GROWTH OF A NEW PRODUCT

by

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Signature of Author. . . .
School of Industrial Management

Certified by. . . . .
Faculty Advisor of the Thesis

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 "Growth of a New Product".

I wish to express my gratitude to many members of the faculty and staff for helpful suggestions in preparing this study. In particular, I should like to express my appreciation for the direction and assistance given by Professor Jay W. Forrester, chairman of my thesis committee. I should also like to thank Professor William F. Massy, the second member of my committee for his helpful assistance. This work was done in part at the Massachusetts Institute of Technology Computation Center. I appreciate the assistance of its personnel and the use of the computer facilities.

My expression of gratitude goes also to Miss Marie Lincoln, Mrs. Faith Richards, and Miss Jean VanDerlip, who have typed the thesis and given helpful comments on the English language.

Sincerely yours,

Ole Christian Nord

ABSTRACT

GROWTH OF A NEW PRODUCT

by

Ole Christian Nord

Submitted to the School of Industrial Management on January 22, 1962, in partial fulfillment of the requirements for the degree of Master of Science.

This thesis is a continuation of the growth dynamics study started by Professor Jay W. Forrester in a graduate student seminar in the spring term of 1961.

It treats the dynamic interactions between the market and the manufacturing of a product. Our objectives of the study are:

1) To develop a better understanding of the dynamic interactions between a market for a new product and the manufacture of it and the influence of related policies upon growth and stability. We shall examine the way the growth behavior is influenced by external disturbances.

2) To redesign the system or reformulate policies to create a more favorable growth rate.

These objectives seem hard to satisfy within the time limits of a Master's thesis, and we have defined our immediate objectives:

1) To demonstrate the different behaviors a growth company might experience as a result of the dynamic interactions between market and manufacturing. We will examine the influence of external disturbances on the growth behavior.

We have selected an industrial dynamics approach to satisfy our objectives. A description of some of the dynamic interactions that create growth has been given, and on the basis of this, we have developed a model containing four sectors: market, market development, production, and research and development.

The four sectors are interrelated with about fifty variables of the selected interactions that are involved in the growth of a new product.

The model has been tested and used to demonstrate the growth of a new product market under conditions where:

1) The growth is determined by the production capacity acquisition policy.

2) The growth is determined by the market development efforts.

The study of product growth is not finished, but interesting ways of future work in the field are opened.

The major conclusions on the study are:

Model:

1) The model is brought to a state where it is a useful description of several dynamic interactions between production and marketing that create growth of a new product.

Specific Results:

1) The growth of a new product market is often limited by the acquisition policy for additional capacity.

2) Under conditions where growth is limited by the capacity acquisition policy, the growth behavior is not sensitive to external disturbances on the product order rate.

3) Under conditions where growth is limited by the capacity acquisition policy, the management problem is not in the forecast of the order rate, but in the fundamental understanding of the principles of growth.

4) By eliminating the barrier to growth from the capacity acquisition policy, the management can increase the market growth rate significantly. The behavior of the company is now more sensitive to external disturbances on the product order rate, and the production sector shows considerable fluctuations in inventory and production capacity orders.

General Results:

1) The study shows the feasibility of treating transient dynamics problems in product growth via an industrial dynamics approach.

2) The study stresses the importance of top level management understanding the structure and dynamics of the system being managed.

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

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CHAPTER I

INTRODUCTION

This thesis is a continuation of the work started on growth of a new product by Professor Jay W. Forrester in a graduate student research seminar in the spring term of 1961 and continued for the first month of the summer by a group of four research assistants in the Industrial Dynamics Group at the M.I.T. School of Industrial Management. The previous work has been revised and carried further by the author. The study is still far from finished, but the author hopes he has made a worthwhile contribution towards the final goals.

Growth is a common occurrence in the industrial community today, and it can be considered as one of the most challenging issues for top-level management. Why do some companies experience 50 percent per year growth rate, while others are unsuccessful? There is a variety of answers. Let us now first consider the ways a company can experience growth. It can be experienced through:

a. merging of companies

b. expansion into new markets

c. introduction of new products

This thesis will only deal with growth caused by introduction of a new product. This has been done not because we find the problems within the other growth groups uninteresting but because we have to limit the extent of the study. The study is meant to be of general value, and accordingly, it has not been limited to a specific new product or company. The model that is developed could be adjusted to many products by changing parameters. In our selection of parameters we have, however, mainly thought of new office equipment, and the reader should keep this in mind when evaluating the plausibility of the selected parameters. The study is not pretending to make any predictions of a specific growth rate; rather we could phrase it as follows: Assuming that we have an idea for a product with a sales potential, how should management act to create a successful growth, and what are the consequences of following other sets of policies. This problem seems, however, to be of too wide a scope for a first attempt at a growth study, and we will therefore limit the problem further.

Among companies that grow, management often has a serious problem in satisfying the demand. It is often found that the growth rate is uneven, which creates stress on management and resources and can possibly be of crucial importance to the existence of the company. This study will concentrate upon the dynamic aspects of growth within the interactions between the market for a product and the manufacturing unit producing it.

What are the factors that cause the growth and the problems with ability to deliver the product? How can the market's and the company's actions interact to give an uneven growth rate? What are the characteristics of the market, the product, and the company that will favor a rapid and stable growth?

Let us now consider some important characteristics in the interactions between a market for a product and the manufacturing unit. Between the market and the company, there exist different feedback loops as:

1. The order flow to the company influences the delivery delay which again influences the order flow.
2. The order flow to the company influences the marketing efforts which again influence the order flow.
3. The usage of the product extends knowledge about it and influences the order flow which again influences the usage of the product.

Within the loops there are delays of physical character (shipping time, capacity delivery time, etc.) and delays in decision making (evaluating need for capacity, deciding to purchase the product, etc.)

The common management policies will also involve amplification.

1. An increase in the order flow to the company will generally cause the company to desire a higher level of inventory.
2. When working at capacity limits, an increased order flow will increase the orders for more capacity not only to take care of the increased order flow, but also to correct a build-up of order backlog or an emptied inventory that occurs during the time it takes to receive the additional capacity.
3. A common policy in establishing the marketing effort is to make marketing effort proportional to sales or expected sales which might be a source of amplification.
4. A forecast of present trends in growth might possibly be a source of amplification.

We will hypothesize that a system with the mentioned characteristics might under certain conditions self-induce an uneven growth rate, while it might under other conditions suppress the importance of the amplifying factors and will not show any oscillatory character.

It is our objective by this study to:

1. Develop a better understanding of the dynamic interactions between a market for a new product and a company producing it and their influence upon growth and stability. We shall examine the way the system is influenced by external disturbances.
2. Redesign the system or reformulate policies to create a more favorable growth rate.

These objectives will be hard to satisfy within the time limits of a Master's thesis, and we will therefore define our immediate objective: to demonstrate the different behaviors a growth company might experience from the dynamic interactions between the market and the manufacturing unit. We will examine the influence of external disturbances on the growth behavior.

We think that our objectives can best be satisfied via an industrial dynamics approach. Industrial dynamics will provide us with a unique opportunity to study the complex dynamic interactions between a company and a market from an over-all viewpoint. It will give us a means for projecting consequences of different policies upon growth rate and stability.

Due to time limitations, the study is not finished, but we think it has opened the way to a better understanding of the dynamics of growth. The major conclusions are:

1. The model is brought to a state where we think it is a valid description of some important dynamic interactions which create growth of a new product.
2. The study shows the feasibility of treating transient dynamic problems in product growth via an industrial dynamics approach.
3. The study stresses the importance of top-level management understanding the fundamental structure of the system being managed.

CHAPTER II

INDUSTRIAL DYNAMICS

It is observed that industrial activities show different characteristics of growth and business fluctuation. Why does this happen and what can be done about it? It has been suggested that it can partly be explained by interactions of different variable industrial and/or economical factors.[1]

Industrial dynamics can help us to study the problems, to give us a better understanding of the interacting factors, and to improve the behavior of the activity. This chapter will briefly describe industrial dynamics philosophy and principles.[2]

The best definition of industrial dynamics comes from Professor Jay W. Forrester's book from which we quote:

> Industrial dynamics is the study of the information-feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decisions and actions) interact to influence the success of the enterprise. It treats the interactions between the flows of information, money, orders, materials, personnel, and capital equipment in a company, an industry, or a national economy.
>
> Industrial dynamics provides a single framework for integrating the functional areas of management--marketing, production, accounting, research and development, and capital investment. It is a quantitative and experimental approach for relating organizational structures and corporate policy to industrial growth and stability.

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[1] Jay W. Forrester, "Industrial Dynamics--A Major Breakthrough for Decision Makers", Harvard Business Review, Vol. 36, July-August, 1958.

[2] Jay W. Forrester, Industrial Dynamics, M.I.T. Press and John Wiley and Sons, Inc., 1961.

By interrelating the variables of an industrial activity into a system of equations, an industrial dynamicist builds up a simulation model of the real activity which he studies. The system of equations is computed on a digital computer (IBM 709) as a function of time, and thus makes it possible for us to compress the time scale of the real world. In a few minutes computation time, we can simulate the real system for years.

Behavior of an activity under different conditions and in response to suggested changes can thus be studied in an inexpensive way to help us in understanding the activity and by suggesting better ways of handling it.

How can we successfully construct an industrial dynamics model? This is a difficult task and no unique solution can be offered. To be successful, the model builder must have a thorough understanding of and insight into the components of the problem which he must have clearly defined. He must be able to select the relevant variables from the irrelevant ones. The system should be considered as an integrated feedback mechanism.

The model should be built in accordance with our physical understanding of the system. In general, a model can include these flows: material, men, equipment, money, orders, and information. Depending upon the size of the problem, one or more of these flows may be included. The model should always be simple, yet still have a real physical meaning. It should contain the relevant variables which are to be studied.

The model is supposed to give us a qualitative representation of the real world, but it does not pretend to match the real world in all details. Rather, the model should contain the major factors and should show the same general behavior as the actual system being represented. An industrial dynamics model usually treats all flows as continuous flows on an aggregated level. This is done for simplicity and, depending upon the particular flow, it is a more or less valid approximation.

The model we construct will also need, besides the equations for the interactions between variables, values for constants and parameters. Industrial dynamics philosophy is here to choose constants on a criterion of plausibility and in agreement with what is known or easily determined. It is believed that in many cases tedious and expensive gathering of data is unnecessary, since the model behavior often has very little sensitivity to the exact value of a constant. The model should therefore be constructed and the constants selected on the basis of plausibility. If a particular constant should turn out to be sensitive in its effect on model behavior, we might then try to determine the exact value of the constant, or we might find it undesirable to have the system sensitive to the one parameter and instead perhaps suggest changes in policies to reduce the sensitivity.

An industrial dynamics model should, however, not be treated as any end in itself. Its value is in its usefulness in helping us understand and solve industrial problems.

Further information about industrial dynamics can be found in Jay W. Forrester's book.

CHAPTER III

SCOPE OF THE STUDY

In Chapter I, we stated our objectives of this study:

1. To develop a better understanding of the dynamic interactions between a market for a product and a company producing it, and the influence of related policies upon growth and stability. We shall examine the way the system is influenced by external disturbances.
2. To redesign the system or reformulate policies to create a more favorable growth rate.

The scope of the study will be limited to include only those factors that are absolutely necessary for a meaningful study within our objectives. This will be done for two reasons:

1. In a preliminary study of a problem, it is generally wise to keep the model simple so that the important interactions can more easily be analyzed and understood.
2. A detailed treatment of the different factors within a system will often be of little importance to the dynamic over-all character of the system.

How extensively do we then have to treat the system with which we are dealing? Industrial dynamics generally lists six interacting flows in an Industrial Activity:

a. materials

b. orders

c. money

d. personnel

e. capital equipment

f. information

Let us now try to decide which of those are crucial to the dynamic behavior of interest here, and which ones could be omitted in a preliminary study of growth. By omitting one or more of the flows, we will get the advantage of a simpler model and a more easily understood system, but we must also be aware that any omission will limit the generality of the study.

A growth company implies a product that can be sent to the market as a response to the orders from the market. Both materials and orders will therefore be included.

It seems that we could justify an omission of a flow of money. Money is more often a means of transaction than an actual determining factor for actions. The purchasing decision in the market will more frequently be determined by the market's feeling of need for the product than the actual flow of money in the market. But how can we so justify excluding money for financial reasons of the company? A company cannot be started without capital, most of which is usually borrowed. If the product or product idea is worthwhile, a company will probably find that the capital is not the limiting factor for getting started. As the company grows, the capital problem may become more dominant. The management often gets into a conflicting situation between expansion of existing plants determined by the expected need of capacity and the expansion justified by retained earnings to keep control of the company. During the growth stage a company may also be going through one or more crises which put financial stress on management. The actual financial position under these conditions might be the determining factor for management decisions. Nevertheless, money will be exluded in this first growth model to keep it simple, and the emphasis will instead be put on problems that are independent of the money flow.[1]

In the dynamic interactions between a market and a company, personnel might or might not be of importance. The training and hiring of high quality salesmen could actually in some cases be a controlling factor for growth. In other circumstances, personnel might be completely unimportant in the growth behavior. In this study, we will exclude personnel to keep the model simple.

We will include the flow of capital equipment. Usually in a growth situation the problem of lack of capacity is a predominant one, and the acquisition of capacity seems to be important to growth.

By omitting money and personnel and including capital equipment, we have limited the generality of the growth study considerably, and the results are therefore only valid under growth conditions where personnel and money are unimportant and capital equipment is important.

We will include a flow of information in the model. Decisions both at customer level and company level are generally taken on the basis of information about what is thought to be the relevant factors to consider for a decision. The flow of information is therefore considered an essential flow to the model.

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[1]It should be noted that even if we omit a flow of money, we will use money as a means of measuring other quantities--for instance, sales.

Our scope has now been limited to include flow of:

a. materials

b. orders

c. capital equipment

d. information

Let us now go further and determine the characteristics of the system within this scope. An industrial dynamics study will be successful only if we are able to show thorough insight into the growth problem as defined by our objectives. The relevant factors have to be separated from the irrelevant ones. It is easy in a study like this to get diverted into detailed and extensive treatment of irrelevant factors, and we will therefore try to limit the study to what we think are the most relevant and fundamental characteristics within a growth study with the defined objectives.

We believe it would be wise not to think of a specific product. The model should rather be of a new product in general, thus making it easier to select the fundamental characteristics that are relevant to growth. The product could be characterized by something called quality, which incorporates all factors appreciated in the product by the market.

The study will include a market and a mechanism for creation of product orders in the market. We shall also include production facilities, since these will respond to market acceptance. In the model, the use of the production facilities and the acquisition of additional facilities will be determined by policies for a hypothetical growth company.

Others might argue that a new company cannot keep the market for itself for a long time. Fairly soon it will meet competition, and much of its behavior will be determined by competitive actions. We agree, but we think that it is of interest first to explore the growth behavior within an aggregated industry or a company without competitors before we extend the model to include competition. We would recommend that the study be extended later to include competitors.

Let us now consider the supplier of production facilities. Do we have to include him, or is the study worthwhile without him? It seems that the supplier of production facilities will have little influence on the market decisions to order the new product. In a growth situation we will usually find that the lack of capacity is due more to cautious ordering of additional capacity than to lack of availability of capacity from the supplier. Accordingly, we have not found it justifiable to include the fine details of a supplier of production capacity in our study. He is adequately represented by the time delay experienced in procuring capacity.

The most fundamental factors for this growth study seem therefore to be (as seen in Figure III-1):

a. a product characterized by quality

b. a market and a mechanism for generation of orders

c. production facilities

This chapter has now outlined the scope and the fundamental characteristics that will be included in this study. We have generally limited the study to include only the most obvious factors, and the study will be open to extensions later. We think, however,

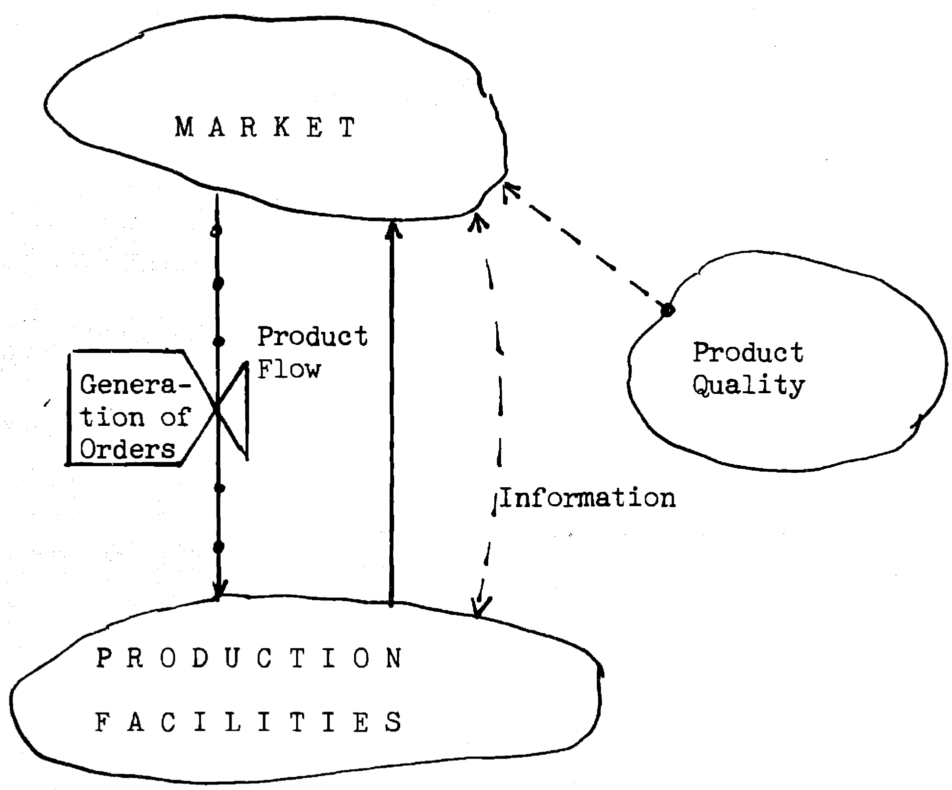

Figure III-1, Fundamental Factors in the System.

that we have included enough relevant characteristics so that the study will be of aid in acquiring a better understanding of the interactions between a market and a company for a new product, and of how these interactions work together to create growth and the possibility of growth rate fluctuations.

In the next chapter the dynamic interactions will be treated further.

CHAPTER IV

THE DYNAMICS OF GROWTH

A necessary requirement for building an industrial dynamics model is a hypothesis expressing the insights we have of the dynamics of the situation under study. The model can never be better than the model-builder's visualization of the real world, and we will now give a dynamic description of the system which we will model.

We will first discuss the life cycle of a product to identify the phase that will interest us. We will describe the interactions between the different sectors in the system, and finally give a description of the dynamics within each sector that are relevant to the interactions between a market for a product and a producer of it.

IV.1 Life Cycle of a Product

Most products go through roughly the same stages in their life: growth, maturity, and decline.[1]

The growth stage consists first of an introduction phase to be followed by a major growth phase. In the introduction phase, there is generally little or no demand for the product. The market for the product is not ready for the new idea and accordingly does not care about the product. Some few innovative people will buy the product in this stage, but the demand is generally too low to make a profit on the new product.

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[1] E. J. McCarthy, Basic Marketing, A Managerial Approach, Richard D. Irwin, Inc., 1960.

Frozen vegetables on the Norwegian market could be mentioned as an example of a product in this phase. Frozen vegetables have been available in the stores for six to seven years now, but to a Norwegian housewife the connotation of a frozen vegetable is still close to a bad vegetable, and very few are willing to try them.

After a certain amount of time, the main body of the market for the new product will be ready to accept it. The order flow to the company will now be rapidly rising, and the company usually experiences high profitability. We will now often find that the high profitability attracts competitors.

Volkswagens are an example of a product in the major growth phase. This car seems to have a technical monopoly and has not yet met any serious competition. The dealers have a major problem in satisfying the demand. Throughout most of the world there are waiting lists for the car.

In the maturity stage the demand for the product is fairly constant. The product is well known, and the market has adopted it where it is suitable. The major sales are now for replacements. The stage is often characterized by declining profit and strong competition. Cars on the United States market could be mentioned as an example of a product in the maturity stage.

A product will stay in maturity until another product that is better able to satisfy the market needs is introduced on the market. The sales of the product will then decline and profit will be low. Bicycles on the European market can be mentioned as an example of a product in this stage. As the standard of living rises, more and

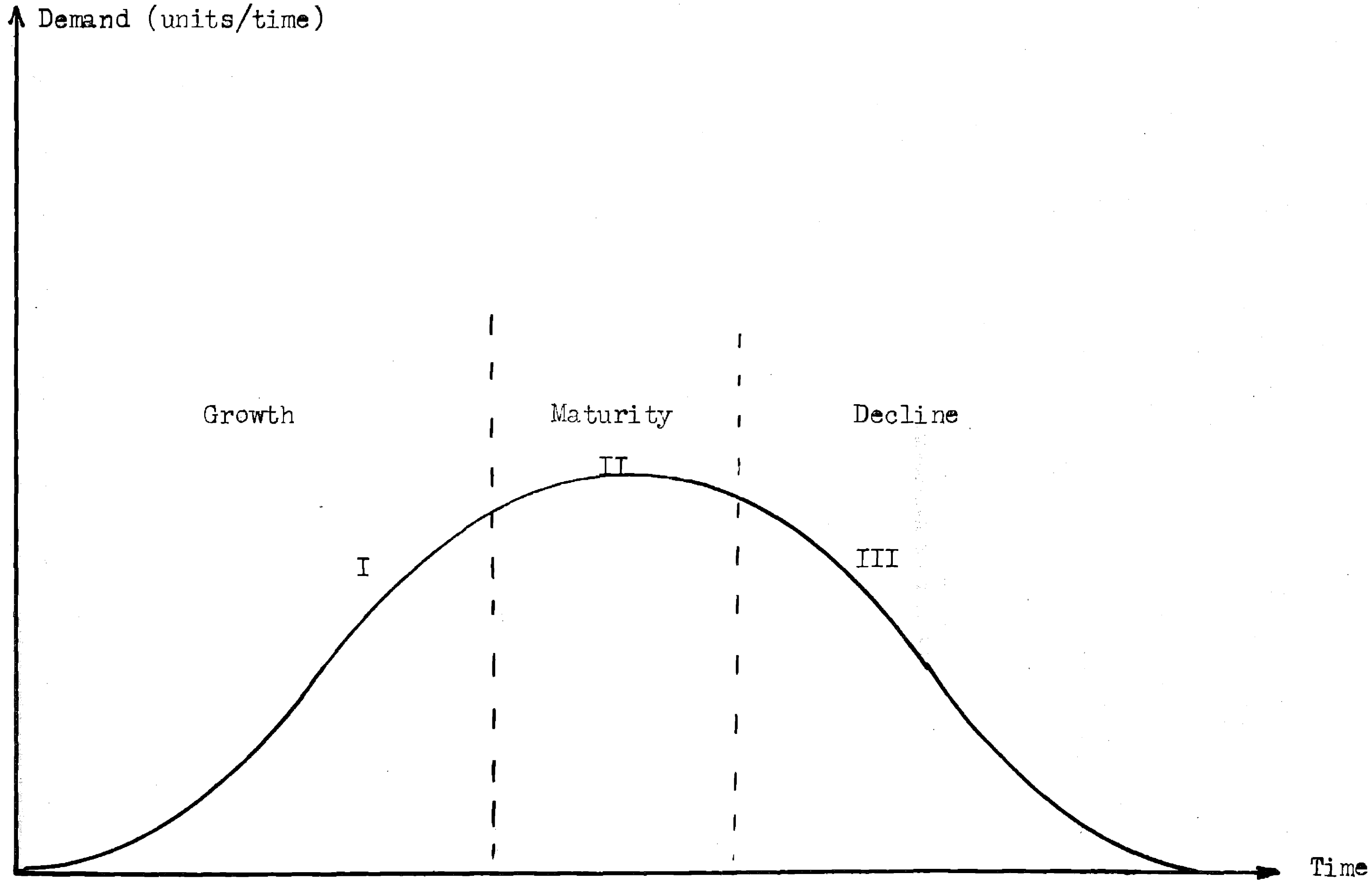

Figure IV-1, Life Cycle of a Product, Demand vs. Time.

more people are going to exchange their bicycles for cars.

Figure IV-1 shows the typical lifecycle of a new product. The scales on the axes on Figure IV-1 are different for every product. Some products, such as hula hoops, might go through the total cycle in a few months, while other products, such as automobiles, may have a life cycle of one hundred years.

This study will deal only with the first stage--growth-- and we will now go further in studying the dynamics within this stage in more details.

IV.2 Over-all Picture

Next is a simple over-all picture of the system under study. The system here consists of a growing market from which orders flow into the company. The orders are filled by the company, and goods flow back to the market. This simple relationship can be seen in Figure IV-2.

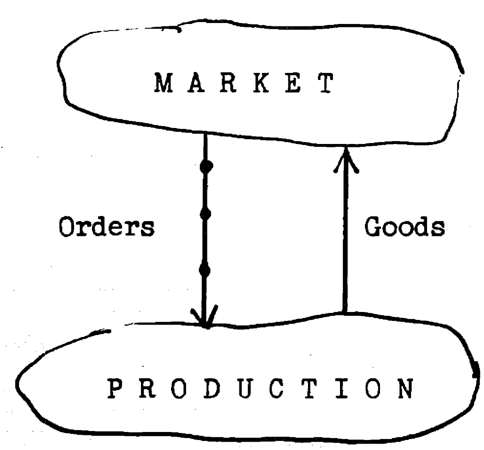

Figure IV-2, Simple Relationship between Market and Production.

What, then, are the determining factors for the order flow and the product flow? The product flow is here taken as determined simply by the ability to fill orders. Most companies will deliver what they have on order as quickly as they can, and the speed will be dependent upon the production capacity.

The order flow is a more complicated mechanism. It will be determined mainly by the market's feeling of need for the new product and the ability of the company to satisfy the need. To a certain degree, it might be assumed that the need for the product is created rationally by the product itself, but it also seems reasonable that the company should be able to influence the desire for the product by proper promotion efforts.

The simple picture in Figure IV-2 has therefore to be extended. In Figure IV-3 a research and development sector and a market development sector are included.

The orders from the market flow into the company, and in response to this flow there is a flow of goods back to the market. The potential size of the market will be dependent upon the product characteristics created by the research and development department, and the decision in the market to purchase will be influenced by the efforts from the marketing department.

To complete this over-all picture of the system, we need the factors that determine the results from the research and development and the marketing departments. It is common policy for many companies to link in some way the funds for the research and development and the marketing departments to sales. It should, however, not be for-gotten that a major determining factor for results from the research and development department is also time. It is easier to turn out a new product as the time gets ripe for it.

To clarify this, look at a new "product" like industrial dynamics analysis itself. It is built upon our state of knowledge and development of servomechanisms and digital computers. Accordingly, it was possible to develop the product with a reasonable amount of research in the 1950's, and it would have been close to impossible to develop the same product in the 1930's. The development of a new product can be considered a problem of both time and research efforts.

The over-all picture of the growth of a new product, therefore, builds up to the one in Figure IV-3.

IV.3 Internal Sector Description

In the above description a picture of the important quantities that flow between the different sectors has been given, but not a description of the actual interactions that take place within each sector. Next are described the relevant dynamics within each sector--market, market development, production, and research and development sectors.

IV.3.1 Market Sector

There has been extensive research on the adoption of a new product in a market, and most studies show the same general pattern.[1] The

[1] The Adoption of New Products, Process and Influence, The Foundation for Research on Human Behavior, Ann Arbor, 1959.

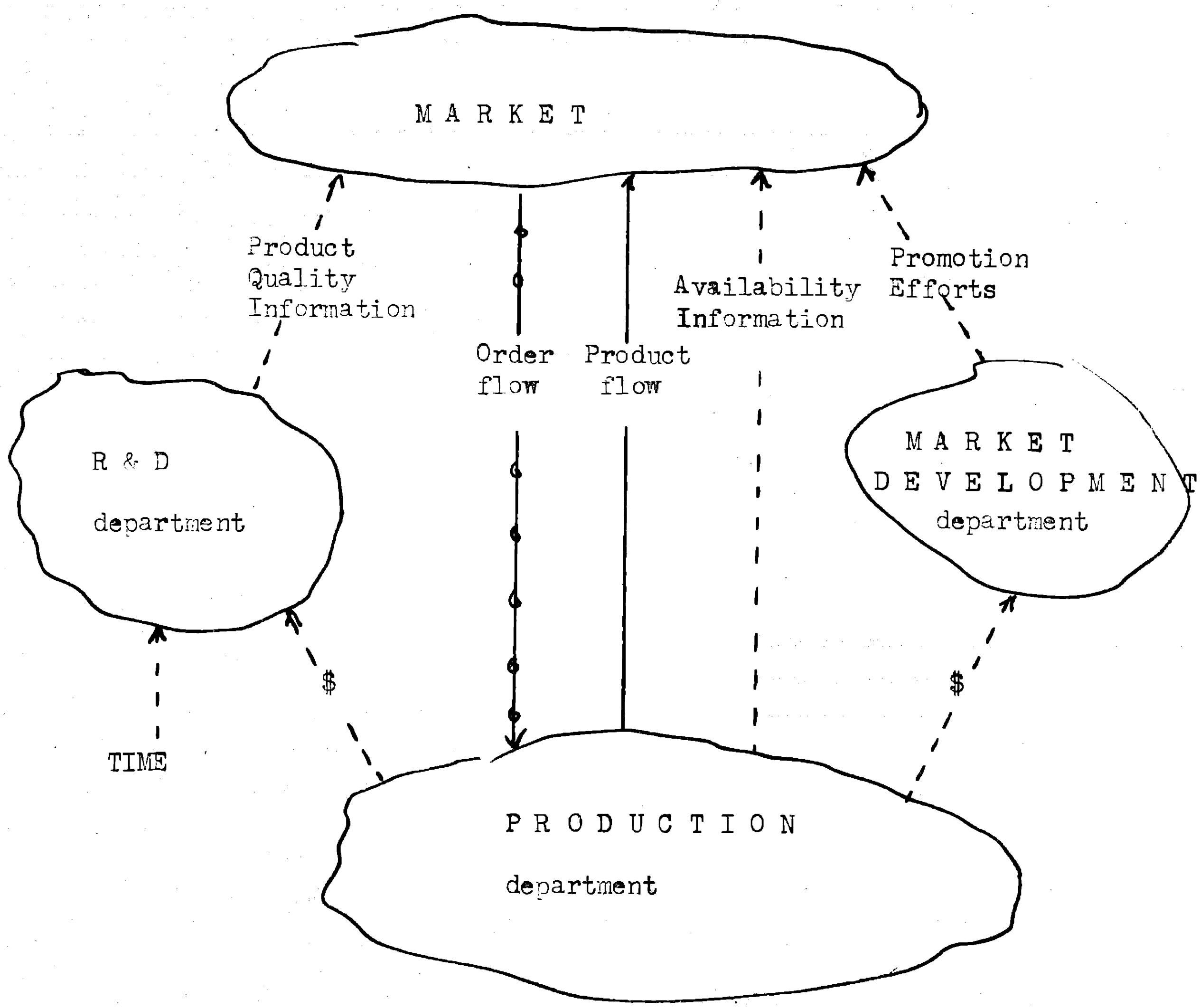

Figure IV-3, Overall picture of the interactions to create growth.

number of customers adopting the product plotted vs. time gives a curve as shown in Figure IV-4.

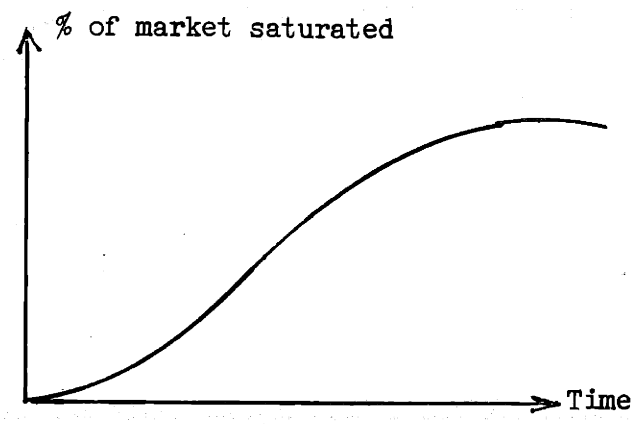

Figure IV-4, Percent of Market Saturated vs. Time.
(The curve is essentially the same as phase I of Figure IV-1.)

The early stage of a new product, as mentioned in Section IV.1, is an introductory phase. The main body of the market for the product is not ready to adopt the product. Only a small category, defined as "innovators", is ready to try out the new product.[1] Therefore, the curve initially rises slowly.

To get the main body of the market to adopt the new product seems to be a "two-dimensional" problem. The market needs time to get ready for a new idea. Most people resist change, and it has to be proved to them that the change is to their advantage. The adoption process will therefore require not only <u>time</u>, but also <u>promotion</u>

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[1] The Adoption of New Products, Process and Influence, The Foundation for Research on Human Behavior, Ann Arbor, 1959.

efforts. As the market grows ready to accept the new product, the demand curve rises more rapidly. The demand will begin to decrease in growth when the main body of the market has adopted the new product, and it will finally settle on a steady-state saturated level.

The time it takes to reach saturation varies for different products. It is dependent upon the complexity of learning to use the product, necessary changes that have to be done in the environments for the adoption of the product, and the price of the product.

The adoption process may be a very slow one. The previous description is only a superfluous one, and a more detailed treatment of the dynamics of the adoption of a new product follows. The description can be followed on Figure IV-5.

It will be assumed that the product has a defined potential market which eventually will adopt it and create a steady-state order flow for the product. We have therefore chosen to define the potential market in the form of a potential demand (units per week) as follows: The potential demand for a given product is equal to the average demand that will exist when the total potential market has fully adopted the product and all relevant purchasing conditions are satisfactory.

The potential demand will be determined mainly by the product characteristics themselves, but factors such as price and general environmental conditions will also influence the size of it.

Let us consider the environments external and constant in their influence on the potential demand. The two major factors for determining the potential demand are then price and product quality. In

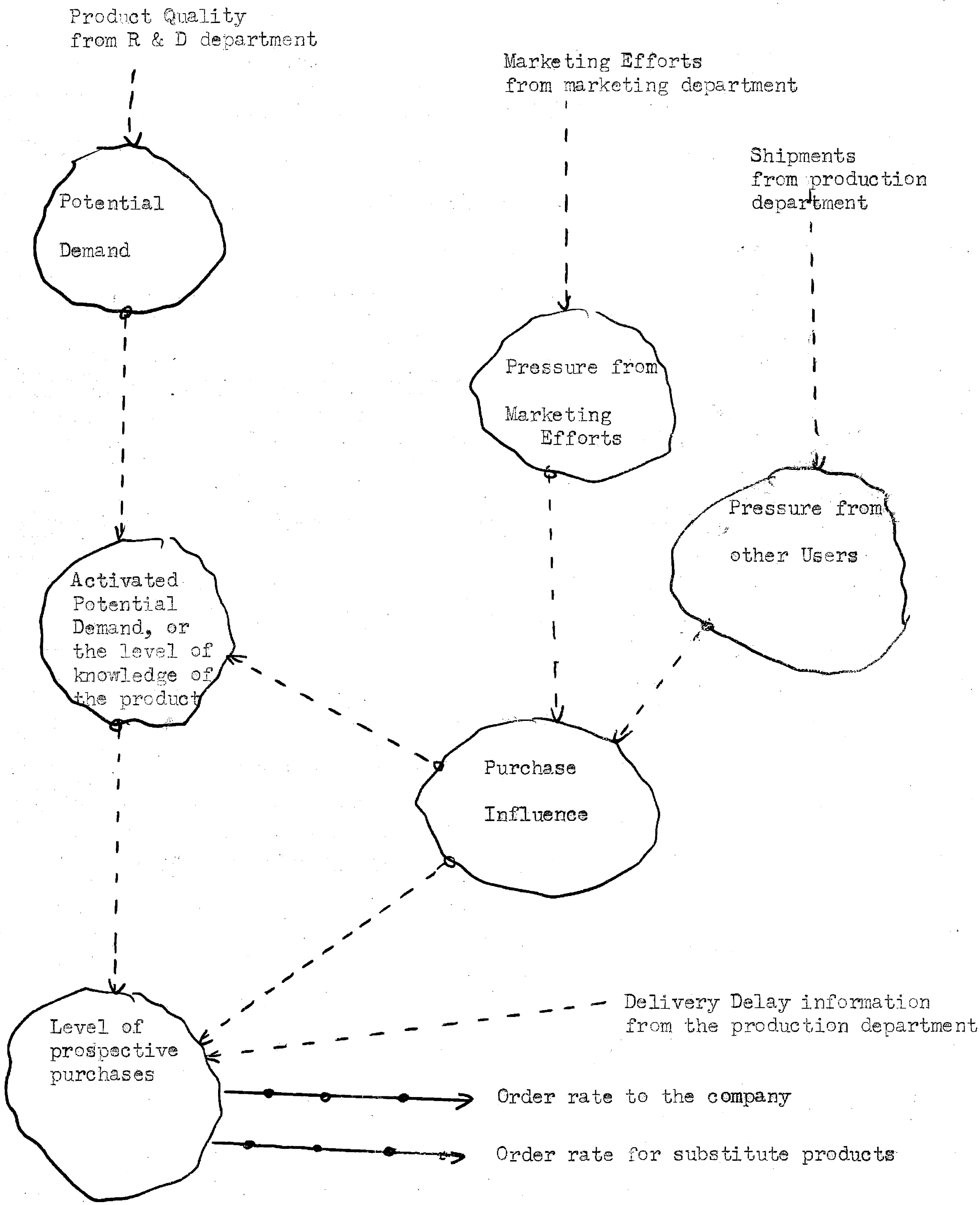

Figure IV-5, Market Dynamics.

many cases those two are correlated, as a high quality means a high price and a low quality a low price. The relative importance of price and quality will be different for different products. For some products, both factors will independently determine the potential demand, while for others only one of them may be of importance. We will concentrate upon products where quality is the determining factor for the potential market and we can think of the price as always being acceptable to the market.

Quality can also be used in a broader sense to include price. The quality of the product is then an aggregated concept of all factors that are appreciated by the market. Within limits, it seems reasonable that an improved "quality" will then increase the potential demand. It also seems reasonable to believe that a little increase in quality on a low level of quality gives little increase in demand. In other words, there has to be some minimum quality before people actually care about the product. An increase in quality on a high quality level should also give little increase in potential demand. The customers cannot benefit from the higher quality of the product and accordingly will not care too much about it.

This discussion of the relationship between quality and demand points to a curve, shown in Figure IV-6.

The potential demand does not, however, result in an immediate order flow. There is a long, complicated adoption process involved before the company will get orders for the product. The first process in the market is to get the potential customers to observe and be aware of the existence of a new product. This seems to be mainly a

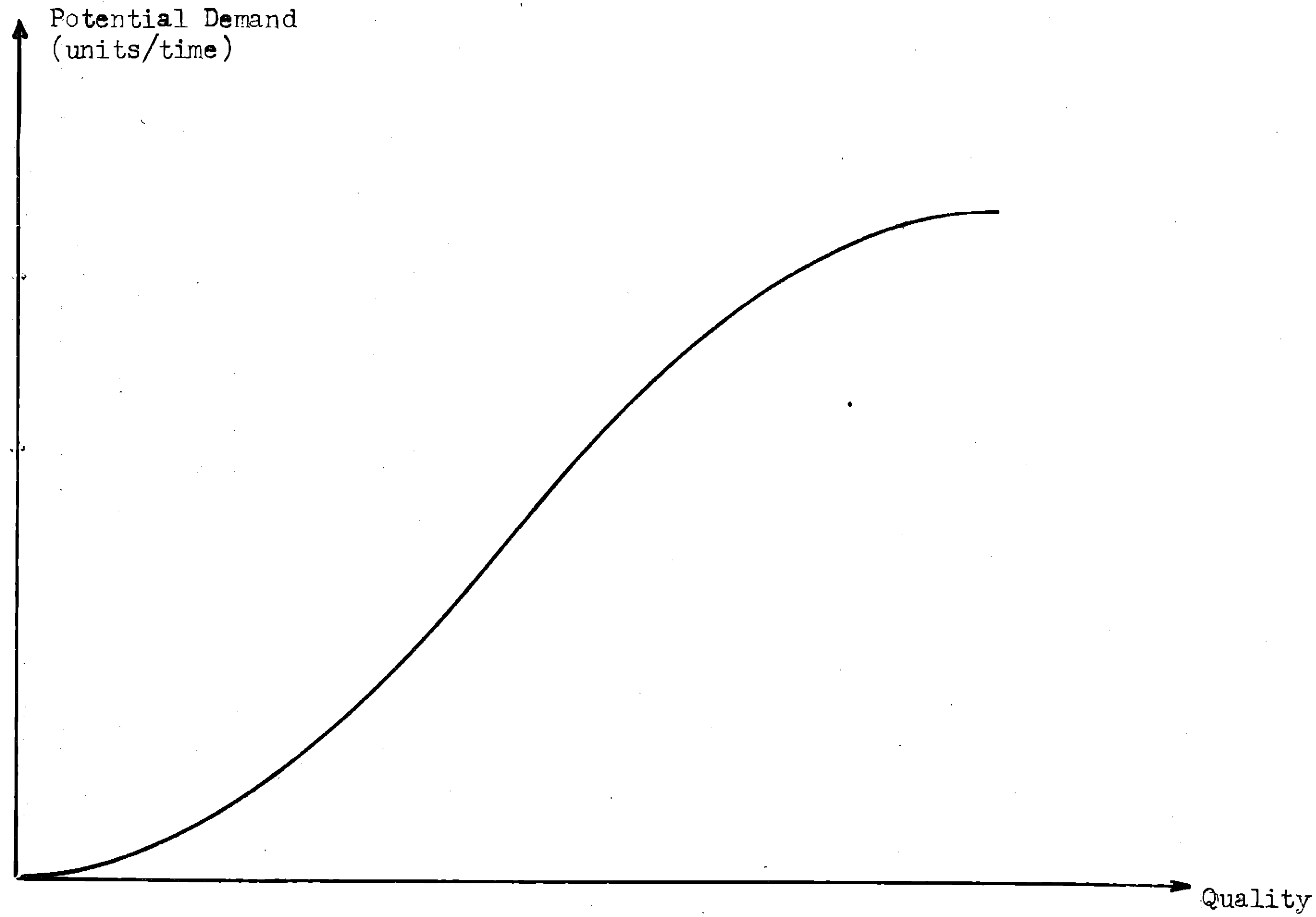

Figure IV-6, Relationship between Potential Demand and Quality.

time delay which could be influenced by promotion efforts and use of the product.

The potential customer now enters a state where he is evaluating his own needs for the product. Many human beings have a psychological resistance to changes. Therefore, the prospective purchaser may often first build up a "defense mechanism" to convince himself that he does not need the product. Depending upon the necessary changes that have to be done either for the customer himself or on his environment, it will now take more or less time and effort to convince him of the superiority of the new product and his needs for it. The customer has to evaluate why this product is so much better. What will a purchase mean to his relationship to other suppliers, the community and/or the family? Each of these questions will need careful consideration and perhaps also some research to answer.

The prospective customer may now find it worthwhile to test the product, and he orders a sample. Having gotten the sample, he will need a new evaluation of it. How is the actual product in comparison to his prior conception of it? The customer will have to learn to use the new product, and he will try it out to see how it works. Once more he has to be convinced of the superiority of the product and the benefits he can gain by adopting it.

All the above-mentioned adoption processes seem to be characterized by an absorption of knowledge about the product, and it seems also that the absorption process could be shortened by information about the product either from early innovators or from the company.

All processes could be combined into one which then is mainly a process of absorbing knowledge of the product. The process will create a level of knowledge of the product, or what we could consider an activated demand for the product. (See Figure IV-5.) This is a simplification of the actual adoption process, but we think it is a valid one which probably will not change the dynamic behavior of the system. The time to absorb the knowledge will be different for each individual in the market, and the model will use distributed delays in the formulation.

Having finally adopted a positive attitude toward the product, the customer then has to decide upon the size of the order. The funds for the purchase will, if necessary, have to be budgeted and the proper time to purchase decided before the actual order will go to the producer. This will create a level of purchases in the market from which the orders flow to the company.

The two levels in the market, the knowledge level and the level of purchases, can be seen in Figure IV-5, page 25.

The actual purchasing decision will depend upon the availability of the product. We often hear expressions like: "This product might be good, but we can't wait for it. We need it now." It seems that a long delivery delay might force some customers to find a substitute for the product. It seems reasonable that the longer the delivery delay becomes, the more people will find substitutes for the product. For a short delivery delay, this effect seems to be unimportant, but for a really long delay there might be no one who will wait for the product. This points to a relationship seen in Figure IV-7.

Information about the delivery delay will flow into the market

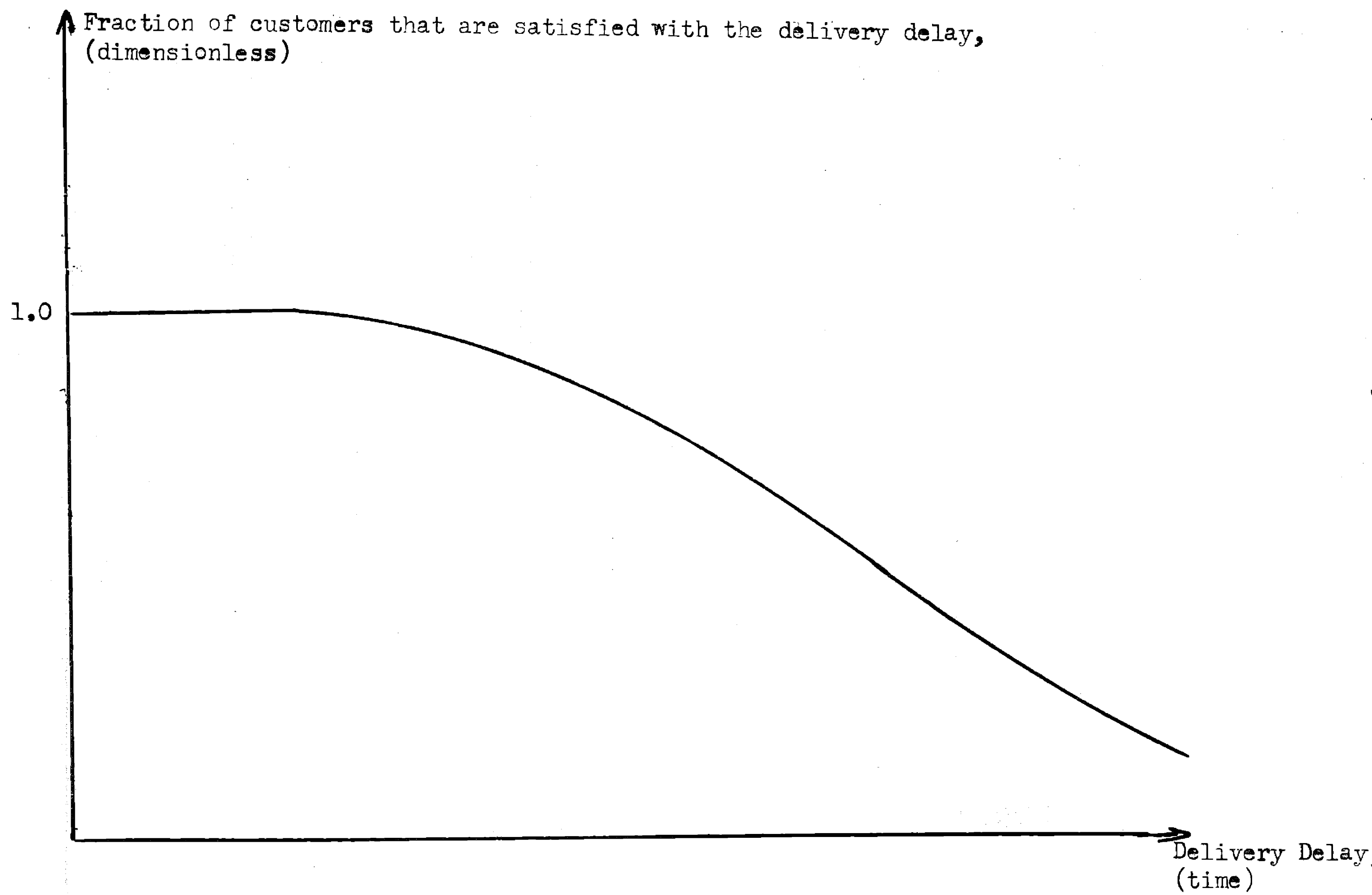

Figure IV-7, Fraction of customers that are satisfied with the delivery delay as a function of the delivery delay.

and determine the placing of orders either at the company or somewhere else where a substitute can be found. (Figure IV-5, page 25.)

The actual magnitude of the delays between the introduction of a new product on the market and the time the market has grown to its steady-state saturated value will be dependent upon the product we have in mind. For some products--for instance, "hula-hoops"--they will be short and some of the delays might approach zero, while for other products--for instance, digital computers--the delays might amount to twenty to forty years.

The adoption process is a function of both time and influence. The market needs time to grow up to the new product, but the adoption time will be dependent upon the influence exerted on the market.

What, then, are the factors that influence the potential customer, and what weight is each given? A research report[1] has dealt with the problem of influence sources and their relative importance. The study is concerned mainly with new farm products, but is considered to be of general value. It points out two separate sources of influence, informal and formal information.

Informal information comes from friends, neighbors, family, and so on, who have tested the new product. The importance of this source has been found to vary with the stage in the adoption process and the particular product in question. The magnitude of it is found to be about 20 percent of total information.

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[1] The Adoption of New Products, Process and Influence, The Foundation for Human Behavior, Ann Arbor, 1959.

The source of formal information is agencies, mass media, and salesmen. The study treats these factors separately and shows the different importance of each of them in different stages of the adoption process. The formal information counts for the rest of the influence on the customer.

How are the market adoption delays influenced by the influence level? We would expect in general that a high influence level should give a shorter delay, and a low influence level a longer delay. It seems reasonable to believe that there is a minimum limit to which we can shorten a delay; and the closer we get to the minimum, we should expect that we need relatively more influence to shorten the delay the same absolute amount of time. It also seems reasonable to assume that the market delays are extremely long if there is no influence at all in the market. The first small amount of influence actually can shorten the market delays relatively more than the same amount of influence at any other level of influence. The numerical values of the market delays will be different, but the general shape of them seems to be similar. According to the above description, we can draw a curve (as seen in Figure IV-8) giving us the relationship between influence and delays.

The effect of the influence from marketing efforts and users in shortening the adoption time is the only effect of influence which we will incorporate in the model. Effect on the market share is irrelevant, since competition is not included in the study. Also a possible effect of marketing efforts to increase the potential demand will be excluded.

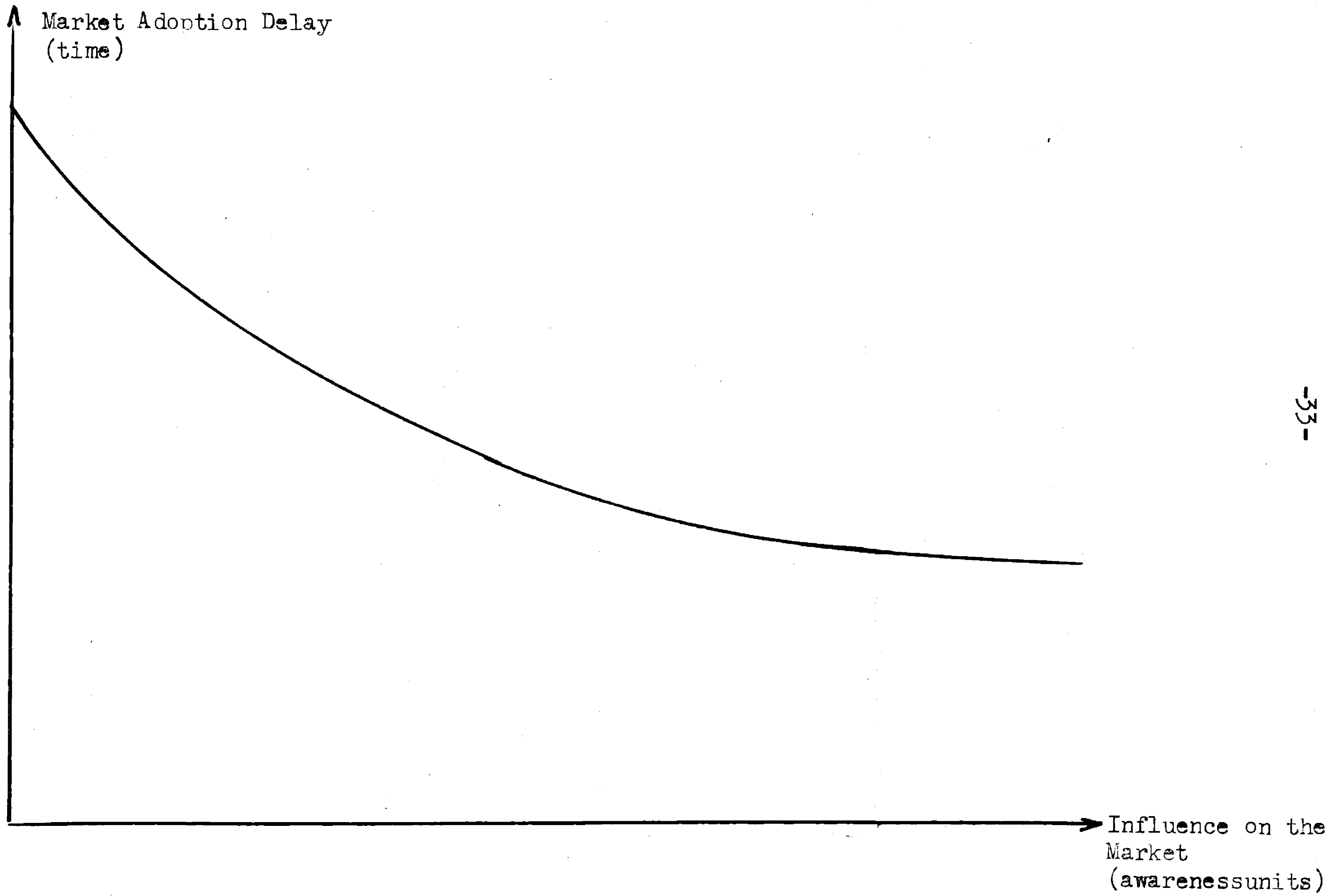

Figure IV-8, Market adoption delay as a function of the influence on the market.

We will often find that the introduction of a new product is done in one region and then extended to other regions later. It is also found that the marketing department is creating new use of the product as time gets on, and in this way actually increases the potential demand by their efforts. Effects of this kind will not be treated in this study, and we should think of the potential demand as a given quantity in the market for a given product quality.

The study will emphasize more the effects of management policies on growth and stability for a given product with a given sales potential.

The previous description gives us a schematic picture as seen in Figure IV-5. Summarized, the market sector has been simplified as follows.

The quality, here exogenous to the sector, will be the determining factor for the potential demand. The demand or the customers behind it will have to be transferred through two different stages:

1) absorption of knowledge about the product;

2) ordering stage.

By the first stage, we mean the combined process of observing the product, learning about it, and evaluating the use of it. The second stage is the stage for the actual purchase decision. Depending upon the delivery delay of the product, the customer will order the product or find a substitute for it.

The time the customer will need to be ready to order the product will thus be dependent upon the pressure that is put upon him. Two sources of pressure conceived of are pressure from other users and pressure from marketing efforts. These two factors combine and influence the customers in the two stages, as seen in Figure IV-5.

The schematic picture of the market sector will be used as the basis for the market formulation. It is no complete treatment of market growth under all conditions. Too many factors are omitted (in specific price and competition) and too many assumptions are made to allow us to construct a general growth model on the basis of Figure IV-5. A useful market sector to study product growth within the assumptions and scope of this study can be constructed.

An extension of the market sector to include the detailed market behavior would mean a more complex sector. The market sector contains the essential characters of the market to create orders as a function of time and influence in favor of the product.

It might be argued against the market formulation that we have used an average adoption time for all purchases. A customer of a new product will be more careful and spend more time ordering the first sample of the product than he will be when reordering more units of the product. Someone might also argue that the customers rebuying the product, after having worn it out, should be treated separately from the new customers, since they do not need a long evaluation time of the product. Both arguments are to a certain degree valid. To include them in the model would, however, mean an extension of the market sector, and it is doubtful if this will make any changes in the dynamic character of the system. We think, therefore, that it is a valid approximation in this first growth study to use an average adoption time for all potential purchases.

IV.3.2 Market Development Sector

In the previous section the effects of marketing efforts on the market were discussed. It was decided to include only the effect of marketing efforts on the adoption time. Excluded in the study is the ability of marketing efforts to increase potential demand or to create loyalty to the producer (competition is not included).

An increased pressure on the market in favor of the product will within limits speed up the adoption process as can qualitatively be seen in Figure IV-8.

The marketing efforts can take different directions. They will go partly to advertisements, personal selling, etc. We will here, however, treat only the marketing efforts on an aggregated level and assume that it is the aggregated effect of the promotion efforts which is influencing the market behavior.

The funds allocated to marketing efforts for the product are commonly budgeted each quarter of a year. They are spent, for a product without seasonal demand, fairly evenly over time. It is a fairly common policy to link the funds to the average sales or expected sales by taking a certain fraction of gross income or expected gross income. The policy is often considered doubtful, and the model will be able to point out the effects of this policy. Later it might be tried out on other policies for the allocation of marketing efforts.

After the funds have been budgeted, there is a time delay before they result in real marketing efforts. This time delay involves time to decide on promotion mix, where and when to promote, planning the campaign, and physical handling of the promotion. The length of this delay may be a couple of months or more.

The actual marketing efforts will not result immediately in any action from the customers. They will first have to observe the marketing efforts, which takes another couple of months. Together with the observed usage of the product, the observed marketing efforts will create an influence that is able to increase the rate of market growth.

A schematic picture of the market development sector can be seen in Figure IV-9.

The marketing department gets the sales data from the production department. On the basis of past sales the expected sales are determined and the decision for marketing efforts is taken. The allocated efforts create delayed actual marketing efforts to which the customers are exposed. The observed efforts influence in the market the delays in the adoption process as seen in Figure IV-5.

In the model it is assumed that limitations do not exist to the marketing efforts in the form of salesmen or lack of funds to follow the stated policy.

IV.3.3 Production Sector

The production scheduling at the company might be done in different ways. Some companies will only produce to order, while others will try to keep sufficient inventory to deliver at minimum time. We will assume that we are talking about a product that can be manufactured and kept in stock and that the company tries to keep an inventory.

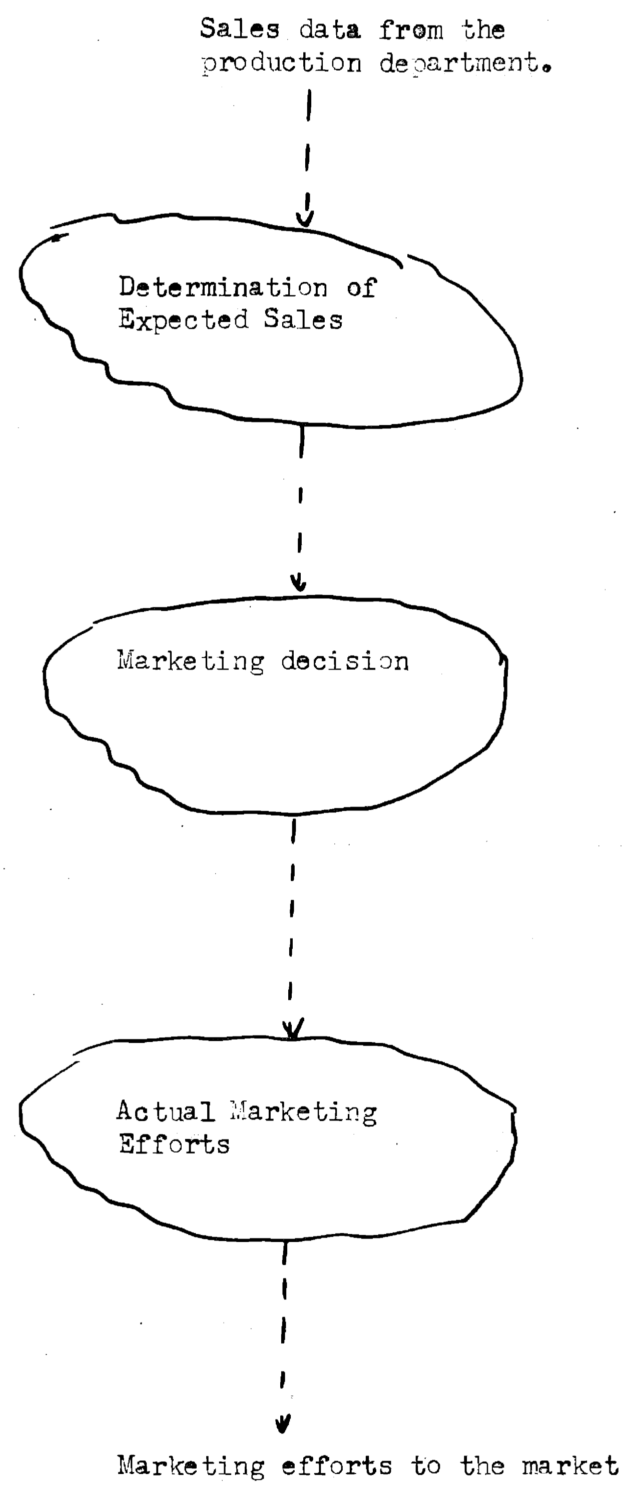

Figure IV-9, Market Development Dynamics.

An order flows from the customer to the company, where it is first checked for credit performance, past relationship, etc. Thereafter, the inventory is checked and if the order is in inventory, it will be shipped. This process might take from a couple of days to a couple of weeks depending upon the product and the order size.

If the order cannot be filled from inventory, it will stay in an unfilled order file until it is produced and can be shipped from inventory. How soon it can be filled will then depend upon how soon it can be produced. The production policy that is commonly followed is to produce to meet average incoming orders and to gradually adjust inventory and unfilled order pools to desired levels. If the company expects an increase in sales in the future, it will often also try to build up its inventory in advance by increased production. The company might or might not be able to fulfill the above production policy depending upon the existing production capacity.

Being limited by production capacity, the company will evaluate the need for capacity and, if necessary, adjust the capacity to desired amount. This will, however, involve a long time lag. The company will have to see that the need for increased production capacity is not only a temporary one, but that the capacity will be needed on a more permanent basis. The decision to order more capacity will now need approval on different levels in the company, and the funds for the purchase have to be budgeted, before the actual purchase decision can be taken.

Depending upon the specific circumstances, this time delay will be in the magnitude of three to four months to a couple of years.

The need for capacity will be estimated by the expected order rate and a measurement for present position. By forecasting the order rate, the company gets some estimate of the expected order rate, and the position of backlog and inventory will serve as an indication of present capacity position.

In some cases, it might be found that the financial position puts up limitations to capacity orders. This factor is not included in the model, and the reader should keep in mind that the model is only able to study growth where capacity decisions are taken on the basis of factors present in the system.

In general, a company wishes to have a certain amount of inventory on hand in order to meet incoming orders as quickly as possible. Similarly, it is often desired to have an amount of orders in backlog to have some insurance of sale of the production. It is commonly found that both these two desired levels are linked to the average volume of business.

The time it takes to fill an order will be determined in the production sector by the company's present position. If the incoming order can be filled from inventory, the delivery time will be determined by the minimum handling time of the order and the shipment. Often in a growth situation we find, however, that a high backlog and no inventory exist. The delivery time will then be determined by the time it takes to work off the backlog. The information about the delivery delay flows back to the market and influences the order flow to the company (Figure IV-5).

The flow of shipments from the production department will create a level of users of the product in the market, and it will also serve as a basis of allocation of efforts to market development. Both factors will work together to influence the pressure on the market to adopt the new product.

IV.3.4 Research and Development Sector

In Section IV.3.1 the product was characterized by an aggregated "quality" incorporating all factors which the market appreciates. The development of this quality will take place in the research and development sector. The quality determines the potential market as seen in Figure IV-5.

What, then, are the relevant factors which determine the product quality? With regard to this study of the dynamic interactions between the market and the manufacturer, there are two major factors which create product quality--time and research and development efforts.

The product will go through different stages as basic research, design, engineering, etc., all of which will require time and effort. The necessary amounts of these two quantities will depend upon the product in mind, and for some products we might find that both time and research and development effort are very small, while for others the development will keep on for years. It seems reasonable that the time to develop a product can be shortened by an increase in efforts. This process has limitations, however. The research and development department and the general technical knowledge have to grow up to the ideas behind the product before any results in the form of a new or improved product can be experienced.

The importance of the two factors, time and research and development efforts, is dependent upon the product we have in mind. In this study it will be assumed that we are treating a product where time is the determining factor for the development of the product. The research and development efforts can always be considered sufficient not to give any limitations to the development product.

The development process is then simplified to be only a function of time. It is an extreme simplification, but we think it is a valid one, as we are not particularly concerned about the internal dynamics of the research and development laboratory. This study emphasizes instead the interactions between the market, production, and the research and development sectors.

It should be noted that by excluding the details of research and development efforts on the product quality, the feedback loops from sales and market acceptance to research and development results are excluded.

It seems reasonable to believe that there is an upper limit to quality which we can reach, and it also seems reasonable to assume that the quality will never decrease with time. What the exact relationship is will depend upon the product we are talking about. Some products increase to a maximum quality extremely fast, while other products will need a great deal more basic research before actually becoming high quality products. In Figure IV-10 are shown some plausible relationships between quality and time. Product A represents a product type which can rapidly be developed to an acceptable quality. Small amounts of research efforts and time are

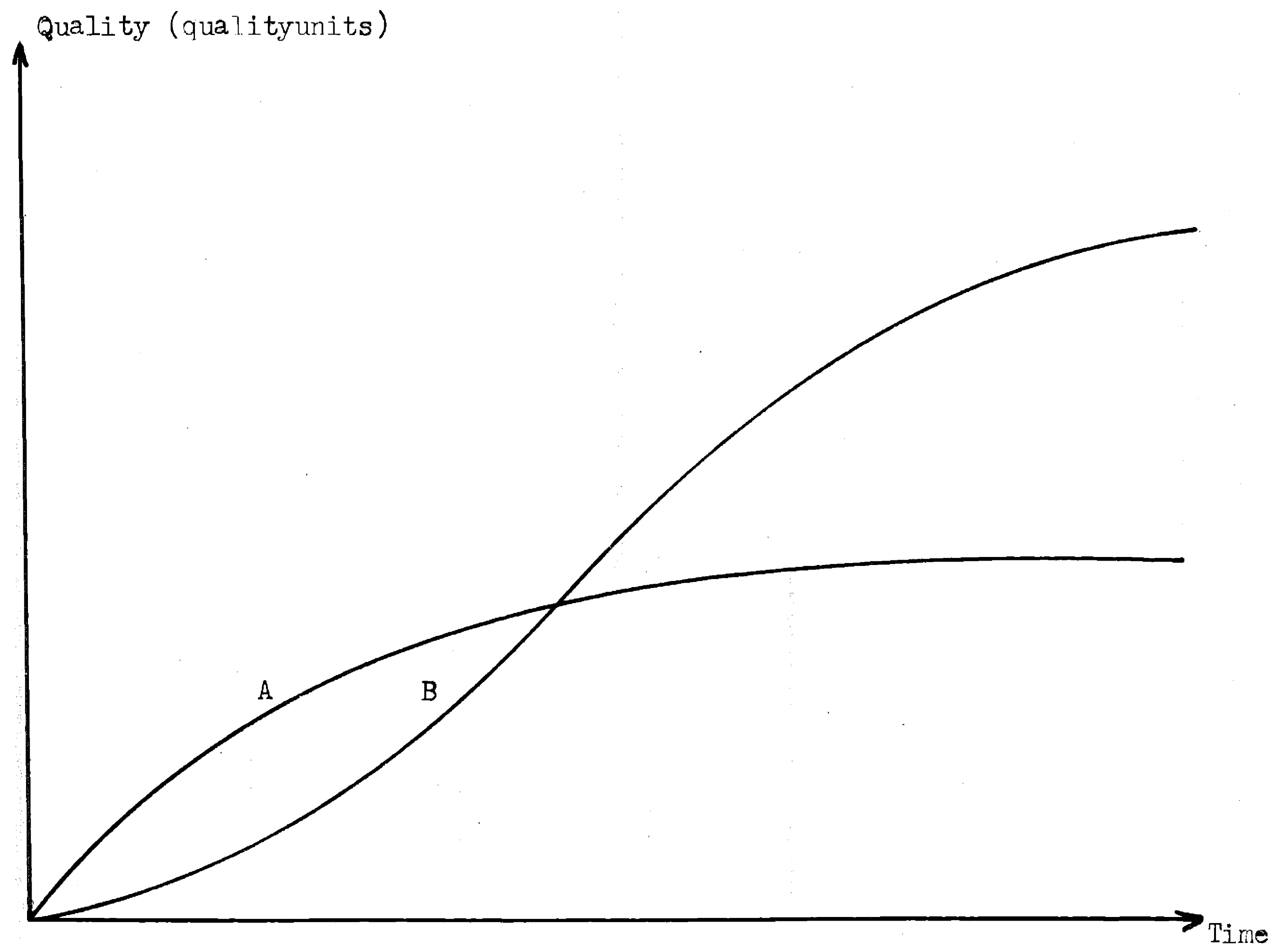

Figure IV-10, Plausible relationships between quality and time.

necessary for this product development. Product B represents another product type which needs considerable amounts of research and time before the quality reaches an acceptable level. Being well founded, this product type has often a potential for high quality.

A schematic diagram of the research and development department can be seen in Figure IV-11.

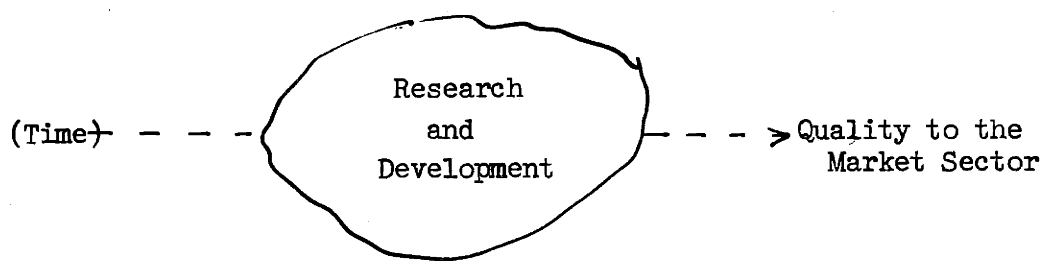

FIGURE IV-11

Research and Development Dynamics

The quality created in the research and development department goes back to the market and determines the potential demand for the product.

CHAPTER V

SUMMARY OF THE MODEL

The model formulation details are given in Appendix A, and a flow diagram is shown in Figure V-1. The model consists of four interacting sectors: market, market development, production, and research and development as seen in Figure V-2. The four sectors are interrelated with 50 equations to describe the selected dynamic interactions between a market and a manufacturer.

V.1 Basic Assumptions for the Model

The model is based upon the previous description, and it is built upon the following basic assumptions:

1) All quantities can be treated as aggregated and continuous ones.
2) The potential demand for the product is a function only of the quality of the product.
3) The adoption process of a new product is mainly a time consuming process.
4) The market development efforts cannot increase the potential market. They can only speed up the adoption process.
5) The product is manufactured and kept in stock.
6) The company will try to ship the product as rapidly as possible.
7) The company is, within limits, always able to turn out a better product with time.

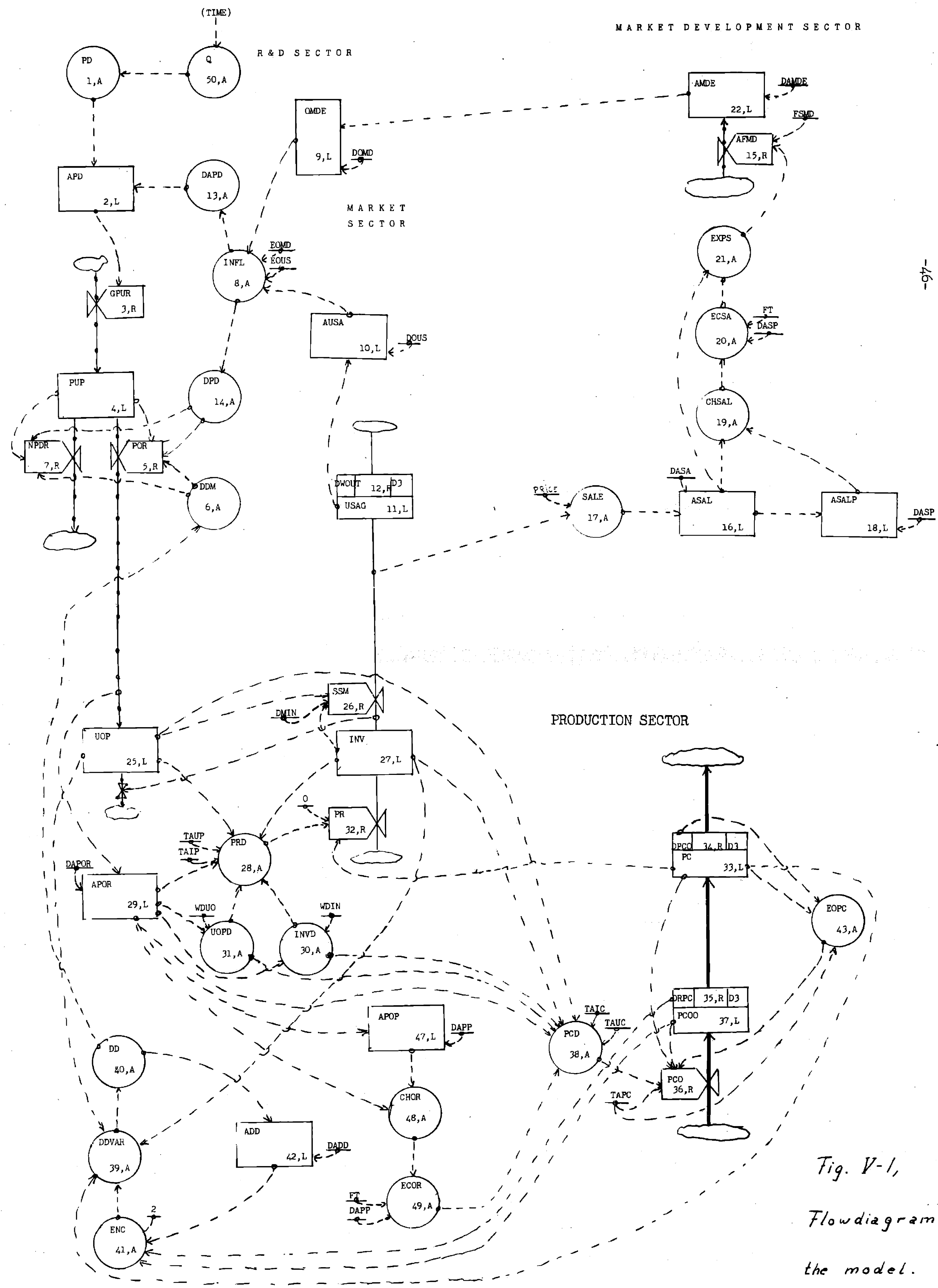

Fig. V-1,

Flowdiagram of

the model.

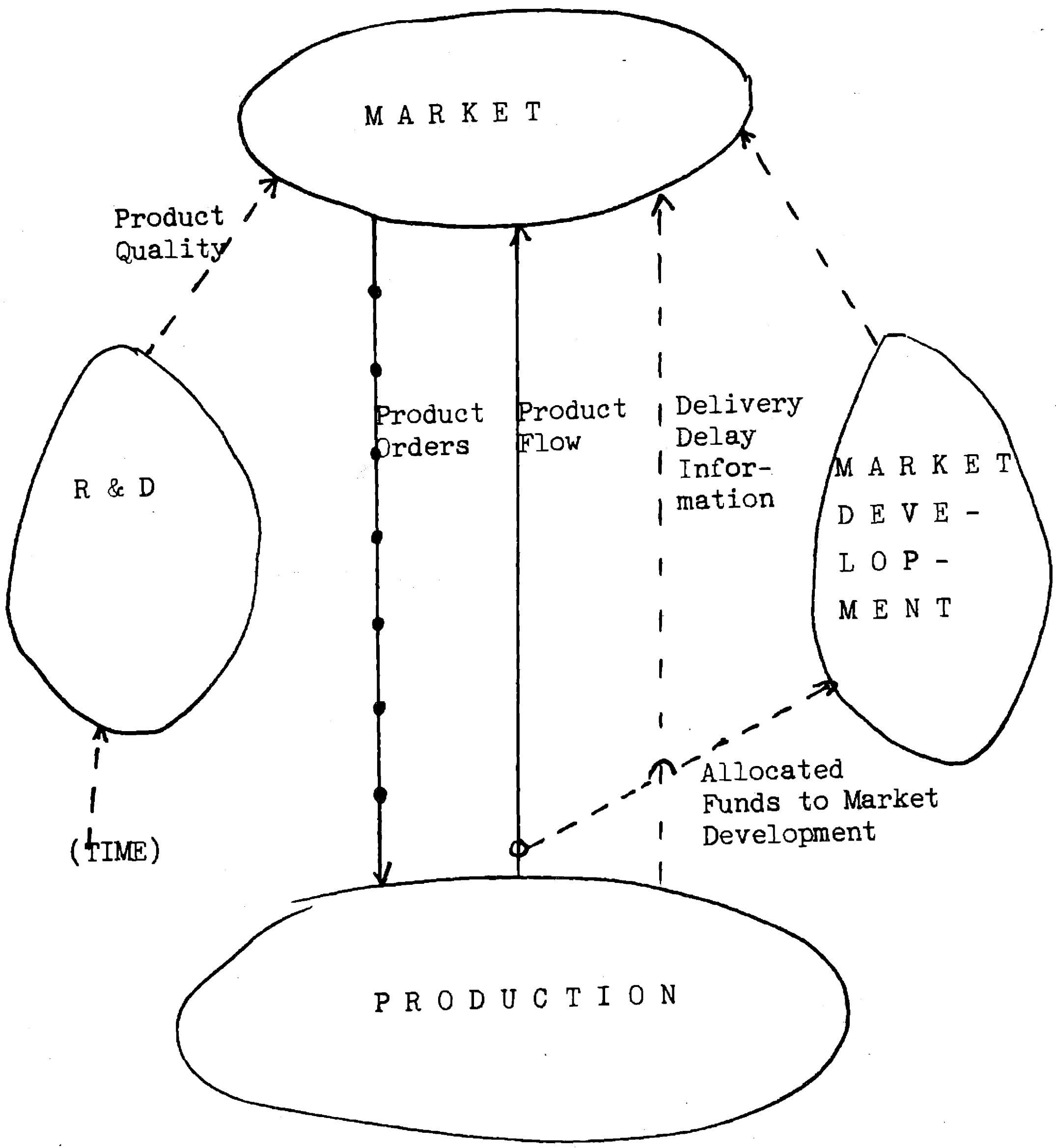

Figure V-2, Interactions between the Different Sectors in the Growth Model.

The assumptions are reasonable and sound for a study of the selected dynamic interactions between a market and a manufacturer, and the model is able to treat interactions to create growth and stablility.

The detailed formulation of the equations can be seen in Appendix A, and we recommend that the reader study this appendix before reading Chapter VI.

Following is a summary of the major factors included in the model.

V.2 Market Sector

On the flow diagram, Figure V-1, can be seen the market sector as formulated in this model.

The market sector creates product orders to the company on the basis of the product quality, the availability of the product, the influence from the marketing department, and the influence from early adopters.

The market sector begins with a potential demand (PD, Eq. 1, A) of the product created by the quality (Q, Eq. 50, A). The potential demand will gradually be activated and gives a level of activated potential demand (APD, Eq. 2, L). The time to activate the demand (DAPD, Eq. 13, A) is a function of the influence exerted on the market (INFL, Eq. 8, A). A higher level of influence gives a shorter delay in activating the demand.

The activated demand is assumed to generate a flow of prospective purchases (GPUR, Eq. 3, R) flowing into a pool of purchases (PUP, Eq. 4, L) that are becoming ready for ordering the product.

The time for the purchase decision (DPD, Eq. 14, A) is assumed to be a function of the influence exerted on the market. A higher level of influence will also give a shorter delay time for the purchase decision. The purchase decision is also dependent on the delivery delay through a delivery delay multiplier (DDM, Eq. 6, A), which determines the split in the market between a product order rate to the company (POR, Eq. 5, R) and a nonpurchase decision rate (NPDR, Eq. 7, R). The latter rate is a rate of lost orders for the company due to the influence of the delivery delay on the market's ordering decision.

A high delivery delay (DD, Eq. 40, A) gives a larger fraction of the market ordering substitute products, and accordingly will be lost orders to the company. The product order rate (POR, Eq. 5, R) flows to the company's unfilled order pool (UOP, Eq. 25, L).

In the model it is conceived that there are two sources of influence, marketing efforts and usage of the product. The observed market development efforts (OMDE, Eq. 9, L) and the average usage of the product (AUSA, Eq. 10, L) combine and determine the influence (INFL, Eq. 8, A) exerted on the market in favor of the product. Both factors are delayed versions of the actual influence sources, the actual market development efforts (AMDE, Eq. 22, L), and the usage of the product (USAG, Eq. 11, L). The usage level is created by the shipments of products to the market (SSM, Eq. 26, R) minus the wearout rate of the product (WOUT, Eq. 12, R). The wearout rate of the product is a third-order delay of the shipments to the market (SSM, Eq. 26, R).

V.3 Market Development Sector

The market development sector creates observed marketing efforts on the basis of a marketing policy linked to past sales.

The allocation policy for market development efforts (AFMD, Eq. 15, R) is in the model linked to the expected sales (EXPS, Eq. 21, A). The expected sales (EXPS, Eq. 21, A) are determined by a linear extrapolation of present sales trend. The sales (SALE, Eq. 17, A) are then determined on the basis of the shipments to the market (SSM, Eq. 26, R). The sales are averaged (ASAL, Eq. 16, L) and compared to a past value of average sales (ASALP, Eq. 18, L) to determine the past change in sales (CHSAL, Eq. 19, A). The expected change in sales (ECSA, Eq. 20, A) is forecasted with a constant trend.

The allocated funds to the market development efforts (AFMD, Eq. 15, R) are delayed before they result in actual market development efforts (AMDE, Eq. 22, L) which go to the market to be observed.

V.4 Production Sector

The production sector produces and ships products to the market as a response to the product orders. Past order rate serves as a basis for determining capacity orders, and the information about the ability to fill orders (the delivery delay) flows to the market and influences the product order rate. The product order rate (POR, Eq. 5, R) flows into an unfilled order pool (UOP, Eq. 25, L). The orders are filled by a shipment rate (SSM, Eq. 26, R) based upon the unfilled order pool (UOP, Eq. 25, L) and inventory (INV, Eq. 27, L) positions. The inventory (INV, Eq. 27, L) is filled by the production rate (PR, Eq. 32, R). A desired production rate (PRD, Eq. 28, A) is determined by the average order rate (APOR, Eq. 29, L) and the positions of unfilled order pool and inventory relative to their desired levels (INVD, Eq. 30, A, and UOPD, Eq. 31, A).

The actual production rate (PR, Eq. 32, R) is equal to the desired rate (PRD, Eq. 28, A) if there is sufficient production capacity (PC, Eq. 33, L). Otherwise it will be limited by the capacity.

A desired production capacity (PCD, Eq. 38, A) is calculated from the average order rate (APOR, Eq. 29, L), the expected change in the order rage (ECOR, Eq. 49, A), and the positions of inventory and unfilled order pool relative to their desired levels (INV, Eq. 27, L; UOP, Eq. 25, L; INVD, Eq. 30, A; UOPD, Eq. 31, A).

The production capacity is ordered (PCO, Eq. 36, R), on the basis of desired production capacity (PCD, Eq. 38, A), actual production capacity (PC, Eq. 33, L), production capacity on order (PCOO, Eq. 37, L), plus the expected obsolete production capacity (EOPC, Eq. 43, A). The additions of production capacity (PCAR, Eq. 35, R) are simply a third-order delay of the production capacity orders (PCO, Eq. 36, R), and the obsolescence rate of capacity (PCOR, Eq. 34, R) is a third-order delay of the production capacity additions rate (PCAR, Eq. 35, R).

The expected change in the product order rate is formulated similarly to the forecast of sales. A past average order rate (APOP, Eq. 47, L) is compared to the average order rate (APOR, Eq. 29, L) and the past change in orders is determined (CHOR, Eq. 48, A). The expected change is forecasted as a linear trend (ECOR, Eq. 49, A).

The delivery delay (DD, Eq. 40, A) is determined by the positions of inventory (INV, Eq. 27, L) and unfilled order pool (UOP, Eq. 25, L) and the average capacity position that will exist during the delivery delay. The latter is equal to the present production capacity position (PC, Eq. 33, L) plus the expected effectiveness of the capacity (ENC, Eq. 41, A) arriving during the average delivery delay (ADD, Eq. 42, L). The delivery delay information flows to the market and influences the order flow to the company (DDM, Eq. 6, A).

V.5 Research and Development Sector

The research and development sector consists of a simple equation to create product quality (Q, Eq. 50, A) as a function of time. The quality determines the potential demand (PD, Eq. 1, A) in the market.

V.6 Feedback Loops in the Model

The model is a complex feedback mechanism of which we here will point out the more important loops.

1) The income from sales gives more funds to the marketing department, which again influences the sales of the product.
2) The sales will create a level of users who will influence other purchaser's orders.
3) The order flow to the company will influence the delivery delay which again influences the order flow.

V.7 Model Validity

The model has been kept simple in order that the different factors can be more easily understood. It is built upon a series of assumptions and accordingly is only valid under conditions where the assumptions are sound. The model is no detailed treatment of the internal factors within each sector, and as such cannot be used in a detailed sectorial analysis.

We should not forget the possibility that the relevant factors to this growth problem have not been included. The model should, therefore, be tested for validity. It should be done as follows:

1) Each relationship between variables per se to see if they make sense. Only by clear conception of the problem can this be done, but it does seem to be the most important test for validity of the model.
2) The overall behavior of the model to see if it shows qualitatively the same characteristics as the system modeled.

As a final point on validity, it should be stressed that the validity of the model is dependent upon the way it is used. The model itself is no end to the study, and the value of it should be estimated on the basis of its usefulness in gaining better insight into growth and suggesting better ways of handling growth problems within the scope of this study.

CHAPTER VI

BEHAVIOR OF THE MODEL

The model is now ready to be used in the study of how the interactions between a market and a manufacturer interact to create growth. The interactions will first be examined for the model as presented in Chapter V and Appendix A, and later other conditions will be explored. The model is built for a hypothetical system, and the results are therefore not specifically applicable to the growth of a particular new product. Only as far as the assumptions are valid for the real world can general conclusions be drawn from the runs.

The factors included in the decision functions (the rate equations) are the main determinants of decisions or policies in the model. Noise in the decision-functions has not been included at this stage in order to have a model that is easier to analyze. The model will therefore show a smooth behavior of all variables. Later, when a more thorough understanding of the system has been obtained, the noise might be included to get a more realistic growth picture.

VI.1 Behavior of the Basic Model as Presented in Chapter V and Appendix A

The behavior of the basic model can be seen in Figure VI-1. A description of how the different factors in the model interact to produce growth follows.

The quality (Q)[1)] is assumed to be a function of time only, and in the model it is created as an exogenous input to the system.

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1) For equations, see Appendix A and flow diagram Figure V-1.

It is gradually rising in 500 weeks (10 years) from its initial value up to a maximum value which is arbitrarily defined as 10 quality units. The initial value of quality has been assigned 2.8 quality units.[1)] The potential demand (PD) is a function of quality only, and therefore in the model is also an exogenous variable. The relationship between the potential demand and the quality (Figure A-2) gives initially a potential demand rising slowly from 715 units/week to 1900 units/week in 100 weeks. About week 100, the quality reaches what is assumed to be an acceptable quality and from this time on each improvement in the product increases the potential demand until it reaches 4000 units/week at week 200. As the quality rises further, it passes a stage where it is acceptable to most of its potential users, and further increases in quality are assumed to have little appeal. The potential demand therefore starts flattening out at about week 200 after the starting point and finally settles on a value of 5000 units/week.

The potential demand (exogenous to the system) creates interactions in the model (Figure VI-1) to give three different growth phases: the introductory phase (week 0 - 200), the major growth phase (week 200 - 750), and the end phase (week 750 - 1000). We will now go through the product order rate in the different phases to decide the characteristics of it, and thus discuss how the factors in the model create the experienced behavior of the product order rate (POR).

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1) The model has been started out with some initial quality and interest in the market to shorten the introductory phase of the growth. See Appendix A, Section A.2.

In the model there is given a small initial value to the purchase pool (PUP). The product order rate does, therefore, not start from zero, but from a value of 250 units/week. It grows very slowly initially due to the long time constants in the market in adopting the new product, and it increases to 600 units/week in 200 weeks (4 years). The influence from the first innovators and from the higher market development efforts (as sales increase) makes the market more ready for adopting the new product, and it can be seen in Figure VI-1 that the product order rate after week 200 increases more rapidly. It grows exponentially from week 300 until week 650 whereafter it grows linearly for 2 years (week 650-750) to 4000 units/week. From week 750 the growth in orders is slow and approaches saturation (5000 units/week). In the different growth stages there are different factors that are the dominant causes for the growth.

In the introductory phase (week 0-200), the company has always enough production capacity, and the product order rate is determined by the market growth which is slow at this stage. From week 200 (the major growth phase), the company finds that it is lacking sufficient production capacity (PC) to take care of the increased order flow and the delivery delay (DD) rises abruptly at week 210. During the rest of the growth phase, the company has the same experience as many growth companies that never seem to be able to keep up with the growing demand. The delivery delay stays at a high value (above 20 weeks) from week 300 until week 650, even though the company is quadrupling its production capacity over the same time.

The high delivery delay causes (through the delivery delay multiplier, Eq. 6, A, Figure A-3) about 40% of the prospective order flow to be directed to a substitute for the product instead of to the company. Under these conditions, the company could increase its product order rate by reducing its delivery delay so that fewer prospective customers would be lost to substitute products. The company is actually in a situation where its product order rate is determined by its own ability to fill orders. In Figure VI-1, it can be seen that the curves for the production capacity and the product order rate have the same slope between week 300 and week 650. The experience that the ability to fill orders is actually the determining factor for the product order rate to the company seems to be a common experience for many growth companies, even though it is seldom realized by management.

From about week 750 (the end phase), the slope of the curve for the product order rate is less than the slope of the production capacity curve. The order rate is, therefore, no longer solely determined by the company's ability to fill orders. The order rate now approaches saturation, and the delivery delay is reduced to two weeks (minimum delivery delay) at week 910.

In Chapter IV it was explained how the product order rate for a new product grows as the market gets ready to adopt the new product. The explanation given here shows, however, that for this model run the major growth in the product order rate is not determined by the market growth, but by the company's ability to satisfy the market needs. The model run is a good illustration of the necessity of treating market growth as a feedback system between the market and production sectors to develop the fundamental understanding of new product growth. In this model the influence of the delivery delay (Figure A-3) controls the growth in the product order rate to equal the growth of the production capacity at the company.

Let us now see how the production capacity orders (PCO) are determined in the model. In the introductory phase, the initial capacity is enough to satisfy the demand and additional capacity is first ordered at week 130. The production capacity orders are determined by a linear extrapolation of the past product order rate (Figure A-7). Due to the influence (INFL) on the potential customers both from the first users (AUSA) and from the observed market development efforts (OMDE), the product order rate grows, however, faster than the linear expectation; and the management of this company finds about week 210 that it is not able to fill orders promptly. The delivery delay unavoidably increases. As the delivery delay increases, more of the prospective purchases are directed away from the product to substitute products that are more able to immediately satisfy the market's demand. The product order rate stays therefore fairly constant between week 210 and 300. This will again cause a constant expected order rate (ECOR) and a falling trend in production capacity orders (PCO) as the production capacity (PC) plus the production capacity on order (PCOO) are approaching the desired level (PCD) week 250-300.

The delivery delay reaches a value of 25 weeks at about 300 weeks. The delivery delay multiplier (DDM) (Figure A-3) will now adjust the product order rate to be equal to the production capacity position, and in Figure VI-1 can be seen that the slope of the curve for the product order rate is equal to the slope of the curve for the production capacity from week 300 and until week 650.

Additions in production capacity will cause a further growth in the product order rate between week 300 and 650, and there are no possibilities for the company to reduce the unfilled order pool (UOP) or build up the inventory (INV). Instead, we find that the unfilled order pool increases from its minimum value of 2 weeks of orders at week 200 until a maximum of 69500 units. The inventory stays at its minimum value during the major growth phase.

The company stays in the major growth phase for about 9 years (week 300-750) and during this phase it grows faster than linear even though the product order rate is forecasted linearly. Production capacity is, however, also ordered for unfilled order pool and inventory adjustments[1)] (PCD, Eq. 38, A) and these quantities are constantly increasing and cause, as seen in Figure VI-1, an increasing trend in the production capacity orders. The production capacity and also the product order rate are the integral of the production capacity orders and the two quantities grow faster than linear during the major growth phase.

In Figure VI-1 should also be noted that the growth in the production capacity orders (PCO) shows a slight S-shape between week 300

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1) For each unit staying in the unfilled order pool during the delivery time on capacity there will be desired capacity (Eq. 38, A),

$$\frac{\text{1 unit in unfilled order pool}}{\text{Time to Adjust Unfilled orders for Capacity decision}} = 1/52 \text{ units/week}$$

which will be equal to the total production capacity for that unit (for a mathematical treatment of this, see Appendix B).

and week 700. This can be explained from the time constants in the equations for production capacity orders (PCO, Eq. 36, R) and production capacity addition rate (PCAR, Eq. 35, R). The time constant to adjust production capacity to desired level (TAPC) is 52 weeks, and the time constant for receiving additional production capacity (DRPC) is 150 weeks. The production capacity on order (PCOO, Eq. 37, L) therefore approaches the desired level faster than the ordered production capacity arrives (PCAR), and the slope on the curve for production capacity orders (PCO) decreases (around week 450 and 650). The slope again increases when the production capacity orders arrive and increase the production capacity (PC, Eq. 33, L) and the product order rate (POR). The effect is hardly visible on the curve for the product order rate, but is more distinct on the curve for the production capacity orders due to the forecast of the product order rate, and the formulation of the production capacity orders (Eq. 36, R) as a difference between quantities of the same magnitude.

An interesting result follows of the forecasting procedure in the model. The forecasted need of production capacity to take care of the future expected growth in the product order rate is based upon a linear extrapolation of past order rate (Figure A-7). Production capacity is ordered on this basis, and the delivery delay multiplier (DDM, Eq. 6, A, Figure A-3) will at the arrival of the capacity adjust the increase in the product order rate so that it will be equal to the production capacity additions. The actual product order rate will be slightly higher than the expected one, since capacity is also ordered to adjust the inventory and the unfilled order pool to the desired levels (Eq. 38, A).

An evaluation of the forecasting method by comparing forecasted order rate with the actual rate will therefore give a favorable impression. Management might erroneously consider the forecasting procedure to be satisfactory and not realize that the product order rate is determined by the capacity position which again is determined by the expected order rate. By its forecasting procedure the management will actually create the expected situation.

This is a good illustration of a common fallacy in management behavior. By making some kind of forecasted expectations about the future and basing its decisions upon these expectations, the management of a company is often creating the expected situation without realizing that the future is not an independent variable, but strongly determined by its own actions.

About week 650 (13 years) after the introduction of the product on the market, the company enters a state of linear growth. The capacity additions are no longer the sole determinant of the growth of the product order rate. The potential market and the adoption time for the product are also coming in to determine the product order rate. In Figure VI-1 it is shown that the slope of the curve for the product order rate is less than the slope of the curve for the production capacity from week 650. The unfilled order pool (UOP) is only slowly increasing and the production capacity orders (PCO) reach a constant value at week 650. The fairly sharp break on the curve for production capacity orders at week 650 can be explained by a coincidence of the factors causing the previously discussed S-shape (TAPC and DRPC) and the take-over of linear growth.

About week 750 the model comes over in what we have called the end phase, and in Figure VI-1 it can be seen that the company is now gradually getting over into a state of excess production capacity, high inventory, and low unfilled order pool (2 weeks of sales). After having experienced a long growth period with a constant growing demand and a serious problem in satisfying the demand, the management finds that its problems are just the opposite of the previous ones. The demand for the product can easily be satisfied and the expected needs of capacity have been highly overestimated and left the company with 31% excess capacity.

This state of affairs is a common occurrence in a growth company, and it puts serious stress on management to bring the company safely through the end period of the growth. At the end of the growth phase (week 750-1000), there are three amplifying factors that enter the production capacity ordering decision and cause the excess capacity.

1) The linear forecast term (Eq. 49, A).
   By extrapolating linearly the growth trend, the company forecasts an increased product order rate and actually orders production capacity to take care of this higher expected level of business.
2) The adjustment terms of the inventory and the unfilled order pool in the equation for the desired production capacity

(Eq. 38, A). At the end of the growth phase the inventory is still low and the unfilled order pool high, and the company orders production capacity to adjust these quantities to desired levels.

3) The influence of the delivery delay on the order flow (Eq. 6, A). As the delivery delay is reduced, an increasing amount of prospective customers will direct their order flow to the company instead of being satisfied with a substitute product. This makes it extremely hard for the management to realize the end of the growth phase, and causes the fairly sharp break in the product order rate around week 850 (Figure VI-1).

Due to these three factors, the company ends up with 31% overcapacity

$$\frac{\text{production capacity - average product order rate}}{\text{average product order rate}} .$$

The major findings of the model run can be summarized:

1) The major growth of the product order rate is for this model limited by the production capacity position through the influence of the delivery delay on the product order rate.

2) The forecasting procedure of the product order rate might seem satisfactory since it always forecasts the product order rate only slightly less than it turns out to be. The major growth of the product order rate is, however, determined by the forecasting procedure through its influence on the production capa-

city position and the delivery delay.

The behavior of the model as discussed here seems like a plausible and common type of growth behavior for a company with a new product. We will now test the model for a step input in quality and for sensitivity to external disturbances to see if the model still behaves reasonably. We will also go further and demonstrate how different growth conditions can influence the growth behavior to give completely different pictures.

VI.2 Step Input in Quality

We will now test the model for a sudden increase in quality to a maximum quality at time equals zero. A sudden increase in quality to a maximum level is actually the case for quite a few new products. It could be thought of as new office equipment with a completely satisfactory quality already at the introduction.

A step input to the model is also highly informative about the model behavior. A step function contains components of all frequencies, and the response of the model to a step will give us an indication of the oscillatory character of the system.

Let us now first consider what kind of behavior we might expect. The model contains a number of feedback loops of which three major ones were pointed out in Chapter V. On different places in the system there are also built in amplifying factors.

1) The production capacity ordering decision amplifies the need for capacity due to the backlog and inventory terms. (Eq. 36, R and Eq. 38, A). An increased product order rate above the production capacity limit causes

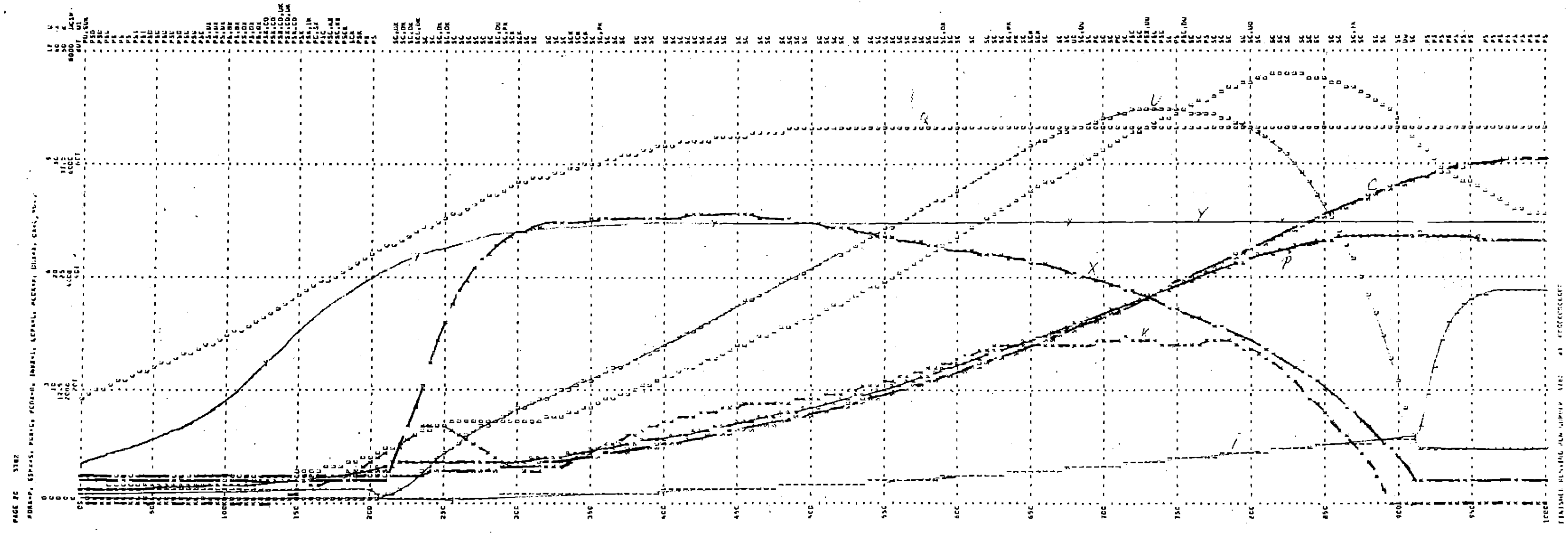

Figure VI-1, MODEL BEHAVIOR FOR MODEL AS PRESENTED IN APPENDIX A.

POR = P
PC = C
INV = I
UOP = U
PCO = K
DD = X
Q = Q
SSM = S
PCD = D
PD = Y

the company to order more production capacity not only to take care of the increased product order rate, but also to take care of the same orders emptying the inventory or building up the unfilled order pool while the company is waiting for additional production capacity.

2) The forecast terms might cause amplification. (Eq. 21, A and Eq. 49, A).

3) The variable delays in the market could create amplification. (Eq. 13, A and Eq. 14, A).

In general, a feedback system with amplification and delays in the loops would be expected to show an oscillatory character as a response to a step input. The model tends to select the frequencies it is sensitive to and accentuate them in its behavior. The response of the model to a step input will therefore give an indication of the natural frequency and the degree of oscillation in the system.

The model does not, however, show any oscillatory character as a response to a step in quality.[1)] Instead the behavior of the model is qualitatively similar to the behavior shown in Figure VI-1, and we have therefore not found it justifiable to include a figure of the behavior in the text.

Let us instead see why the model does not show any oscillatory character. In the previous section (VI.1) it was found that the

---

1) Q.K = STEP(10,0)

Q--Quality (quality units)
STEP--DYNAMO notation for a STEP function
10--step value of quality (quality units)
0--time of step occurrence (weeks)

The equation replaces Equation 50, A in Appendix A.

product order rate to the company is during the major growth determined by the company's ability to fill orders. The amplification terms in the production capacity ordering policy (PCO, Eq. 36, R) would therefore be the only relevant ones that could influence the model behavior. The amplifying factors [1)] in this policy cause, however, only a faster growth rate in the product order rate and do not cause any oscillation.

At the end of the growth phase, the amplification from the adjustment terms of inventory and the unfilled order pool, the forecast of the product order rate and the increased product order rate due to the reduction of the delivery delay combine to give the company a serious amount of overcapacity.

As a response to a step in quality, the product order rate grows up to 60% of the maximum potential demand in 540 weeks. The delivery delay and the unfilled order pool reach about the same values as can be seen for the same quantities in Figure VI-1.

VI.3 Periodical Fluctuations in the Product Order Rate

Next is a test of the model for a periodical fluctuation in the product order rate. From the previous experience with the step test (Section VI.2), the model would not be expected to show too much sensitivity to periodical disturbances in the product order rate, but we would expect the production capacity orders to show more

---

1) A separate study has been done of the amplification from the adjustment terms for the inventory and the unfilled order pool in the production capacity ordering policy (PCO, Eq. 36, R). The study points out the amplification and the sensitivity of the policy, as seen in Appendix B.

sensitivity than the other variables in the model.

The formulation of a periodical fluctuation has been done with a 10% sine wave.[1)] The formulation should be thought of more as a pure test input to the model than a representation of the real order pattern. The model has been tested for periods of 104 weeks (2 years), 208 weeks (4 years), and 416 weeks (8 years).

Two components are now involved in the product order rate:

1) The growth trend as in Section VI.1.

2) The periodical variations.

The model does not for any of the different fluctuations in the product order rate show a distinctly different character from the behavior as seen in Figure VI-1, and we have therefore not included figures of the runs in the text.

The production capacity orders (PCO, Eq. 36, R) fluctuate more than any of the other variables in the model. This is due to the formulation of the capacity orders as a difference between quantities

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1) PORN.K = (PUP.K)(DDM.K)/DPD.K

POR.KL = PORN.K(1+SINV.K)

SINV.K = (0.1)SIN((2PI)(TIME.K)/PER)

PUP--PUrchase Pool (units) (Eq. 4, L)
DDM--Delivery Delay Multiplier (dimensionless) (Eq. 6, A)
PORN--Product Order Rate, Normal (units/week)
POR--Product Order Rate (units/week)
SINV--SINe Variations (dimensionless)
SIN--DYNAMO notation for a SINusoidal function
TIME--TIME(weeks)
PER--PERiod (weeks)
0.1--amplitude of sine wave
2PI--2.3.14

These equations replace Equation 5, R in Appendix A.

of the same magnitude. A small relative change in the desired level of production capacity (PCD, Eq. 38, A) gives a large relative change in the production capacity orders.

The behavior of the production capacity orders for a period of 104 and 416 weeks, respectively, in the product order rate can be seen in Figures VI-2 and VI-3. In the same figures is also plotted the behavior of the production capacity orders without a periodical fluctuation in the product order rate. The capacity orders are not very sensitive to an extremely low frequency disturbance as 1/416 $week^{-1}$, but for a period of 104 weeks there exists a stronger sensitivity. The behavior of the production capacity orders for a period of 208 weeks is qualitatively similar to the behavior as seen in Figure VI-2. The period is different and the actual values are slightly less than the ones in the figure.

One might argue that the behavior of the production capacity orders as seen in Figure VI-2 is an unlikely behavior. If the product order rate really should show up such a periodical fluctuation, the company would change their policies to be more applicable to the periodicity. The intention has, however, been more to test the sensitivity to different frequencies of disturbances than to match the real order pattern, and the behavior is of interest in showing the sensitivity of the production capacity orders to low frequency disturbances.[1)]

The production capacity orders at any one time are in the magnitude of 1% of the total production capacity and variations in them,

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1) A detailed treatment of the production capacity ordering decision can be seen in Appendix B.

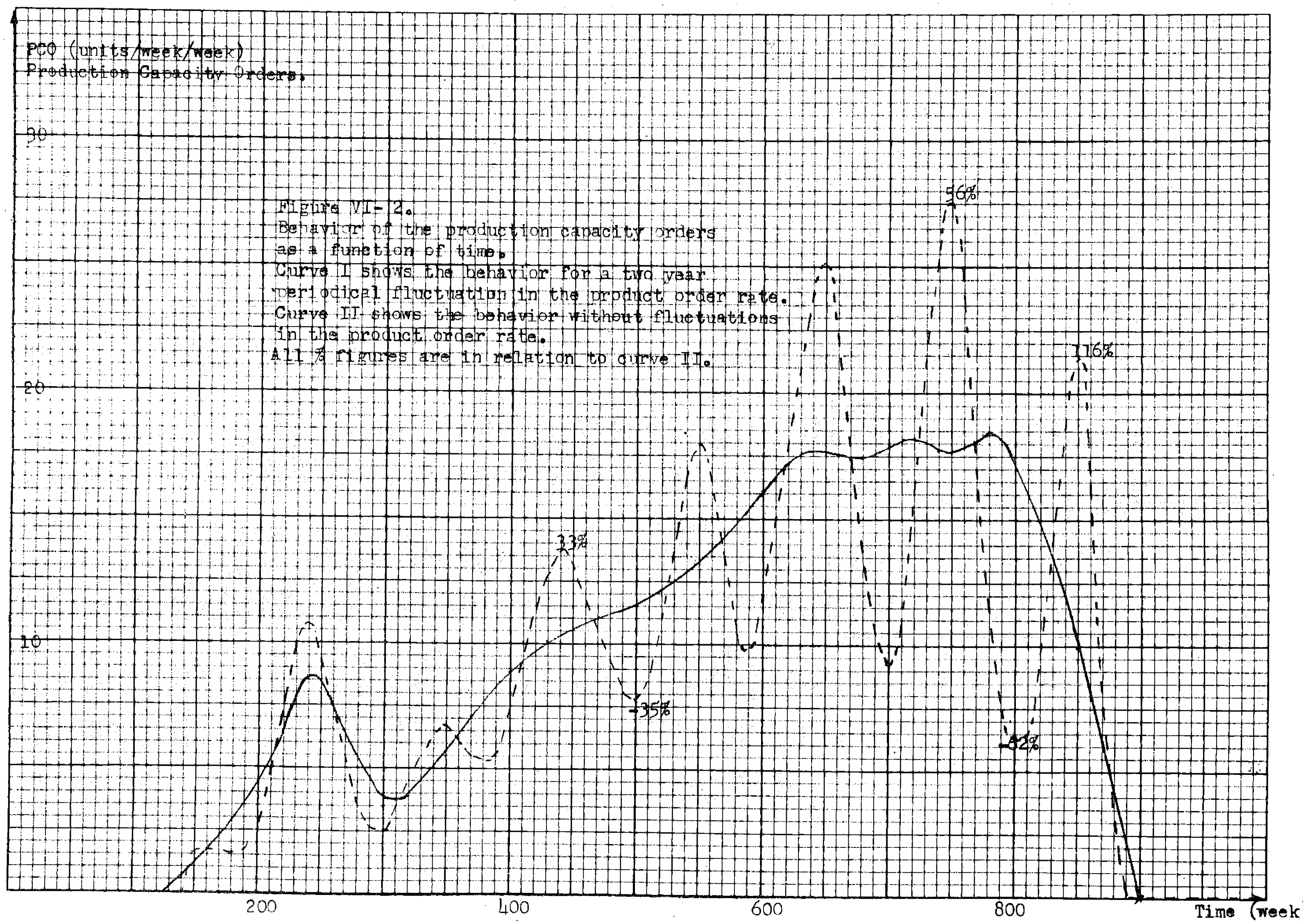


Figure VI- 2.
Behavior of the production capacity orders as a function of time.
Curve I shows the behavior for a two year periodical fluctuation in the product order rate.
Curve II shows the behavior without fluctuations in the product order rate.
All % figures are in relation to curve II.

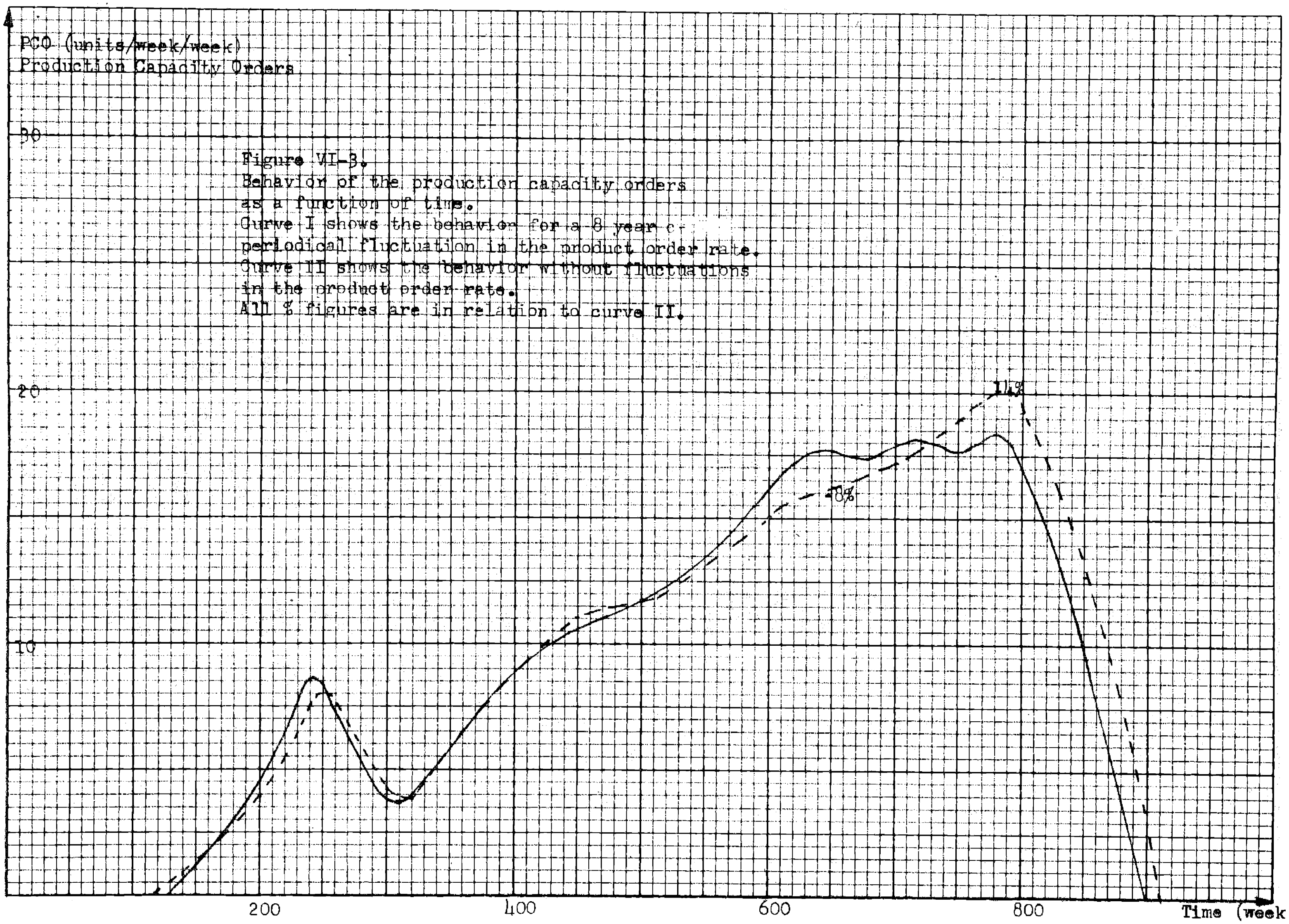


Figure VI-3.
Behavior of the production capacity orders as a function of time.
Curve I shows the behavior for a 8 year c[illegible] periodical fluctuation in the product order rate.
Curve II shows the behavior without fluctuations in the product order rate.
All % figures are in relation to curve II.

will give a small influence on the production capacity. All other variables in the model vary less than 10% relative to the same quantity at the same time without a periodical fluctuation in the product order rate (as seen in Figure VI-1).

The model response to a step input in quality and to external disturbances in the product order rate seems like plausible behavior for a growth company. It seems reasonable that a company, having a major problem in satisfying a growing demand, should not show cyclical character or sensitivity to external disturbances.

VI.4 Exponential Forecast of Needs for Additional Capacity

In the model run for section VI.1, it was found that the company's acquisition policy for capacity is actually the determining factor for the growth of the product order rate to the company during the major growth phase. To increase the market growth rate, the company should therefore not increase its expenditures on market development efforts, but instead order more production capacity.

We will now demonstrate how the company can experience a more rapid growth by increasing the forecasted need of production capacity. Instead of forecasting (as in Appendix A) the same amount of change in the product order rate each time period, the policy is changed to forecast the same percentage change in the product order rate each time period. The formulation of this policy can be seen in Appendix D. Except for the formulation of the expected change in product order rate to go into the equation for the desired production capacity (Eq. 38,A), the model is identical to the one described in Appendix A, with behavior as seen in Figure VI-1.

The run shows (Figure VI-4), as expected, a faster growth rate in the order flow than we experienced in the run for Figure VI-1. The production capacity (PC) and the product order rate (POR) are now also following each other closely (week 300-650). A comparison of the growth of orders as a response to the two different ways of forecasting can be seen in Table VI-1. The time to reach 60 percent (3000 units/week) of maximum potential demand has been decreased with about 10 percent (665-595/665).

TABLE VI-1

Growth in the product order rate (POR) for an exponential and a linear trend forecast.

	Exponential Forecast	Linear Forecast
Time for reaching 60% of maximum potential demand (weeks)	595[1]	665[2]

By forecasting exponentially the need for additional capacity, we are in fact introducing a stronger amplification in the policy for production capacity orders (Eq. 36,R); and accordingly, the company will at the end of the growth end up with a higher amount of excess production capacity which will put greater stress on the management in the end period. A comparison of the amount of excess capacity can be seen in Table VI-2.

TABLE VI-2

Amount of overcapacity for an exponential and a linear trend forecast.

	Exponential Forecast	Linear Forecast
Overcapacity (%)	46[1]	31[2]

$$\text{Overcapacity} = \frac{\text{Production capacity} - \text{average product order rate}}{\text{average product order rate}}$$

[1]From Figure VI-4.

[2]From Figure VI-1.

Examination of Figure VI-4 shows that the product order rate (POR) stays constant on a value less than the maximum potential demand (PD) for a 3-year period between week 750 and 900. This can be explained by the market development policy. As the growth approaches saturation, the unfilled order pool (UOP) can be worked off, and accordingly the sales (SALE, Eq. 17, A) and the allocated funds to market development (AFMD, Eq. 15, R) keeps on growing until the unfilled order pool is empty. The sales will now drop (see Figure VI-4) and so will the marketing efforts, which will temporarily limit the product order rate in further growth. The same effect is also present in Figure VI-1 but it is less distinct.

The run (Figure VI-4) is a nice demonstration of how management can act on the basis of expectations and actually create the expected situation. It should be noted that in a growth condition like this, it is a waste of effort for management to put emphasis on sophisticated forecasting methods on the basis of past experience in order flow. The results stress instead the importance of better management understanding of the fundamental structures of the system; and in particular for this system, a recognition of the effects of the delivery delay multiplier (Eq. 6, A) on the system behavior.

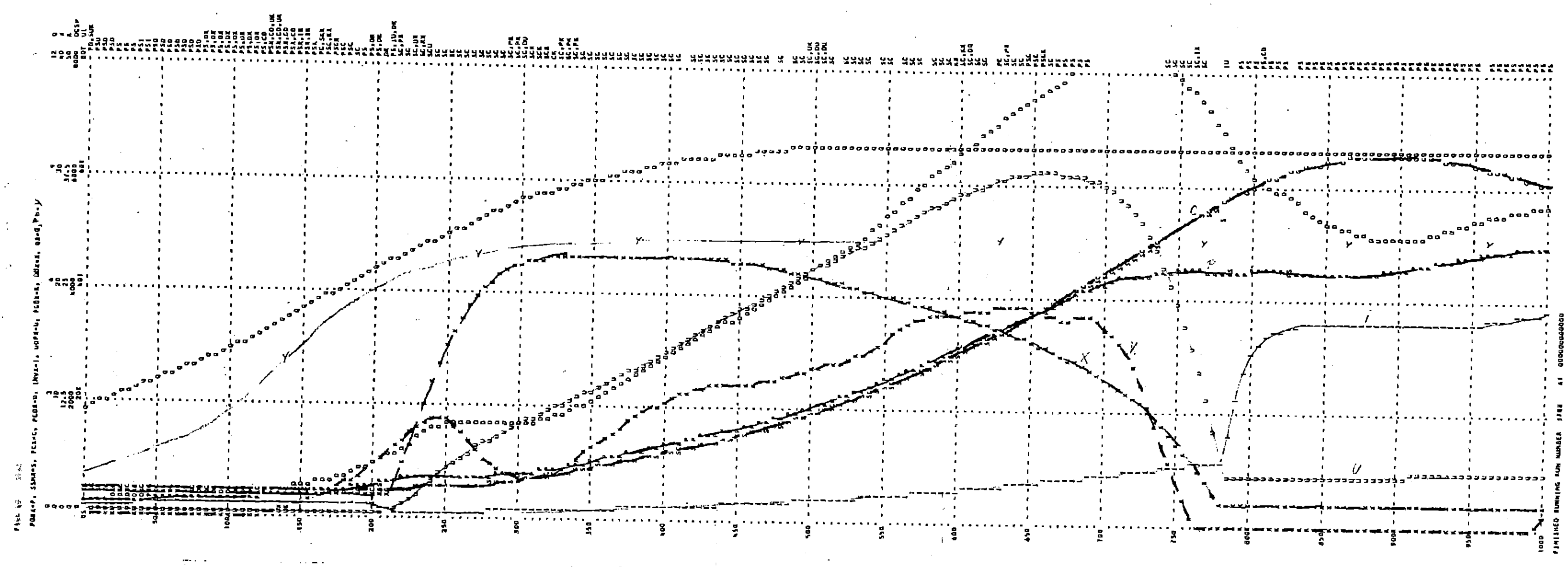


Figure VI-4,

MODEL BEHAVIOR FOR MODEL WITH EXPONENTIAL FORECAST IN PRODUCT ORDER RATE AS PRESENTED IN APPENDIX D.

POR = P
PC = C
INV = I
UOP = U
PCO = K
DD = X
Q = Q
SSM = S
PCD = D
PD = Y

VI.5 Delay in Receiving and Installing Production Capacity (DRPC) Shortened

In the previous runs, the limitation to growth was in the aquisition policy for production capacity. The problem rose mainly from the delay in receiving and installing production capacity (DRPC) which allowed the unfilled order pool to build up to high values. Following is a run where the delay is shortened to 10 weeks from the original 150 weeks. The model is otherwise identical to the one in Appendix A.

Ten weeks might seem like a very short delivery time on production capacity; and for some products (chemicals, etc.), it would probably be physically impossible to delivery and install capacity at that time. For other products where plants in operation already exist and the additional capacity is more a question of installing additional equipment, it seems like 10 weeks might be a plausible value.

By shortening the time constant to ten weeks, we will expect the unfilled order pool and the delivery delay to be kept on low values. It seems like the production capacity ordering policy (PCO, Eq. 36, R) would no longer be the determining factor for growth of the product order rate to the company. Instead, the marketing policy (AFMD, Eq. 15, R) will determine the product order rate; and the change in the constant will therefore be a demonstration of how the growth of a new product market can be determined by completely different factors from the ones in the previous sections.

The behavior of the model with the new time constant on the delivery time on capacity (DRPC) can be seen in Figure VI-5. The behavior is, as we would expect, completely different. The delivery delay (DD) reaches only about ten weeks as a maximum, and it is only staying at higher than minimum level half the time (weeks 220-500) of our previous experience (Figure VI-1). The unfilled order pool (UOP) is accordingly also kept on a low level, and the inventory (INV) can be built up to a desired level on a much earlier time (week 600) in the growth phase than what we experienced before (Figure VI-1).

The product order rate (POR) reaches 60 percent (3000 units/week) of maximum potential demand in about 500 weeks against the previous experience of about 665 weeks (Figure VI-1). In other words, by avoiding a high delivery delay, the company can cut down the time for the product order rate to reach 60 percent of the product's maximum potential demand by more than 3 years or about 25 percent (165/670).

It should be noted (Figure VI-5) that the model is still for a three-year period (week 270 to 410) limiting the growth of the product order rate (POR) by the policy for production capacity orders (PCO). The limitations the company puts upon itself in this period are, however, of minor importance to the growth as the percentage of the product order rate lost due to the delivery delay is only about 1 percent to 2 percent (DDM, Eq. 6, A, Figure A-3).

The curve for product order rate (POR) is in the major growth phase more than the minimum adoption time (DAPD, Figure A-4 and DPD, Figure A-5) behind the curve for the potential demand (PD) and the main determinant for the growth of the product order rate is therefore the allocation policy for funds to market development (AFMD, Eq. 15, R).

The company is now to a certain degree into a similar situation to the one in the previous. By expecting some future sales and allocating its marketing efforts (AFMD) on this basis, management is actually creating the future sales. This should, however, not be understood as an increase in market development efforts always can increase sales. By increasing its marketing efforts, the management will find other limitations to growth either from the development of the product, capacity limitations or from factors not included in this model as, for example, hiring and training of marketing men.

An examination of Figure VI-5 shows a slight cyclical behavior of the production capacity orders (PCO, Eq. 36, R) after week 450. The behavior can be traced back[1] to effects of the positive feedback loop, from product order rate around the market development sector and back to the product order rate as seen in Figure VI-6. An increase in the product order rate (POR) will give an increase in the sales (SALE) which will increase the marketing efforts (AFMD) at the company. After proper delays, this will again give an increase in the product order rate. The positive feedback loop might, through the forecast term, increase the product order rate faster than the potential demand (PD) grows, and as the purchase pool (PUP) is emptied, the product order rate cannot be kept up on the high level and will instead fall. The falling product order rate causes less market development efforts and again less orders until the purchase pool has been built up again to increase the product order rate. Up till week 450 this loop adjusts itself to a position where the growth of the product order rate is in equilibrium with the

[1]A detailed analysis of the computed values of the variables has been done.

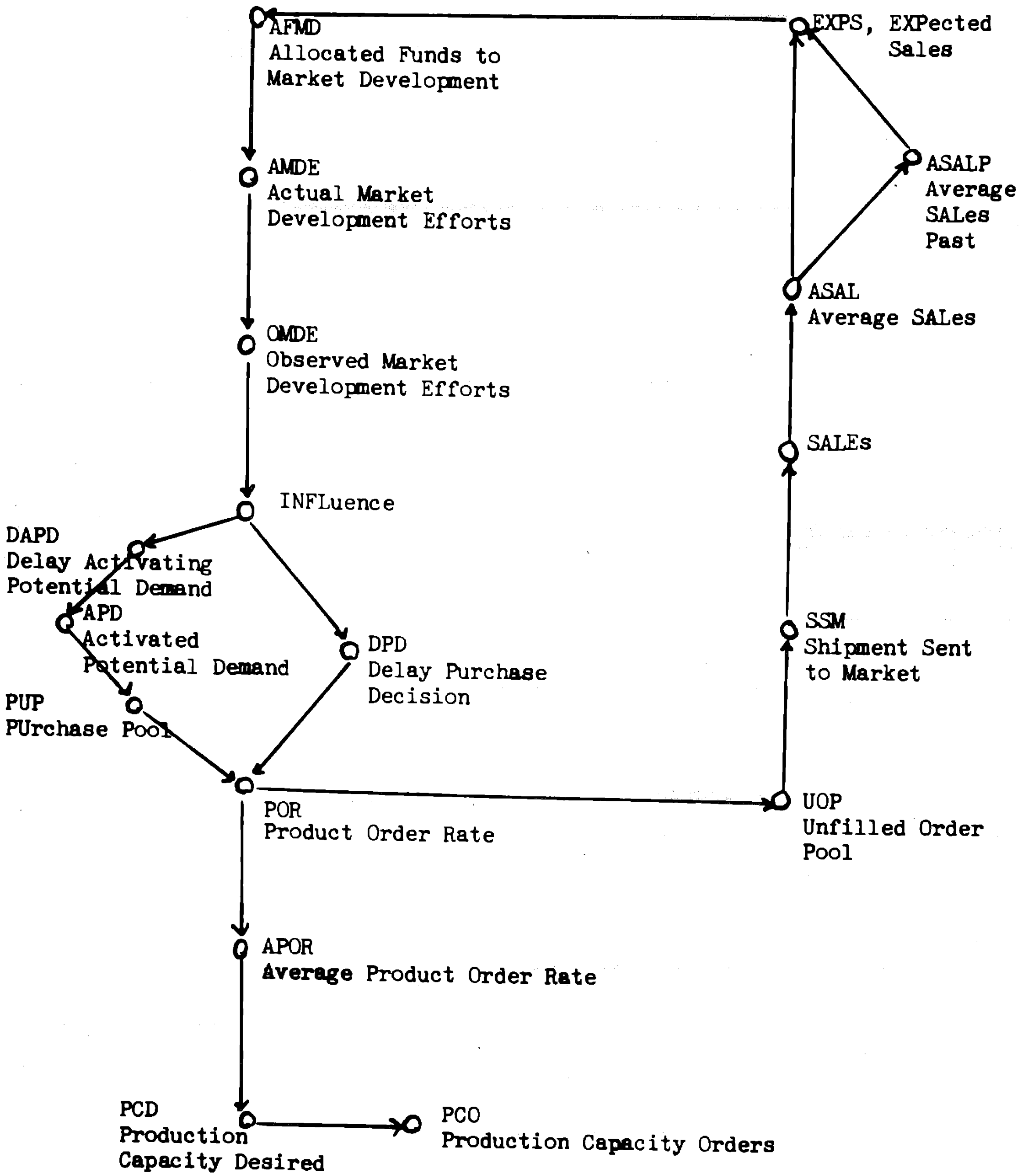


Figure VI-6, Identification of feedbackloop that determines growth for conditions as VI.5.

growth of the potential market.

The system is disturbed from its equilibrium position by the increase in sales (SALE) from the reduction of the unfilled order pool (UOP) around week 450. The increase in sales is transmitted around the loop and gives a slight transient fluctuation on the product order rate (POR) with peaks about week 525 and 625. The effect is hardly visible on the product order rate (POR) of Figure VI-5, but is distinct on the production capacity orders (PCO). The fluctuations in the product order rate will be amplified by the forecasting procedure and cause larger fluctuations in the desired amount of capacity (Figure VI-6). A small change in the desired amount of capacity (PCD) will give a relatively bigger change in the production capacity orders (PCO) since they are determined by a small difference between desired and actual capacity position (Eq. 36, R).

The critical end period discussed in section VI.1 is eliminated in Figure VI-5. There were three amplifying factors causing the over-capacity (Figure VI-1) at the end of the growth phase:

1. The forecast term (Eq. 49, A).
2. The unfilled order pool and inventory adjustment terms (Eq. 38, A).
3. The influence of the reduction of delivery delay on the product order rate (Eq. 6, A).

The amplification from the forecast term is now of a much smaller magnitude as the forecast time (equal to factor acquisition time) is reduced. The two other factors do not cause any amplification since both the unfilled order pool and the inventory are at the desired levels and the delivery delay is kept at minimum delay.

Accordingly, the company will not end up with excess capacity, and the problems entering the maturity stage are much smaller. It should also be noted that the product order rate (POR) in both Figure VI-1 and Figure VI-4 shows a fairly sharp break at the end of the growth phase due to the influence of the delivery delay reduction on the product order rate. This factor is now eliminated and the product order rate grows very smoothly up to its maximum value (5000 units/week) as seen in Figure VI-5.

The results from this run seem like a desirable growth behavior, but we should be aware that the production sector of the model under these conditions probably will be sensitive to disturbances in the product order rate. The adjustment term for inventory and the forecast term of the product order rate in the equation for desired production capacity (PCD, Eq. 38, A) will both amplify disturbances in the product order rate (POR). The model will in the next section be tested for a periodical fluctuation in the product order rate.

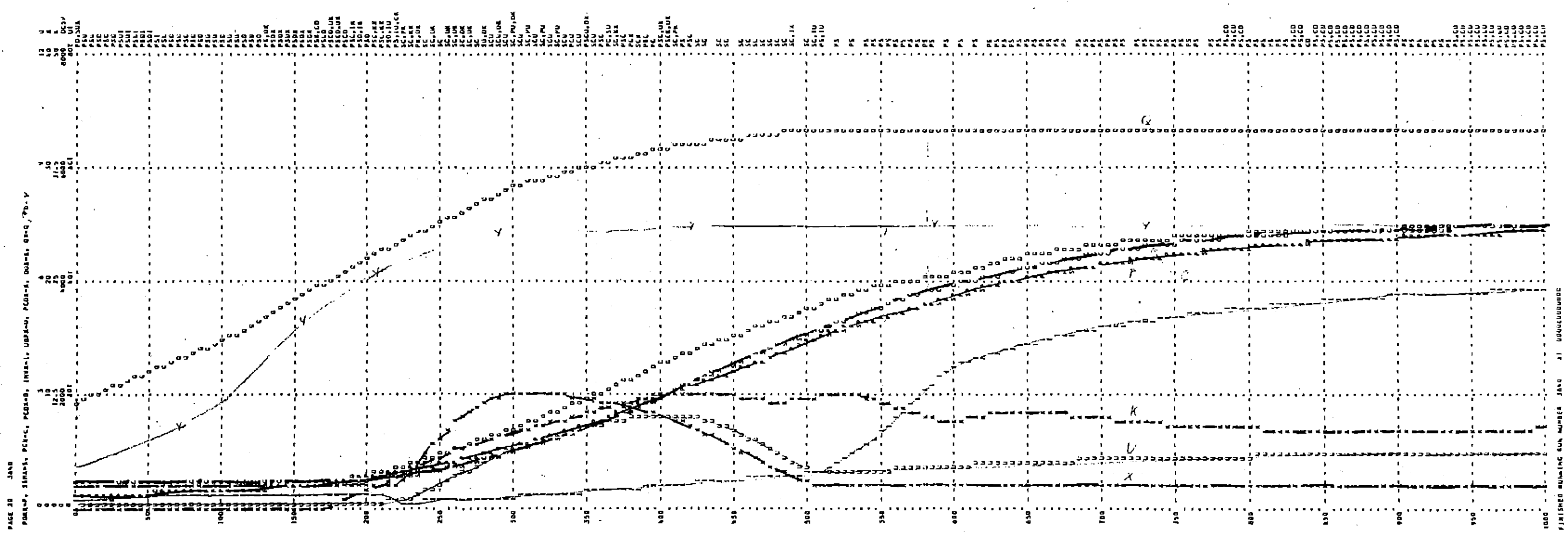


Figure VI-5,
MODEL BEHAVIOR FOR MODEL AS PRESENTED IN APPENDIX A WITH A SHORTENED TIMECONSTANT IN RECEIVING ADDITIONAL PRODUCTION CAPACITY.

POR = P
PC = C
INV = I
UOP = U
PCO = K
DD = X
Q = Q
SSM = S
PCD = D
PD = Y

VI.6 Periodical Fluctuations in the Product Order Rate with a Shortened Time Constant for Receiving Production Capacity

In the previous section, we saw how a shortening of the time constant to receive additional production capacity (DRPC) transferred the determination of the growth of the product order rate from the acquisition policy of capacity (PCO, Eq. 36, R) to the market development policy (AFMD, Eq. 15, R). It was also pointed out that this policy is included in a positive feedback loop (Figure VI-6).

Let us now test the model's behavior as a response to a 10 percent external periodical disturbance in the product order rate.[1] The variations should (as in section VI.3) be thought of more as a test input to the model than a representation of the real order pattern. There are now involved two main components in the product order rate.

1. The growth trend as in section VI.5.
2. The periodical variations.

The period on the disturbances has been selected equal to 208 weeks (4 years).

The model for this run is then similar to the one presented in Appendix A except for a change in the delay in receiving and installing production capacity (DRPC) from 150 weeks to 10 weeks, and a superimposed 10 percent cyclical variation in the product order rate. The effects of the variations in the product order rate can be seen by comparing this model run (Figure VI-7) with the run for the previous section (Figure VI-5).

---

[1] A sine wave in POR as formulated in section VI.3.

The behavior of the model under the new condition (Figure VI-7) is fairly similar to the one in Figure VI-5. The external disturbance on the product order rate has, however, caused a fluctuating character of the production sector.

The product order rate (POR) varies as imposed, about ± 10 percent of the product order rate of Figure VI-5. The positive feedback loop has not created any distinct further fluctuations in the product order rate. During the major growth phase the marketing efforts are dominated by the general strong growth trend in the market and the variations in the product order rate are not of significance in the allocation policy (AFMD, Eq. 15, R). As the market approaches saturation, the company is, in this model, assumed to be less able to shorten the market adoption time further (Figure A-4 and Figure A-5), and the product order rate will therefore not be influenced by fluctuations in the marketing efforts at this stage.

In the production sector, there are, as expected, fairly big variations in some of the variables. Let us now see how the different factors interact to create the behavior (Figure VI-7). In the equation for the desired production capacity (PCD, Eq. 38, A), there are now two amplification terms:

1. Forecast of the product order rate.
2. Adjustment of inventory.

These two factors will amplify the need for production capacity and cause it (PCD) to vary ± 20 percent of the desired production capacity in Figure VI-5. (The model without a sine wave on the product order rate). Small relative fluctuations in the desired amount of production capacity (PCD, Eq. 38, A) give large relative fluctuations in the production capacity orders (PCO, Eq. 36, R) which now vary over a range of +165 percent to -100 percent (compared to PCO in Figure VI-5).

In Figure VI-7 can be seen that the production capacity desired (PCD, Eq. 38, A) peaks shortly (26 weeks) after the product order rate due to the time constant in averaging product order rate (DAPOR). The production capacity (PC, Eq. 33, L) reaches a peak about 60 weeks after the desired production capacity due to the time constant in ordering and receiving production capacity (TAPC and DRPC). The adjustment time in ordering production capacity (TAPC) smooths out the variations in the desired level of capacity (PCD), and the production capacity (PC) only varies $\pm$ 10 percent of the values for production capacity in the model without a sine wave on the product order rate.

In Figure VI-7 it should be noted that the upturns in the product order rate cause a drop in inventory (INV) to about 50 percent of the desired level.

The runs for sections VI.5 and VI.6 have shown how the management of this hypothetical company can increase the growth rate by increasing the ability to fill orders. The policy involves, however, that the company will be sensitive to external disturbances in the product order rate.

As a final point, we would like the reader to note that the factors causing the fluctuations in the production sector are also present in the model used for section VI.3, but the factors were suppressed by other factors in the model.

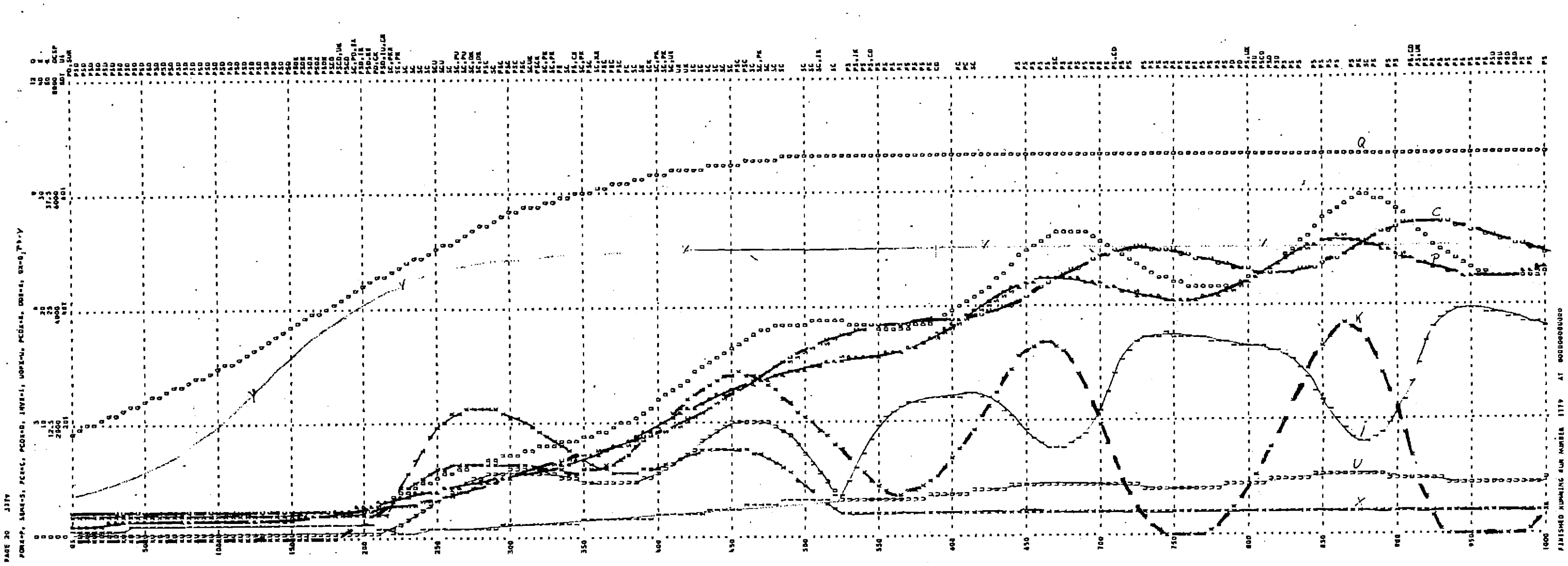


Figure VI-7,
MODEL BEHAVIOR WITH SHORTENED TIME CONSTANT IN RECEIVING ADDITIONAL PRODUCTION CAPACITY AND 4 YEARS PERIODICAL FLUCTUATIONS IN THE ORDER RATE

POR = P
PC = C
INV. I
UOP. U
PCO. K
DD. X
Q. Q
SSM. S
PCO. D
PD. Y

CHAPTER VII

FINAL REMARKS, CONCLUSIONS, AND RECOMMENDATIONS

The final remarks and conclusions of this study can be divided into three groups:

a) The model

b) Specific results

c) General results

VII.1 The Model

A model has been developed to describe the dynamic interactions between a market for a new product and the manufacturing unit. The model contains four sectors: market, market development, production, and research and development.

The four sectors are interrelated with about fifty variables describing selected characters of the interactions which create growth of a new product.

The model is simple and is not intended to be a complete treatment of all interactions that can influence growth. The most obvious factors that are omitted are: competition, price, and details of research and development. The reader should be aware of the omissions when evaluating the generality of the results.

We can conclude that the model is brought to a state where it is a useful description of several dynamic interactions between production and marketing that create growth of a new product.

VII.2 Specific Results

Our immediate objective has been to demonstrate some important dynamics within growth of a new product, and on the basis of this we can conclude:

1) The growth of a new product market is often limited by the acquisition policy for additional capacity.
2) Under conditions where growth is limited by the capacity acquisition policy, the growth behavior is not sensitive to external disturbances in the product order rate.
3) Under conditions where growth is limited by the capacity acquisition policy, the management problem is not in the forecast of the order rate, but in the fundamental understanding of the principles of growth.
4) By eliminating the barrier to growth from the capacity acquisition policy, the management can increase the market growth rate significantly. The behavior of the company is now more sensitive to external disturbances on the product order rate, and the production sector shows considerable fluctuations in inventory and production capacity orders

VII.3 General Results

In a more general way we would like to conclude:

1) The study shows the feasibility of treating transient dynamic problems in product growth via an industrial dynamics approach.

2) The study stresses the importance of top level management understanding the structure and dynamics of the system being managed.

VII.4 Recommendations

The study has opened the way to a better understanding of the dynamic interactions between a market for a new product and the manufacturing unit. Due to time limitations the study is far from finished, and we will here outline the directions in which further work should be directed.

First, the broad range of behavior of this model should be tested further. It should be tested to show what kind of growth behavior would result if the order rate was limited by the product development instead of the capacity acquisition policy or the market development policy. The model should also be tested for sensitivity in the growth behavior to variations in parameters. Having explored this, there seem to be two ways to go:

1) Study the effects on growth behavior of different sets of policies for a given product.
   This study did not get as far as beginning to test out the consequences of other policies on the growth behavior, and we think this is one of the primary tasks to be done. Policies that are desirable or undesirable for different conditions should be studied.
2) Study the effects of different products on the growth behavior.
   This study could probably best be started by studying

the importance of the product characteristics (in quality and development time) on the growth behavior for a given set of policies. It could then be extended to study the effects of different policies for different products. The consequences of different policies for different conditions should be stressed.

After having finished the above studies, it seems reasonable to extend the model to include:

a) The feedback loops from market to research and development

b) Price generating mechanism

c) Profit calculation

d) Competition

Research and Development

In the model given in Appendix A, all feedback loops from the market to the research and development department are excluded. This was an extreme simplification, and we think the model could be extended to include these loops both to study the effect of the simplification, and to see the importance of these loops on the growth behavior of the company.

Price Generation

The price or the price-quality relationship will for quite a few new products be a determining factor to the market's purchase decision. A mechanism for generation of price and influence of price and quality on the purchase decision should be included to extend the generality of the study.

Profit

As far as price and profit objectives or cost considerations are interrelated, the model should also include a profit or cost calculation. This could also be used as a performance criterion.

In Appendix C can be seen a suggested way of calculating the profit of the company at any one time and the total profit accrued to the company. The objective for the formulation is to get a relative performance criterion, but the formulation could easily be extended to serve as a basis for price determination on the basis of either cost or profit.

Competition

In Chapter III competition was excluded in order that the study of new product growth first be done without the complexity of two competing products. Having explored the behavior of the model as presented in Appendix A, competition should be included in the study. The study should emphasize for each firm and for the industry as a whole the consequences of the policies of both the original company and the competitor on growth and stability.

Extension of the Scope

The scope of this study was fairly arbitrarily defined to include capital equipment flow and exclude money and personnel flows. Having explored the growth behavior within the scope of this study, problems within finance and personnel should be taken up to complete a study of new product growth.

APPENDIX A

MODEL FORMULATION

The formulation of the model is based on the description given in Chapter IV. The formulation is not a complete treatment of the growth of a new product. It is a plausible and qualitatively correct formulation that can be an aid for us in studying top management questions within the dynamic interactions between a market and the manufacturer of a new product.

The model is generally applicable to any new product. Different products will, however, have different parameters; and the selection of parameters should, therefore, always be done with a particular product in mind. We have here chosen to think of a new office equipment in the selection of parameters. We could in particular think about a new typewriter. The results should, however, be considered of general value rather than of specific aid for growth of a particular product. The detailed treatment of the essential dynamic characteristics involved in product growth for this study follows. All equations are formulated according to DYNAMO.[1]

A.1 Equations

A.1.1 Market Sector, Flow Diagram, Figure A-1

In Chapter IV the relationship between the potential demand and the quality was discussed. It was assumed that the potential demand

[1] See A.L. Pugh, DYNAMO User's Manual, M.I.T. Press, 1961.

was a function only of product quality, and the discussion led us to a S-shaped curve for the relationship as seen in Figure IV-6.

We will now put numbers on the curve. We will then first decide the maximum potential demand for the product. The sale of typewriters in the United States in 1959 was about $1.25 \cdot 10^6$ units. Let us assume that the product we are talking about here can ever capture one-fifth of this market. At maximum quality which we arbitrarily will assign 10 quality units, we will, therefore, have a demand of about $\frac{1.25}{5} \cdot 10^6 \cdot \frac{1}{52}$ or 5000 units/week. We will also assume that a zero quality has a zero demand, and that the potential demand has reached 2500 units per week at a quality equal to five. In between, we will so draw an arbitrary curve which fits our qualitative perception of the shape the curve should have, as seen in Figure A-2.

The information on the curve can be formulated in an equation,

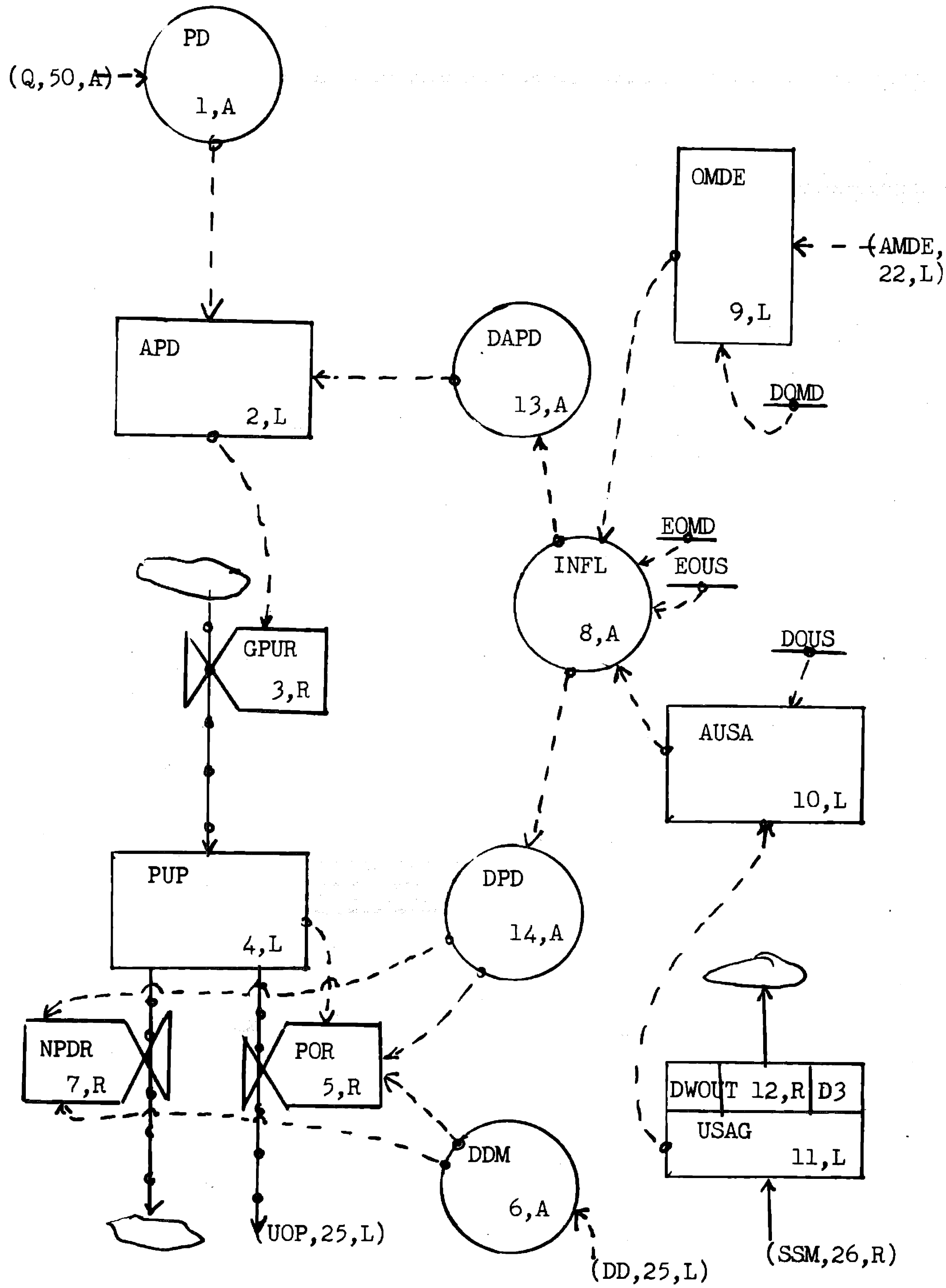
PD.K=TABLE(QTAB,Q.K,0,10,1) 1,A

PD--Potential Demand (units/week)
Q--Quality (quality units)
QTAB--Quality TABle
0--beginning value of quality (quality units)
10--end value of quality (quality units)
1--interpolating interval for quality (quality units)

The equation form is an acceptable way for DYNAMO to store the information of the curve in Figure A-2. The values of the potential demand have to be specified at regular interpolating intervals of the quality (here 1); and they will be defined in the name of the table, QTAB. Between the interpolating intervals, DYNAMO will itself do a linear interpolation. The specification of the values of QTAB can be found in Section A.3 Constants.

Figure A-1,

Flowdiagram, Market Sector.



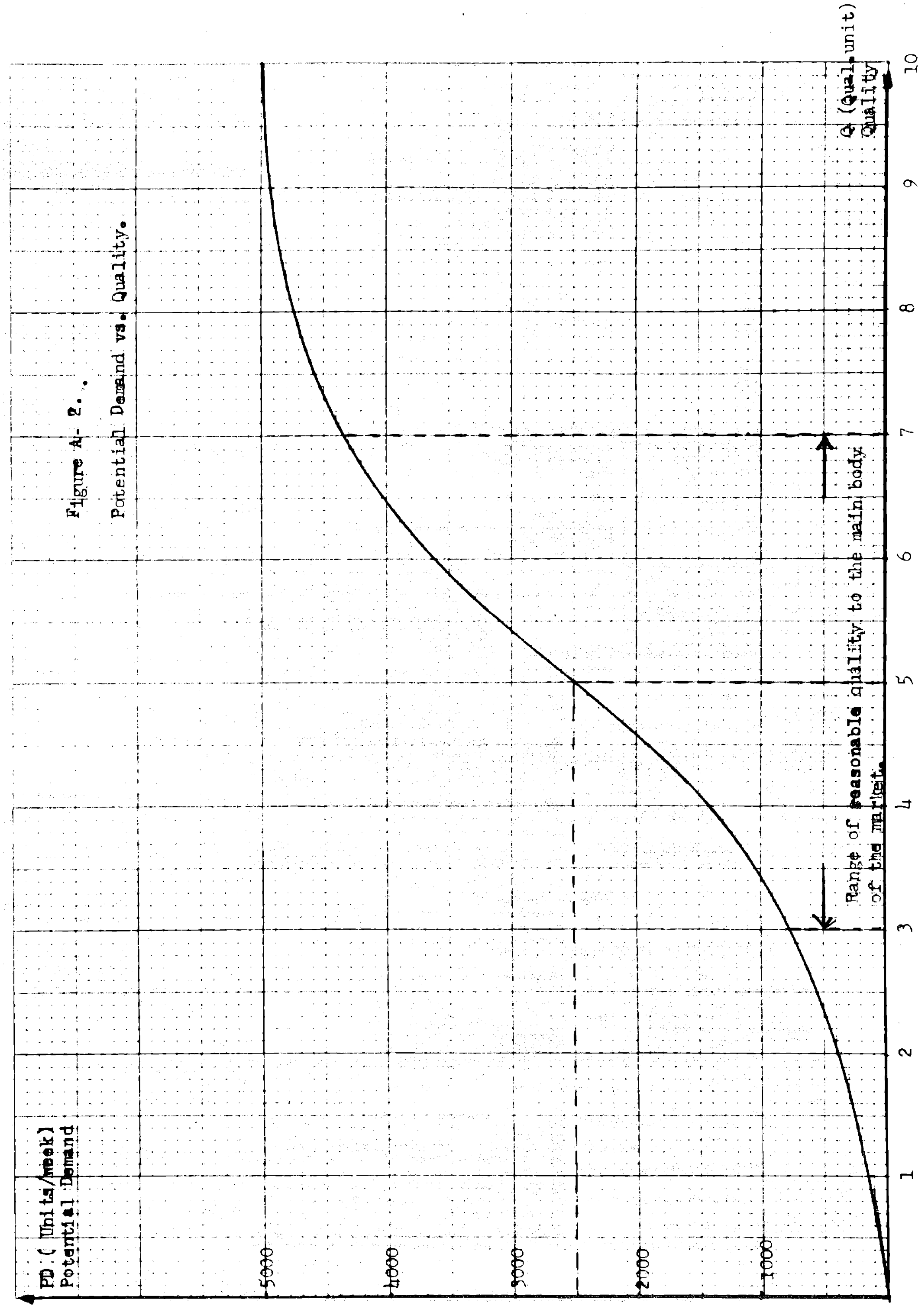


Figure A- 2.

Potential Demand vs. Quality.

The equation for the potential demand describes a concept of the market, and represents auxiliary knowledge. The equation is therefore called an auxiliary equation[1] (noted with an A after the equation number).

The value of an auxiliary equation is calculated for each time step[2] on the basis of the values of auxiliary variables or levels at the same time step (.K).

The potential demand will not result immediately in an order flow to the company. As discussed in Chapter IV, there is first involved a process of perceiving the product and its use. By this we will mean the combined processes of observing the product, sampling it, learning to use it, trying it out and evaluating it; all of which are mainly an absorption of information about the product; and the market's reaction could be formulated as a delayed version of the potential demand. This will mean that by proper delay, the market will always absorb the information of the product; and the potential demand will be transferred to an activated level.

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[1] A more detailed treatment of the different equation types in industrial dynamics can be found in : Jay W. Forrester, Industrial Dynamics, M.I.T. Press and John Wiley and Sons, Inc.,1961.

[2] .K is used to note the value of a variable at time now.

.J is used to note the value of a variable at the past time step.

.KL is used to note the value of a variable during the next time step.

.JK is used to note the value of a variable during the last time step.

DT--Delta Time, the time between each time step.

The delay in activating the demand will not be a constant but dependent upon the influence exerted on the market.

APD.K=APD.J+(DT)(1/DAPD.J)(PD.J-APD.J) 2,L

APD--Activated Potential Demand (units/week)
PD--Potential Demand (units/week)
DAPD--Delay Activating Potential Demand (weeks)

It might be argued against this formulation that we are actually combining more processes into one. The processes, to observe the product quality, to learn to use it and to evaluate it, are, however, mainly time delays following each other; and we have, for simplicity, combined them as this probably will have little influence on the dynamic behavior of the model.

The equation is, in its concept, different from the auxiliary equation for the potential demand. It represents basically the level (noted by an L after the equation number) of active demand (knowledge level) for the product. In specific, it is a first-order exponential smoothing equation with a variable delay.

The value of a level equation at time now (.K) is calculated on the basis of previous happenings in the system (variables noted with .J or .JK).

As the market is activated, there will be similar increase in the needs for the product. The activated potential demand generates a flow of prospective purchases.

GPUR.KL=APD.K 3,R

GPUR--Generated PUrchases Rate (units/week)
APD--Activated Potential Demand (units/week)

The equation is describing an actual rate (noted by an R after the equation number) of flow. The equation implies an implicit decision in the market, and is accordingly basically different from the two other types of equations, the auxiliary equation and the level equation.

A rate equation is controlling what is happening next in the system (.KL). It is calculated on the basis of variables at present time (.K).

The generated prospective purchases will not result immediately in an order flow for the company. There is first involved a time delay in the purchase decision. The funds to purchase have to be budgeted, the proper time to buy decided, and if necessary, the environments have to be made ready for the new product. The generated prospective purchases will, therefore, flow into a level of prospective purchases that are at the stage of deciding to purchase the new product. The outflow from this level will either be a flow of orders to the company or a flow of orders for substitute products.

PUP.K=PUP.J+(DT)(GPUR.JK-POR.JK-NPDR.JK) 4,L

PUP--PUrchase Pool (units)
GPUR--Generated PUrchases Rate (units/week)
POR--Product Order Rate (units/week)
NPDR--Non-Purchase Decision Rate (units/week)

The equation is actually stating that the value on the level of the purchase pool at time now (.K) is equal to the value at a previous time step (.J) plus the difference between the inflow and outflow of the level during this time step (.JK). The equation is a typical example of a regular level equation. It simply counts up the quantity in the level.

The order rate to the company will now be determined by the level of prospective purchases and the delay in making a purchase decision. For some products that might need approval of more people in an organization, the delay might be very long, while for other products, like shoelaces, it is close to zero. Given satisfactory purchase conditions, the order rate would be equal to the level of purchases in the pool divided by the delay in purchase decision (DPD):

POR.KL=PUP.K/DPD.K

The actual purchase decision will, however, also be dependent upon the purchase conditions in price and delivery delay. As discussed in Chapter IV, we will exclude price and always assume that it is satisfactory. The delivery delay will, however, play an important role for the purchase decision; and we will include the influence of this on the order rate as a multiplier.

POR.KL=(PUP.K/DPD.K)(DDM.K) 5,R

POR--Product Order Rate (units/week)
PUP--PUrchase Pool (units)
DPD--Delay Purchase Decision (weeks)
DDM--Delivery Delay Multiplier (dimensionless)

The length of the purchasing delay is assumed to be a function of the influence exerted on the market.

The equation is a rate equation stating the decision of the market to order the product.

In Chapter IV the influence of the delivery delay upon the order rate was discussed. As the delivery delay is increased, more orders are lost to substitute products. The qualitative shape of the fraction lost from the delivery delay influence can be seen in Figure IV-7. We will now have to give values to the curve for the delivery delay multiplier. For a new typewriter, we might assume that most customers are willing to wait about two months on a delivery. As the delivery delay increases, more and more people will find a way of getting along without the product. It seems reasonable that about 60 percent of the prospective buyers are willing to wait about one half of a year for a typewriter. The curve that fits this description can be seen in Figure A-3.

The formulation follows:

DDM.K=TABLE(DMTAB,DD.K,0,40,2) 6,A

DDM--Delivery Delay Multiplier[1] (dimensionless)
DMTAB--Delivery delay Multiplier TABle
DD--Delivery Delay (weeks)
0--minimum value of delivery delay (weeks)
40-maximum value of delivery delay (weeks)
2--interpolating interval (weeks)

A fraction of the customers might find the delivery delay too long and therefore find a substitute for the product. This fraction will be equal to (1-DDM.K), and the non-purchase decision rate will be:

NPDR.KL=(PUP.K/DPD.K)(1-DDM.K) 7,R

NPDR--Non-Purchase Decision Rate (units/week)
PUP--PUrchase Pool (units)
DPD--Delay Purchase Decision (weeks)
DDM--Delivery Delay Multiplier (dimensionless)

In Equations 2,L and 5,R there were involved two delays,

1. An information delay for the perception of the product.

2. A physical delay in ordering the product.

It seems reasonable that both these delays can be influenced by sales promotion efforts and/or usage of the product. An auxiliary variable called influence could be defined as the weighted sum of the factors influencing the delays in the market. The most relevant factors for influence are the observed usage of the product and marketing efforts. The unit for the influence of the market will be defined as an awareness

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[1]The delivery delay multiplier is better thought of as a fraction than a multiplier, and we will suggest that the name is changed in future work on the model. It is also unfortunate to have the first letter "D" as this is used for delays.

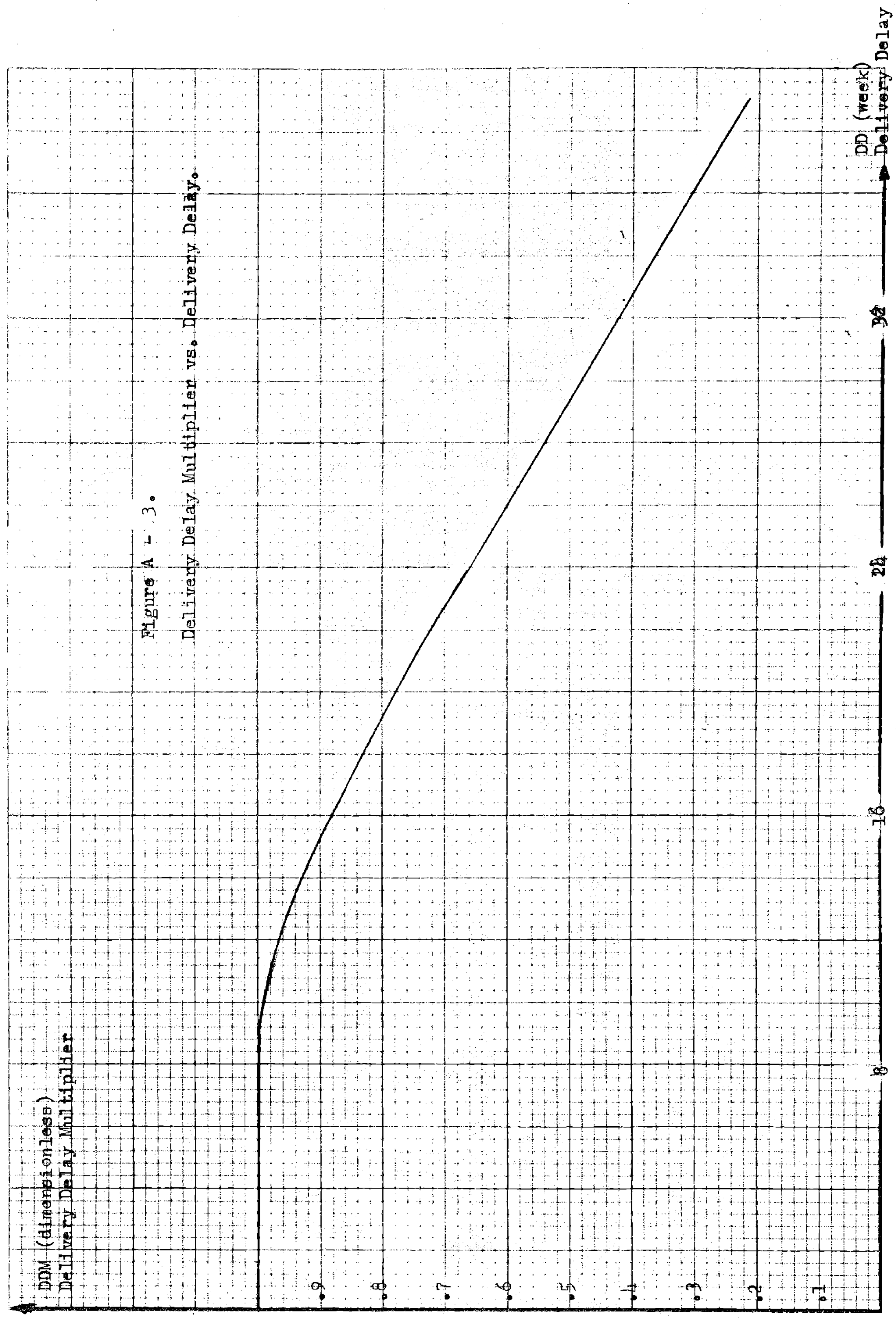

Figure A - 3.

Delivery Delay Multiplier vs. Delivery Delay.

unit which is of the same magnitude as the product unit. Under normal conditions, one awareness unit will create one order for the product.

The influence equation follows:

INFL.K=(EOMD)(OMDE.K)+(EOUS)(AUSA.K) 8,A

INFL--INFLuence (awareness units/week)
EOMD--Effect Of Market Development efforts (awareness units/$)
EOUS--Effect Of USage (awareness units/week/unit)
OMDE--Observed Market Development Efforts ($/week)
AUSA--Average USAge (units)

The market will not observe immediately the sources of influence, and the influence equation is therefore formulated on the basis of the observed influence factors. The weight factors (EOUS and EOMD) are assumed constant. This is a simplification and a research report[1] shows them to vary slightly with the adoption stage of the product. The observed influence factors (OMDE.K and AUSA.K) are both mainly a delayed version of the actual sources to count for the delay in influence becoming effective.

OMDE.K=OMDE.J+(DT)(1/DOMD)(AMDE.J-OMDE.J) 9,L

OMDE--Observed Market Development Efforts ($/week)
DOMD--Delay Observing Market Development efforts (weeks)
AMDE--Actual Market Development Efforts ($/week)

AUSA.K=AUSA.J+(DT)(1/DOUS)(USAG.J-AUSA.J) 10,L

AUSA--Average USAge (units)
USAG--USAGe (units)
DOUS--Delay Observing USage (weeks)

The market development efforts are defined in the next sector.

The usage level of the product is built up of the products sent to the market minus the products worn out. The usage equation can be

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[1] The Adoption of New Product, Process and Influence; The Foundation for Human Behavior, Ann Arbor, 1959.

written,

USAG.K=USAG.J+(DT)(SSM.JK-WOUT.JK) 11,L

USAG--USAGe (units)
SSM--Shipment Sent to Market (units/week)
WOUT--Wear OUT of product (units/week)

The wear-out rate is simplified as a third-order delay of the in-flow of new products.

WOUT.KL=DELAY3(SSM.JK,DWOUT) 12,R

WOUT--Wear OUT of product (units/week)
SSM--Shipment Sent to Market (units/week)
DWOUT--Delay Wear OUT (weeks)

There is now left to be defined how the influence on the market shortens the adoption delays. The qualitative shape of the delays was discussed in Chapter IV and can be seen in Figure IV-8.

First, an equation for the delay in activating potential demand has to be formulated.

It seems reasonable that the total activating process of the demand is a slow one. At no influence we will assume that the maximum length of the delay (DAPD) is equal to 780 weeks (15 years) for this product, and the shortest we can ever get it to be is 150 weeks (3 years).

Let us assume further that the delay has been shortened to 260 weeks (5 years) when the market has reached an order rate equal to 50 percent of the maximum potential demand (2500 units/week).

According to these figures, we will now draw a curve for the delay in activating potential demand as seen in Figure A-4.

The next step is to give values to the delay in purchase decision. It seems reasonable that the purchase decision process is a faster one than the activating process. We have, for this one, assumed a maximum

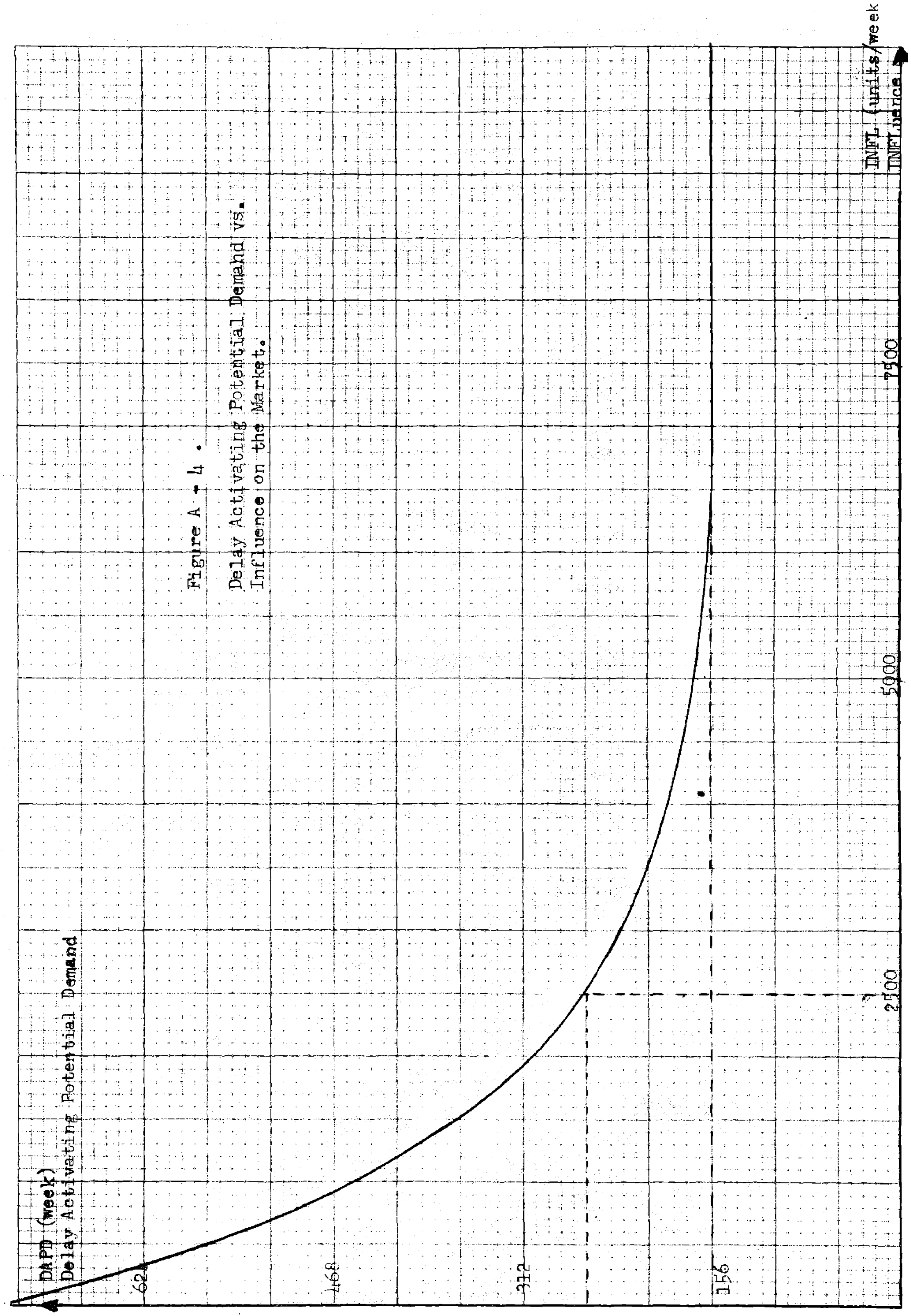


Figure A - 4 .

Delay Activating Potential Demand vs. Influence on the Market.

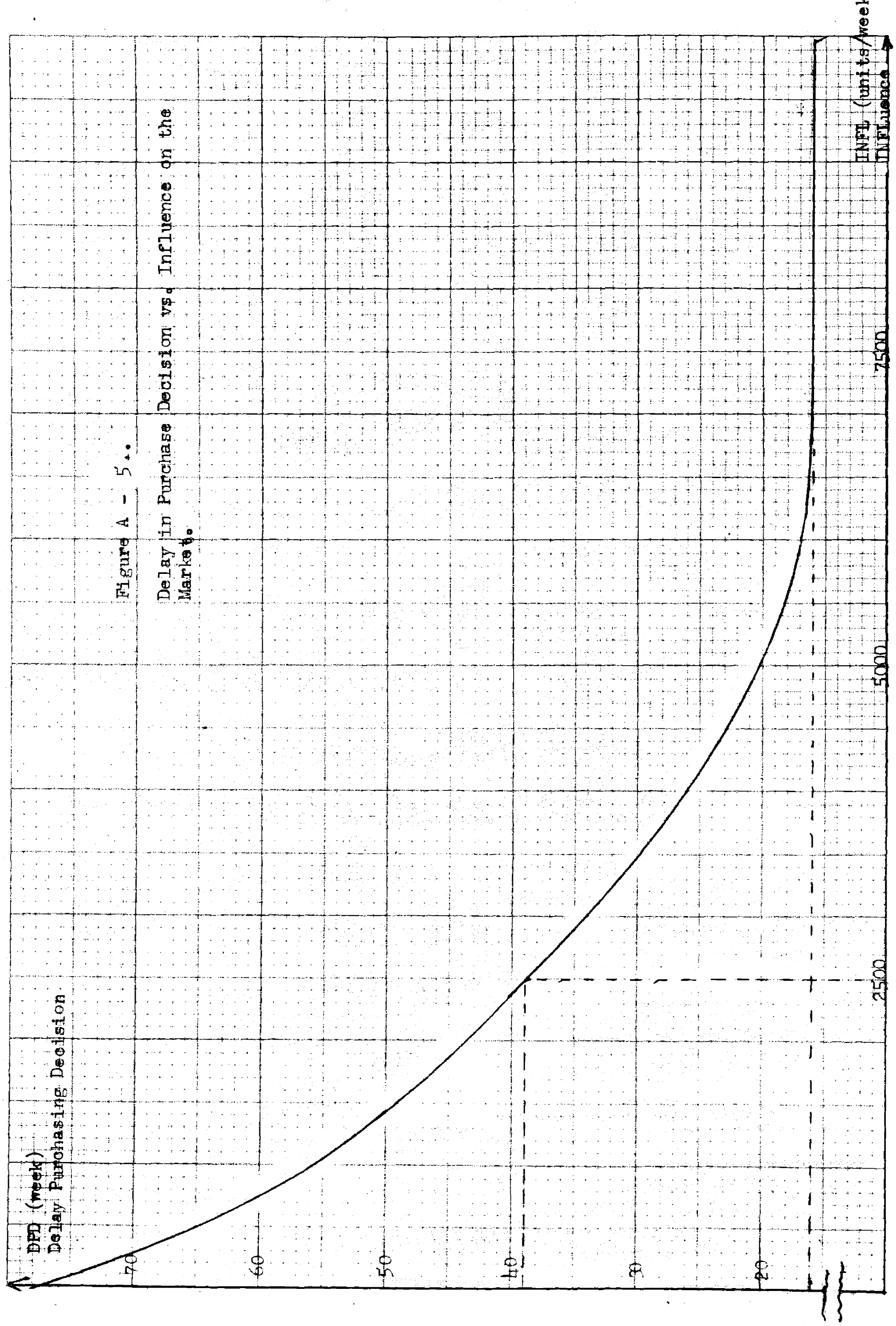


Figure A - 5.

Delay in Purchase Decision vs. Influence on the Market.

delay of 79 weeks (1 1/2 years) and a minimum of 16 weeks. At an order rate equal to 50 percent of the maximum potential demand, we will assume the delay to be thirty-nine weeks. We get a curve for the delay as shown in Figure A-5.

The equations for the two delays can be written:

DAPD.K=TABLE(ITABA,INFL.K,0,7500,500) 13,A

DPD.K=TABLE(ITABP,INFL.K,0,7500,500) 14,A

DAPD--Delay Activating Potential Demand (weeks)
DPD--Delay Purchase Decision (weeks)
ITABA--Influence TABle for Activating demand
ITABP--Influence TABle for Purchase decision
INFL--INFLuence (awareness units/week)
0--minimum value of influence (awareness units/week)
7500--maximum value of influence (awareness units/week)
500-interpolating interval (awareness units/week)

A.1.2 Market Development Sector, Flow Diagram, Figure A-6

The first problem in the market development sector is to formulate a policy for the allocation of efforts. It is fairly common to link the marketing efforts to the expected sales. This can be formulated:

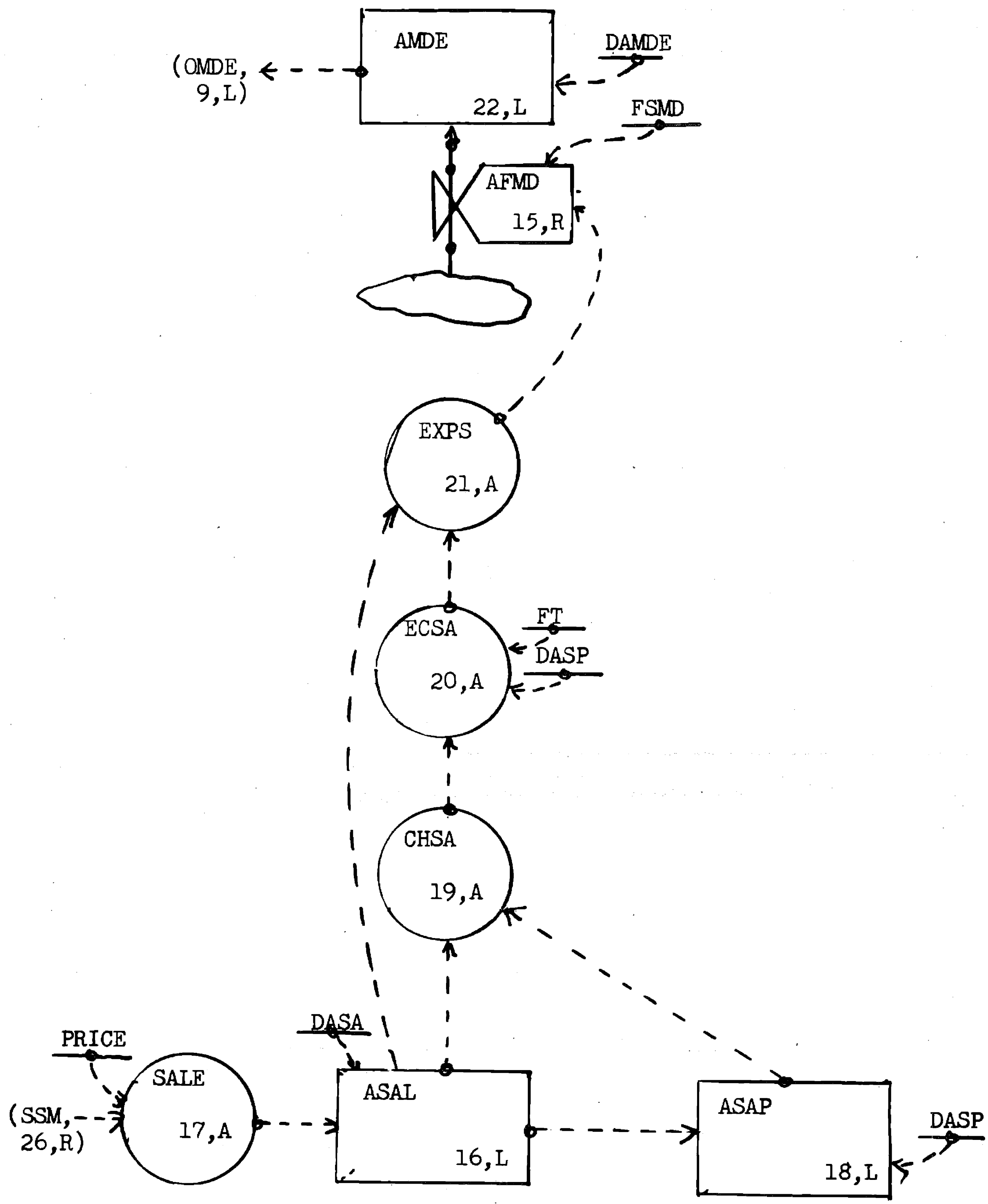
AFMD.KL=(FSMD)(EXPS.K) 15,R

AFMD--Allocated Funds to Market Development ($/week)
FSMD--Fraction of Sales to Market Development (dimensionless)
EXPS--EXPected Sales ($/week)

The importance of this policy will be explored on the model, and later on it can possibly be changed to explore effects on the model behavior of other policies if the results should make this desirable.

The expected sales will often be taken from the past experience in sales by some extrapolation. It will here be assumed that the company forecasts linearly the present trend. To determine the trend, a point of the sales now and a point in the past for comparison will be

Figure A-6,
Flowdiagram, Market Development
Sector.



needed. The extrapolation is illustrated in Figure A-7.

The most recent reference point will be found in the average sales over some recent time.

ASAL.K=ASAL.J+(DT)(1/DASA)(SALE.J-ASAL.J) 16,L

ASAL--Average SALes ($/week)
SALE--SALEs ($/week)
DASA--Delay Average SAles (weeks)

And the sale is equal to the shipment sent to the market times the price.

SALE.K=(PRICE)(SSM.JK) 17,A

SALE--SALEs ($/week)
PRICE--PRICE ($/unit)
SSM--Shipment Sent to Market (units/week)

A point in the past may be arrived at by delaying the existing average sales over some past time.

ASALP.K=ASALP.J+(DT)(1/DASP)(ASAL.J-ASALP.J) 18,L

ASALP--Average SALes, Past ($/week)
ASAL--Average SALes ($/week)
DASP--Delay Average Sales, Past (weeks)

The change in sales over the period DASP is then equal to the difference between the two sales levels.

CHSAL.K=ASAL.K-ASALP.K 19,A

CHSAL--CHange in SALes ($/week)
ASAL--Average SALes ($/week)
ASALP--Average SALes, Past ($/week)

The change in sales per time period will then be equal to the previous change in sales divided by the time in which the change has taken place. The expected change in sales between now and some future point will be equal to the past change in sales per time period multiplied by the forecasting time.

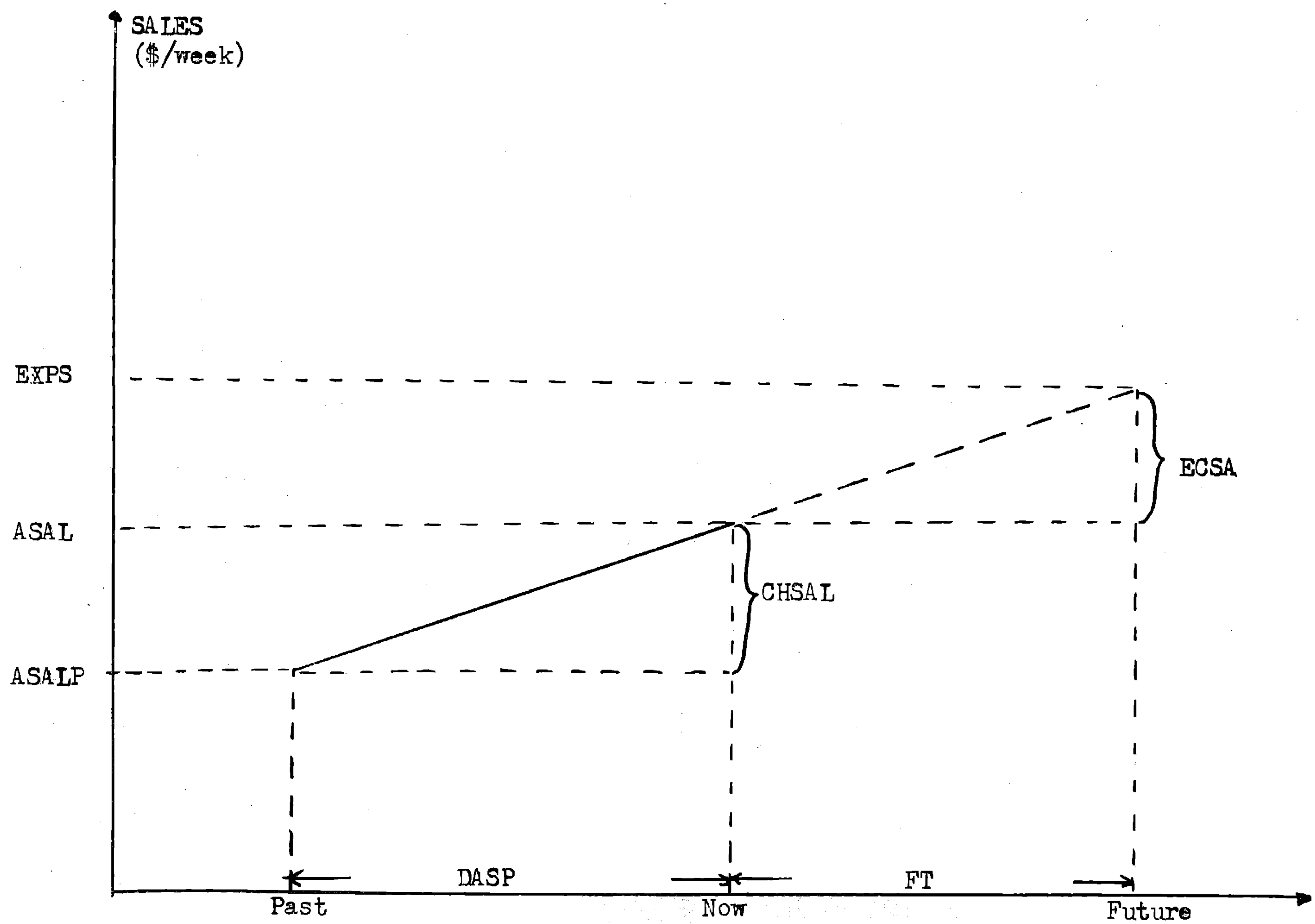


Figure A - 7, Illustration of the forecasting procedure in the model.

We get:

$$ECSA.K=(CHSAL.K)\left(\frac{FT}{DASP}\right) \qquad 20,A$$

ECSA--Expected Change in SAles ($/week)
CHSAL--CHange in SAles ($/week)
FT--Forecast Time (weeks)
DASP--Delay Average Sales, Past (weeks)

The expected sales at some time in the future are then equal to the average sales plus the expected change in sales during the forecast time.

$$EXPS.K=ASAL.K+ECSA.K \qquad 21,A$$

EXPS--EXPected Sales ($/week)
ASAL--Average SALes ($/week)
ECSA--Expected Change in SAles ($/week)

Between the allocation of funds for market development efforts and until we have an active marketing effort, there is a time delay to decide what kind of promotion is desired, where to apply it, time at agencies, etc. This has all been formulated in an aggregated delay.

$$AMDE.K=AMDE.J+(DT)(1/DAMDE)(AFMD.JK-AMDE.J) \qquad 22,L$$

AMDE--Actual Market Development Efforts ($/week)
AFMD--Allocated Funds to Market Development ($/week)
DAMDE--Delay for Actual Market Development Efforts (weeks)

A.1.3 Production Sector, Flow Diagram, Figure A-8

The flow of orders to the company flows into a pool of unfilled orders which is emptied by the filling of orders as they are shipped. This can be described by a regular level equation.

$$UOP.K=UOP.J+(DT)(POR.JK-SSM.JK) \qquad 25,L$$ [1]

UOP--Unfilled Order Pool (units)

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[1] Equation numbers 23 and 24 have not been used.

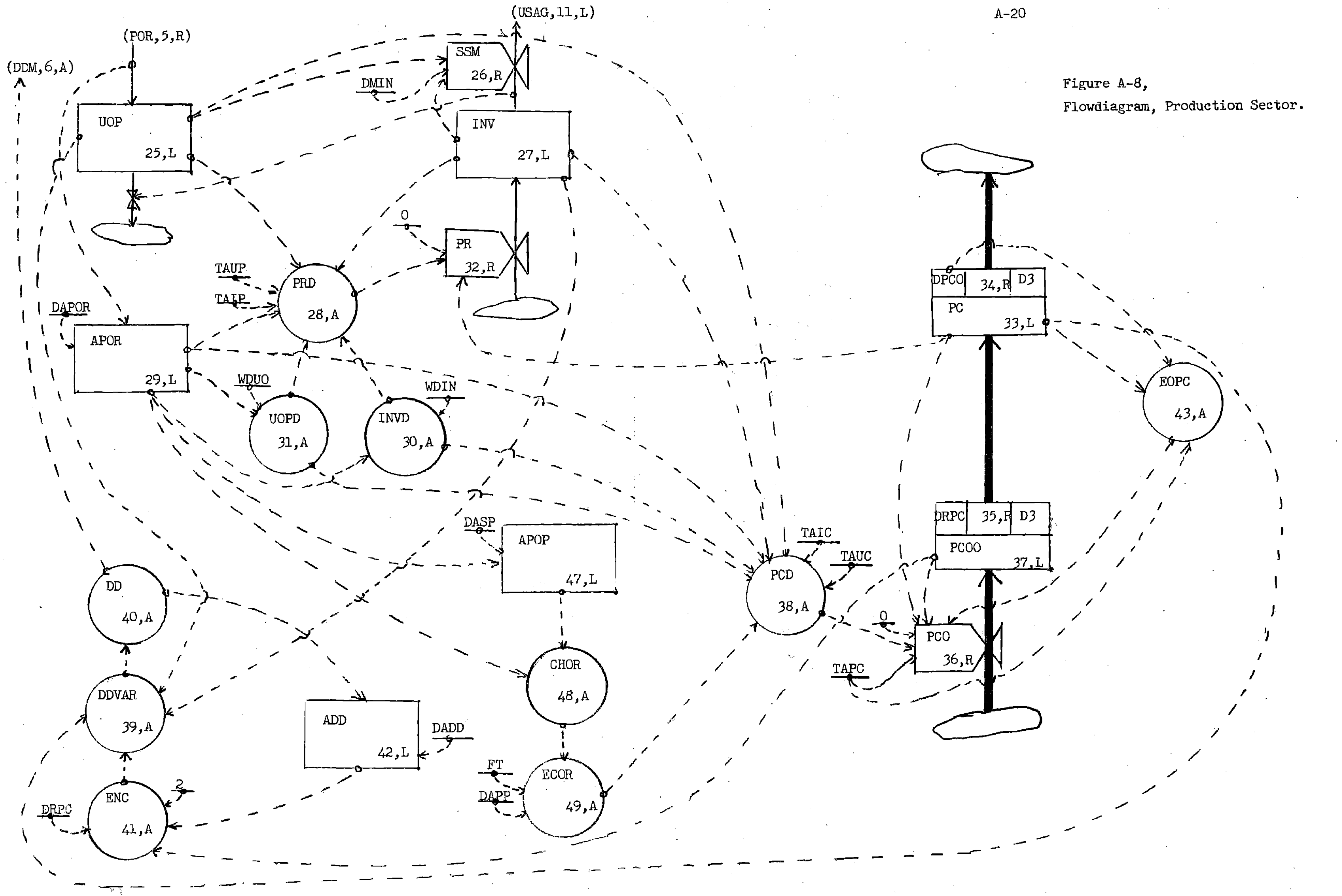

Figure A-8,
Flowdiagram, Production Sector.

POR--Product Order Rate (units/week)
SSM--Shipments Sent to Market (units/week)

The shipments to the market will be dependent upon the positions of the inventory and the unfilled order pool. We will assume that the company will try to fill an order as fast as possible. If there are unfilled orders, the company will ship the products in its inventory as fast as possible. If there is more inventory than unfilled orders, the company will try to fill the orders promptly; and the shipping rate will be determined by the unfilled order position.

The shipment sent to the market will therefore be:

$$\text{SSM.KL} = \begin{cases} \text{INV.K/DMIN} & \text{INV.K} < \text{UOP.K} \\ \text{UOP.K/DMIN} & \text{INV.K} \geq \text{UOP.K} \end{cases} \qquad 26,\text{R}$$

SSM--Shipment Sent to Market (units/week)
INV--INVentory (units)
UOP--Unfilled Order Pool (units)
DMIN--Delay MINimum (weeks)

The minimum delay is then the sum of the clerical delays in treating an order plus the physical handling delays.

We will assume that the production of the company always flows into the inventory before it can be shipped to the market. The inventory position will then be equal to a previous inventory position plus the change in inventory that has taken place since the previous position. The change will be equal to the difference between the addition of products to the inventory (production rate) minus the shipments from the inventory.

$$\text{INV.K=INV.J+(DT)(PR.JK-SSM.JK)} \qquad 27,\text{L}$$

INV--INVentory (units)
PR--Production Rate (units/week)
SSM--Shipment Sent to Market (units/week)

Our next task is to formulate a production rate policy. A production rate equal to the average order flow seems reasonable. The production rate should, however, also be adjusted for the positions of unfilled order pool and inventory. It seems a reasonable policy that these adjustments will be made gradually to desired levels. We can write the policy for the desired production rate.

$$PRD.K=APOR.K+\frac{UOP.K-UOPD.K}{TAUP}+\frac{INVD.K-INV.K}{TAIP} \qquad 28,A$$

PRD--Production Rate Desired (units/week)
APOR--Average Product Order Rate (units/week)
UOP--Unfilled Order Pool (units)
UOPD--Unfilled Order Pool Desired (units)
INV--INVentory (units)
INVD--INVentory Desired (units)
TAUP--Time to Adjust Unfilled orders for Production decision (weeks)
TAIP--Time to Adjust Inventory for Production decision (weeks)

In words, the equation says production rate desired is equal to the average product order rate plus the difference between the unfilled order pool and the desired unfilled order divided by the time to adjust the unfilled orders to the desired level plus the same term for adjustment of the inventory to its desired level.

The average product order rate is then simply an average of the order rate over some recent time.

$$APOR.K=APOR.J+(DT)(1/DAPOR)(POR.JK-APOR.J) \qquad 29,L$$

APOR--Average Product Order Rate (units/week)
DAPOR--Delay Average Product Order Rate (weeks)
POR--Product Order Rate (units/week)

For the desired levels of unfilled orders and inventory, it seems most reasonable to link those to the average order rate. We will write this:

INVD.K=(WDIN)(APOR.K) 30,A

UOPD.K=(WDUO)(APOR.K) 31,A

INVD--INVentory Desired (units)
WDIN--Weeks Desired of INventory (weeks)
UOPD--Unfilled Order Pool Desired (units)
WDUO--Weeks Desired of Unfilled Orders (weeks)
APOR--Average Product Order Rate (units/week)

The equations say that we would like to have a certain number of weeks of average order flow in inventory and unfilled order pool.

The actual production rate will be equal to the desired rate if this one is less or equal to the capacity. Otherwise, it will be equal to the production capacity.

$$PR.KL = \begin{cases} PRD.K & PRD.K \leq PC.K \\ PC.K & PRD.K > PC.K \end{cases}$$ 32,R[1]

PR--Production Rate (units/week)
PRD--Production Rate Desired (units/week)
PC--Production Capacity (units/week)

The production capacity is then equal to the previous production capacity plus the addition of capacity minus the capacity becoming obsolete during the last time step.

PC.K=PC.J+(DT)(PCAR.JK-PCOR.JK) 33,L

PC--Production Capacity (units/week)
PCAR--Production Capacity Addition Rate (units/week/week)
PCOR--Production Capacity Obsolescence Rate (units/week/week)

We have here assumed that the company does not sell capacity in case of excess capacity.

The obsolescence rate is simply formulated as a third-order delay

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[1]The production rate is clipped to assure it not to go negative.

of the addition rate.

PCOR.KL=DELAY3(PCAR.JK,DPCO) 34,R

PCOR--Production Capacity Obsolescence Rate (units/week/week)
DPCO--Delay Production Capacity Obsolescence (weeks)
PCAR--Production Capacity Addition Rate (units/week/week)

We will assume that the company can always get the capacity it orders. The production capacity addition rate will therefore be a simple third-order delay of the production capacity orders.

PCAR.KL=DELAY3(PCO.JK,DRPC) 35,R

PCAR--Production Capacity Addition Rate (units/week/week)
PCO--Production Capacity Orders (units/week/week)
DRPC--Delay Receiving and installing Production Capacity (weeks)

Additional capacity will basically be ordered as a gradual adjustment of the actual capacity to the desired level. The capacity orders will, however, also need adjustments for the capacity that is already ordered but not yet arrived, plus the expected obsolete production capacity.

We will formulate this:

$$PCO.KL=\frac{PCD.K-PC.K-PCOO.K+EOPC.K}{TAPC} \qquad 36,R^{1}$$

PCO--Production Capacity Orders (units/week/week)
PCD--Production Capacity Desired (units/week)
PC--Production Capacity (units/week)
PCOO--Production Capacity On Order (units/week)
TAPC--Time to Adjust Production Capacity (week)
EOPC--Expected Obsolete Production Capacity (units/week)

---

[1] In the initial and end phase of the growth, we might find this quantity less than zero; and we have therefore for simplicity used a clip equation to assure it not to go negative.

The equation says that the production capacity orders are equal to the difference between desired and actual capacity minus already ordered capacity plus the expected obsolete capacity divided by the time to adjust production capacity to the desired level.

The production capacity on order is then:

$$PCOO.K=PCOO.J+(DT)(PCO.JK-PCAR.JK) \qquad 37,L$$

PCOO--Production Capacity On Order (units/week)
PCO--Production Capacity Orders (units/week/week)
PCAR--Production Capacity Addition Rate (units/week/week)

The next problem is now to decide how the company determines its desired capacity. The capacity is necessary to take care of the actual orders coming in, the unfilled orders, and eventually to build up the inventory to a desired level. Since there is a delay in receiving and installing capacity, the company will also try to make some estimation of future change in orders and on this basis, determine the desired capacity. This suggests, therefore, that the desired capacity should be a sum of the average order flow, adjustment factors for unfilled orders and inventory, and a forecasted change in product orders. We get:

$$PCD.K=APOR.K+ECOR.K+\frac{INVD.K-INV.K}{TAIC}+\frac{UOP.K-UOPD.K}{TAUC} \qquad 38,A$$

PCD--Production Capacity Desired (units/week)
APOR--Average Product Order Rate (units/week)
ECOR--Expected Change in Order Rate (units/week)
INV--INVentory (units)
INVD--INVentory Desired (units)
UOPD--Unfilled Order Pool Desired (units)
UOP--Unfilled Order Pool (units)
TAIC--Time to Adjust Inventory for Capacity decision (weeks)
TAUC--Time to Adjust Unfilled orders for Capacity decision (weeks)

It remains to formulate the equation for the delivery delay.

The information about the delivery delay goes to the market and determines, as discussed in the market sector, the order flow to the company. We will, in formulating the delivery delay, assume that the company follows a policy of first in, first served.

If an order can be filled from inventory, the delivery delay will be on its minimum value. In other words, if INV > UOP, the delivery delay should always be equal to the minimum delay. If there is an excess amount of orders, the delivery delay should increase with the size of the excess amount. The amount of orders that cannot be filled from inventory is equal to the difference between the unfilled order pool and the inventory (UOP-INV). If we divide this by the existing production capacity ($\frac{UOP-INV}{PC}$), we get the time it should take to produce the complete amount of orders with the existing capacity. The actual delivery delay for the last incoming order on the basis of existing capacity will then be equal to the preceding production time plus the time it takes for clerical processes and physical handling. In a growth situation, it is kind of unreasonable to assume that the production capacity should stay constant during the delivery delay. We will, therefore, have to adjust the expression $\frac{UOP-INV}{PC}$. We will add in the denominator an expression for the effect of the new capacity. The expression for the delivery delay can then be written $\frac{UOP.K-INV.K}{PC.K+ENC.K}$ where ENC--Effective New Capacity (units/week).

It seems also reasonable that there is a maximum to the delivery delay. The company can always order new capacity and get it within the delivery time for the capacity. All this can be seen in Figure A-9.

The delivery delay variable (DDVAR, an auxiliary variable) is

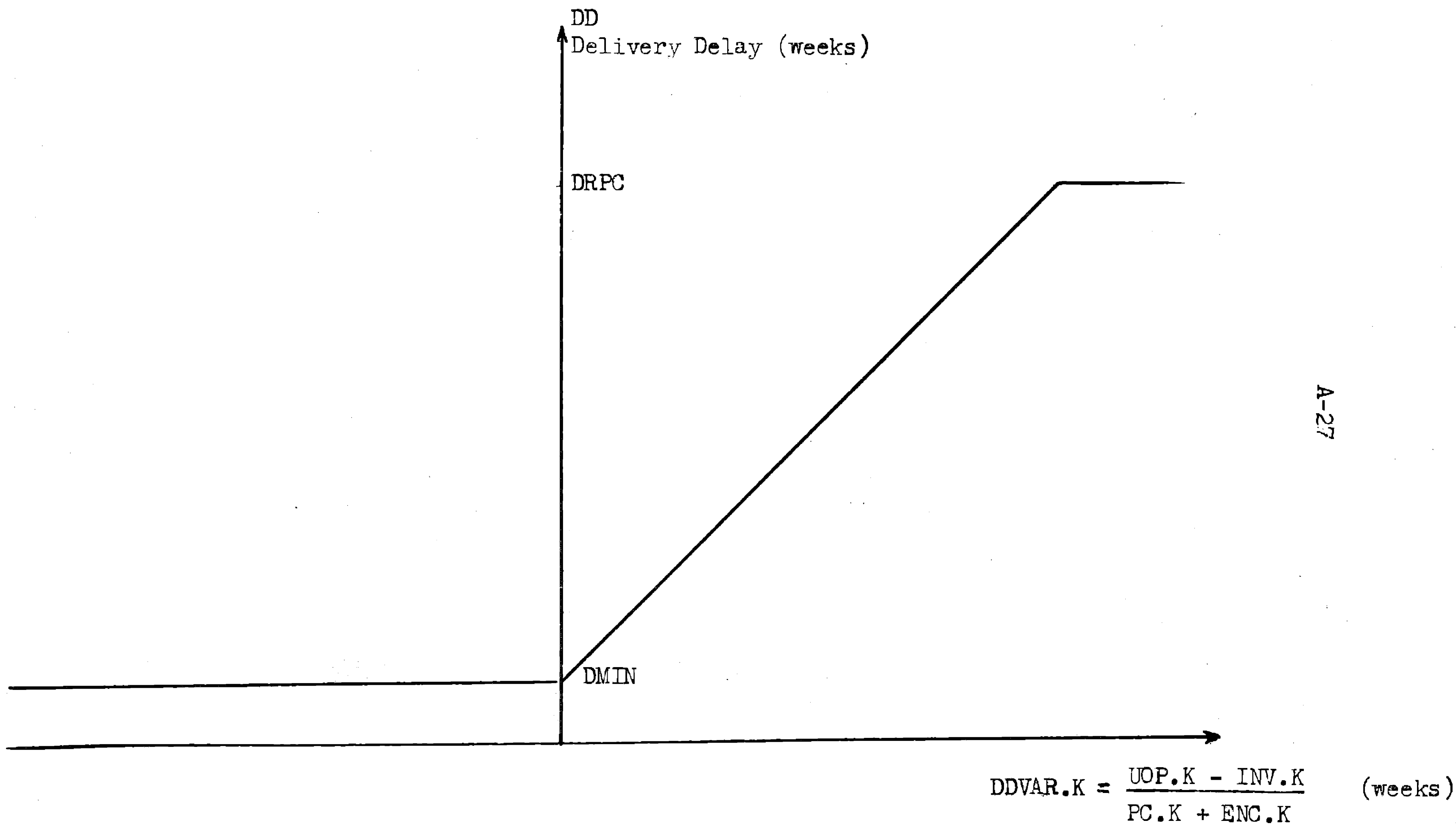

Figure A - 9, Determination of the Delivery Delay.

negative when inventory (INV) is bigger than the unfilled order pool (UOP), and the delivery delay should therefore be equal to its minimum value for negative DDVAR. For positive values on DDVAR, the delivery delay is equal to the expression for DDVAR plus the minimum delay. The curve for the delivery delay has therefore a slope of unity up to the maximum value of the delivery delay (the delay in receiving and installing production capacity, DRPC).

From Figure A-9 we formulate:

$$\text{DDVAR.K}=\frac{\text{UOP.K-INV.K}}{\text{PC.K+ENC.K}} \qquad 39,\text{A}$$

$$\text{DD.K=TABLE(DDTAB,DDVAR.K,-150,300,150)} \qquad 40,\text{A}$$

DDVAR--Delivery Delay VARiable (weeks)
UOP--Unfilled Order Pool (units)
INV--INVentory (units)
PC--Production Capacity (units/week)
ENC--Effective New Capacity (units/week)
DD--Delivery Delay (weeks)
DDTAB--Delivery Delay TABle
DMIN--Delay MINimum (weeks)
DRPC--Delay Receiving and installing Production Capacity (weeks)(150 weeks)
-150--minimum value of DDVAR (weeks)
300--maximum value of DDVAR (weeks)
150--interpolating interval of DDVAR (weeks)

Now the effective new capacity has to be defined. In a real situation, the company will probably make a trial-and-error computation on the basis of the files for production capacity orders to compute the delivery delay. This will, however, be complicated and probably not be a worthwhile effort in this model. We have, therefore, simplified it. We will assume that the production capacity on order is evenly distributed over time. Each time step the company will then receive the production capacity on order divided by the delay in receiving production capacity, $\frac{PCOO.K}{DRPC}$. During the delivery delay, the company will then get this amount times the delivery delay, $\frac{PCOO.K}{DRPC}$ x DD.K. However, since the delivery delay might fluctuate, it seems more reasonable to use an average delivery delay here.

$$ADD.K=ADD.J+(DT)(1/DADD)(DD.J-ADD.J) \qquad 42,L$$ [1]

ADD--Average Delivery Delay (weeks)
DADD--Delay Averaging Delivery Delay (weeks)
DD--Delivery Delay (weeks)

The capacity will, however, not be effective more than half the time of delivery delay. The total expression for the effective new capacity is therefore:

$$ENC.K=\frac{PCOO.K}{DRPC}\cdot\frac{ADD.K}{2} \qquad 41,A$$

ENC--Effective New Capacity (units/week)
PCOO--Production Capacity On Order (units/week)
ADD--Average Delivery Delay (weeks)
DRPC--Delay Receiving and installing Production Capacity (weeks)

We will now determine the equation for the expected obsolete production capacity to go into the equation for the capacity orders, Equation 36,R. Let us assume that the production capacity needs replacement evenly over time. The obsolete capacity each time step will then be equal to the existing production capacity divided by the average life-time of the capacity. Since there is a time lag in ordering production capacity, we must order production capacity to take care of the replacement as follows:

---

[1] Equations 42 and 41 are in reverse order.

$$EOPC.K=\frac{(PC.K)(TAPC)}{DPCO} \qquad 43,A$$

EOPC--Expected Obsolete Production Capacity (units/week)
PC--Production Capacity (units/week)
TAPC--Time to Adjust Production Capacity (weeks)
DPCO--Delay Production Capacity Obsolescence (weeks)

In the same way, we have forecasted the sales (Figure A-7). We can also forecast the product order rate. A point in the past can be obtained by delaying the present average order rate.

APOP.K=APOP.J+(DT)(1/DAPP)(APOR.J-APOP.J) 47,L[1]

APOP--Average Product Order rate, Past (units/week)
DAPP--Delay Average Product orders, Past (weeks)
APOR--Average Product Order Rate (units/week)

The change in orders in the period DAPP is then:

CHOR.K=APOR.K-APOP.K 48,A

CHOR--CHange in Order Rate (units/week)
APOR--Average Product Order Rate (units/week)
APOP--Average Product Order rate, Past (units/week)

The expected change in the order rate between now and some future time:

$$ECOR.K=(CHOR.K)\left(\frac{FT}{DAPP}\right) \qquad 49,A$$

ECOR--Expected Change in Order Rate (units/week)
CHOR--CHange in Order Rate (units/week)
FT--Forecast Time (weeks)
DAPP--Delay Average Product orders, Past (weeks)

A.1.4 Research and Development Sector, Flow Diagram, Figure A-10

The primary input to the research and development department is time. As time goes on, we will within limits assume that the company

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[1]Equation numbers 44, 45, and 46 have not been used.

always can turn out a better product. It seems reasonable to believe that there is an upper maximum to quality which we can ever reach, and it seems also reasonable to assume that the quality will never decrease with time. How the exact relationship is, will be dependent upon the product or product-type we are talking about. In Figure IV-11 some plausible relationships between quality and time are shown.

Let us assume arbitrarily that the quality of the product (a new typewriter) can vary between 0 and 10 quality units. The quality is initially 0 and maximally 10. It will take the company 18 years to reach the maximum quality and about 12 years to reach 2/3 of the quality. It seems reasonable that the quality first is increasing slowly, for so to rise faster when the product has passed the initial phase with all its problems. The curve for quality vs. time can be seen in Figure A-11.

We will assume that the quality initially does not start from zero, but from some small value which we have selected equal to 2.8. The quality is from this value following the curve. The formulation of the equation can be written:

```
Q.K=TABLE(RDTAB,TIME.K,0,1000,100)                   50,A

    Q--Quality (quality units)
    RDTAB--Research and Development TABle
    TIME--TIME (weeks)
    0--first value of time (weeks)
    1000--last value of time (weeks)
    100--interpolating interval (weeks)
```

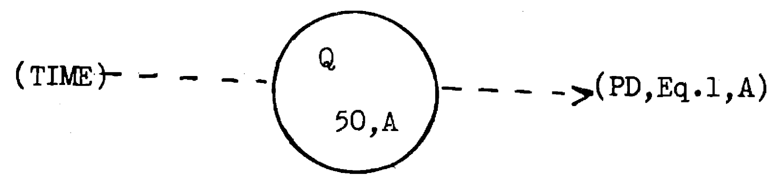

Figure A-10, Flowdiagram, Research and Development Sector.

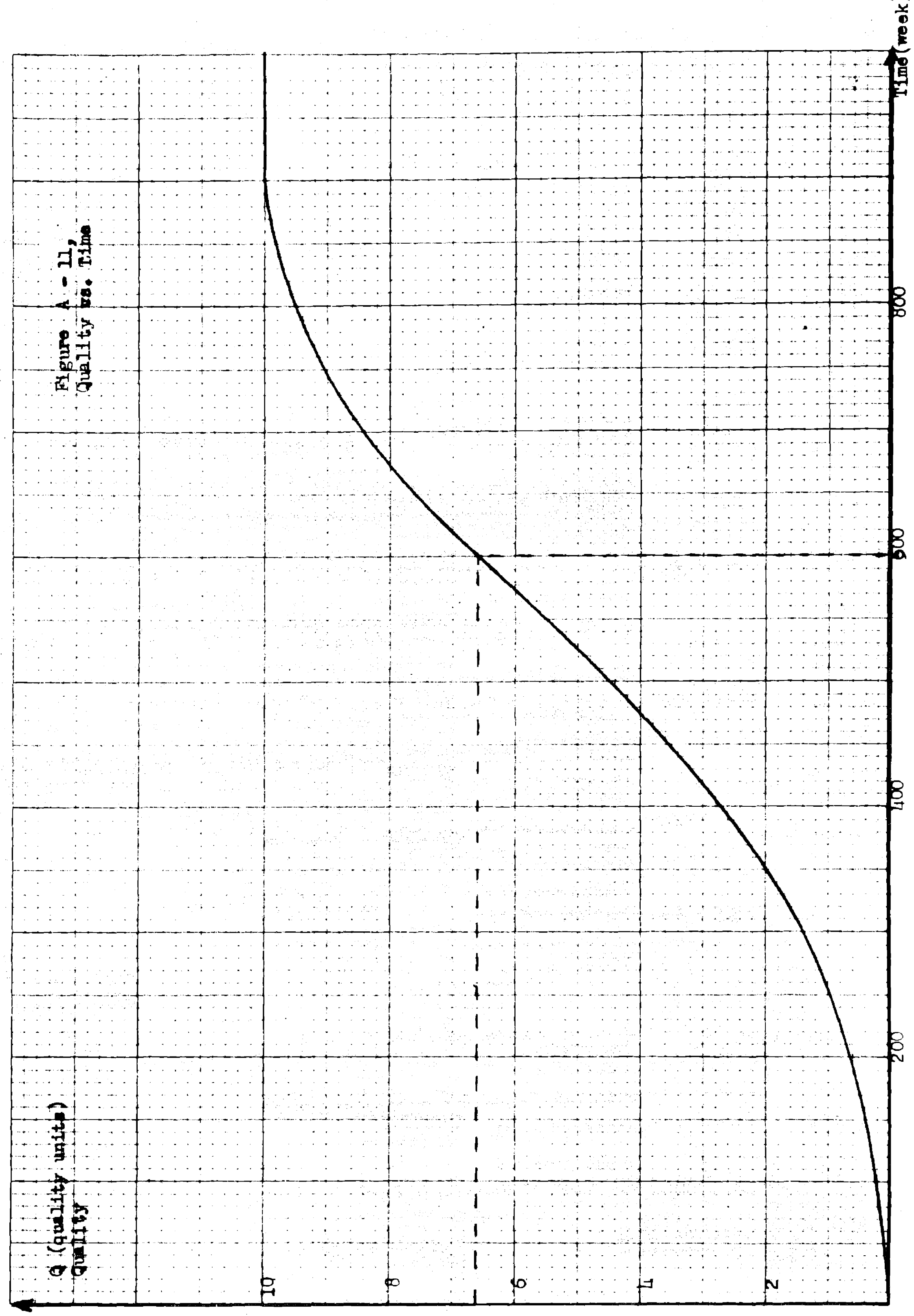

Figure A - 11,
Quality vs. Time

A.2 Initial Conditions

In order to determine where to start the model, the initial conditions on all levels must be defined. The model is built to describe the complete growth stage, and it would therefore seem reasonable to start the model from zero conditions. The long time constants in the adoption of a new product indicate, however, that in this model there will be very little growth for the first years; and to save computer time, the model has therefore been started with positive values on some levels. The initial conditions have been selected on the following basis. There exists a product with some quality here selected 2.8 quality units which gives a potential demand of 715 units per week (Figure A-2).

A.2.1 Market Sector

The first level that has to be specified is the level of activated potential demand. This level will be assumed to be initially considerably less than the potential demand. It will be selected arbitrarily.

APD=250

APD--Activated Potential Demand (units/week) (Eq. 2,L)

Most of the market and the market development sectors will be determined as steady state values based upon the value selected on the activated potential demand.

The level of the purchase pool will accordingly be defined as the input to the level multiplied by the purchasing delay.

PUP=(APD)(DPD)

PUP--PUrchase Pool (units) (Eq. 4,L)
APD--Activated Potential Demand (units/week)
DPD--Delay Purchase Decision (weeks)

The observed marketing efforts are selected equal to the influence level which we would have in steady state for an order rate equal to the activated potential demand.

OMDE=(APD)(PRICE)(FSMD)

OMDE--Observed Market Development Efforts ($/week) (Eq. 9,L)
APD--Activated Potential Demand (units/week)
PRICE--PRICE ($/week)
FSMD--Fraction of Sales to Market Development (dimensionless)

The usage and average usage levels will be selected assuming that there have not been done any previous sales. The levels are therefore equal to zero. It should be noted that these levels, accordingly, are not in steady-state conditions with the activated potential demand.

AUSA=USAG

AUSA--Average USAge (units) (Eq. 10,L)
USAG--USAGe (units)

USAG=0

USAG--USAGe (units) (Eq. 11,L)

A.2.2 Market Development Sector

Initially we will assume that the actual market development efforts are equal to the observed efforts.

AMDE=OMDE

AMDE--Actual Market Development Efforts ($/week) (Eq. 22,L)
OMDE--Observed Market Development Efforts ($/week)

Initially no sales of the product have been made, and the levels of average sales and past average sales will both be equal to zero.

ASAL=0

ASAL--Average SALes ($/week) (Eq. 16,L)

ASALP=0

ASALP--Average SALes, Past ($/week) (Eq. 18,L)

A.2.3 Production Sector

In the production sector we will assume that the company starts out without any unfilled orders and with some inventory and some initial production capacity.

UOP=0

UOP--Unfilled Order Pool (units) (Eq. 25,L)

INV=(WDIN)(APD)

INV--INVentory (units/ (Eq. 27,L)
WDIN--Weeks Desired of INventory (weeks)
APD--Activated Potential Demand (units/week)

PC=PCI

PC--Production Capacity (units/week) (Eq. 33,L)
PCI--Production Capacity Initially (units/week)

The shipment to the market and the production capacity orders have to be specified being inputs to a third-order delay.

Since there are no unfilled orders initially, the shipment rate is selected equal to zero.

SSM=0

SSM--Shipment Sent to Market (units/week) (Eq. 26,R)

Initially, the production capacity will be given an adequate value, and the production capacity orders will be zero.

PCO=0

PCO--Production Capacity Orders (units/week/week)
(Eq. 36,R)

The production capacity on order is also defined initially equal to zero.

PCOO=0

PCOO--Production Capacity On Order (units/week) (Eq. 37,L)

The company is able to fill the incoming orders, and the average delivery delay will therefore be equal to the minimum delay.

ADD--DMIN

ADD--Average Delivery Delay (weeks) (Eq. 42,L)
DMIN--Delay MINimum (weeks)

The initial conditions now remain to be defined on the average order rate and the past average order rate. Both will initially be selected equal to the activated potential demand (equal to product order rate).

APOR=APD

APOP=APD

APOR--Average Product Order Rate (units/week) (Eq. 29,L)
APOP--Average Product Order rate, Past (units/week) (Eq. 47,L)
APD--Activated Potential Demand (units/week) (Eq. 2,L)

A.3 Constants

All constants in the model have been selected on a criterion of plausibility. In the following, the selected values without further justification will be given. On some of the constants, we will justify selection.

A.3.1 Market Sector

The first constants to be defined in the market are the value for the potential demand vs. quality in Eq. 1,A. The values are taken out of the curve (Figure A-2) at the interpolating intervals. In DYNAMO format the information can be stored.

QTAB*=0/125/375/800/1400/2500/3650/4350/4750/4900/5000

QTAB--Quality TABle

In a similar way we get the values for the delivery delay multiplier from Figure A-3.

DMTAB*=1/1/1/1/1/.99/.97/.93/.88/.83/.78/.73/.66/.60/.54/.48/
.42/.36/.30/.25/.19

DMTAB--Delivery delay Multiplier TABle

The values of the constants in the equation for influence (Eq. 8,A) are the next ones to be determined. An empirical study[1] shows us that the new customers of a product put about 20 percent importance on the influence from informal sources and about 80 percent importance on the more formal information sources.

Now let us assume that these values are approximately right when the orders have reached about 50 percent of what they can ever reach with maximum quality, and let us assume further that the influence measured in awareness units per week is about equal to the actual order rate at this point.

The influence level is, therefore, equal to

2500 awareness units/week

of which the usage (informal influence) counts for about

500 awareness units/week (20%)

and the promotion effort (formal influence) for the rest (2000 awareness units/week). The promotion efforts at this point are about

---

[1] The Adoption of New Products, Process and Influence; The Foundation for Human Behavior, Ann Arbor, 1959.

$(2500)(300)(0.05)=\$37,500/\text{week}$

(sale units/week)(price)(fraction of sales to promotion)

and we get

$$EOMD=\frac{2000}{37,500}=0.054\sim 0.05 \text{ awareness units/\$}$$

EOMD--Effect Of Market Development effort (awareness units/ $)

The rest of the influence (500 awareness units/week) can be attributed to influence of users of the product. With 2/3 saturated market and a lifetime of 150 weeks of the product, we will at an order rate of 2500 units/week have an amount of users as follows:

$2500 \times 150 \times 2/3 = 250,000$ units

Those quarter-million products in use will then influence a sale of 500 units/week, and we get:

$$EOUS=\frac{500}{250.000}=\frac{1}{500}=0.002 \text{ awareness units/week/unit in use}$$

EOUS--Effect Of USage (awareness units/week/unit)

This might seem like a fairly arbitrary way of selecting constants. We think, however, that values selected are plausible.[1]

---

[1]Let us now consider the reasonability of EOMD and EOUS.

EOMD=0.05 awareness units/$

To create a sale of one unit ($300), the constant tells us that it will require $20 (1/.05) of marketing effort, which seems to be of the right magnitude.

EOUS=0.002 awareness units/week/unit

The constant tells us that each user during the life of the product will create 0.31 awareness units (EOUS x lifetime of product = 0.002 x 156=.31) or in other words, three users are required to create one awareness unit or one purchase if the new customer was not exposed to any other source of influence. The value of EOUS seems, therefore, reasonable.

The following constants have been selected on the basis of plausibility.

DWOUT=156

DWOUT--Delay Wear OUT (weeks)

DOMD=4

DOMD--Delay Observing Market Development efforts (weeks)

DOUS=8

DOUS--Delay Observing USage (weeks)

The values for the tables for the delay in activating potential demand and the delay in the purchase decision is obtained from Figure A-4 and Figure A-5, respectively.

ITABA*=780/570/455/370/310/260/235/210/192/182/172/165/159/154/152/150

ITABA--Influence TABle for Activating demand

ITABP*=78/64/56/48/43/39/34/30/26/23/20/18/17/16/16/16

ITABP--Influence TABle for Purchase decision

A.3.2 Market Development Sector

Many companies will allocate 5 to 10 percent of their expected sales to promotion of their product. We will here choose:

FSMD=0.05

FSMD--Fraction of Sales to Market Development (dimensionless)

The following constants have been chosen on plausibility.

DASA=26

DASA--Delay Average SAles (weeks)

PRICE=300

PRICE--PRICE ($/unit)

DASP=104

DASP--Delay Average Sale, Past (weeks)

FT=TAPC+DRPC

FT--Forecast Time (weeks)
TAPC--Time to Adjust Production Capacity (weeks)
DRPC--Delay Receiving and installing Production Capacity (weeks)

DAMDE=26

DAMDE--Delay for Actual Market Development Efforts (weeks)

A.3.3 Production Sector

DMIN=2

DMIN--Delay MINimum (weeks)

TAUP=12

TAUP--Time to Adjust Unfilled orders for Production decision (weeks)

TAIP=12

TAIP--Time to Adjust Inventory for Production decision (weeks)

DAPOR=26

DAPOR--Delay Average Product Order Rate (weeks)

WDIN=8

WDIN--Weeks Desired of INventory (weeks)

WDUO=2

WDUO--Weeks Desired of Unfilled Orders (weeks)

DPCO=500

DPCO--Delay Production Capacity Obsolescence (weeks)

DRPC=150

DRPC--Delay Receiving and installing Production Capacity (weeks)

TAPC=52

TAPC--Time to Adjust Production Capacity (weeks)

TAIC=52

TAIC--Time to Adjust Inventory for Capacity decision (weeks)

TAUC=52

TAUC--Time to Adjust Unfilled order for Capacity decision (weeks)

DDTAB*=2/2/150/150

DDTAB--Delivery Delay TABle

DADD=8

DADD--Delay Averaging Delivery Delay (weeks)

PCI=500

PCI--Production Capacity Initially (units/week)

DAPP=104

DAPP--Delay Average Product orders, Past (weeks)

A.3.4 Research and Development Sector

The values for the quality vs. time curve are found in Figure A-11.

RDTAB*=2.8/4.4/6.6/8.5/9.5/10/10 /10/10/10/10

RDTAB--Research and Development TABle

APPENDIX B

A SIMPLIFIED STUDY OF THE PRODUCTION CAPACITY ORDERING POLICY

In Chapters I and VI, it has been discussed how the production capacity ordering policy works as an amplifier between the actual order flow and the desired amount of capacity. According to Eq. 36,R, capacity is ordered not only to take care of an increased level of business, but also to take care of the same orders staying in backlog or emptying inventory while the company is waiting for the arrival of new capacity.

In the original model, it is hard to separate the effect of the capacity ordering policy from the overlapping effects of other policies on the model behavior. We have therefore made a study of the effect of the capacity ordering policy per se. The system has been further simplified, but it contains the major amplifying factor.[1] The system is built on the following assumptions:

1. The order rate is exogenous.
2. The production rate and the shipment rate are always equal to the capacity.
3. The capacity does not become obsolete.

The equations follow:

The order rate is, as mentioned, an exogenous input. It will initially be selected equal to 100, and a term that can be used for different test inputs is added.

O.KL=100+CH.K B-1,R

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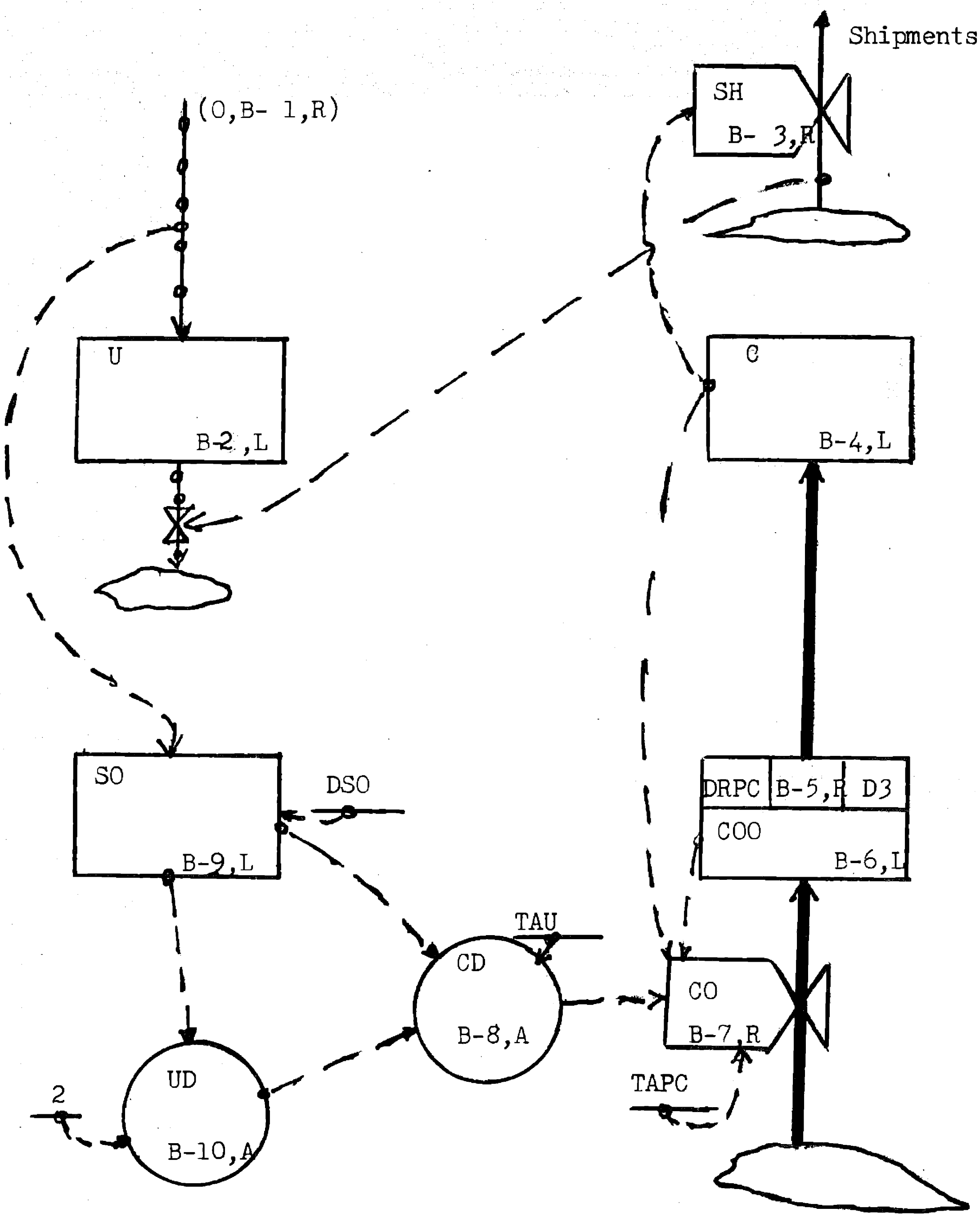
[1]The amplification of the forecast term is excluded.

F I G U R E, B - I

A simplified system to study effects of production capacity ordering policy.



O--Order rate (units/week)
100--steady-state order rate, initial (units/week)
CH--CHange in order rate (units/week)

The order rate goes into an unfilled order pool which is emptied by the shipping rate.

U.K=U.J+(DT)(O.JK-SH.JK) B-2,L

U--Unfilled order pool (units)
O--Order rate (units/week)
SH--SHipment rate (units/week)

We have now assumed that the shipping rate is equal to the capacity.

SH.KL=C.K B-3,R

SH--SHipment rate (units/week)
C--Capacity (units/week)

This might allow the unfilled order pool to go negative, which could be thought of as inventory, and the shipping rate could then be thought of as either being shipments to the market or to the inventory.

The capacity at the company is then equal to the previous capacity plus the additional amount of new capacity arrived between the computations.

C.K=C.J+(DT)(CA.JK-O) B-4,L

C--Capacity (units/week)
CA--Capacity Arrival (units/week/week)

The arrival of capacity is a third-order delay of the capacity orders.

CA.KL=DELAY3(CO.JK,DRPC) B-5,R

CA--Capacity Arrival (units/week/week)
CO--Capacity Orders (units/week/week)
DRPC--Delay Receiving Production Capacity (week)

The amount of capacity on order will now be:

COO.K=COO.J+(DT)(CO.JK-CA.JK) B-6,L

COO--Capacity On Order (units/week)
CO--Capacity Orders (units/week/week)
CA--Capacity Arrival (units/week/week)

The capacity orders will now be equal to the difference between the desired amount of capacity and the actual amount adjusted for the already ordered capacity, all divided by the adjustment time for adjusting the actual capacity to the desired level, corrected not to go negative.

$$CO.KL=MAX\begin{cases}\frac{CD.K-C.K-COO.K}{TAPC}\\0\end{cases} \qquad \text{B-7,R}$$

CO--Capacity Orders (units/week/week)
CD--Capacity Desired (units/week)
C--Capacity (units/week)
COO--Capacity On Order (units/week)
TAPC--Time to Adjust Production Capacity (week)

The desired amount of capacity is then equal to the average order rate plus an adjustment factor for backlog.

$$CD.K=SO.K+\frac{U.K-UD.K}{TAU} \qquad \text{B-8,A}$$

CD--Capacity Desired (units/week)
SO--Smooth Order rate (units/week)
U--Unfilled order pool (units)
UD--Unfilled order pool Desired (units)
TAU--Time to Adjust Unfilled orders (week)

The average order rate is equal to:

$$SO.K=SO.J+(DT)(1/DSO)(O.JK-SO.J) \qquad \text{B-9,L}$$

SO--Smooth Order rate (units/week)
O--Order rate (units/week)
DSO--Delay Smoothing Orders (week)

The only variable left to define is now the desired unfilled order pool. We will link this one to the level of business.

$$UD.K=(2)(SO.K)^{1} \qquad \text{B-10,A}$$

---

[1]If we think of negative unfilled orders as being inventory, the desired level of unfilled orders should probably have been negative, which will cause an even stronger amplification in the capacity ordering decision.

UD--Unfilled orders, Desired (units)
SO--Smooth Order rate (units/week)
2--desired weeks of orders in backlog (week)

The initial conditions are now left to be defined. The model is originally assumed to be in steady state. Initial conditions are:

U=200

U--Unfilled order pool (units)

C=100

C--Capacity (units/week)

CA=0

CA--Capacity Arrival (units/week/week)

COO=0

COO--Capacity On Order (units/week)

CO=0

CO--Capacity Orders (units/week/week)

SO=100

SO--Smooth Order rate (units/week)

The constants for the model will be selected as the ones in Appendix A.

DRPC=150

DRPC--Delay Receiving Production Capacity (week)

TAPC=52

TAPC--Time to Adjust Production Capacity (week)

TAU=52

TAU--Time to Adjust Unfilled orders (week)

DSO=26

DSO--Delay Smoothing Order rate (week)

The model is now ready to be tested.

STEP in the Order Rate

First we will test the model for a 10-percent step in the order rate.[1]

The behavior of the model as a response to the step test can be seen in Figure B-2 . As we would expect, we end up with a serious amount of overcapacity, which is due to the amplification built into the capacity ordering decision.

At the time of the occurrence of the increased order flow, the company has just enough capacity for the regular amount of business. All the increased orders will therefore have to go in an unfilled order pool until additional capacity arrives. With a delivery time on capacity of 150 weeks and an ordering time for capacity of 52 weeks, the backlog will build up to about

$$10(150+52) = 2000 \text{ units}$$ [2]

at week 200.

The average excess backlog over the first 200 weeks will then be:

$$\frac{2000}{2} = 1000 \text{ units}$$

---

[1] CH.K=STEP(10,5)

CH--CHange in order rate (units/week)
STEP--DYNAMO notation for a STEP function
10--value of step (units/week)
5--time for occurrence of step (weeks)

[2] The delays are average delays and some capacity will arrive before this time. The backlog does not actually built up to more than about 1700 units (as seen in Figure B-2).

Let us now consider the capacity orders due to this backlog. The equation is

$$CO.KL=(1/TAPC)(CD.K-COO.K-C.K) \qquad \text{B-7,R}$$

where

$$COO.K=COO.J+(DT)(CO.JK-CA.JK) \qquad \text{B-6,L}$$

$$C.K=C.J+(DT)(CA.JK) \qquad \text{B-4,L}$$

CO--Capacity Orders (units/week/week)
CD--Capacity Desired (units/week)
COO--Capacity On Order (units/week)
C--Capacity (units/week)
CA--Capacity Arrival (units/week/week)
TAPC--Time to Adjust Production Capacity (week)

The sum of capacity on order and actual capacity is the integral of the capacity orders. We can, therefore, write Eq. B-7,R as follows:

$$\frac{dy}{dt} = \frac{1}{TAPC}(CD.K-y)$$ [1]

where y=COO.K+C.K

The backlog is now gradually building up in excess of the desired level with 10 units per week, and the desired amount[2] of capacity to take care of this backlog will be

$$\frac{10 \times TIME.K}{TAU}$$

---

[1] With a constant desired amount of capacity, the solution would have been

$$y = CD(1-e^{-t/TAPC})$$

which for $t \gg TAPC$ gives

y=CD (capacity desired)

[2] Excluding the influence of the higher level of business on the desired level of backlog, and the arrival of capacity to reduce the backlog.

This expression can now be substituted in Eq. B-7,R, and we get

$$\frac{dy}{dt} = \frac{1}{TAPC}\left(\frac{10}{TAU}\ t - y\right)$$

where t = TIME

y = COO+C (the total amount of capacity ordered at any one time to take care of the backlog)

The equation can now be solved for y as a function of t. We get

$$y=10\ \frac{TAPC}{TAU}\left(e^{-TIME.K/TAPC} + \frac{TIME.K}{TAPC} - 1\right)$$

for TIME equals 200 weeks (DRPC+TAPC) we get

$$y=10\ (e^{-4} + 4 - 1) = 30 \text{ units/week}$$

According to the above calculation, the company would be expected to end up with an overcapacity of 30 units per week. From Figure B-2, we see that the actual amount of overcapacity is about

134-110=24 units/week

The difference is due to the fact that some capacity will arrive before week 200, and accordingly the unfilled order pool will not grow with 10 units per week when time approaches 200. The calculation has its value in showing us the importance of the amplifying factor in the capacity ordering policy.

In this model we have not allowed the capacity to be reduced, and the model will therefore not show any distinct oscillatory character. We would, however, expect the model to show different sensitivity to different frequencies of the disturbances in the order rate. The model will therefore be tested for a periodical fluctuation in the order rate.

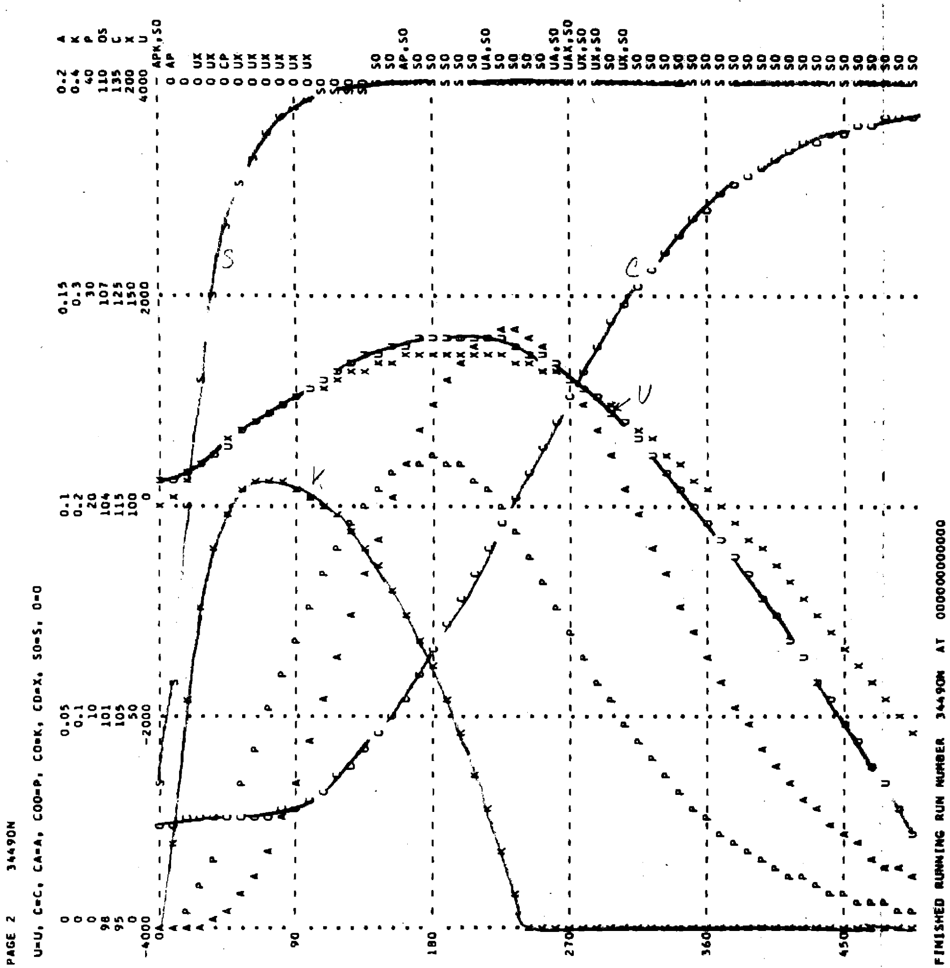


Fig B-2,

A SIMPLIFIED STUDY OF THE PRODUCTION CAPACITY ORDERING POLICY.
STEP INPUT IN ORDERS.

C = C, CAPACITY
V = U, UNFILLED ORDER POOL
CO = K, CAPACITY ORDERS
SO = S, SMOOTHED ORDER RATE
CA = A, CAPACITY ARRIVAL
COO = P, CAPACITY ON ORDER
CD = X, CAPACITY DESIRED
O = O, ORDER RATE

Sine Wave in the Order Rate

We will now test the model for a 10 percent sine wave in the order rate.[1]

In Figure B-3 can be seen the behavior of the capacity orders for different periods, and in Table B-I can be seen the amount of capacity the company will end up with.

It should be noted the strong sensitivity to low frequency disturbances. The model has very low sensitivity to a yearly variation in the order rate due to the long smoothing time of the order flow (26 weeks). The average order flow will therefore never go above 103 units per week and not below 97 units per week for a yearly cycle in the order rate, while for a 4-year cycle, the average order flow is varying between 108 and 92 units per week.

TABLE B-I

Final amount of production capacity at the company as a response to a periodical sine wave in the order rate for the simplified model of Appendix A.

PER (week)	52	208	416
PC (units/week)	103.5	113	124

---

[1] CH.K=(10)SIN((2PI)(TIME.K)/PER)

CH--CHange in order rate (units/week)
10--maximum change in order rate (units/week)
SIN--DYNAMO notation for a sine wave
2PI--2·3.14
TIME--TIME
PER--PERiod of sine wave

The runs have not been included in the text.

The model has been tested for an increase in the adjustment time for unfilled orders (TAU), which means a reduction of the amplification. In Table B- 2 can be seen the amount of capacity the company will end up with for an increase in the adjustment time from 52 to 208 weeks. In the same table is also tabulated the maximum value on the orders for additional capacity (PCO).

We see that the total amount of capacity that the company will end up with is now reduced considerably. The maximum value on capacity orders is also reduced. We should, however, be aware that a slow adjustment time on backlog could cause a higher backlog and less ability of the company to fill orders, which again might mean loss of sales for the company.

TABLE B-2

Final amount of production capacity at the company as a response to a periodical sine wave in the order rate for the simplified model of Appendix A, with a 4-year period to adjust backlog to desired level.

PER (week)	52	208	416
PC (units/week)	102.5	107	112
PCO (max. value) (units/week/week)	.08	.12	.11

This appendix has served to show us the behavior of the capacity ordering policy per se. The results show the amplification that is built into the function and the sensitivity of the function to the low frequency disturbances. The mentioned factors are certainly also present

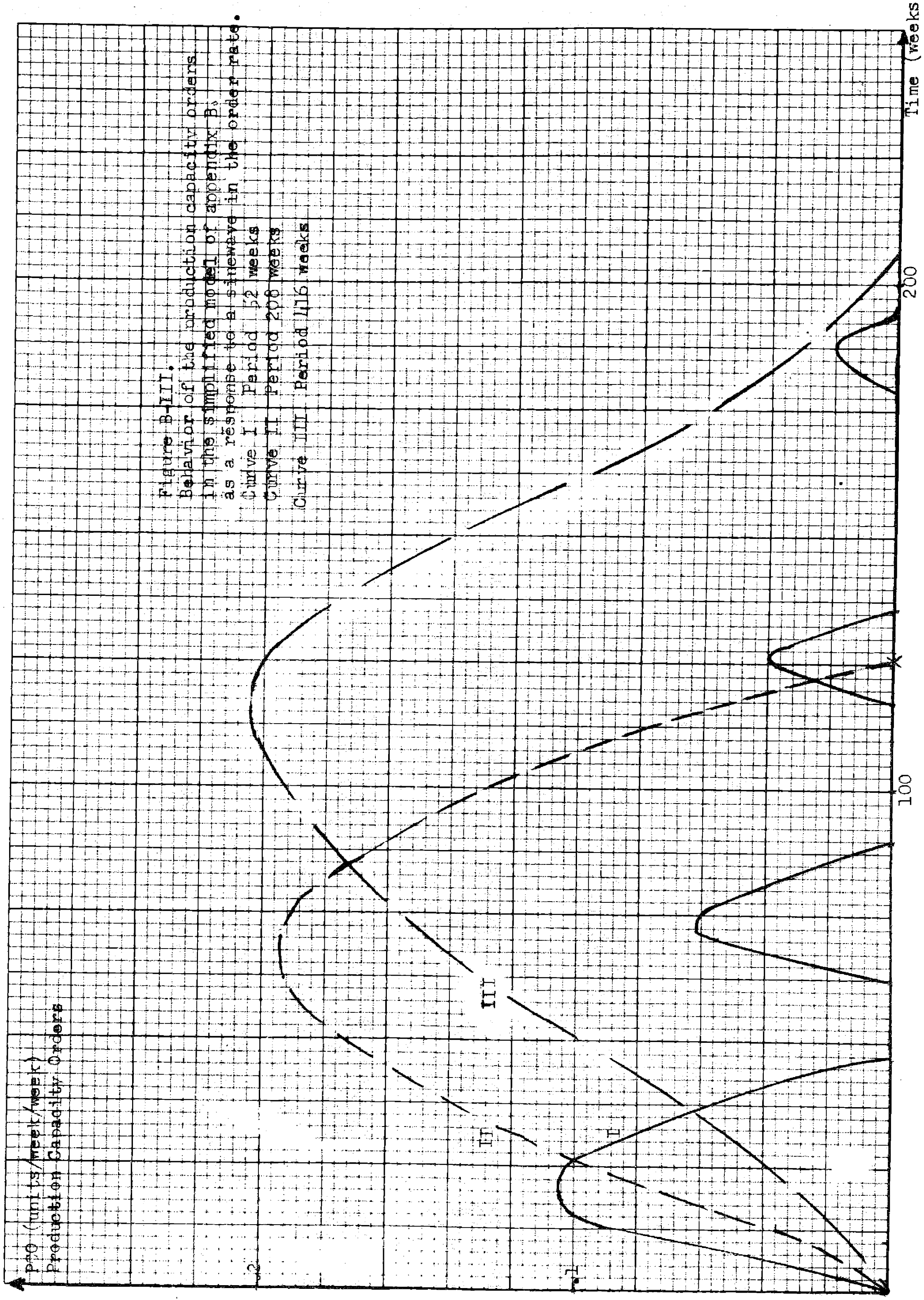


Figure B-III.
Behavior of the production capacity orders in the simplified model of appendix B. as a response to a sinewave in the order rate.
Curve I Period 52 weeks
Curve II Period 208 weeks
Curve III Period 416 weeks

in the actual growth model, but the implications of the policy are not as obvious as here due to the overlapping effect of other factors in the model.

APPENDIX C

PROFIT CALCULATION

This appendix outlines a formulation of a profit calculation. The objective is to get a relative criterion for company results from different policies.

The profit rate of the company in a certain period of time is equal to the income minus the expenditures in this period.

PRN.K=SALE.K-EXP.K C-1,A

PRN--Profit Rate Now ($/week)
SALE--SALE (defined in Appendix A, Eq. 17,A) ($/week)
EXP--EXPenditures ($/week)

The total amount of profit accrued to the company is equal to the sum of all profit rates accrued over time and adjusted for the importance of time on the value of money. The profit rate total is therefore equal to the previous amount of profit plus the additional profit during the last time step plus the increased value of the previous profit over the last time step. We get:

TPRN.K=TPRN.J+(DT)(PRN.J+IVPP.J) C-2,L

TPRN--Total PRofit Now ($)
PRN--Profit Rate Now ($/week)
IVPP--Increased Value of Previous Profit ($/week)

The increased value is then equal to the accrued interest to the profit balance.

IVPP.K=(TPRN.K)(INTR) C-3,A

IVPP--Increased Value of Previous Profit ($/week)
TPRN--Total PRofit Now ($)
INTR--INTerest Rate ($ interest/$ investment/week)

The profit rate now is then calculated on the basis of sales and expenditures. The sales are gotten from Eq. 17,A, Appendix A, and the formulation of the expenditures is following.

The expenditures in a time period (a week) are then equal to a fixed cost, production costs, research and development costs, marketing costs, and expenditures on purchases of new equipment.

EXP.K=FC.K+CPR.K+CRD.K+CMA.K+EQPU.K C-4,A

EXP--EXPenditures (\$/week)
FC--Fixed Cost (\$/week)
CPR--Cost, PRoduction (\$/week)
CRD--Cost, Research and Development (\$/week)
CMA--Cost, MArketing (\$/week)
EQPU--EQuipment PUrchases (\$/week)

In the fixed cost, we will include all the fixed cost in the different sectors of the company. It seems reasonable that the fixed cost is dependent upon the size of the company and we will formulate it.

FC.K=(FCCU)(PC.K) C-5,A

FC--Fixed Cost (\$/week)
FCCU--Fixed Cost per Capacity Unit (\$/week/units/week)
PC--Production Capacity (units/week)

The production cost is formulated proportional to the production rate.

CPR.K=(PR.K)(UCP) C-6,A

CPR--Cost PRoduction (\$/week)
PR--Production Rate (units/week)
UCP--Unit Cost, Production (\$/week)

The next cost we have to consider is the research and development cost. In the model we have not included any flow of efforts to the research and development department, and accordingly it is hard to estimate the cost of this department on the basis of the model. However, since this profit calculation is meant to be more of a relative performance criterion than an actual quantitative measurement of performance, we think it is justifiable to set the research and development costs equal to a constant.

CRD.K=CCRD C-7,A

CRD--Cost Research and Development ($/week)
CCRD--Constant Cost Research and Development ($/week)

In the original model we have a flow of funds to the marketing department measured in dollars per week, and the cost of the marketing department will be set equal to this flow.

CMA.K=AFMD.JK C-8,A

CMA--Cost MArketing ($/week)
AFMD--Allocated Funds Market Development ($/week)

The only expenditure left to define is now the expenditures in connection with equipment purchase. Since we are mainly concerned about the relative performance, we think it is justifiable to simplify and accrue all expenditures on equipment purchase at the time the equipment is received at the company.[1] We get:

EQPU.K=(PCAR.JK)(PCP) C-9,A

EQPU--EQuipment PUrchase ($/week)
PCAR--Production Capacity Additional Rate (units/week/week)
PCP--Production Capacity Price ($/week/week)

This appendix has now outlined a profit calculation formulation to serve as a relative performance criterion. The model has not been run, and it is only included here to be a guide for someone who would like to continue this study.

---

[1] A gradual depreciation of the equipment could be formulated with boxcars.

APPENDIX D

EXPONENTIAL FORECAST

In Appendix A it was used a forecasting policy for linear forecast of present trend. A change in the order flow of, for instance, 1000 units/week last year would be forecasted as an expected change for next year as 1000 units/week.

This appendix will now formulate a policy for exponential forecasting. A change in the order flow of, for instance, 10% last year will be forecasted as an expected change for next year of 10 %. The difference between the two methods for forecasting is illustrated in Figure D-1. In the figure are used different times for forecast time and time back for reference to past value.

The expected product order rate is now equal to the present product order rate plus the expected change in the order rate.

EXPO.K=APOR.K+ECOEF.K   D-1,A

EXPO--EXPected Order rate (units/week)
APOR--Average Product Order Rate (units/week)
ECOEF--Expected Change in Orders,Exponential Forecast (units/week)

The expected change in orders will now be equal to the fractional past increase in orders times the average order rate.

ECOEF.K=(EIOR.K)(APOR.K)   D-2,A

ECOEF--Expected Change in Orders,Exponential Forecast (units/week)
EIOR--Expected Increase in Order Rate (dimensionless)
APOR--Average Product Order Rate (units/week) (Appendix A, Eq. 29,L)

The expected increase in the order rate over the forecast time will now be equal to the previous increase in order rate over some past time

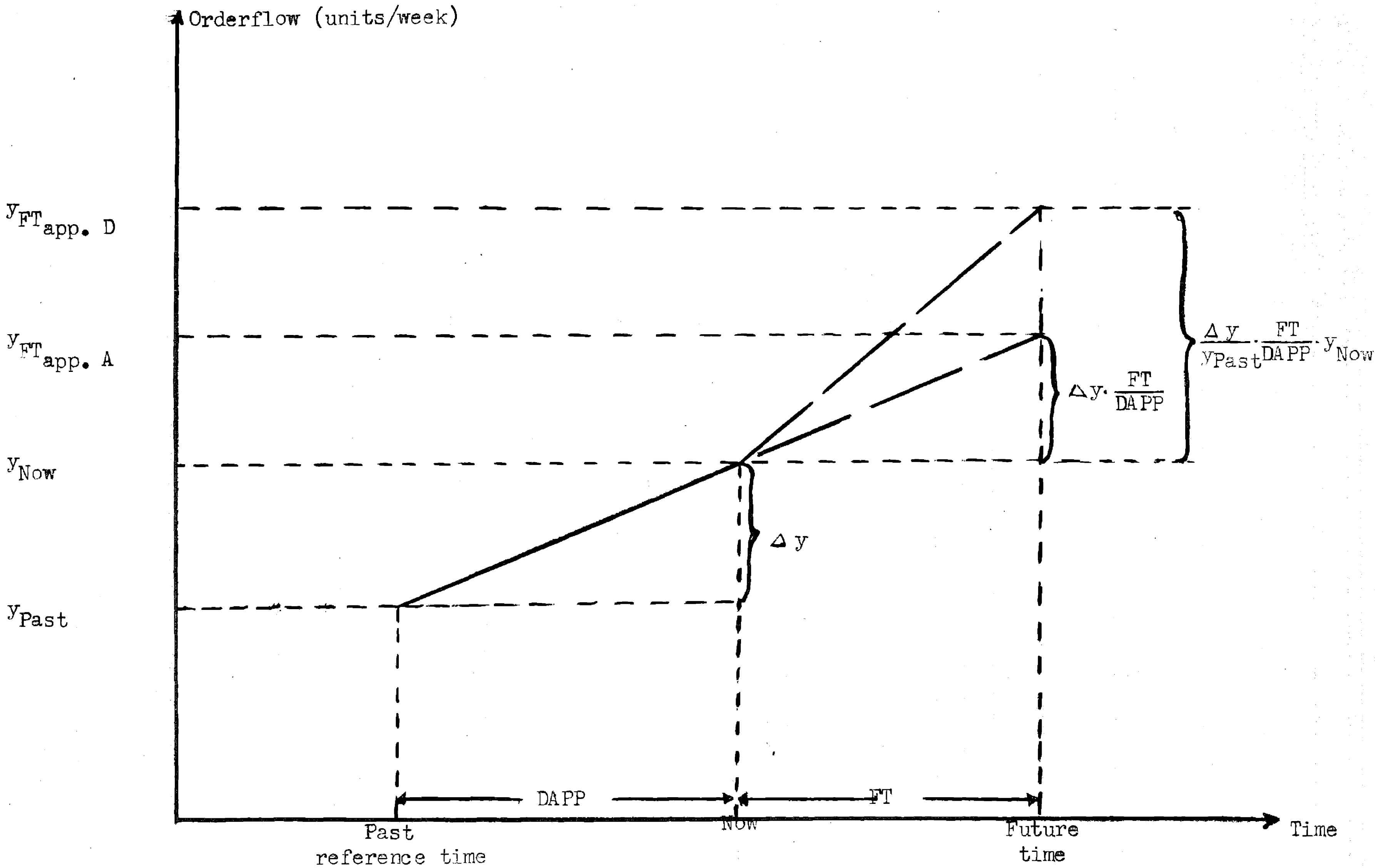


Figure D- 1, Exponential Forecast.

multiplied by the relationship between the forecast time and the delay back in time for the reference point for past orders.

EIOR.K=(PIOR.K)(FT/DAPP) D-3,A

EIOR--Expected Increase in Order Rate (dimensionless)
PIOR--Past Increase in Order Rate (dimensionless)
FT--Forecast Time (week)
DAPP--Delay Average Product order rate, Past (week)

The fractional past increase in the order rate is now equal to the difference between the average order rate now and the past average order rate divided by the past average order rate.

PIOR.K=(APOR.K-APOP.K)/APOP.K D-4,A

PIOR--Past Increase in Order Rate (dimensionless)
APOR--Average Product Order Rate (units/week)
(Appendix A, Eq. 29,L)
APOP--Average Product Order rate, Past (units/week)
(Appendix A, Eq. 47,L)

APPENDIX E

ALPHABETICAL LIST OF SYMBOLS

ADD--Average Delivery Delay (weeks)
AFMD--Allocated Funds to Market Development ($/week)
AMDE--Actual Market Development Efforts ($/week)
APD--Activated Potential Demand (units/week)
APOP--Average Product Order rate, Past (units/week)
APOR--Average Product Order Rate (units/week)
ASAL--Average SALes ($/week)
ASALP--Average SALes, Past ($/week)
AUSA--Average USAge (units)

CHOR--CHange in Order Rate (units/week)
CHSAL--CHange in SALes ($/week)

DADD--Delay Averaging Delivery Delay (weeks)
DAMDE--Delay for Actual Market Development Efforts (weeks)
DAPD--Delay Activating Potential Demand (weeks)
DAPOR--Delay Average Product Order Rate (weeks)
DAPP--Delay Average Product orders, Past (weeks)
DASA--Delay Average SAles (weeks)
DASP--Delay Average Sales, Past (weeks)
DD--Delivery Delay (weeks)
DDM--Delivery Delay Multiplier (dimensionless)
DDTAB--Delivery Delay TABle
DDVAR--Delivery Delay VARiable (weeks)
DMIN--Delay MINimum (weeks)
DMTAB--Delivery delay Multiplier TABle
DOMD--Delay Observing Market Development efforts (weeks)
DOUS--Delay Observing USage (weeks)
DPD--Delay Purchase Decision (weeks)
DPCO--Delay Production Capacity Obsolescence (weeks)
DRPC--Delay Receiving and installing Production Capacity (weeks)
DWOUT--Delay Wear OUT (weeks)

ECOEF--Expected Change in Orders, Exponential Forecast (units/week)
ECOR--Expected Change in Order Rate (units/week)
ECSA--Expected Change in SAles ($/week)
EIOR--Expected Increase in Order Rate (dimensionless)
ENC--Effective New Capacity (units/week)
EOMD--Effect of Market Development efforts (awareness units/$)
EOPC--Expected Obsolete Production Capacity (units/week)
EOUS--Effect Of USage (awareness units/week/unit)
EXPO--EXPected Order rate (units/week)
EXPS--EXPected Sales ($/week)

FSMD--Fraction of Sales to Market Development (dimensionless)
FT--Forecast Time (weeks)

GPUR--Generated PUrchases Rate (units/week)

INFL--INFLuence (awareness units/week)
INV--INVentory (units)
INVD--INVentory Desired (units)
ITABA--Influence TABle for Activating demand
ITABP--Influence TABle for Purchase decision

NPDR--Non-Purchase Decision Rate (units/week)

OMDE--Observed Market Development Efforts ($/week)

PC--Production Capacity (units/week)
PCAR--Production Capacity Addition Rate (units/week/week)
PCD--Production Capacity Desired (units/week)
PCI--Production Capacity Initially (units/week)
PCO--Production Capacity Orders (units/week/week)
PCOO--Production Capacity On Order (units/week)
PCOR--Production Capacity Obsolescence Rate (units/week/week)
PD--Potential Demand (units/week)
PER--PERiod (week)
PIOR--Past Increase in Order Rate (dimensionless)
POR--Product Order Rate (units/week)
PORN--Product Order Rate Normal (units/week)
PR--Production Rate (units/week)
PRD--Production Rate Desired (units/week)
PRICE--PRICE ($/week)
PUP--PUrchase Pool (units)

Q--Quality (quality units)
QTAB--Quality TABle

RDTAB--Research and Development TABle

SALE--SALE ($/week)
SINV--SINe Variations
SSM--Shipment Sent to Market (units/week)

TAIC--Time to Adjust Inventory for Capacity decision (weeks)
TAIP--Time to Adjust Inventory for Production decision (weeks)
TAPC--Time to Adjust Production Capacity (weeks)
TAUC--Time to Adjust Unfilled orders for Capacity decision (weeks)
TAUP--Time to Adjust Unfilled orders for Production decision (weeks)
TIME--TIME (weeks)

UOP--Unfilled Order Pool (units)
UOPD--Unfilled Order Pool Desired (units)
USAG--USAGe (units)

WDIN--Weeks Desired of INventory (weeks)
WDUO--Weeks Desired of Unfilled Orders (weeks)
WOUT--Wear OUT of product (units/week)

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