Market Growth as Influenced by Capital Investment

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The manager, by evolving the policies that guide decision making, designs a corporate system. Such systems have a feedback loop structure that determines the growth and stability of the enterprise. The complexity of these systems usually precludes intuitive determination of how a policy change will affect the total system. A simulation model of the feedback structure and policies allows one to try policy changes to see how the system reacts. But to build such a model, one should be guided by principles of system structure that help one to interrelate the diverse observations that arise from any real system.

In this paper, structure is organized in a hierarchy. A closed system should be defined, within which the difficulties are generated and solutions are to be sought. Within the boundary, feedback loops form the system substructure. Feedback loops contain only two types of variables — levels and rates — into which all aspects of the real system can be fitted. The rates are the system policies and in turn contain component concepts — goal, observed conditions, discrepancy, and action.

Growth and stagnation of a new product is taken as an example to show how the ideas of feedback structure can explain a common occurrence in market behavior. Very often early sales grow rapidly, only to level off even while the market demand continues to rise, as shown by competitors capturing an increasing share of the market. One cause is found in the capital investment policy of the firm, as shown in a model involving salesmen, market reaction to delivery delay, and capital equipment expansion.

Introduction to Systems To speak of systems implies a structure of interacting functions. Both the separate functions and the interrelationships as defined by the structure contribute to the system behavior. To describe a system, one must describe not only the separate functions but their method of interconnection. To identify the structure of a specific system, one should understand the fundamental nature of the structure common to all dynamic systems.

A dynamic system is one which changes with the progress of time. The parts interact to create a progression of system conditions. There is a basic structure common to all such systems, whether they be the systems encountered in engineering, in management, in economics, in nature, in psychology, or in any purposeful relationship of components.

The theory of system structure will here be described and exemplified in terms of four steps in a hierarchy:

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A Closed boundary
1 Feedback loops
a Levels
b Rates
(1) Goal
(2) Observed condition
(3) Discrepancy
(4) Desired action

If one has a theory of structure and confidence that the structure is universal in its applicability, such a theory greatly expedites the process of identifying and classifying the available information about an actual system. It is here asserted that such a theory of structure does exist, that it can be precisely stated, that it can be rigorously applied, and that it is of major practical value in organizing knowledge. The four hierarchies in the general theory of structure will now be discussed briefly and then illustrated by an example.[1]

Closed Boundary In defining a system, we start at the broadest perspective with the concept of the closed boundary. The boundary encloses the system of interest. It states that the modes of behavior under study are created by the interaction of the system components within the boundary. The boundary implies that no influences from outside of the boundary are necessary for generating the particular behavior being investigated. So saying, it follows that the behavior of interest must be identified before the boundary can be determined. From this it follows that one starts not with the construction of a model of a system but rather one starts by identifying a problem, a set of symptoms, and a behavior mode which is the subject of study. Without a purpose, there can be no answer to the question of what system components are important. Without a purpose, it is impossible to define the system boundary.

But given a purpose, one should then define the boundary which encloses the smallest permissible number of components. One asks not if a component is merely present in the system. Instead, one asks if the behavior of interest will disappear or be improperly represented if the component is omitted. If the component can be omitted without defeating the purpose of the system study, the component should be excluded and the boundary thereby made smaller. An essential basis for identifying and organizing a system structure is to have a sharply and properly defined purpose.

Feedback Loops as Building Blocks Inside the closed boundary one finds a structure of interacting feedback loops. The feedback loop is the structural setting within which all decisions are made. The feedback loop is a closed path. A decision is based on the observed state of the system. The decision produces action which alters the state of the system and the new state gives rise to new information as the input to further decisions. The feedback loop implies the circularity of cause and effect, where the system produces the decision which produces the action which produces change in the system. One has not properly identified the structure surrounding a decision point until the loops are closed between the consequences of the decision and the influence of those consequences on future decisions.

[1] For a more complete discussion of structure see [1].

Level and Rate Variables Within the feedback loop we find the next lower hierarchy of structure. To represent the activity within a feedback loop requires two and only two distinctly different kinds of variables — the levels and the rates. The levels represent the system condition at any point in time. In engineering, the level variables are often referred to as the system state variables. In economics, the system levels are often spoken of as stocks. The levels are the accumulations within the system. Mathematically they are integrations.

The rate variables represent the system activity. The rate equations are the policy statements in the system which define how the existing conditions of the system produce a decision stream controlling action.

The clear separation of system concepts into the two classes of variables — levels and rates — has interesting and useful consequences. The level variables are the integrations of those rates of flow which cause the particular level to change. It follows that a level variable depends only on the associated rates and never depends on any other level variable. Furthermore, in any system, be it mechanical, physical, or social, rates of flow are not instantaneously observable. No rate of flow can depend on the simultaneous value of any other rate. Rates depend only on the values of the level variables. If levels depend only on rates and rates depend only on levels, it follows that any path through the structure of a system will encounter alternating level and rate variables.

Policy Structure An important substructure exists within the equation that defines a rate variable. A rate equation defining a rate variable is a statement of system policy.[2] Such a policy statement describes how and why decisions are made. A policy statement incorporates four components — the goal of the decision point, the observed conditions as a basis for decision, the discrepancy between goal and observed conditions, and the desired action based on the discrepancy.

A decision is made for a purpose. The purpose implies a goal that the decision process is trying to achieve. The policy statement that determines a rate variable does so in an attempt to bring the system toward the goal. The goal is sometimes adequately represented as a constant objective; more often the goal is itself a result of the past history of the system that has established traditions to guide present action. Whether or not the goal is actually achieved depends on how the system as a whole responds to the particular decision point. Usually, the competition for resource allocation results in the system falling short of most of the goals. The goal at the particular decision point is compared with the observed system condition as a guide to action.

One must distinguish observed conditions from the actual conditions of a system. A system model must incorporate both actual and apparent system levels (the levels describe the condition or state of the system). Where an important difference can exist between what the system is and what it is thought to be (and these differences are especially prevalent in the marketing sector of a company), one represents both, and explicitly shows how the apparent states arise out of the true states. A decision can be based only on the observed conditions, that is, the available information. Very often, substantial deviations exist between the true conditions of a system and the observed conditions. The discrepancy can arise from delay in recognizing changes in the sys-

[2] For a more complete description of a policy statement see [2], Chapter 10.

tem, random error, bias in not wanting to believe what is visible, distortion, insensitivity, and misinterpretation of meaning.

The policy statement makes a comparison of the goal and apparent condition to detect a discrepancy. The discrepancy may be in the form of a difference, a ratio, or some other indicator of lack of agreement.

On the basis of the discrepancy, the policy describes the action to be taken.

A System Example in Marketing The preceding concepts of system structure will now be illustrated in terms of a set of relationships often encountered in the growth of a new product.

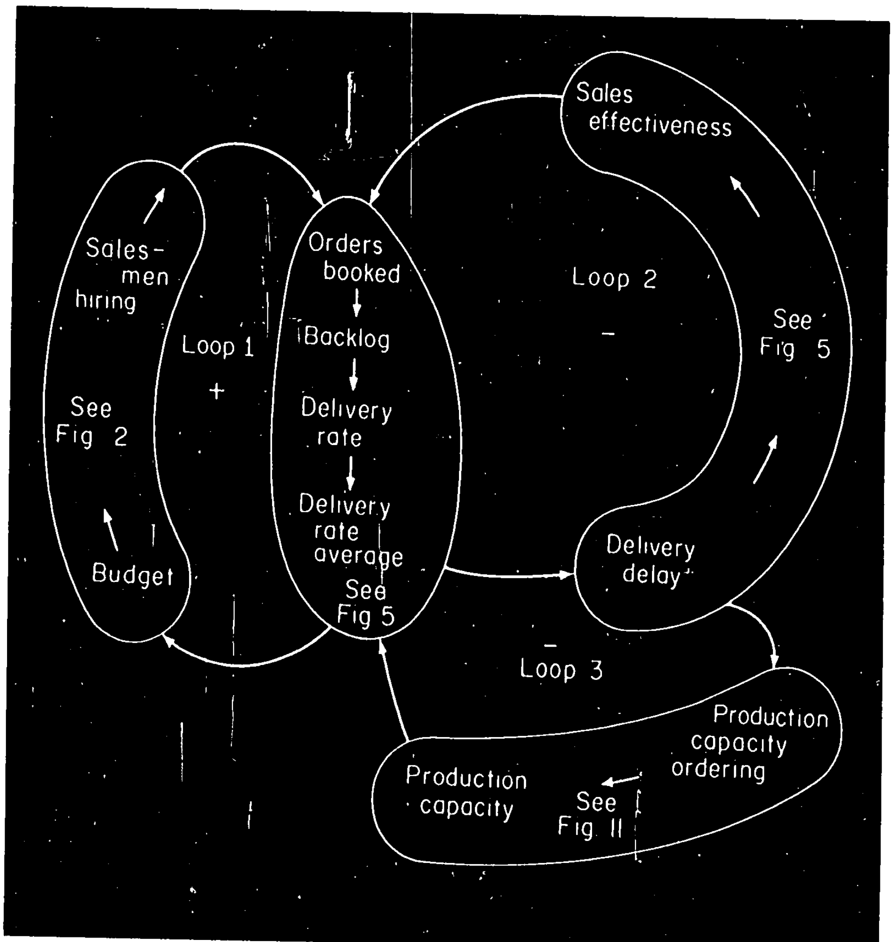
Marketing couples the resources of a company to the desires of the customers. As such it represents the interface across which flow goods, services, money, and information. But these flows across the boundary are a consequence of interactions within the company, within the market, and between the two. Market dynamics can be understood only in the context created by other company functions because these other functions produce the variables with which marketing must deal.

As stressed above, one can identify a system only in terms of an objective. Here the objective is to identify and to explain one of the systems which can cause stagnation of sales growth even in the presence of an unlimited market. In particular, we deal here with that system which causes sales stagnation, or even sales decline, to arise out of an overly cautious capital investment policy. In this system inadequate capacity limits the growth in product sales.

Figure 1 illustrates the scope of the system being considered. The closed boundary surrounds the relationships shown. No other influences from the outside are necessary for creating the sales growth and stagnation patterns which will presently be developed.

Within the closed boundary the system consists of interacting feedback loops as illustated in Figure 1. Three major loops are shown. Loop 1 is a positive feedback loop involving the marketing effort here described in terms of hiring of salesmen. It provides the driving power for sales growth. Only positive feedback loops can produce sustained growth. A positive loop is one in which activity changes the condition of the system in such a direction as to produce still greater activity. Assuming a favorable set of conditions around the loop, here is a situation in which salesmen book orders followed by product delivery which generates revenue which produces the sales budget which permits hiring still more salesmen. In short, salesmen produce revenue to pay for the further expansion of the sales effort.

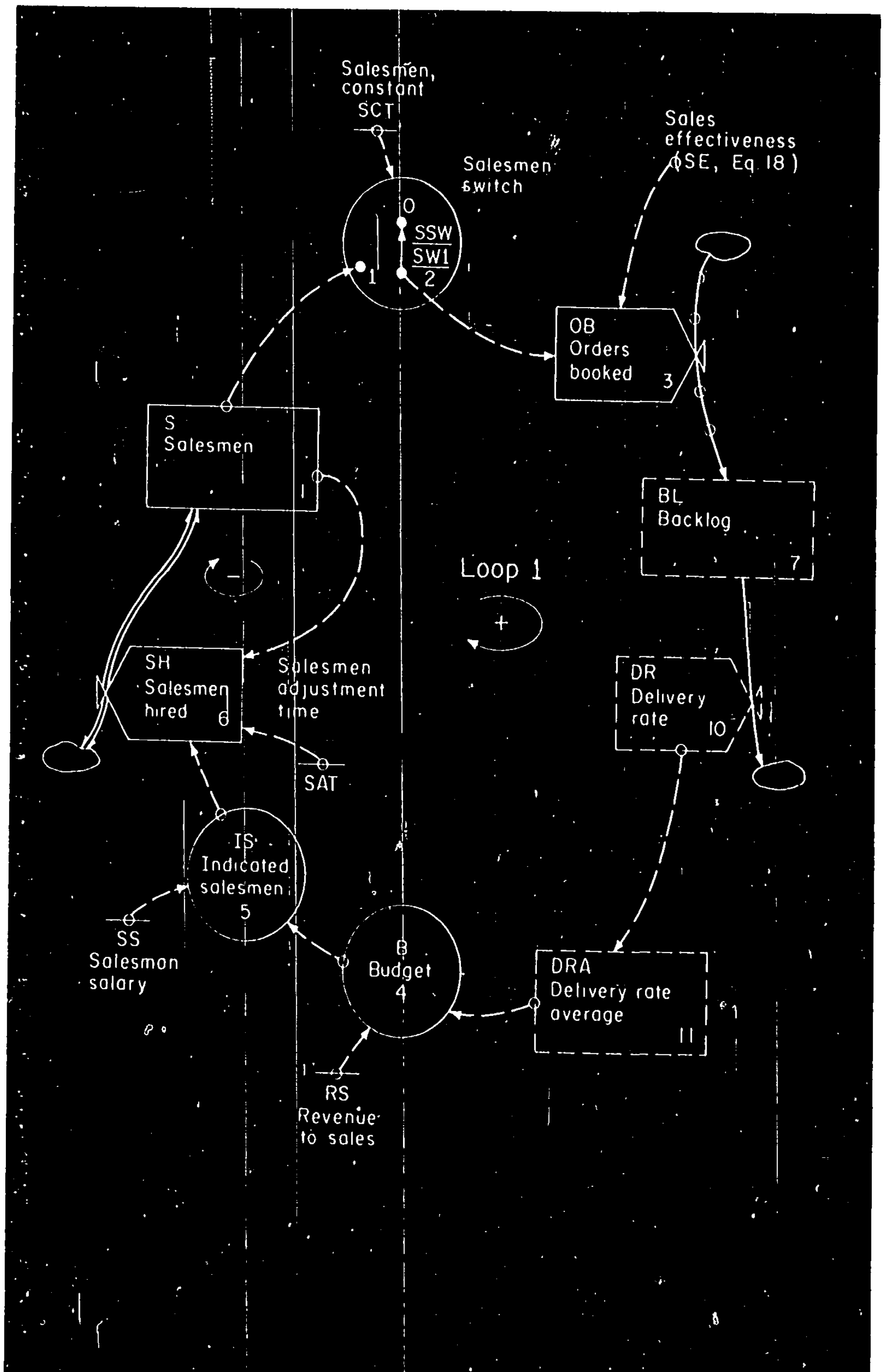
However, Loop 2, on the upper right, involves delivery delay and sales effectiveness and can make the product sufficiently unattractive that the sales loop is no longer able to generate revenue greater than its current expenditures. The delivery delay in Loop 2 can convert the salesmen-hiring in Loop 1 from positive-feedback growth behavior to negative-feedback goal-seeking behavior. Negative loops are goal seeking and adjust activity toward some target value. Here Loop 2 is a negative feedback loop and tends



1 Loop Structure for Sales Growth, Delivery Delay, and Capacity Expansion.

to adjust the incoming order rate to equal the production capacity. It is common to think of the order rate as determining the production capacity, but under many circumstances production capacity is instead determining the order rate. This phenomenon takes place within Loop 2. Orders booked increase the order backlog which increases the delivery delay which makes the product less attractive and reduces the order rate. Were the order rate to be sustained above the production capacity, the backlog and the delivery delay would continue to increase until the product could no longer be sold.

Production capacity is determined in Loop 3. Here a very simplified capital investment policy will be represented to keep the example within permissible size. The ordering of new production capacity is a function of delivery delay only. Rising order backlog, as indicated by delivery delay, is taken as an indication of inadequate capacity, and orders for more capacity are placed. These orders, after an acquisition delay, add to the production capacity. Loop 3 is a negative feedback loop which is attempting to



2 Salesmen-Hiring Loop with Sales Generating Revenue to Support Selling Effort.

change production capacity to adjust the order backlog to a value determined by a management goal for proper delivery delay. As the delivery delay rises, production capacity is raised to bring down the delivery delay.

These loops will be examined in turn to show their detailed structure and their behavior. The flow diagrams and system equations define a complete simulation model of the simplified company-market system so that the time sequences implied by the system description can be computed and plotted.[3]

Salesmen-Hiring Loop The detailed structure of the positive feedback loop governing the hiring and level of salesmen is shown in Figure 2.

In the flow diagrams, the level equations are shown as rectangles, as for salesmen in this figure. The rate variables are shown by the valve symbol, as for salesmen hired. The circles are "auxiliary" variables which are algebraically substitutable into the following rate equations and are structurally part of the rate equation.

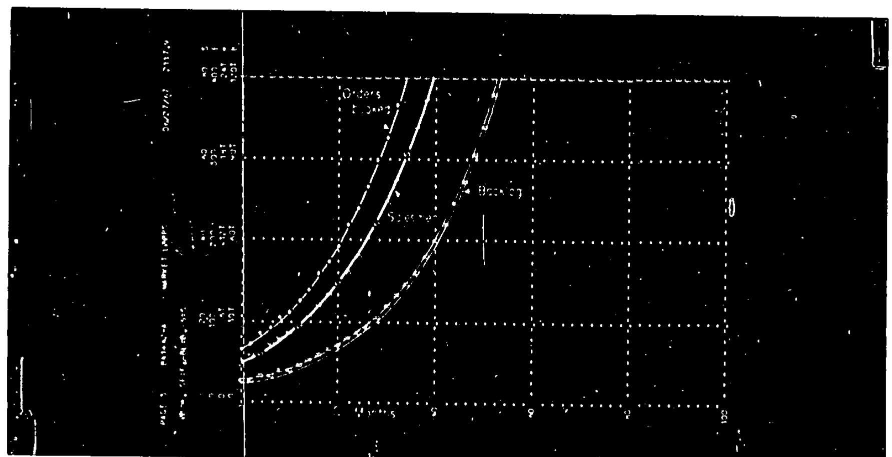
Considering that the auxiliary variables are part of the associated rate variables, we see in Figure 2 the alternating rate and level substructure within a feedback loop. The salesmen-hiring rate feeds the salesmen level. The salesmen level controls the orders booked rate. Orders booked as a rate flows into the backlog level. The backlog level is depleted by the delivery rate. The delivery rate is an input to the delivery rate average, which is a level. (All averages are generated by an accumulation process and by both mathematical form and structural location are necessarily system levels.) The delivery rate average, being a level, feeds into the salesmen-hired rate.

In Figure 2 the "Salesmen Switch" SSW at the top of the figure has been put in to agree with the specific equations in the Appendix. The switch allows activation or deactivation of the loop in simulation model runs. For the purpose of this discussion it should be considered in Position 1.

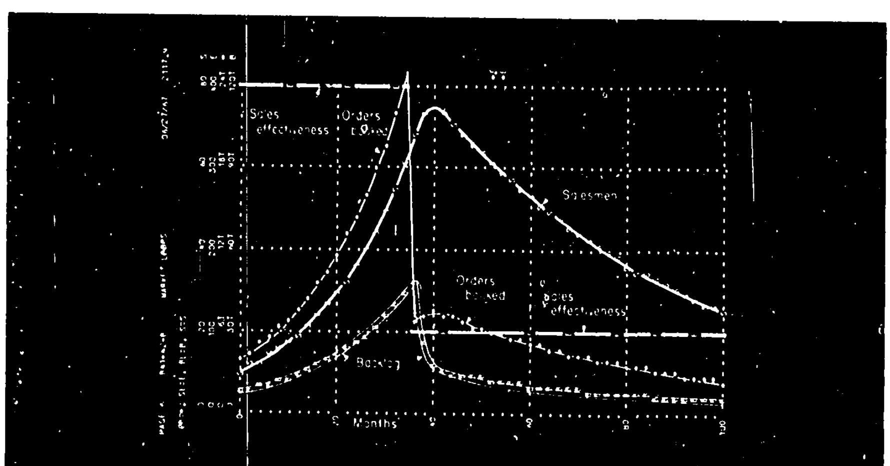
The positive feedback character of Loop 1 shown in Figure 2 gives this market system its growth tendencies. With a sufficiently attractive product and a sufficiently high fraction of revenue devoted to the sales budget, conditions are such that salesmen produce orders booked which increase backlog which increases delivery rate which increases the budget which increases the indicated salesmen that can be supported which causes a salesmen-hiring rate which increases the number of salesmen.

Such a positive feedback loop has an exponential growth character as shown in Figure 3. Here, Loop 1 alone causes ever increasing growth without limit in the loop variables. The growth rate depends on the delays around the loop and on the conversion coefficients that determine loop amplification. Delays around the loop occur in the order backlog, in the delivery rate averaging, which here represents the billing and collection delay, and in the salesmen adjustment time SAT, which here represents the delays in budgeting and the delay in finding and training salesmen. The value of 20 months for SAT is probably shorter than correct for most systems. If any of these delays are increased, the growth rate will be slower.

[3] The detailed equations and their descriptions are given in the Appendix. Equation structure is described in [2]. Equation details conform to the DYNAMO compiler as described in [3].

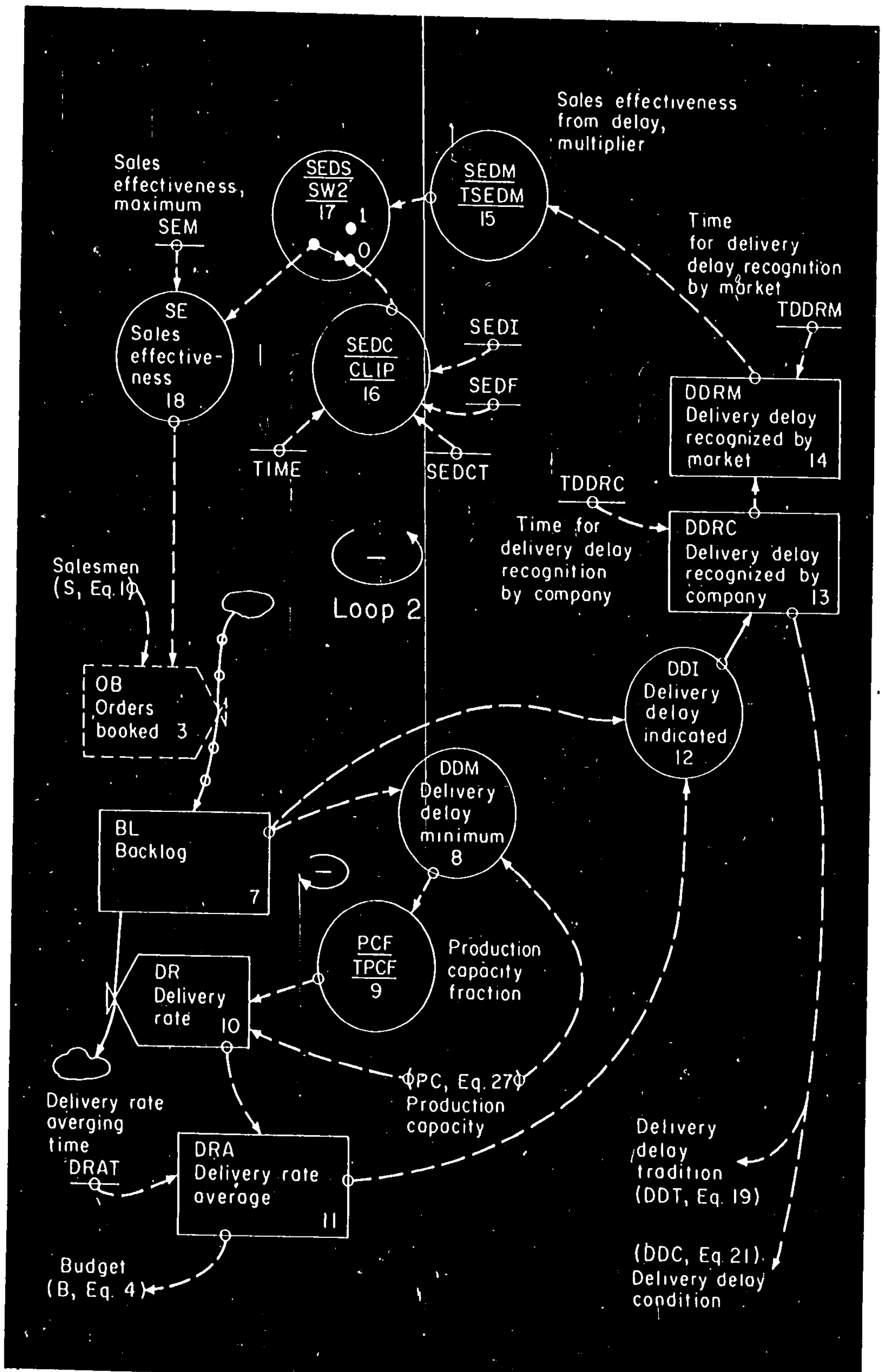


3 Unlimited Exponential Growth in Loop 1.



4 Initial Growth in Loop 1 Followed by Decline when Sales Effectiveness is Reduced.

The effect of changing the gain around the sales-hiring loop in Figure 2 can be shown by making a large change in the sales effectiveness. If sales effectiveness is reduced, it means that a given number of salesmen will book fewer orders and produce less revenue and thereby support a smaller sales budget. If the sales effectiveness were made small enough, a given number of salesmen would produce revenues too small to support themselves. Under these circumstances the indicated salesmen would be less than the existing number of salesmen and salesmen-hiring would become salesmen reduction. Under such circumstances, the positive feedback loop would have been converted to a negative feedback loop tending toward zero salesmen and zero activity. This change in sales effectiveness is shown in Figure 4. Here conditions are as in Figure 3 until week 36. At week 36 the sales effectiveness has been reduced from 400 units/man-month (400 units per month sold by each salesman) to 100 units/man-month. In other words, the imaginary condition has been created where the product is



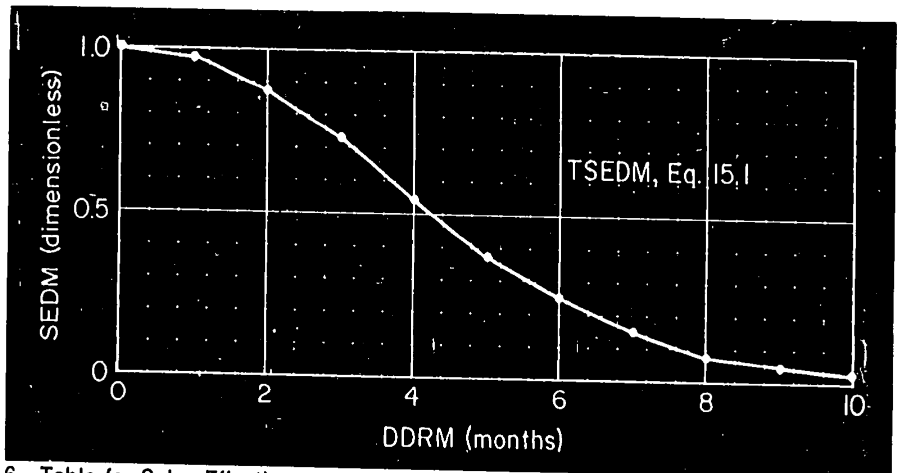
5 Market Loop with Delivery Delay Determining Product Attractiveness.

four times harder to sell. Orders booked drop immediately but rise again by a small amount because the number of salesmen is still increasing. After the time for the lower order rate to propagate through the order backlog and the delay in delivery rate averaging, the number of salesmen starts to decline, and, along with the declining salesmen there is a corresponding decline in orders booked and in backlog. Figure 4 is included to give a feeling for the behavior of the loop in Figure 2. The sudden change in product attractiveness and the four-fold decrease in sales effectiveness would of course not be expected in an actual system.

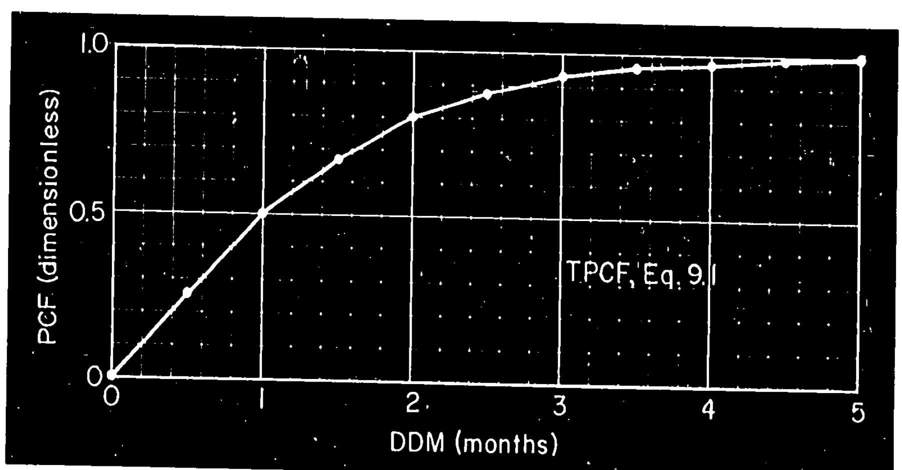
Market Loop In Figure 5, the major loop, Loop 2 from Figure 1, connects delivery delay of the market, generates sales effectiveness, and influences the rate of orders booked. A minor loop relates order backlog and production capacity to generate the delivery rate.

The delivery delay of a product is given approximately by the ratio of backlog to delivery rate. In other words, the time to fill an order is indicated by how long the present delivery rate will require to work its way through the present order backlog. The delivery delay indicated, DDI, is the ratio of the present backlog to the present short-term average of the delivery rate, DRA. But this present condition of delivery delay, as implied by present backlog and present delivery rate, ordinarily does not immediately reach the attention of decision makers within the system. The delivery delay recognized by the company, DDRC, is a delayed version of delivery delay indicated, DDI. The delivery delay recognized by the company is an input to the production capacity ordering decision and also forms the basis of delivery quotations to the market. The market takes time to respond to changing delivery delay quotations and so a further delay intervenes before the delivery delay is recognized by the market, at DDRM. On the basis of DDRM the attractiveness of the product to the customers is determined. Figure 6 shows the general kind of relationship which must necessarily exist between delivery delay and sales effectiveness. The figure shows the sales effectiveness from delay as a multiplier SEDM, which is a fraction given in terms of its maximum value. The maximum value of unity occurs at zero delivery delay. For very small increases in delivery delay the sales are unaffected. As delivery delay becomes long enough to be of concern to the customer, sales effectiveness drops rapidly and then levels out as the remaining customers are those who particularly want this specific product and are unwilling to change to competitive suppliers unless delivery delay becomes too long.

The switch at SEDS in Figure 5 permits opening of the market loop in the simulation runs. The sales effectiveness, SE, is given by multiplying the sales effectiveness from delay multiplier, SEDM, by the value of sales effectiveness maximum, SEM. SEM represents the sales effectiveness when delivery delay is zero, assuming some particular and constant set of conditions with respect to price, quality, competence of salesmen and other influences on the selling process. In Figures 5 and 6, one can see that, as the order backlog increases (assuming some constant production capability and therefore a limited delivery rate), the delivery delay indicated will increase. After a delay, the delivery delay recognized by the company, DDRC, increases and after a further delay the delivery delay recognized by the market, DDRM, increases. This causes the sales effectiveness multiplier, SEDM, to decrease as shown in Figure 6, which causes sales effectiveness, SE, to decline and thereby reduces orders booked, OB, until the order backlog, BL, no longer rises.



6 Table for Sales Effectiveness from Delay Multiplier as It Depends on DDRM.



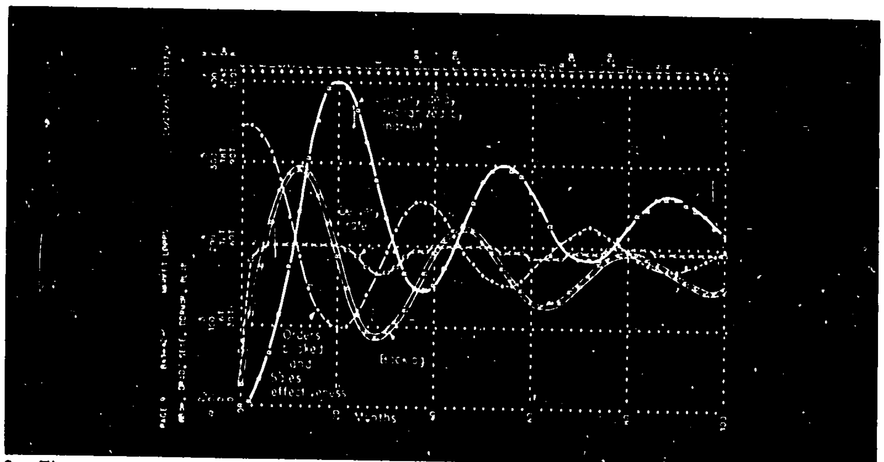
7 Table for Production Capacity Fraction as It Depends on Delivery Delay Minimum.

In Figure 5 the small lower negative loop determines delivery rates in terms of backlog and production capacity. These relationships have two objectives. First, for a given production capacity they should properly relate delivery delay to backlog. When the backlog is low, the delivery rate should be such that the delivery delay is the minimum order filling and manufacturing time, taken here as two months. As the backlog rises, the delivery rate increases but gradually levels off as it approaches the production capacity. As the second objective, the relationships should permit changing the level of production capacity while retaining a proper relationship between backlog and delivery rate. This is done by first generating the concept of delivery delay minimum, DDM, which is the ratio of backlog to the maximum production capacity. DDM then enters a table as given in Figure 7, which yields the fraction of the production capacity actually utilized. The rising slope of the curve in Figure 7 determines the minimum delivery delay caused by order handling and minimum manufacturing time. The curve is for a delivery delay of two months when capacity is lightly loaded. To see the effect, assume that backlog divided by maximum production capacity would yield an implied one-month delivery for DDM. The value of one month enters on the horizontal axis of Figure 7 and yields a production capacity fraction of 0.5. In other words, only half of the production capacity will be utilized. A delivery rate which is half the production capacity will work its way through the backlog in two months. Likewise, smaller backlogs yielding smaller values of delivery delay minimum will produce still smaller values of the production capacity fraction. Going in the other direction, as the backlog increases, the fraction of capacity utilization increases but not as rapidly as the increase in backlog. As shown in Figure 7 the delivery delay minimum must increase to five months before the theoretical maximum capacity is achieved. This extra time permits scheduling, ordering of materials, rearrangement of work load, and backlogging items in front of each machine so that it can be fully utilized.

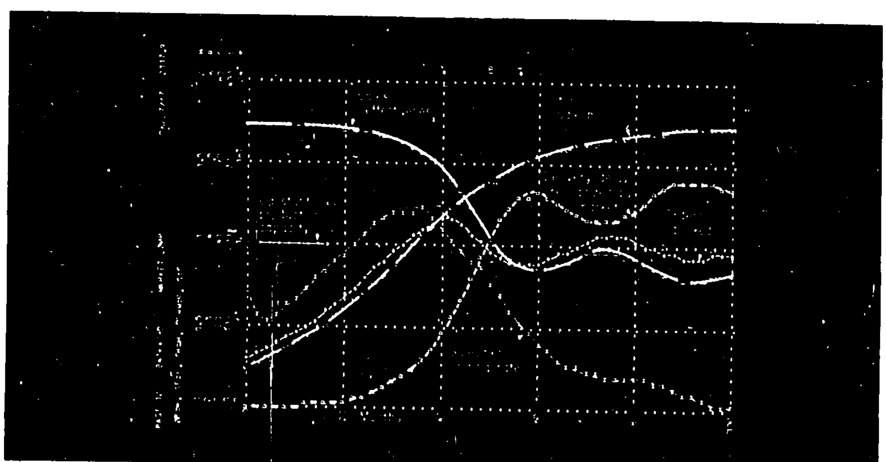
A negative feedback loop, as in Loop 2 of Figure 5, is goal seeking. Here the loop tends to adjust the rate of order booking to equal the delivery rate. If order booking is too high, the backlog rises and decreases the rate of order booking and vice versa. But such adjustment does not necessarily progress smoothly to the equilibrium conditions. Because of the three delays around the loop — in the order backlog, in the company recognition of delivery delay, and in the market recognition of delivery delay — the adjustments may occur too late and cause a fluctuating condition in the system. Such is shown in Figure 8, which illustrates the behavior of Loop 2 when the number of salesmen is constant and the production capacity is constant (although delivery rate still depends on order backlog in the region below maximum production capacity). Figure 8 starts with a backlog and a delivery rate below their equilibrium values for the number of salesmen and the production capacity which have been used. The rate of order booking is initially too high because of the low backlog and the low delivery delay. But the order rate in excess of delivery rate causes backlog to rise and causes the delivery delay recognized by the market to rise. Sales effectiveness and orders booked fall. The rate of order booking declines below the delivery rate, thereby causing a decline in the order backlog. Fluctuations of decreasing amplitude continue over the period of 100 months shown in the figure.

This fluctuating condition is often found in actual market situations. Many factors enter to create the behavior in addition to those identified in Figure 5. When delivery delays become long, not only are the customers unwilling to order, but, previously placed orders are likely to be delivered later than had been promised and salesmen spend time explaining late orders rather than obtaining new orders. Salesmen become demoralized and feel there is no point in trying to sell a product which is not available. These factors reinforce one another to cause a downturn in orders. But orders must fall below the delivery capability before there is a reduction in the order backlog. One then finds a reverse situation. Backlog is falling, inventories are rising, deliveries are improving, pressure is put on salesmen to sell the product, the product becomes more attractive, and the order rate rises.

Combined Salesmen and Market Loops If Loops 1 and 2 of Figure 1, as detailed in Figures 2 and 5, are combined, system performance is as shown in Figure 9. Here a constant production capacity is assumed. The system starts with an initial number of



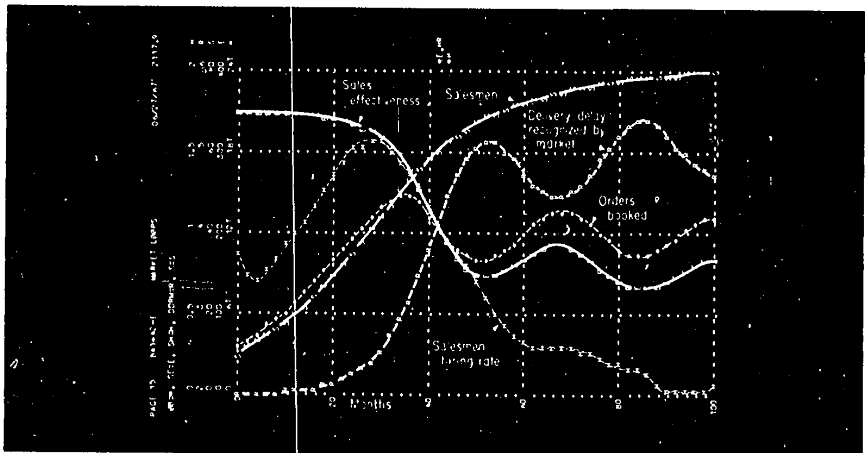
8 Fluctuation Caused by Delayed Responses within Loop 2.



9 Sales Growth and Stagnation Caused by Interaction of Loops 1 and 2.

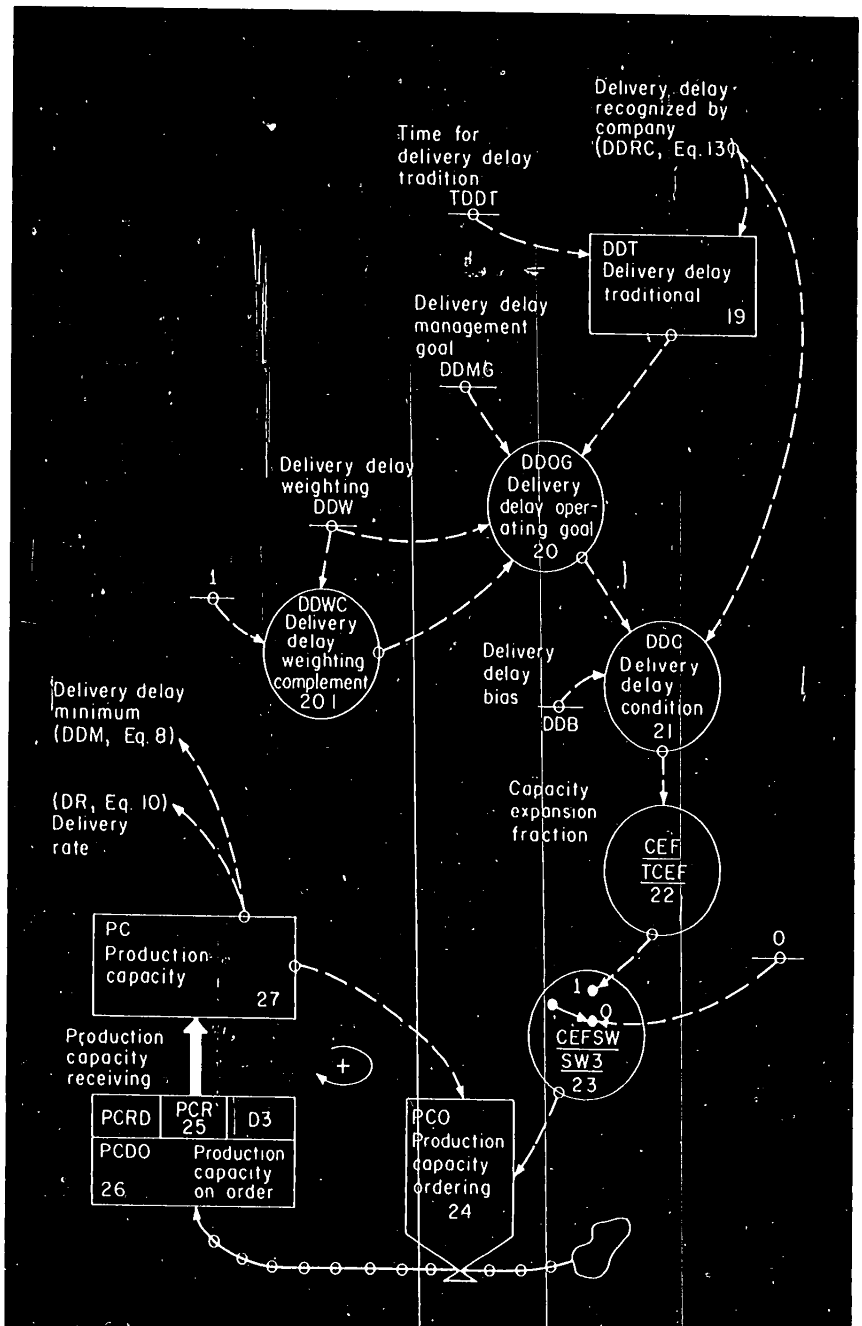
salesmen but the number can change. The capacity is greater than needed to produce what the salesmen can sell. In Figure 9 exponential growth occurs until about the 30th month. But at that time delivery delay recognized by the market begins to increase. Sales effectiveness begins to decrease, order rates begin to level off, and revenue no longer supports the rapid expansion of the sales force. The right hand section of Figure 9 shows generally the kind of behavior already seen in Figure 8. Sales overshoot and then return toward production capacity. The number of salesmen continue to increase for a time as the sales effectiveness continues to fall toward a value low enough that the salesmen generate only sufficient sales budget to maintain themselves.

The combined system consisting of Loops 1 and 2, as illustrated in Figure 9, can serve to show one of the broad classes of hazards in the changing of policies. Very often the symptoms of a difficulty superficially suggest a policy change which the system



10 Higher Budget to Sales Effort.

itself will defeat. Suppose that in the preceding system one were not aware of the importance of delivery delay in limiting sales. Such lack of awareness is found repeatedly on the industrial scene. As illustrated in a later figure, the lack of appreciation of the influence of delivery delay can arise simply from becoming accustomed to a particular level of order backlog. Or the lack of awareness can occur because the industrial system is so complex that few people see all of its manifestations at one time and are unaware of the implications on one section, such as the marketing effort, of conditions that exist elsewhere, as in production. Suppose, therefore, that the leveling off and stagnation of sales in Figure 9 were interpreted as a signal to increase the marketing effort. Such would be represented in this model by inceasing the fraction of revenue going to sales RS in Figure 2. The particular numbers used here are incidental but, for the sake of the example, RS in Figure 9 represented a $12 contribution from revenue to sales for each unit of product sold where the unit selling price is $50. Suppose that this revenue to sales is raised from $12 to $13.60. One then finds the behavior shown in Figure 10. Here again the constant production capacity is 12,000 units per month. However, production capacity is often not clear and evident when one product is immersed in a manufacturing organization involving a multitude of products. The effect in Figure 10 is to increase slightly the early rate of product growth. The peak in orders booked is somewhat higher and occurs at 36 months instead of 42 months. However, in the long run, the effect of the higher budget allocation to sales is to increase the total number of salesmen and to decrease the sales effectiveness in exactly the right proportions so that the average orders booked continue to equal the available production capacity. The higher sales effort increases the selling pressure on the market, increases the order backlog, increases the product delivery delay, decreases the sales effectiveness, and results in the same level of sales. Profitability is, however, reduced because of the greater expenditure to support sales and may also be reduced because of the higher order backlog, the greater likelihood of factory confusion caused by rearranging schedules to expedite priority orders and a less than optimum use of production equipment.

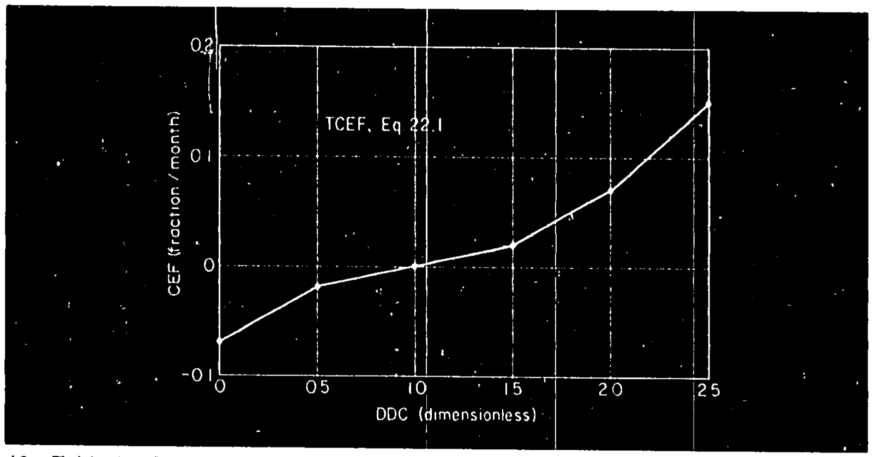


11 Capacity Expansion Loop.

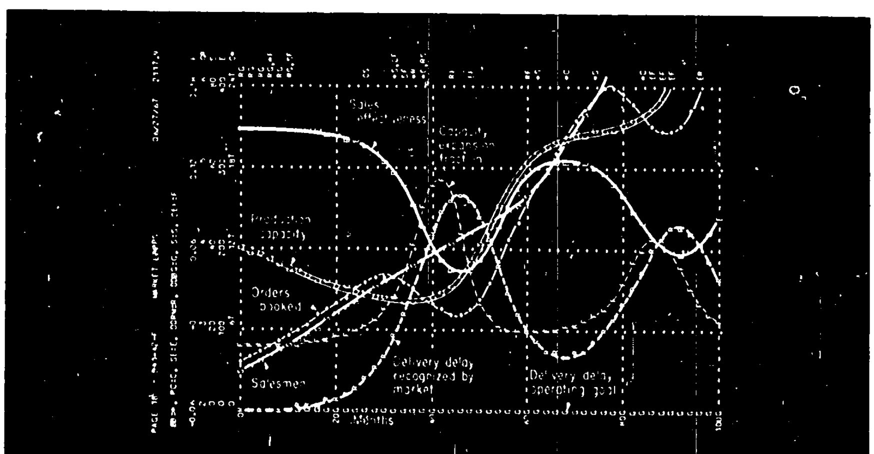
The differences between Figure 9 and Figure 10 illustrate a very common characteristic of multiple-loop, non-linear systems. A change in policy can have quite unexpected equilibrium effects as well as having unexpected dynamic effects. The change in policy may be aimed at a specific point in the system, here to increase the rate of order booking. The consequence, however, may be an indirect warping of the system to defeat the intended result. Here the number of salesmen does indeed go up but the sales effectiveness goes down correspondingly.

Capital Investment Clearly, the fixed production capacity of Figures 9 and 10 is not typical. One should then explore capital investment policies. For the sake of illustration, one of these has been incorporated into the present example to show how capital investment policy can couple to market variables.

Figure 11 shows a basic part of the decision making process for addition of production capacity. The addition of capacity is of course contingent on many factors such as projection of sales trends, financial condition, and product profitability. However, all of these tend to produce variations on a basic capacity addition rate which depends on the adequacy of the present capacity in terms of market demand. One of the most persuasive indicators of the adequacy of existing capacity is the size of the order backlog and the length of time the customer must wait for delivery. As the delivery delay rises above the company's goal, the pressure increases for expanding capacity. Figure 11 relates delivery delay to production capacity. In an earlier section of this paper it was suggested that a policy (rate equation) contains a statement of the decision making goal and a detection of the related system state. In Figure 11, the delivery delay operating goal, DDOG, is generated in Equations 19, 20, and 20.1. Here the goal can be a fixed goal determined by management and adhered to rigidly as a constant goal. Or, at the other extreme, the goal can be the goal of matching the traditional delivery delay. Or any intermediate weighting factor can be used to blend these two extremes of goals. Consider first a fixed delivery delay goal given by the constant DDMG which is here taken as two months and equals the minimum order processing and manufacturing time. The delivery delay condition, DDC, in Equation 21 is the ratio of the delivery delay recognized by the company, DDRC, to the delivery delay goal, DDOG. From this ratio is subtracted a delivery delay bias, DDB, which simply represents the competition for resources throughout the company and represents the deviation between goal and performance that is necessary to sustain any given level of resource allocation. A company under great pressure on resources would fall further behind its goals than a company not under pressure. The coefficient DDB would, in a more complete model, be a variable generated by such things as financial pressure within the organization and by the extent to which other operating goals were not being met. Once the ratio of performance to goal has been established and offset by the bias created by other pressures, the resulting delivery delay condition, DDC, is conceived to operate through a relationship similar to that in Figure 12. Here, as DDC rises above 1.0, capacity expansion occurs. When DDC falls, pressure on production capacity is reduced and resources are diverted to other areas. The vertical scale is given in terms of the fraction of existing capacity which is ordered each month. Again, the switch at CEFSW exists not in the real system but in the model to permit de-activating the capacity expansion loop. A minor positive feedback loop exists in the figure where capacity ordering adds to capacity, which adds to the capacity ordering rate because



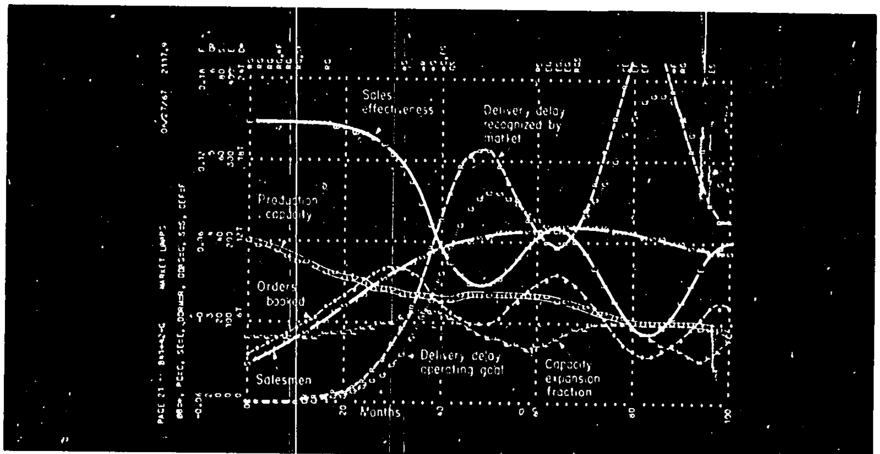
12 Table for Capacity Expansion Fraction as It Depends on Delivery Delay Condition.



13 Capital Expansion Loop 3 Responds to Delivery Delay and Restores Growth.

the variable coming in from CEF is in terms of the fraction per month of the existing capacity. The effect is to make capacity ordering a function of the operating scale that the system has currently achieved.

Consider first the case of a constant goal of management to hold a two-month delivery delay. The effect of delivery delay tradition is not active. The coefficient DDW in Equation 20.1 is zero. Figure 13 shows the consequence and should be compared with Figure 9. Production capacity starts at 12,000 units per month which is well above the initial rate of sales. As a consequence, production capacity is diverted to bring capacity more in line with the rate of order booking. For this reason the initial increase in sales is somewhat slower because sales reach capacity and delivery delay rises sooner than in Figure 9. The rate of order booking rises above the production capacity



14 Delivery Delay Goal Based on Past Performance.

at about the 24th week. At this time order backlog is rising rapidly, capacity is falling slowly, and the delivery delay is climbing steeply. As delivery delay rises above the two-month goal, the capacity expansion fraction moves from a small negative value to a large positive value. As a result of the capacity ordering, the production capacity rises steeply after the 40th week. It overtakes the orders booked, which have fallen because of the earlier poor deliveries; delivery delay as recognized by the market again falls; this signals a reduction in the rate of capacity expansion; and production capacity levels off around the 70th week. Because delivery delay is low and sales effectiveness is high, the order rate again climbs and exceeds production capability. Production capacity continues to climb but with a repeating fluctuation of capacity and order rate crossing one another. One sees here a classic form of growth instability. High delivery delay simultaneously causes the expansion of capacity and the suppression of orders. Very sharp crossovers of capacity and orders occur which at the 84th week are almost in a right angle relationship to one another.

But Figure 13 is based on management consistently adhering to its delivery delay goal of two months even under circumstances where actual delivery delays have fluctuated between 2.5 and 4.5 months. An organization which has experienced sales growth and periods in which capacity exceeded sales would be inclined to shift its goal structure. The shift would be to compare present performance with historical or traditional performance. The historical performance simply means the average perception of past performance. In Figure 11 this average is generated in Equation 19 for the delivery delay traditional, DDT. Suppose that this tradition is initially set at two months and the weighting factor, DDW, is set at 1, meaning that full weight is given to tradition and none to the delivery delay management goal, DDMG. Here a rather short averaging time of 12 months has been taken for the time to establish delivery delay tradition, TDDT. The goal structure of the organization is now floating. It simply strives to achieve its historical accomplishments. For the more subtle goals in an organization, this striving to equal the past, and conversely being satisfied if one equals the past, is a strong influence.

The result of changing the goal structure from a fixed goal to a goal set by tradition is shown in Figure 14, which should be compared with Figure 13. The delivery delay recognized by the market, DDRM, and the delivery delay operating goal, DDOG, of the company are shown. After delivery delay rises, the operating goal rises after a time delay. (The goal is responsive to DDRC, not plotted, which is six months earlier than DDRM, which is plotted as the symbol R.) This means that delivery delay does not produce the degree of concern that it did when the goal was fixed and low. As a consequence, expansion does not seem so justified or so important. In Figure 14 the goal structure continues to collapse. Delivery delay continues to rise, the traditional goal rises after it, the discrepancy is never great enough to produce active expansion of capacity, and there is a constant erosion of capacity. As capacity goes down, the rate of order booking declines to correspond, because in the long run, average orders can not exceed capacity. Sales effectiveness declines, the revenue to sales declines, and the revenue becomes insufficient to support the existing number of salesmen. After about the 70th week the number of salesmen begins to decrease and stagnation has turned into decay.

Implications for Marketing Marketing is not an activity limited to one corporate subdivision. Marketing interacts with research to guide product design. Marketing interacts with price policy to determine profitability. Marketing interacts with production to determine product availability and quality. Marketing interacts with personnel policy and training to determine skill in the marketing activities. Marketing interacts with the corporate information system in determining how market information guides resource allocation within the company. The relationship of marketing policy to the market, to the other corporate functions, and to competition is particularly intimate. There are many interacting feedback loops. These loops are capable of producing product growth or stagnation and decline. How the loops are balanced determines product profitability. Misplaced emphasis can raise costs, as illustrated by the increased marketing cost in Figure 10, whereas the solution to product growth lies in the capital investment policies.

Numerous feedback loops of importance exist in the market complex beyond those illustrated here. The preceding example assumes a market of unlimited extent. Although the market responds to delivery delay, for a fixed delay the rate of order booking is proportional to the number of salesmen. This assumption of an unlimited market is true for a much wider range of market situations than normally believed. But given a specific product, there is an upper limit to demand and the demand limiting process within the market represents additional important loops in the market system. As an example, one of the most important market loops concerns the kind of product where the product inventory in the hands of the customer generates customer satisfaction rather than the rate of product consumption. Customer satisfaction is obtained from the size of the customer inventory in capital items such as automobiles and household appliances. Here the sale of a new product fills an inventory and sales then decline to a replacement level. The recent steep rise and decline in the sale of pin-setting machines for bowling alleys illustrates a situation where customer inventory can dominate the dynamic behavior.

Market interactions are so complex that they cannot be intuitively appreciated. One must have a concept of feedback system structure for organizing his knowledge about the system. Such a structure has been suggested at the beginning of this paper. The structure can be used for arranging the parts of a system so that behavior can be simulated as shown in the preceding examples. Market research should be directed toward identifying the structures that can cause the many dynamic modes that exist in actual market situations. Emphasis should be reduced on numerical data gathering in market research and should be increased on conceptualizing the structures which produce typical classes of market behavior.

Appendix The following pages give the equations used for the system simulation in this paper. Knowledge of the system structure described in *Industrial Dynamics*[4] and the *DYNAMO User's Manual*[5] is assumed. To understand fully the equation format and structure the reader will need to be familiar with those books. These equations are included primarily for those who may want to experiment further with the model herein described.

Following is the full set of equations as they appear in the model. The basic system structure extends through Equation 27.2. Control cards follow and then the variations of coefficients used to produce the different computer runs in this paper for Figures 3, 4, 8, 9, 10, 13, and 14.

[4] See [2]. [5] See [3].

```
PAGE 1       FILE 41+B42  MARKET LOOPS                01/03/68   1724.9
 0.1              MARKET LOOPS
 0.2     RUN    STD
 0.3     NOTE   U. OF ILL.--CONVERSE AWARDS SYMPOSIUM, APRIL 13, 1967
 0.4     NOTE
 0.5     NOTE   POSITIVE LOOP--SALESMEN
 0.6     NOTE
 1       1L     S.K=S.J+(DT)(SH.JK+0)
 1.1     6N     S=10
 2       49A    SSW.K=SWITCH(SCT,S.K,SW1)
 2.1     C      SCT=60
 2.2     C      SW1=0
 3       12R    OB.KL=(SSW.K)(SE.K)
 4       12A    B.K=(DRA.K)(RS)
 4.1     C      RS=12
 5       20A    IS.K=B.K/SS
 5.1     C      SS=2000
 6       21R    SH.KL=(1/SAT)(IS.K-S.K)
 6.1     C      SAT=20
 6.4     NOTE
 6.5     NOTE   NEGATIVE LOOP--MARKET
 6.6     NOTE
 7       1L     BL.K=BL.J+(DT)(OB.JK-DR.JK)
 7.1     6N     BL=8000
 8       20A    DDM.K=BL.K/PC.K
 9       58A    PCF.K=TABHL(TPCF,DDM.K,0,5,.5)
 9.1     C      TPCF*=0/.25/.5/.67/.8/.87/.93/.95/.97/.98/1
10       12R    DR.KL=(PC.K)(PCF.K)
11       3L     DRA.K=DRA.J+(DT)(1/DRAT)(DR.JK-DRA.J)
11.1     6N     DRA=DR
11.2     C      DRAT=1
12       20A    DDI.K=BL.K/DRA.K
13       3L     DDRC.K=DDRC.J+(DT)(1/TDDRC)(DDI.J-DDRC.J)
13.1     6N     DDRC=DDI
13.2     C      TDDRC=4
14       3L     DDRM.K=DDRM.J+(DT)(1/TDDRM)(DDRC.J-DDRM.J)
14.1     6N     DDRM=DDRC
14.2     C      TDDRM=6
15       58A    SEDM.K=TABHL(TSEDM,DDRM.K,0,10,1)
15.1     C      TSEDM*=1/.97/.87/.73/.53/.38/.25/.15/.08/.03/.02
16       51A    SEDC.K=CLIP(SEDF,SEDI,TIME.K,SEDCT)
16.1     C      SEDF=1
16.2     C      SEDI=1
16.3     C      SEDCT=36
17       49A    SEDS.K=SWITCH(SEDC.K,SEDM.K,SW2)
17.1     C      SW2=0
18       12A    SE.K=(SEDS.K)(SEM)
18.1     C      SEM=400
18.4     NOTE
18.5     NOTE   CAPITAL INVESTMENT
18.6     NOTE
19       3L     DDT.K=DDT.J+(DT)(1/TDDT)(DDRC.J-DDT.J)
19.1     6N     DDT=DDRC
19.2     C      TDDT=12
20       15A    DDOG.K=(DDT.K)(DDW)+(DDMG)(DDWC)
20.1     7N     DDWC=1-DDW
20.2     C      DDW=0
20.3     C      DDMG=2
21       27A    DDC.K=(DDRC.K/DDOG.K)-DDB
```

```
PAGE 2       FILE 41+B42  MARKET LOOPS                    01/03/68    1724.9
21.1   C      DDB=.3
22     58A    CEF.K=TABHL(TCEF,DDC.K,0,2.5,.5)
22.1   C      TCEF*=-.07/-.02/0/.02/.07/.15
23     49A    CEFSW.K=SWITCH(0,CEF.K,SW3)
23.1   C      SW3=0
24     12R    PCO.KL=(PC.K)(CEFSW.K)
25     39R    PCR.KL=DELAY3(PCO.JK,PCRD)
25.1   C      PCRD=12
26     1L     PCOO.K=PCOO.J+(DT)(PCO.JK-PCR.JK)
26.1   12N    PCOO=(PCO)(PCRD)
27     1L     PC.K=PC.J+(DT)(PCR.JK+0)
27.1   6N     PC=PCI
27.2   C      PCI=12000
27.5   NOTE
27.6   NOTE   CONTROL CARDS
27.7   NOTE
27.8   PLOT   OB=*,PC=C(0,24000)/SE=E(0,400)/S=S(0,80)
27.9   NOTE   B42, RERUNS OF B41
28     NOTE
28.1   RUN    A
28.2   NOTE   UNLIMITED EXPONENTIAL GROWTH
28.3   SPEC   DT=.5/LENGTH=100/PRTPER=100/PLTPER=2
28.4   PRINT  1)S
29     C      SW1=1
29.1   C      PCI=100000
29.4   PLOT   OB=*(0,24000)/SE=E(0,400)/BL=B(0,120000)/S=S(0,80)
29.5   RUN    B
29.6   NOTE   GROWTH AND DECLINE
30     C      SW1=1
30.1   C      SEDF=.25
30.2   C      PCI=100000
30.5   RUN    C
30.6   NOTE   NEGATIVE LOOP OSCILLATION
31     C      SW2=1
31.3   PLOT   OB=*,DR=D(0,24000)/SE=E(0,400)/DDRM=R(2,6)/BL=B(0,120000)
31.4   RUN    D
31.5   NOTE   SALES STAGNATION
32     C      SW1=1
32.1   C      SW2=1
32.4   PLOT   OB=*(0,24000)/SE=E(0,400)/SH=H(0,2)/DDRM=R(2,6)/S=S(0,80)
32.5   RUN    E
32.6   NOTE   INCREASED SALES BUDGET ALLOCATION
33     C      SW1=1
33.1   C      SW2=1
33.2   C      RS=13.6
33.5   RUN    F
33.6   NOTE   CAPACITY EXPANSION
34     C      SW1=1
34.1   C      SW2=1
34.2   C      SW3=1
34.5   PLOT   OB=*,PC=C(0,24000)/SE=E(0,400)/DDRM=R,DDOG=G(2,6)/S=S(0,80)/CEF=F(
34.6   X1     -.06,.18)
34.7   RUN    G
34.8   NOTE   GOAL=TRADITION WITH DELIVERY DELAY BIAS PRESSURE
35     C      SW1=1
35.1   C      SW2=1
35.2   C      SW3=1
35.3   C      DDW=1
```

References

1 Forrester, Jay W. "Industrial Dynamics — After the First Decade," forthcoming *Management Science*, March, 1968.

2 Forrester, Jay W. *Industrial Dynamics*. Cambridge, Mass.: M.I.T. Press, 1961.

3 Pugh, Alexander L. III. *DYNAMO User's Manual*, Second Edition, Cambridge, Mass.: M.I.T. Press, 1963.

4 Slate, Daniel M. and Ferber, Robert (eds.). *Systems Analysis: Research and Implications for Marketing*. Urbana, Ill.: Bureau of Economic and Business Research, University of Illinois, forthcoming, 1968.