown in Figure 4-15. Because the firm should recognize that customers are not reacting to the instantaneous quotation of the delay, and also because it is desirable to smooth out the short-term variations which may be present in the quoted delay, a smoothed (or averaged) value will be used in the decision.

\[
EDMOI.K = TABHL(TEDM, SSDI.K, 0,12,1)
\]

\[
TEDM = 1/1/0.98/0.9/0.8/0.67/0.5/0.35/0.25/0.15/0.1/0.07/0.05
\]

\[
SSDI.K = SSDI.J + (DT) \left( \frac{1}{TSDDI} \right) (DDQI.J - SSDI.J)
\]

\[
TSDDI = 3
\]

EDMOI - Estimate of the Delivery Multiplier of Orders at the Innovator (dimensionless)
TEDM- Table for Estimate of Delivery Multiplier
SSDI - Smoothed Delivery Delay at the Innovator (months)
TSDDI- Time to Smooth Delivery Delay at the Innovator (months)
DDQI- Delivery Delay Quoted by the Innovator (months)

For the initial exploration of this policy, it will be assumed that the estimate of the delivery delay multiplier curve is perfect; the values for TEDM will be identical to the values for TDM (0, 48, 49). Three months seems a reasonable period over which to smooth the delay.

A change in the estimate of the present demand would also be expected to change the forecast of future demand. Under the assumption that things which were observed a long time in the past are regarded as fact, the past average order rate \( PAORD (\text{ equation 81,} L) \) will remain the same but the change in the order rate \( CHORD \)
EDMO1 -- Estimate of Delivery Multiplier
of Orders at the Innovator (Dimensionless)

![Diagram showing EDMO1 and SDDI graphs]

- Effect of Delivery Delay Underestimated (2)
- True Curve (1)
- Effect of Delivery Delay Overestimated (3)

SDDI -- Smoothed Delivery Delay at the Innovator (Months)
(equation 80, A) will now be the difference between the estimate of the potential demand EPDI and the past average order rate PAORI. The expected change in the order rate ECORI (equation 78, A) will be unchanged, but will use the new value of CHORI, while the expected order rate EORI will now be the sum of the estimated potential demand EPDI and the expected change ECORI. Figure 4-16 shows how the change is produced in the forecast. The changed equations are:

\[ \text{CHORI}_K = \text{EPDI}_K - \text{PAORI}_K \]

\[ \text{EORI}_K = \text{EPDI}_K + \text{ECORI}_K \]

CHORI—Change in Order Rate at the Innovator (units/month)
EPDI—Estimate of Potential Demand at the Innovator (units/month)
PAORI—Past Average Order Rate to the Innovator (units/month)
EORI—Expected Order Rate to the Innovator (units/month)
ECORI—Expected Change in the Order Rate to the Innovator (units/month)

Figure 4-17 is a flow diagram of the new policy.

The results of a simulation with the new policy in effect are shown in Figure 4-18. The innovator has gained by almost any standard. The market share held by the innovator has approximately doubled; growth has been much more rapid, meaning that far less orders were lost to substitute products. Price has been driven lower by the excess capacity which occurs, and this excess capacity has at the same time increased cost slightly, squeezing the unit profit from both ends. The benefits of the increased market share far outweigh these disadvantages, and the net improvement for the innovator is great. Only if the demand were very inelastic and the relative cost of capital equipment were very high would the behavior cease to be an improvement.
Figure 4-16. Change Produced in Forecast
Figure 4-17. Flow Diagram of the New Policy
The new policy does almost nothing toward reducing the first peak in delivery delay. Up to the point where order rate first exceeds capacity and delivery delay starts to climb, the estimated delivery delay multiplier is unity, and this policy behaves in exactly the same way as the old one. After the delay begins to climb the new policy begins to take effect, but the results do not show up until after the time required to get production capacity has elapsed, preventing the new policy from affecting the first peak. After about month 32, however, the effects are felt, and delivery delay falls to a near normal value much earlier. The delay continues to fluctuate a little above normal because of the forecast. The market has the potential for exponential growth and the forecast is for linear growth. This causes a cycle within which future demand is underestimated, delivery delay begins to rise, the new policy reevaluates both present demand and the forecast, capacity is ordered at a more rapid rate, and delivery delay is once more brought under control.

This fluctuation in the delivery delay is amplified in the loop controlling shifts between suppliers and in the price loop, causing the substantial fluctuations observed in the market shares, prices, and order rate. The order rate fluctuations cause much of the overcapacity, by the same sequence of events discussed relative to the effect of an increase in the initial production capacity, in Section 4.2.

The new policy has proven to be quite successful when the delivery delay multiplier was estimated perfectly, but a prefect estimate will probably never be made in a real world situation,
and if the new policy required an accurate estimate it would be of very little use. Figure 4-15 showed two estimates of the delivery delay multiplier which were in error in opposite directions. Curve 2 greatly underestimates the magnitude of the effect of delivery delay, while curve 3 overestimates the effect. Figure 4-19 shows the behavior resulting from the use of curve 2, and Figure 4-20 shows the way in which decisions based on curve 3 change the behavior.

Underestimating the effects of delivery delay falls somewhere between estimating it accurately and completely ignoring it, which was the implicit estimate in the old policy. The behavior follows from this; it is better than the old policy but not as good as the accurate estimate. The behavior is more stable because the action taken is less vigorous. The innovator's market share increases by 68 percent, while the unit profit declines by only 3.6 percent. It can be concluded that a firm need not fear estimating on the low side, for any low estimate produces some improvement.

Figure 4-20 shows the behavior resulting from overestimating the effect of delivery delay. After the initial peak in the delay, which the policy does not eliminate for the reasons explained before, delivery delay is very rapidly brought under control. The innovator is able to retain almost 90 percent of the market, and the price is only slightly lower than the price resulting from the accurate estimate. There are some fluctuations in the delivery delay caused by the linear forecast, as discussed earlier, but here these
Figure 4-19. Behavior of the New Policy With the Effect of Delivery Delay Underestimated
Figure 4-20. Behavior of the New Policy With the Effect of Delivery Delay Overestimated
fluctuations seem to have little effect on the order rate. Because the competition acquires so few customers, the gain in the loop controlling the shifting between suppliers is very low. In the simulation with the accurate estimate of the delivery delay multiplier, the market shares were of roughly equal magnitudes, and if one supplier had a delivery or price advantage enough customers would shift to change conditions substantially. Here, if the innovator gains an advantage, there are so few customers to gain that the effect on the innovator is slight.

The behavior of this run shows the self-correcting character of the policy. The firm overestimates potential demand because of the overestimate of the effect of delivery delay, and as a result orders too much production capacity. The extra capacity then causes delivery delay to drop sharply, the actual demand can be seen, and capacity can be ordered at the proper rate.

Because the behavior of the overly aggressive estimate produces the most desirable behavior of the three cases, it might appear that it is wise to overestimate the effect of delivery delay. It is not safe to draw this conclusion, however, because one of the original assumptions of this model was that the underlying need for the product remained constant. If there was only a short period of time over which there was any real desire for the product, overestimating the effect of delivery delay would be likely to lead to much over capacity. Hula hoops are an extreme example. Shortly after their introduction, they were in very short
supply. If the number of customers which would have bought them had they been readily available had been greatly overestimated and steps taken to acquire this capacity, a few months later when there was no longer any real desire for the product the industry would have been faced with a great deal of overcapacity. In fact, the actual behavior did indeed seem to follow this pattern fairly closely.

In summary, this policy seems to meet all the criteria for improvement. It is easily implemented, produces dramatic improvements in behavior, and success is not dependent upon great accuracy in estimates of parameters.

**Price Used to Control Order Rate**

Orders cannot exceed production capacity indefinitely. Delivery delay will climb until a sufficient number of the customers are discouraged from using the product. Sales will be lost and never recovered, and competition will be encouraged to enter the market. It would seem far more reasonable for the firm to raise the price of the product until orders equal capacity. For a particular value of production capacity, no more units will be sold under this policy, but the units that are sold will produce far more revenue. Also, the lower delivery delay attracts fewer competitors. As the firm brings capacity in line with the demand, they can reduce price, as they choose, to increase volume.

This policy is really only a "stop-gap" measure. It is far more desirable for a firm to always have sufficient capacity to meet the demand. Often it is not possible to grow this
rapidly, however, because of factors such as the rate at which new people can be absorbed by an organization without creating chaos. Packer has done work on some of the problems faced by a firm attempting rapid growth. 16 The policy discussed here should be thought of as being somewhat less desirable, relatively, than the previously discussed policy, but it makes the best of an unsatisfactory situation.

The control which can be exerted through the price loop is a function of the elasticity of demand. Quite obviously, if the elasticity is zero, price is completely ineffective as a means of controlling demand. No matter how great the price change, the order rate will not change. The greater the elasticity, the higher the gain is in this loop, and control becomes more effective. The elasticity of industry demand in the basic model was approximately one. This did not prove to be sufficiently high to allow significantly improved behavior with the new policy. For demonstration of the policy, a demand curve with an elasticity of two over the range of interest was substituted. This required the following constant change:

\[ \text{TPM}^* = 4.0/3.93/3.77/3.5/3.11/2.46/1.48/0.985/0.703/0.527/0.41/0.328/0.268/0.223/0.189/0.162/0.1405/0.123/0.1085/0.096/0.086 \]

The old values were:

\[ \text{TPM}^* = 3/2.45/1.98/1.58/1.27/1.0/0.8/0.66/0.55/0.47/0.41/0.36/0.325/0.296/0.27/0.25/0.23/0.215/0.2/0.187/0.175 \]

The values were selected so that the multipliers at the initial price, $2.00 per unit, were identical at 0.41, thus keeping the initial conditions identical.

The behavior of the new policy must be judged against the behavior of the system with the higher elasticity, and not against the behavior of the basic system. Figure 4-21 shows the behavior of the old policies with the new demand curve. Discussion of this simulation will be delayed until the discussion of the behavior of the new policy, at which time a comparison will be made.

The indicated price at the innovator IPRII was reformulated as the product of the indicated price in the basic model and an additional multiplier to control the order rate. The variable which was called the indicated price in the basic system was renamed the normal indicated price, to reflect the fact it would be the indicated price if the average order rate did not exceed the production capacity.

\[ \text{IPRII}.K = (\text{PMCDI}.K)(\text{NIPI}.K) \]

\[ \text{NIPI}.K = (\text{PRII}.K)(1 + \text{FCPII}.K) \]

- IPRII- Indicated PRIce at the Innovator (dollars/unit)
- PMCDI- Price Multiplier for Control of Demand at the Innovator (dimensionless)
- NIPI- Normal Indicated Price at the Innovator (dollars/unit)
- PRII- PRIce at the Innovator (dollars/unit)
- FCPPII - Fractional Change in Price Indicated at the Innovator (dollars/unit)

The innovator is attempting to reduce the order rate to a value near the production capacity. If the order rate is twice the production capacity, the innovator will wish to raise price sufficiently to cut the order rate almost in half. In order to do this, an
estimate of the elasticity of demand is required. For a particular estimate of the elasticity of demand, there will be a relationship between the multiple of the present price which appears necessary to bring demand into line and the present fraction of capacity at which orders are being received. Because the instantaneous order rate is never actually observable, the average order rate AORI (equation 75, L) must be compared with production capacity PCI (equation 64, L). This ratio is already available in the basic model as the fraction of full capacity FFCI (equation 92, A). Figure 4-22 shows the relationship between FFCI and PMCDI for three different estimates of the elasticity. It was assumed that because of the uncertainty of the estimate, the innovator will allow a 10 percent threshold above full capacity before taking action.

\[ \text{PMCDI}.K = \text{TABLE (TMCDI, FFCI}.K, 1.0, 2.0, 0.1) \]
\[ \text{TMCDI}^* = 1.0/1.0/1.05/1.1/1.15/1.2/1.25/1.3/1.35/1.4/1.45 \]
\[ \text{FFCI}.K = \text{AORI}.K/\text{PCI}.K \]

92, A

**PMCDI**- Price Multiplier for Control of Demand at the Innovator (dimensionless)
**TMCDI**- Table for Multiplier for Control of Demand at the Innovator
**FFCI**- Fraction of Full Capacity at the Innovator (dimensionless)
**AORI**- Average Order Rate to the Innovator (units/month)
**PCI**- Production Capacity at the Innovator (units/month)

Figure 4-23 shows the system behavior with the new policy. The minimum market share held by the innovator increased from 23.8 percent to 27.6 percent. This is a 16 percent gain for the innovator, but 16 percent is small compared to the gain of approximately 100 percent
Figure 4-22. Price Multiplier for Control of Demand at the Innovator versus the Fraction of Full Capacity at the Innovator
which the delivery delay estimate policy produced. While the higher price reduced the delivery delay at the innovator, thus attracting less of the potential competition and reducing the losses to competition because of delivery delay, more customers were lost to the competition due to the large price gap during the early stages of growth.

At the times of the respective delivery delay minimums, the net income was $112,400 per month with the new policy compared with $119,400 per month for the basic system with an elasticity of two, a decline of 5.85 percent. This occurred because the new policy led to a higher price at this time and a loss of volume greater than the price increase because of the elasticity of demand. By month 300, however, prices fell to a point where the higher market share began to make a noticeable contribution, and net income was $166,800 per month with the new policy compared to $137,100 without the change.

Even at the point of minimum market share, the higher unit profits with the new policy led to a return on investment 64.5 percent higher than with the old policies. While all of the financial measures of success must be viewed with some suspicion, as both the absolute and relative values are largely dependent upon the particular

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17 Defined as:

\[ \text{NET INCOME} = (\text{PRII} \cdot \text{K} - \text{UCI} \cdot \text{K})(\text{SSI} \cdot \text{KL}) \]

PRII - Price at the Innovator (dollars/unit)
UCI - Unit Cost at the Innovator (dollars/unit)
SSI - Shipments Sent by Innovator (units/month)
assumptions about the relative costs of manpower, capital
equipment, and materials, it does seem that the behavior produced
by the new policy is substantially improved over the behavior
with the old policies.

The implementation of this policy required that an estimate be
made of the elasticity of demand. Before accepting the usefulness of
the policy, it is necessary to investigate the sensitivity of the
behavior to the estimate. Figure 4-22 showed price multiplier curves
which would be used if the estimate was for elasticities of one or four,
instead of the correct figure of two.

The results were similar in nature to the results of the
misestimates of the delivery delay multiplier curve in the previous
improved policy. With an elasticity estimate of four, the firm failed
to raise prices as far as they did with the accurate estimate.
The peak price was about $2.55 per unit compared to $3.12 per unit.
Behavior was improved, based on the standards used above, but the
improvement was slight.

The low estimate of elasticity caused more aggressive action
to be taken, and improvement in the innovator's minimum market share was
greater. The higher prices depressed the order rate more, however,
and the net income over most of the growth period was slightly
lower than with the accurate estimate. Just as with the accurate
estimate, net income was slightly lower than with the old policies
at the point of minimum market share (for the innovator), but the
continuing decline of prices soon reversed the situation. The
elasticity estimate of one produced the highest return on
investment of any of the estimates.
The policy meets the same criteria for success as did the first improved policy. Any application of it leads to some improvement, and there is a large margin of safety for the estimates. The most important reservation one might have about this policy involves the basic assumption of the model that delivery delay and volume, not price and unit profits, attract competition. Price and unit profits cannot increase indefinitely without being noticed by potential competition. The model does not answer the question of whether or not new assumptions are in order.

**Improved Policies Combined** (Figure 4-24)

It was stated in Chapter 1 that the policies followed by management are part of an information feedback system, and are not independent of each other. For this reason it seems advisable to test the improved policies together to insure that they are not in conflict. A simulation of the system with the policies combined is shown in Figure 4-24.

The improvement in behavior is great. The minimum market share of the innovator is 64.3 percent, a 170 percent improvement. Net income at month 300 has increased by approximately the same percentage.

The best qualities of both policies are brought out by their combination. The forecast of delivery delay did not become active until delivery delay had already begun to climb, and thus could not reduce the delay for some time after it reached a peak. The price policy comes into play earlier, and is effective in reducing the early peak in delivery delay. The price is held up during the period of above normal delivery delay, thus reducing the delay throughout
Figure 4-24. Behavior With New Policies
Combined (Accurate Estimates)
the growth phase, providing less encouragement for competition. In Figure 4-21, the peak estimate of the unfilled market EUMC was for 60,861 units per month, but the combined improved policies reduced this figure to 21,846 units per month. The delivery delay advantage of the competition was much less and they gained far fewer customers because of it.

At the same time, the delivery delay multiplier estimate brought production capacity in line with potential demand much faster, and the innovator's price dropped to meet the price at the competition much earlier. In this simulation the innovator's price first met the competitors' price during month 84, compared to month 118 with the price policy (accurate elasticity estimate) alone. Therefore, the competition gained fewer customers because of a price advantage.

The policies are indeed complementary, and with the combined policies the question about the assumptions of the model becomes less important. Price does not rise as high, and falls more rapidly. Even if competitors are sensitive to price and unit profit, they would be less attracted here then under the price control policy alone.
CHAPTER 5

Conclusions

This chapter summarizes the major results and conclusions of the study, and offers some suggestions for possible areas for future work.

5.1 Conclusions of the Study

The results of the study indicate that it is possible to explain many of the problems of product growth within the scope of the system modeled here. The behavior of the model, discussed in Chapter 4, shows many of the common patterns which are observed in real world markets.

The fact that the limited number of variables involved here are sufficient to generate the behavior is significant. Factors such as technological advantage, financial and accounting flows, and distinct types of marketing effort appear to be unnecessary to create some of the dominant modes of growth behavior.

System structure and certain key parameters were shown to be of great importance in determining the success of the firms in the market. The information feedback approach explains why the results of some policies and decisions have effects which often appear contradictory on the surface. Having been viewed in their system context, the improved policies appear simple and obvious, yet it is questionable that they would have been arrived at by another method than that used here.

Finally, policies producing dramatic improvement in behavior were
designed and tested. The policies have potential for application by firms entering a growing product area, but more important than the policies themselves is the demonstration of the magnitude of the improvement which properly designed policies can produce. Much of the work being done by management science and industrial engineering groups is aimed at finding ways to save 0.1 percent here and increase the profit by 0.2 percent there. All of the improvements may add up to produce gains of real importance, but the results of this study indicate that time might be better spent seeking improvements which double or triple profits.

5.2 Suggestions for Further Study

The potential for gaining insight from the model as it now stands is by no means exhausted. The sensitivity of the system to many of the important parameters has not been thoroughly tested. Still other improved policies could certainly be found. It seems, in fact, that there is almost no limit to the insight which can be gained from even a very simple system.

Probably the first addition which should be made if the model were expanded would be to incorporate the effects of high profit margins on the competitors' decisions to enter the market. This is a step which should be taken before the second of the improved policies in Section 4.3 is recommended for implementation in any real world situation.

Quality as a variable was excluded by the scope of the study, but it is certainly a potentially important determinant of growth
behavior. Likewise, no consideration was made of the possible effects of marketing efforts on the competitive interaction. Both of these factors might serve to explain still other characteristics of growth behavior.

Here the problem of product growth was considered in isolation, separate and distinct from the corporate growth which might parallel it. The problems of absorbing new people into the organization, maintaining the proper allocation of effort among the various demands, and conquering the financial difficulties often accompanying growth may strongly affect behavior.

One can keep listing almost indefinitely areas into which this study might be expanded. Research should, however, be concerned with solving problems, and it is only the problem to be solved which determines the direction of any future study in this area.


Products", *Harvard Business Review*, Cambridge, Massachusetts:


**Effects of Capacity Acquisition**

A publication in 1963

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