THE IMPACT OF RESOURCE ACQUISITION POLICIES
ON CORPORATE GROWTH

by

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Signature of Author

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Certified by

Faculty Advisor of the Thesis
May 24, 1963

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

Dear Professor Franklin:

In accordance with the requirements for graduation, I herewith submit a thesis entitled "The Impact of Resource Acquisition Policies on Corporate Growth."

Many people have contributed to the ideas developed in this thesis. I am especially indebted to Professor Jay W. Forrester, who has offered continued guidance and counsel. The basis for the study springs from his own stimulating work in the field of growth dynamics. The Digital Equipment Corporation of Maynard, Massachusetts, has provided financial support for the study. The personal interest of its management has also contributed to the study's progress.

I am also grateful to Professor Warren Bennis for his encouragement and interest in the research.

To Miss Joan Surprenant and Mrs. Jean Lewellen goes my sincere gratitude for the tangible contribution of typing the manuscript.

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

Sincerely yours,

David W. Packer
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Submitted to the Department of Industrial Management on May 24, 1963, in partial fulfillment of the requirements for the degree of Master of Science.

ABSTRACT

This study is concerned with the corporate growth process. It uses the approach and methodology of industrial dynamics to examine the impact of managerial policies on growth performance and to design corporate policies which would allow successful attainment of growth objectives.

The policies focused on control: (1) the production resources of the firm and (2) the professional (engineering and managerial) resources of the firm. The study has two objectives -- to increase understanding of interactions creating corporate growth and its problems and to design policies for improved control of growth behavior. The study treats the interactions between a firm and the market for its products. An industrial dynamics model depicting these interactions is used to show how organizational policies controlling production and professional resource acquisition influence growth performance. The model represents a firm which acquires production and professional resources in response to the perceived opportunity for growth, as reflected in its order backlog and inventory conditions.

Model experimentation clearly shows that a firm may grow successfully and rapidly during the period when it can build its professional staff at a high rate. During this period, the firm's resource acquisition policies control its growth rate; an aggressive firm grows rapidly, a conservative firm grows slowly. However, as the firm expands, rapid expansion of professional resources becomes increasingly difficult. A point is reached where growth can no longer take place at the traditional rate. If continued expansion at this rate is attempted, a collapse occurs as the firm's production capacity outruns the potential demand for its products. Long-term growth ceases and the firm goes through cyclical periods, alternating between growth and collapse.
By employing policies which base expansion activity on backlog and inventory conditions, a firm can avoid severe instabilities only by acquiring resources slowly. Thus stability is gained, but the firm may grow at a rate far below its potential.

An improved policy for controlling resource acquisition is designed. This policy attempts to control resource growth rate so as to maintain the potential demand for the firm's products above its production capacity. This allows continuing growth at a rate commensurate with the firm's potential, and avoids the stagnation and fluctuations characteristic of the original system. The policy utilizes information not normally available, but which could become accessible were the need for it evident.

Thesis Supervisor: Jay W. Forrester
Title: Professor of Industrial Management
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Chapter 1

Introduction

1.0 Corporate Growth

Corporate growth is an integral part of economic activity throughout the industrialized nations of the world. In the United States, over 80 percent of manufacturing concerns employ less than twenty-five people. For most of these, as well as larger concerns, growth is a primary objective. New advances in technology, such as the move from vacuum tube to solid state electronics, have often been led by small, growth-directed companies. The astronomic price-earnings ratios of "growth stocks" and the willingness of investors to supply venture capital indicate the importance of corporate growth to the economy.

Attempts for corporate growth, however, more often end in despair than in success. Over 50 percent of newly formed corporations fail within their first two-and-one-half years. Many more never achieve their objective of growth as they stagnate at a level of activity low relative to initial desires. Others grow, but in an erratic way that brings them near collapse several times.

Such failures are often attributed to "lack of market" or "bad luck". A Dun and Bradstreet report, however, looks more deeply into the causes of business failure. In 1958 about 60 percent of reported failures involved companies with liabilities of less than $25,000, and 80 percent involved companies with less than $100,000 of liabilities. For manufacturing enterprises, 53.2 percent of the
failures are attributed to managerial incompetence, and another 40 percent to lack of managerial experience, even though the failures were evidenced by such factors as inadequate sales, competitive weakness, inventory problems, and so on.\footnote{Dun and Bradstreet, Inc., The Failure Record through 1958, (New York: Dun and Bradstreet Economics Department, 1959), p. 12.} It is quite likely that a large fraction of the total business failures in the United States stem from a lack of managerial ability to cope with the corporate growth process.

1.1 A Study of the Growth Process

This thesis probes the nature of the corporate growth process. It examines the impact of managerial control of two broad corporate resources on embryonic enterprise growth. The resources considered are production capacity and professional effort. Production capacity denotes those resources, such as labor, used to create the physical output of the firm. Professional effort denotes the managerial and engineering staff of the organization.

The study has two objectives -- to improve understanding of the growth process and to design managerial policies for successful attainment of growth objectives. Although it considers but a few factors influencing growth performance, it aims at providing a valuable first step toward understanding the fundamental interactions creating corporate growth and its problems.
1.2 Approach and Methodology

The study utilizes the approach and methodology of industrial dynamics. Being concerned with the way an organization changes through time and managerial control of corporate performance, this study ideally suits the philosophy and methodology of industrial dynamics. The industrial dynamics approach

"treats the time-varying (dynamic) behavior of industrial organizations . . . Industrial Dynamics is the study of the information-feedback characteristics of industrial activity to show how organization structure, amplification (in policies), and time delays (in decisions and actions) interact to influence the success of an 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 . . . It is a quantitative and experimental approach for relating organizational structure and corporate policy to industrial growth and stability." ²

The structure of the thesis reflects the research approach. The first step was the development of a hypothesis for the way that corporate policies controlling a firm's production capacity and professional effort interact within a system containing the firm and its market to create common patterns of growth. Chapter 2 describes this hypothesis. Second, a mathematical model depicting the system involved in the hypothesis was built. Chapter 3 contains a complete description of the model. Third, model experimentation, utilizing computer simulation, permitted detailed examination of system interactions. This phase of study, covered by

Chapter 4, led to deeper understanding of system behavior and evaluation of the hypothesis. Chapter 5 culminates the study by describing improved policies for controlling growth performance. Chapter 6 briefly summarizes the key points of the thesis and gives suggestions for continued research in the area of corporate growth.

1.3 Major Conclusions

The major conclusion of the study is that resource acquisition policies can crucially influence growth behavior. During the period in which a firm can rapidly expand its professional capability (its managerial and technical competence), growth rate is determined by the rate at which resources are acquired. However, when a firm is unable to rapidly expand professional capability, attempts to increase production and professional resources at a high rate lead to behavior characterized by demand stagnation and wide fluctuations in organizational size and production.

A second conclusion is that great promise lies in the design of corporate policies for improving growth performance. One such improved policy is explored in the thesis. It makes use of information not normally available for decision making, but which could be acquired were the need evident. This policy promotes growth at a rate neither below the potential of the firm nor above that which leads to stagnation and fluctuating behavior.
Chapter 2

The Dynamics of Growth

2.0 Introduction

This chapter sets the stage for the thesis. It first describes the characteristics of production capacity and professional resources, then presents the dynamic hypothesis which serves as a basis for the following work. The hypothesis outlines how management actions regulating production capacity and professional effort can crucially affect the performance of an expanding enterprise.

The study focuses on the managerial policies controlling:

(1) Changes in the firm's production capacity.

(2) Changes in the firm's professional effort supply.

In the case of a firm producing labor intensive products, these policies regulate the hiring and firing of production workers and professional employees.

It is my thesis that variations in the above two policies can create many of the problems of growth rate and stability which plague expanding firms. A key assertion here is that many growth problems arise not from external conditions but from internal policies. The following comment, made during a congressional investigation of small business failures, recognizes this point of view.

"...it is interesting to note that where one business has failed, other businesses, in the same lines and otherwise comparable, have been successful at the same time and in the same area."1

1Statement of Robert E. Witschey before the Select Committee on Small Businesses, United States Senate, June 25-27, 1962.
2.1 Resource Characteristics

Let us examine the gross characteristics of production and professional resources. Production capacity is often readily absorbed into operations. It can be acquired and become operational in a short time interval. In the case of labor, a common capacity resource, the interval between the time a worker is hired and the time he can effectively produce usually ranges between several weeks and several months. The effect of production capacity resources on a firm's operation is straightforward. The capacity available primarily determines the rate at which physical production can be maintained.

Professional effort, derived from engineering and managerial employees, is less readily absorbed into an organization than production capacity. Because of the unprogrammed nature of professional activities, a new engineer or manager may not be fully effective until he has been with the organization several years. The following comment suggests the potential significance of the long professional absorption time to growth performance.

"Individuals with experience within a given group cannot be hired from outside the group, and it takes time for them to achieve the requisite experience. It follows, therefore, that if a firm deliberately or inadvertently expands its organization more rapidly than the individuals in the expanding organization can obtain experience with each other and with the firm that is necessary for the effective operation of the group, the efficiency of the firm will suffer ... in extreme cases this may lead to such disorganization that the firm will be unable to compete efficiently in the market..." ²

The amount of professional effort available to a firm influences performance in many ways. Its ability to market products, do research and development, and be sensitive to customer's needs are all affected by the availability of professional effort. The impact of professional activities often appears over a long time interval. A firm may operate for many years with inadequate staff before neglect of research and development or poor customer service significantly hampers sales volume.

Expansion itself places demands on the professional staff of the organization. During growth, professional effort must be expended recruiting and training new employees. Also the changing nature of the firm may induce inefficiencies in the work of professional employees. These factors are likely to be important in describing the impact of professional effort on growth performance.

2.2 Dynamic Growth Behavior -- A Hypothesis

The interactions between a growing firm and its market are many and complex. Here we isolate several interacting elements in an attempt to develop an understanding of the processes of corporate growth. Figure 2.1 shows the interactions considered.

Two factors generated by the firm affect the market. First, professional activity, ranging from direct marketing to new product development, creates customer interest in the firm's products. Second, product availability affects the market; as delivery delay rises, an increasing fraction of potential customers turn to alternative sources of supply. The order flow to the firm, then, depends
upon both the firm's professional activities and the availability of its products.

The firm adds production capacity and professional effort in response to conditions it appears to be facing. If demand exceeds capacity to produce (and if growth is desired), expansion is undertaken by acquiring additional production and professional resources.

The regenerative process creating growth becomes clear. Expansion of production capacity increases product availability. Expansion of professional effort results in activities which stimulate
increased market interest in the products. Both factors tend to increase the order flow to the firm, which, in turn, leads to further expansion of its resources. The result is continuing growth.

To see how the system outlined above can create growth problems, we turn to a detailed examination of the interactions involved, with special emphasis on factors governing the acquisition of resources by the firm and the absorption of these resources into operations.

Figure 2.2 is a detailed representation of the system under consideration. Four major feedback loops appear. By treating each loop separately, we can gain an understanding of some of the growth dynamics and see how different resource policies influence growth performance.

Loop 1, Figure 2.3, links inventory and backlog, delivery delay, and the order rate. If the order rate rises, order backlog rises and inventory falls, increasing the delivery delay. As delivery delay rises, some customers who would otherwise have placed orders are discouraged from ordering, depressing the order rate. This is a negative feedback loop, since an increase in the order rate sets into motion a chain of events which eventually cause a decrease in the order rate. The control exerted here by delivery delay serves to keep the order rate in line with production capacity. Should orders come in at a rate greater than production, a rising delivery delay acts to decrease the incoming order flow.
Figure 2.2. System Outline
Figure 2.3. **Loop 1**

Loop 2, Figure 2.4, links inventory and backlog, pressure for expansion within the firm, and production capacity. A high order backlog and low inventory increase the pressure for expansion, since such conditions indicate inadequate capacity to meet demand. Increased pressure for expansion stimulates capacity addition.

Figure 2.4. **Loop 2**

Greater production increases the ability to fill orders, which reduces order backlog and builds inventory. Loop 2 is also a negative feedback loop, since an increase in order backlog and a decrease in inventory set in motion a chain of events which tend to
decrease backlog and increase inventory.

Loop 3, Figure 2.5, contains the variables of both loops 1 and 2. It links inventory and backlog, pressure for expansion, production capacity, delivery delay, the effect of delivery delay on the market, and the order rate. An increase in the order rate causes order backlog to rise and inventory to fall. Pressure for expansion increases, precipitating acquisition of production capacity. Increased production makes products more readily available and reduces delivery delay. The improved delivery performance increases the order rate. Loop 3 is a positive feedback loop, since an increase in the order rate generates a sequence of events which tend to cause further increases in the order rate.

The combined effect of the above three loops produces sustained growth as long as the potential demand facing the firm exceeds the firm's production capability. In other words, if, given complete availability (low delivery delay) more orders would be placed by
the market than the company can produce for, the "excess" business is discouraged by a high delivery delay. The high delivery delay, in turn, stimulates the firm to expand production capacity. Thus, expansion continues unless, for some reason, potential demand fails to stay well above the firm's production capability.

Potential demand, as used here, denotes the order flow that would come to the firm were products immediately available. It is not exogenous to the system; rather it is created by a number of factors, such as the product suitability, product quality, customer satisfaction rendered, and marketing. All these factors, broadly speaking, result from activities of the firm's professional (managerial and engineering) personnel.

Loop 4, Figure 2.6, includes the professional capability of the firm. It links professional effort, professional capability, potential demand, order rate, backlog and inventory conditions, and the organizational pressure for expansion. An increase in professional capability leads, through diverse professional activities, to
greater potential demand for the firm's products which tends to increase the order rate, expansion pressure, and professional hiring. As new professional employees are absorbed into the firm, its professional capability rises. This is a positive feedback loop because an increase in professional capability sets in motion events which generate further increases in professional capability.

The underlying tendency for the entire system to grow can now be explained. Loops 1, 2, and 3 create sustained expansion pressure as long as potential demand exceeds production capability. Loop 4 creates a continued increase in potential demand through its positive feedback action. Thus, if professional capability can increase as rapidly as production capacity, potential demand remains above production capacity and growth is sustained.

Professional capability, however, may be a limiting factor on growth. Increasing the number of professional employees does not, in itself, increase total professional capability. New employees must be absorbed into the organization before they add to its capability for performing professional activities. This may require more time than is required for absorbing new production capacity. Adding to the problem of expanding professional capability are the recruiting, training, and inefficiency burdens placed on existing professional resources during rapid expansion. An attempt to expand the number of professional employees very rapidly may temporarily decrease professional capability.

Let us now see how expansion policies can affect growth performance. Take, for example, a firm which attempts growth at a rate
limited only by its ability to add production capacity. Steady growth continues as long as professional capability can be expanded as rapidly as production capacity. This might plausibly occur when the firm is small and hiring experienced professional employees whose abilities are known. As the size of the organization grows and the pool of known, experienced professional talent decreases, a point will be reached where the delay for absorbing new professional employees lengthens beyond that for adding production capacity. Although capacity expansion can be continued at the same rate as before, professional capability can no longer be so rapidly increased, and, because of inefficiencies and training, might actually decrease. The delays between the occurrence and recognition of inadequate professional capability are likely to be long -- they include the time for professional activities to affect potential demand (perhaps several years) and the time for perceived conditions to affect the expansion rate. Capacity growth continues, but potential demand stagnates. The result is that production capability outruns potential demand; a period of decline ensues until (if the firm is still in business) professional capability can be rebuilt and growth resumed.

The unstable growth behavior described above is often observed. A firm experiences impressive growth, then collapses. We hypothesize that such behavior can result from the internal resource acquisition policies followed, not by an uncontrollable "collapse of the market." The critical policies are those that regulate 1) capacity expansion, and 2) professional expansion.
The instability described above arose from overly-aggressive expansion policies. Alternatively, a firm could adopt very conservative expansion policies. While conservatism might avoid the problem of unstable performance, it could also lead to a growth rate far below that which could be successfully maintained.

The model described in the next chapter is used both to evaluate the hypothesis presented here and to aid in designing policies which control growth rate so that it is neither below the potential of the firm nor above that necessary for stability.
Chapter 3

Model Description

3.0 Introduction

This chapter describes an industrial dynamics model of the system under consideration. The model contains four sectors.

(1) The market sector represents both generation of potential demand for the firm's products by professional activities and the actual order flow to the firm, determined by potential demand and delivery delay.

(2) The production sector represents the firm's production capacity, acquisition and discharge of production capacity, the production process, and order filling.

(3) The professional sector represents the firm's professional effort, acquisition and discharge of professional effort, and the effects of growth on professional efficiency.

(4) The pressure for expansion sector describes how information about perceived operating conditions creates pressure to expand or contract the organization.

Figure 3.1 shows the four model sectors and the interconnections among them. A detailed description of each sector follows.

3.1 Market Sector

The market sector contains two parts, generation of potential demand and determination of the actual order rate to the firm.
Figure 3.1. Sector Interactions
Figure 3.2 includes a flow diagram of the sector.

Potential demand is the order rate which would persist were products immediately available. It represents potential market interest in the firm's products and derives from diverse factors such as marketing activity, applicability of products to customer needs, product engineering, and service. All these factors stem initially from managerial and engineering efforts in areas affecting the market.

This study combines the many effects of professional activities by considering potential demand to result from the firm's total expenditure of professional effort. The following equation gives potential demand as the professional effort influencing the market multiplied by the effectiveness of professional effort in generating potential demand. The potential demand generated by each unit of professional effort is arbitrarily set at 8 units/man-month.

\[ PD.K = (PREIM.K)(PDGPR) \]

\[ PDGPR=8 \]

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<tr>
<td>PREIM</td>
<td>Professional Effort Influencing the Market (men)</td>
</tr>
<tr>
<td>PD</td>
<td>Potential Demand (units/month)</td>
</tr>
<tr>
<td>PDGPR</td>
<td>Potential Demand Generated by Professional effort (units/man-month)</td>
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Because professional activities have long-term effects, professional effort influencing the market is an average of the firm's professional capability over the time interval required for results of professional activities to affect the market. The formulation here sets this time interval at 18 months. The interval depends on
Figure 3.2. Market and Production Sectors Flow Diagram
the nature of those professional activities which influence potential demand. For conventional products where direct sales effort is the prime market influence, the time interval could be much less than 18 months; for frontier technology products where less tangible factors, such as quality and assistance to customers critically influence the market, a time interval of five or more years might be justified. Initially, a small amount of professional effort is assumed to be affecting the market.

\[ \text{PREIM}.K = \text{PREIM}.J + (\text{DT})(1/\text{TPREM})(\text{PRC}.J - \text{PREIM}.J) \]

\[ \text{TPREM} = 18 \]

\[ \text{PREIM} = 2 \]

PREIM -- Professional Effort Influencing the Market
TPREM -- Time for Professional Effort to influence Market (months)
PRC -- Professional Capability (men)

The order rate to the firm depends on both potential demand and delivery delay. As delivery delay rises, it discourages an increasing fraction of potential customers from ordering. The following equation equates the order rate to potential demand times a multiplier. The multiplier gives the fraction of potential customers ordering under current delivery delay conditions.

\[ \text{OR}.KL = (\text{PD}.K)(\text{DDM}.K) \]

OR -- Order Rate (units/month)
PD -- Potential Demand (units/month)
DDM -- Delivery Delay Multiplier (dimensionless)

The delivery delay multiplier describes how observed delivery delay affects customer ordering. The graph below plots the multi-
plier versus the ratio of the firm's delivery delay to the normal
industry delay. If the firm's delivery delay is low, the multiplier
is near one and most potential orders are placed. When delivery de-
lay rises, the multiplier falls as potential customers either place
orders with competitors who offer quicker delivery or decline to
purchase altogether.

![Graph showing the relationship between DDM and DDRO]

The next equation generates the above relationship.

\[ \text{DDM} \cdot K = \text{TABHL(DDM, DDRO, K, 0, 3.5, 0.5)} \]
\[ \text{TDDM} = 1 / 6.45 / 35 / 30 / 27 / 25 \]

DDM -- Delivery Delay Multiplier (dimensionless)
TDDM -- Table for Delivery Delay Multiplier
DDRO -- Delivery Delay Ratio Observed (dimensionless)

The next equation calculates the ratio of the observed deliv-
er delay of the firm to the industry normal delivery delay, set at
three months.
DDRO.K=DDO.K/DDN
DDN=3

DDRO--Delivery Delay Ratio Observed (dimensionless)
DDO --Delivery Delay Observed (months)
DDN --Delivery Delay Normal (months)

The delivery delay observed is a smoothed version of current delivery delay. The smoothing time, taken as four months, is the time for broad market awareness of the company's delivery performance to build up. Initially, lacking other information, the market assumes the firm's delivery delay to be normal.

\[ \text{DDO.K} = \text{DDO.J} + \left( \text{DT} \right) \left( 1/\text{TDDO} \right) \left( \text{DDO.J} - \text{DDO.J} \right) \]
\[ \text{TDDO}=4 \]
\[ \text{DDO}=\text{DDN} \]

TDDO--Time for Delivery Delay Observation (months)
DD--Delivery Delay (months)
DDN--Delivery Delay Normal (months)

The market sector formulation is now complete.

3.2 Production Sector

This sector represents the production capacity of the firm, the policy controlling capacity changes, the production process, and order filling. To simplify terminology and add concreteness, we assume a labor intensive production process. In this case, the principle capacity resource is manpower and the firm's labor hiring and firing policy controls capacity changes. Figure 3.2 includes a flow diagram of the sector.

The firm's total labor force appears in two levels. The first contains recently hired workers still in a training process. The
second contains trained, productive workers. New employees work up to average productivity over a time interval equal to the average training delay. For simplicity the model says that men in training contribute nothing to actual production, while those in the trained pool work at average productivity. A distributed delay between hiring and becoming productive depicts the worker learning process.

The following equation gives the level of trained workers. The inflow is the rate of capacity acquisition (hiring); the outflow is the rate of capacity discharge (firing and voluntary departure). Initially, the firm employs 15 production workers.

\[ \text{PC.K} = \text{PC.J} + (\text{DT})(\text{PCBE.JK} - \text{PCDR.JK}) \]

\[ \text{PC} = \text{PCI} \]

\[ \text{PCI} = 15 \]

PC  --Production Capacity (men)
PCBE--Production Capacity Becoming Effective (men/month)
PCDR--Production Capacity Departure Rate (men/month)
PCI--Production Capacity Initial (men)

The rate at which capacity is becoming effective is a delayed version of the capacity acquisition rate. The delay time is the average interval for worker training. This delay depends on factors such as job complexity, labor supply availability, and supervisory effectiveness. Here, we assume the training time to be about three months.

\[ \text{PCBE.KL} = \text{DELAY3(PCR.JK, DAPC)} \]

\[ \text{DAPC} = 3 \]

PCBE--Production Capacity Becoming Effective (men/month)
PCAR -- Production Capacity Acquisition Rate (men/month)
DAPC -- Delay for Absorbing Production Capacity (months)

The next equation calculates the amount of capacity in the absorption process. It is a level with the rate of capacity acquisition flowing in and the rate of capacity becoming effective flowing out.

\[ \text{PCBA}.K = \text{PCBA}.J + (\text{DT})(\text{PCAR}.JK - \text{PCBE}.JK) \]

PCBA = (PCAR)(DAPC)

PCBA -- Production Capacity Being Absorbed (men)
PCAR -- Production Capacity Acquisition Rate (men/month)
PCBE -- Production Capacity Becoming Effective (men/month)

The next equation formulates the capacity acquisition rate as the total current level of capacity times the fraction per month by which capacity is being expanded. The fractional expansion rate used in this equation will later be related to pressure for expansion in the firm.

\[ \text{PCAR}.KL = (\text{TPC}.K)(\text{FIPC}.K) \]

PCAR -- Production Capacity Acquisition Rate (men/month)
TPC -- Total Production Capacity (men)
FIPC -- Fractional Increase of Production Capacity (1/months)

Total production capacity is the sum of fully productive capacity and capacity being absorbed.

\[ \text{TPC}.K = \text{PC}.K + \text{PCBA}.K \]

TPC -- Total Production Capacity (men)
PC -- Production Capacity (men)
PCBA -- Production Capacity Being Absorbed (men)
The graph below shows the relationship assumed between the fractional capacity increase rate and organizational pressure for expansion. Pressure for expansion is on an arbitrary scale ranging from -5 to +5. Positive pressure values denote pressure to expand operations, negative pressure values denote pressure to contract them.

As shown by the plot, new capacity is acquired even at low pressure values to replace capacity lost through turnover, obsolescence, etc. As pressure rises into positive regions, it stimulates increasingly rapid capacity acquisition up to the point where physical limitations preclude more rapid expansion.

The following equation generates the relationship between the fractional capacity increase rate and pressure for expansion.

\[
FIPC.K = TABHL(TFIPC, PE.K, -1, 5, 1)
\]

\[
TFIPC* = 0.07/0.02/0.058/0.09/0.107/0.11/0.115
\]

16A, C
FIPC—Fractional Increase of Production Capacity (1/months)
TFIPC—Table for Fractional Increase of Production Capacity
PE — Pressure for Expansion (pressure units)

The representation of capacity discharge takes the same form as the representation of capacity acquisition. The discharge rate is the total level of capacity times a fractional discharge rate.

\[ \text{PCDR}.k = (\text{TPC}.k)(\text{FDPC}.k) \]

PCDR—Production Capacity Discharge Rate (men/month)
TPC—Total Production Capacity (men)
FDPC—Fractional Discharge rate of Production Capacity (1/months)

The relationship between the fractional discharge rate and pressure for expansion, shown below, shows that as negative pressure for expansion increases, the capacity discharge rate also increases. Even for positive pressures, however, some capacity is always being released, reflecting voluntary worker leaving or normal wear and tear on machinery. The equation following the graph calculates the fractional discharge rate as plotted.
FDPC.K=TABHL(TFDPC,PE.K,-5,1,1) 18A
TFDPC*=.1/.09/.08/.06/.03/.007/.005 18A,C

FDPC--Fractional Discharge rate of Production Capacity (1/months)
TFDPC--Table for Fractional Discharge rate of Production Capacity
PE  --Pressure for Expansion (pressure units)

The firm's production starting rate depends on the amount of effective production capacity and the productivity of this capacity. Other factors which might affect production, such as raw materials and factory space, are assumed more readily available than capacity and will have little influence on dynamic behavior.

PS.KL=(PC.K)(PROD.K) 19R

PS  --Production Starts (units/month)
PC  --Production Capacity (men)
PROD--PRODUCTivity (units/man-month)

The productivity of capacity varies directly with expansion pressure. During times of stress capacity is utilized fully, overtime may be used, and productivity is high. As pressure decreases, assignment of workers to indirect labor, less efficient operations, and individual reactions to slack conditions all tend to decrease productivity. The graph and equation below describe the variation of productivity with pressure for expansion. Normal productivity is 1 unit/man-month. Under maximum pressure, productivity rises to 1.3 units/man-month and under minimum pressure, productivity falls to .65 units/man-month.
PROD.K = TABHL(TPROD, PE.K, -5, 5, 1)  \[20A\]

TPROD* = 0.65/0.68/0.75/0.85/0.9/1/1.1/1.2/1.25/1.28/1.3

PROD -- PRODuctivity (units/man-month)
TPROD -- Table for PRODuctivity (units/man-month)
PE -- Pressure for Expansion (pressure units)

A three-month third-order delay represents the entire production process.

PF.KL = DELAY3(PS.JK, DP)  \[21R\]

DP = 3  \[21R,C\]

PF -- Production Finishes (units/month)
PS -- Production Starts (units/month)
DP -- Delay for Production (months)

All finished products flow into an inventory from which orders are filled. The equation for inventory, a level with production finishes flowing in and shipments flowing out, appears below. Initially, inventory is at its normal level relative to demand.
\[ \text{INV}_{K} = \text{INV}_{J} + (\text{DT})(\text{PF}_{JK} - \text{SR}_{JK}) \]

\[ \text{INV} = \text{NINV} \]

- \text{INV} -- \text{INVentory (units)}
- \text{PF} -- \text{Production Finishes (units/month)}
- \text{SR} -- \text{Shipping Rate (units/month)}
- \text{NINV} -- \text{Normal INVentory (units)}

The next equation calculates the shipping rate as a delayed version of incoming orders. It gives the number of unfilled orders divided by the normal order filling delay, which, taken alone, would be the shipping rate if inventory permitted order filling in the normal time, multiplied by a term describing the effect of inventory level on shipping. The multiplier increases as inventory rises, since a large inventory usually means more items in stock match orders and can be shipped immediately. The normal order filling delay for the firm is set at the industry normal delivery time.

\[ \text{SR}_{KL} = \left( \frac{\text{UO}_{K}(\text{IAM}_{K})}{\text{DDN}} \right) \]

- \text{SR} -- \text{Shipping Rate (units/month)}
- \text{UO} -- \text{Unfilled Orders (units)}
- \text{IAM} -- \text{Inventory Availability Multiplier (dimensionless)}
- \text{DDN} -- \text{Delivery Delay Normal (months)}

The next equation calculates the number of unfilled orders. It is a level equation with orders placed flowing in and orders shipped flowing out. Initially, this pool contains a number of orders equal to the desired months of backlog times the average production rate. The desired backlog is three months of production.
UO = UO.J + (DT)(OR.JK-SR.JK)  \(25L\)
UO = (BLD)(AP)  \(26N\)
BLD = 3  \(26N,C\)

UO -- Unfilled Orders (units)
OR -- Order Rate (units/month)
SR -- Shipping Rate (units/month)
BLD -- BackLog Desired (months)
AP -- Average Production (units/month)

The graph below relates the inventory availability multiplier to the ratio of actual and normal inventory. For a normal level of inventory, the multiplier is one, allowing shipping with the normal delivery delay. Less inventory than normal leads to multiplier values less than one, so that the shipping rate decreases, reflecting an increased delivery delay. More inventory than normal increases the shipping rate up to the point where physical order handling restrictions preclude more rapid delivery. The equation below generates the relationship in the graph.
IAM.K=TABHL(TIAM,IR.K,0,4,1)  
27A

TIAM*=0/1/2/2.8/3.4  
27A,C

IAM --Inventory Availability Multiplier (dim.)
TIAM--Table for Inventory Availability Multiplier
IR  --Inventory Ratio (dim.)

The following equation calculates the inventory ratio used above as actual inventory divided by normal inventory.

IR.K=INV.K/NINV.K  
28A

IR  --Inventory Ratio (dim.)
INV  --INVentory (units)
NINV--Normal INVentory (units)

Normal inventory, the inventory level necessary to fill orders in a time interval equal to the industry normal delivery delay, is expressed as a constant number of months of average orders. Here, we take the normal inventory to be two months of incoming orders.

NINV.K=(MIN)(AOR.K)  
29A

MIN=2  
29A,C

NINV--Normal INVentory (units)
MIN  --Months INventory Normal (months)
AOR  --Average order Rate (units/month)

The next equation gives the average incoming order rate as the actual order rate smoothed over three months.

AOR.K=AOR.J+(DT)/(1/TAOR)(OR.JK-AOR.J)  
30L

TAOR=3  
30L,C

AOR=OR  
31N

AOR  --Average Order Rate (units/month)
TAOR--Time to Average Order Rate (months)
OR  --Order Rate (units/month)
The delivery delay experienced by orders is approximated by dividing the number of unfilled orders by the average shipping rate.

\[ DD.K = \frac{UO.K}{ASR.K} \]

\( DD \) --Delivery Delay (months)
\( UO \) --Unfilled Orders (units)
\( ASR \)--Average Shipping Rate (units/month)

The final production sector equation calculates the average shipping rate. The averaging time constant is set at three months.

\[ ASR.K = ASR.J + (DT)(1/TASR)(SR.JK-ASR.J) \]

\( TASR = 3 \)

\[ ASR = SR \]

\( ASR \)--Average Shipping Rate (units/month)
\( TASR \)--Time to Average Shipping Rate (months)
\( SR \)--Shipping Rate (units/month)

3.3 Professional Sector

This sector represents the firm's professional effort, the hiring and firing of professional employees, and the amount of effort actually expended in activities affecting potential demand for the firm's products.

Figure 3.3 is a flow diagram of the sector. First, we represent the total number of managerial and engineering employees employed by the firm. This entails describing the firm's professional hiring and firing policies. Second, we describe the way that factors such as training, recruiting, and inefficiencies reduce the amount of professional effort available for activities
Figure 3.3. Professional Sector Flow Diagram
which ultimately affect the market. Here, we use the term "professional capability" to denote the amount of professional effort actually working in areas creating potential demand.

Professional effort, like production capacity, appears in two levels, one containing those employees who have been with the firm long enough to be fully effective, the other containing newer employees who are in the process of being absorbed into the organization.

The equation below gives the number of fully effective professional employees. It is a level with the rate of professional effort becoming effective flowing in and the rate of professional departures flowing out. Initially, the firm's founders, here taken as six men, are in this level.

\[
\begin{align*}
\text{PEE.K} &= \text{PEE.J} + (\text{DT})(\text{PEBE.JK-PRDE.K}) \\
\text{PEE} &= \text{PEEI} \\
\text{PEEI} &= 6
\end{align*}
\]

\[
\begin{align*}
35L \\
36N, \\
36N,C
\end{align*}
\]

PEE --Professional Effort Effective (men)  
PEBE--Professional Effort Becoming Effective (men/month)  
PRDE--Professional Departures from Effective effort (men/month)  
PEEI--Professional Effort Effective Initial (men)

The next equation gives the rate of professional effort becoming effective as the level of effort in the absorption process divided by a variable delay time. This indicates that new employees remain in the absorption process for a time interval equal, on the average, to the delay time.
Unlike production capacity, which often can be brought to average effectiveness over a relatively constant time interval, the delay for absorbing professional effort can vary significantly. Here we consider one important source of variation, the size of the firm, and contend that in many instances the absorption interval increases as the firm grows.

One important aspect of the absorption interval is the time required for a new employee to become familiar with the environment and to grasp the firm's goals and standards to the extent that others "trust" his work, understand his strengths and weaknesses, and assign him to tasks for which he is best suited. In a small firm, the freedom of contact and structural fluidity often makes the evaluation process easier than in a large firm where standards are less accessible, personal contact more regimented, and structure more rigid.

The absorption interval also depends on the type of individual recruited. Many small firms initially hire people with whom they are familiar. This tends to shorten the absorption interval by expediting the evaluation process. Inevitably, however, the supply of known effort runs out, and further expansion requires hiring individuals who need more time to become fully effective.
In describing the absorption delay, we must also consider its magnitude. The following three comments suggest that it takes considerable time, perhaps a number of years, for assimilating a man to the point of being a fully effective member of a firm's professional team.

Referring to development of atomic bomb production in 1947, David Lilienthal states:

"Most important...these...capabilities of research, industrial techniques and operation had to be combined in the same team, with experience in working together. To go out and create such an organization was out of the question. There was not time."¹

Peter Drucker, speaking of the time span of concern to the manager, says:

"The human organization, such as a sales force or a management group, may take even longer (than ten years) to build or pay for itself."²

An OR team, deciding, upon parameters for an insurance company management game, states:

"Unless actual company data indicates some other period, it can be assumed that it will take one year for any new agent to reach average sales volume"³


The graph below shows how we relate the absorption delay to organizational size, as indicated by the current number of professional employees. The delay increases rapidly as the firm expands until the organization is so large that changes in size cease to lengthen the interval appreciably. The maximum absorption time assumed here is two years, although it could conceivably be much longer. The following equation generates the above relationship.

\[ \text{DAPE}_K = \text{TABHL}(\text{TDAPE}, \text{TPE}, 0, 90, 10) \]

\[ \text{TDAPE} = 3/4/5/6/9/12/17/20/22/24 \]

DAPE -- Delay in Absorbing Professional Effort (months)
TDAPE -- Table for Delay in Absorbing Professional Effort
TPE -- Total Professional Effort (men)

Total professional effort is the sum of effective effort and effort being absorbed.
TPE.K = PEE.K + PEBA.K

TPE -- Total Professional Effort (men)
PEE -- Professional Effort (men)
PEBA -- Professional Effort Being Absorbed (men)

The next equation computes the amount of effort being absorbed. It is a level equation with the hiring rate the inflow and the rates of professional effort becoming effective and professional departures from the absorption process the outflows. Initially, the firm employs only fully effective professional people.

PEBA.K = PEBA.J + (DT)(PRAR.JK-PEBE.JK-PRDA.JK)

PEBA = 0

PEBA -- Professional Effort Being Absorbed (men)
PRAR -- Professional Acquisition Rate (men/month)
PEBE -- Professional Effort Becoming Effective (men/month)
PRDA -- Professional Departures from Absorption process (men/month)

Below, we formulate the professional hiring rate as a fractional increase rate times total professional effort.

PRAR.KL = (FIPR.K)(TPE.K)

PRAR -- Professional Acquisition Rate (men/month)
FIPR -- Fractional Increase of Professional effort (1/months)
TPE -- Total Professional Effort (men)

The professional fractional increase rate depends on expansion pressure as shown in the following graph. We assume that the firm adds professional effort at the same rate as production capacity.

FIPR.K = TABHL(TFIPR, PE.K, -1, 5, 1)

TFI PR* = .007/.02/.058/.9/.105/.11/.115

FIPR -- Fractional Increase of Professional effort (1/months)
TFI PR -- Table for Fractional Increase of Professional effort
PE -- Pressure for Expansion (pressure units)
Next we formulate professional departures from the firm. Employees depart from both levels of professional effort. The departure of professional effort from each level appears as the fractional departure rate multiplied by the amount of professional effort in the level. The rate of departures from the pool of effective effort is:

\[ \text{PRDE}.K.L = (\text{FDPR}.K)(\text{PEE}.K) \]  

**PRDE**—Professional Departures from Effective effort (men/month)  
**FDPR**—Fractional Decrease of Professional effort (l/months)  
**PEE**—Professional Effort Effective (men)

The departure rate of effort being absorbed is:

\[ \text{PRDA}.K.L = (\text{FDPR}.K)(\text{PEBA}.K) \]  

**PRDA**—Professional Departures from Absorption process (men/month)  
**FDPR**—Fractional Decrease of Professional effort (l/months)  
**PEBA**—Professional Effort Being Absorbed (men)

The total fractional departure rate depends upon expansion pressure as shown below. For small positive and negative expan-
sion pressures, the fractional rate represents normal turnover. An expansion pressure goes distinctly negative, an increasing departure rate reflects discharge of professional employees and increased voluntary terminations stimulated by slack conditions.

\[ TFDPR \]

\[ PE \rightarrow \]

\[ \text{Pressure in units} \]

FDPR\( .K = \text{TABHL}(TFDPR, PE.K, -5, 1, 1) \]  
TFDPR* = .1/.09/.08/.06/.03/.007/.005  
FDPR -- Fractional Decrease of Professional Effort (1/months)  
TFDPR* -- Table for Decrease of Professional Effort  
PE -- Pressure for Expansion (pressure units)

The following equation computes the fraction of total professional effort in the absorption process and completes our representation of the firm's supply of professional effort.

FPRA\( .K = \text{PEBA}.K/TPE.K \]  
FPRA -- Fraction Professional effort being Absorbed (dimensionless)  
PEBA -- Professional Effort Being Absorbed (men)  
TPE -- Total Professional Effort (men)
The preceding equations represent only the firm's professional effort supply. Next we will determine the firm's professional capability by describing how several factors reduce the availability of professional effort for performing activities leading to the generation of potential demand.

First, we represent effects of expansion on the effort supply. In times of expansion, factors such as training of new employees and the inevitable inefficiencies of a changing environment serve to reduce the amount of professional effort available for the firm's basic work. The equation below determines how much effort for other work after training and inefficiencies have taken their toll. It equates available professional effort to the total effort supply times a multiplier expressing the impact of training and inefficiencies.

\[ \text{PREA}_K = (\text{PEE}_K)(\text{AIM}_K) \]

PREA -- Professional Effort Available (men)
PEE -- Professional Effort Effective (men)
AIM -- Absorption and Inefficiency Multiplier (dimensionless)

We use the fraction of total professional effort being absorbed as an indicator of the demands expansion places on professional efficiency. If the fraction is high, many new employees are draining professional effort for training, evaluation, and remolding the organizational structure. The graph plots the relationship between the fraction of effort being absorbed and the efficiency multiplier. It shows that if all effort is effective, the multiplier is one, denoting complete availability of professional effort.
for work other than internal expansion activities. As the fraction rises, an increasing portion of the effort supply goes to internal activities or is lost through inefficiencies.

\[
\text{AIM} = \text{TAIM, FPRA.K, 0, 8} \]

TAIM = 1 / .95 / .9 / .75 / .6 / .45 / .35 / 28 / 25

AIM -- Absorption and Inefficiency Multiplier (dim.)
TAIM -- Table for Absorption and Inefficiency Multiplier
FPRA -- Fraction Professional effort being Absorbed (dim.)

During growth available professional effort must also be used recruiting new professional talent. Thus the firm's over-all professional capability is the amount of available effort minus effort expanded recruiting.
The following equation determines the effort expended recruiting. The first two terms, taken alone, give the professional hiring rate; the third term is the firm's recruiting effectiveness, the man-months of professional effort necessary to recruit one new employee. Recruiting effectiveness is set at .5 man-months/man.

\[
PRER.K = (FIPR.K)(TPE.K)(RCE)
\]

\[
RCE = .5
\]

PRER -- Professional Effort Recruiting (men)
FIPR -- Fractional Increase of Professional effort (1/months)
TPE -- Total Professional Effort (men)
RCE -- Recruiting Effectiveness (man-months/man)

The professional sector formulation is now complete.

3.4 Pressure for Expansion Sector

This sector represents the generation of expansion pressure in response to perceived operating conditions.

The stimulus for expansion could have many sources. Here we choose to represent one common basis for expansion -- the promotion of growth activity whenever there is tangible evidence that additional sales could be made were production increased. Backlog and inventory levels provide such evidence, for when backlog accumulates and inventory declines it means that orders are out-running production. Conversely, falling backlog and increasing inventory signal slack conditions, warranting contraction of operations.
Figure 3.4. Pressure for Expansion Sector Flow Diagram
The following equations describe backlog and inventory observations and the generation of organizational pressure for expansion (or contraction) on the basis of these observations. Two components of expansion pressure are generated, one arising from backlog status, the other from inventory status. By summing the components we determine over-all pressure for expansion. Figure 3.4 is a flow diagram of the sector.

The first pressure sector equation gives the value of the backlog component of pressure for expansion warranted by the observed ratio of backlog to desired backlog. The graph below plots the relationship. We express expansion pressure in arbitrary units ranging between ±5; positive pressures induce expansion, negative pressures induce contraction and zero pressure is neutral. As the graph shows, pressure is negative when backlog is less than desired (the ratio is less than one), is slightly positive when backlog equals desired, and increases sharply as backlog becomes noticeably greater than desired. Saturation sets in when backlog is so large that generation of further pressure is impossible.
PEB.K=TABLE(TPEB,BLRO.K,0,4,5) 52A
TPEB*=-1/.5/.5/2.5/3.7/4.5/4.8/5/5 52A,C

PEB --Pressure for Expansion from Backlog (pressure units)
TPEB--Table for Pressure for Expansion from Backlog
BLRO--BackLog Ratio Observed (dimensionless)

The next equation gives the observed backlog ratio as a
smoothed version of the actual backlog ratio; the smoothing time,
here set at three months, represents the time for observation and
for conviction that changes in the ratio are meaningful, not random
fluctuations.

BLRO.K=BLRO.J+(DT)(1/TBLRO)(BLR.J-BLRO.J) 53L
TBLRO=3 53L,C
BLRO=BLR 54N

BLRO --BackLog Ratio Observed (dimensionless)
TBLRO--Time for BackLog Ratio Observation (months)
BLR --BackLog Ratio (dimensionless)

The computation of backlog ratio follows. It is simply the
actual backlog divided by backlog desired. Backlog desired is
taken as three months of production.

BLR.K=BL.K/BLD 55A

BLR --BackLog Ratio (dimensionless)
BL --BackLog (months)
BLD--BackLog Desired (months)

Backlog, as used here, denotes the months of production rep-
resented by unfilled orders. The next equation computes backlog
by dividing the number of unfilled orders by average production
rate.
BL.K = UO.K / AP.K

BL -- BackLog (months)
UO -- Unfilled Orders (units)
AP -- Average Production rate (units/month)

The average production rate appears below as the rate of production finishes smoothed over three months.

\[ AP.K = AP.J + (DT)(1/TAP)(PF.JK-AP.J) \]

TAP = 3

AP = PF

AP -- Average Production rate (units/month)
TAP -- Time to Average Production rate (months)
PF -- Production Finishes (units/month)

The description of the backlog component of pressure is now complete. Next we turn to the inventory component. The following equation and graph show how the pressure relates to the ratio of actual to normal inventory. If inventory exceeds normal, negative pressure is generated; for inventory less than normal, positive pressure is generated.
PEI.K=TABHL(TPEI, IRO.K, 0, 4, 5) 59A
TPEI*=-1.8/-0.8/-1.8/-2.8/-3.5/-3.8/-4 59A,C

PEI -- Pressure for Expansion from Inventory (pressure units)
TPEI -- Table for Pressure for Expansion from Inventory
IRO -- Inventory Ratio Observed (dimensionless)

The observed inventory ratio is the actual inventory ratio
smoothed over three months.

IRO.K=IRO.J+(DT)(1/TIRO)(IR.J-IRO.J) 60L
TIRO=3 60L,C
IRO=IR 61N

IRO -- Inventory Ratio Observed (dim.)
TIRO -- Time for Inventory Ratio Observation (months)
IR -- Inventory Ratio (dim.)

The next equation sums the two pressure components and com-
putes the total pressure for expansion currently warranted.

PECW.K=PEB.K+PEI.K 62A

PECW -- Pressure for Expansion Currently Warranted
(pressure units)
PEB -- Pressure for Expansion from Backlog (pres-
sure units)
PEI -- Pressure for Expansion from Inventory (pres-
sure units)

The equation below represents the pressure for expansion under-
lying the firm's current actions as a smoothed version of the pres-
sure currently warranted. The smoothing time, here set at three
months, indicates the time necessary to mobilize the organization
to effective action on the basis of a given level of pressure.
PE.K = PE.J + (DT) (1/TPES) (PECW - PE.J)  
TPES = 3  
PE = PECW

PE --- Pressure for Expansion (pressure units)  
TPES --- Time for Pressure to Effectively Stimulate action (months)  
PECW --- Pressure for Expansion Currently Warranted (pressure units)

The model formulation has now been completed. In the following chapter we turn to a detailed exploration of the system's behavior.
Chapter 4

Model Behavior

4.0 Introduction

This chapter explores model behavior. First, we examine the performance of the system with the parameters given in Chapter 3. Next, we consider how parameter changes affect system performance, to see what factors under managerial control crucially influence growth behavior. Finally, on the basis of model experimentation, we evaluate our hypothesis for the causes of growth instability and draw conclusions about several aspects of the corporate growth process.

4.1 Basic System Behavior

Figure 4.1 reproduces the plotted results of a simulation of the basic system. The firm grows steadily for about 80 months (6 and 2/3 years). At the end of this period, it employs 168 production workers and 60 professional employees. Then, quite suddenly, its record of successful expansion ends. Between months 30 and 92 employment and production drop over 40%. Months 96 to 114 exhibit strong recovery, with employment and capacity tripling. Thereafter, fluctuations in employment and capacity continue around slightly declining long-term trend.

The performance of the simulated system shows a plausible pattern -- a period of successful growth followed by a period of stagnation exhibiting alternating terms of expansion and contraction.
To gain understanding of the causal factors creating this kind of performance, let us look in detail at the system interactions.

Two distinct periods of the hypothetical firm's history are considered. Period 1, between months zero to 60, is characterized by continued expansion. Period 2, from month 60 on, is characterized by stagnation and wide fluctuations.

During period 1 the firm grows without setback. As seen in the plot, both potential demand and the incoming order rate increase, on the average, at about the same rate. At all times, potential demand is at least 30% above the order rate. The factors creating these variables appear clearly in the plot. Potential demand is the result of the firm's professional activities. The potential demand increase rate depends on how rapidly the firm can build its professional capability. In its first few years, the firm is small and draws professional talent from a pool of known, experienced effort. New men are easily absorbed into the organization and contribute effectively soon after being hired. Not only does professional effort increase steadily, and at the same rate as production capacity, but professional capability also increases at about the same rate. Rising professional capability leads to rising potential demand. Thus, throughout this period, potential demand stays well above production capacity.

Growth during period 1 persists, but it is not smooth. Rather, periods of expansion, as between months 30 and 45 are followed by periods of level operations, as between months 46 and 58. Pressure for expansion fluctuates with a period of 36 months. To see why these fluctuations occur, let us refer to the simplified flow diagram
below. It contains three of the four major feedback loops in the system, those concerned with production capacity, delivery delay, and the order rate. The loop omitted links the order rate and potential demand -- but since potential demand remains well above production capacity for the first 60 months of operation, this loop does not importantly affect fluctuations in growth rate.

![Diagram](image)

Figure 4.2. Factors Affecting Fluctuations
Referring to Figure 4.2, we can trace the interactions creating the fluctuations. At month 30 the firm has a high order backlog (not on figure), pressure for expansion is strongly positive, and capacity is being increased. By month 36 production exceeding the incoming order rate has reduced delivery delay to the industry normal, indicating that order backlog is near the level desired. Yet pressure for expansion remains positive until month 42, and further expansion is undertaken. As a result, delivery delay falls somewhat below the three-month normal value.

The delays in loops 1 and 2 of Figure 4.2 account for such behavior. Loop 2 contains the delay for observing the backlog and inventory conditions and the delay for pressure for expansion to stimulate action. The total delay between actual conditions and action is about 6 months. Thus, between months 36 and 43, pressure for expansion remains positive, stimulating capacity addition even though delivery delay is below its desired level. Because potential demand is above capacity, meaning there are many "excess" potential orders in the market, we might think the falling delivery delay would increase the order flow and counteract the effect of the firm's over-expansion. This indeed happens, but not instantaneously. The three-month delay in loop 1 for market awareness of delivery delay precludes an immediate response. The order rate does rise, but the delay in loop 1 reduces its effectiveness in damping fluctuations resulting from the company's delayed response.

Ultimately, however, the reduced delivery delay does increase the order flow, increasing the firm's order backlog, generating
pressure for expansion, and causing acquisition of both production
and professional resources. The result is continuing growth. The
interactions leading to long-term growth are in loop 3 of Figure
4.2, a positive feedback loop which indicates that an increased order
flow builds the order backlog, raising the pressure for expansion,
leading to increases in production capacity which serve to reduce
delivery delays and further increase the order flow.

In summary, during its first five years the firm grows without
major problems. Because potential demand remains well above capacity,
delivery delay acts to bring the incoming order rate in line with
production capacity over the long run. Short-term fluctuations in
growth rate occur because of both delays in the firm's response to
backlog and inventory conditions and the delayed market response to
the firm's delivery delay.

To see why this growth pattern suddenly ends in collapse, let
us examine the interactions occurring between months 60 and 80. In
this interval, employment increases 80%. Expansion has been success-
fully undertaken at about this rate, so the firm is following a pat-
tern justified by experience.

By month 69, capacity expansion has reduced delivery delay to
its desired level of three months. But pressure for expansion remains
positive until month 75, again because of the delays in observing and
responding to actual conditions. Capacity increases until month 78,
where it equals potential demand. By month 80, the firm is in severe
difficulty -- its order backlog (not on figure) is less than half of
what is considered normal and inventory (not on figure) is almost
twice normal.
Two factors produce this situation. First, the combination of aggressive expansion activity and the delays in responding to actual conditions cause the firm to continue expansion beyond the point necessary to bring backlog and inventory to their desired levels. This has, of course, happened before. Now, however, it produces severe difficulty because the consequent reduction of delivery delay is not effective in stimulating an increased order flow. Delivery delay is powerless to exert control because the gap between potential demand and production capacity has disappeared. There are few "excess" potential orders in the market by month 80.

The fundamental problem is, in fact, that potential demand failed to increase between months 60 and 80 at a rate commensurate with capacity increases. While the firm almost doubled production, potential demand rose but 25%.

What led to the stagnation of potential demand? The firm expanded its professional staff as rapidly as it added production capacity. Why, then, did not the increased professional staff create the increase in potential demand necessary to sustain growth?

Between months 60 and 80 professional capability rose only 36%, although professional effort rose by 80%. Two related factors explain the divergent growth of professional capability and professional effort. First, at month 64 the firm was at a size where the delay for absorbing new professional employees -- for making them effective members of the managerial and engineering staff -- began to lengthen appreciably. The delay lengthens both because it is now necessary to hire people who have had little previous experience with the
professional employees of the firm and because organizational size precludes rapid transmittal of the firm's objectives and standards to new employees. At month 60, this delay (not on figure) was seven months. By month 80, it had increased to 17 months.

Second, the increased training burden on the existing, fully-effective professional employees reduced their ability for doing work creating potential demand. This is shown by the decline of the absorption inefficiency multiplier (AIM, Equation 48A) from .92 at month 60 to .63 at month 74.

Both the increased delay for absorbing professional effort and the inefficiencies encountered in expanding professional employment combined to preclude building of professional capability at the same rate as production capacity was increased.

In response to the low backlog and high inventory, the firm cuts back operations between months 80 and 94. Potential demand continues to rise. Note that professional capability rises between months 80 and 84, even though total professional employment declines. Many of the employees released come from the absorption pool. Also, hiring has been curtailed. The result is a substantial decrease in the training burden. The absorption inefficiency multiplier rises 50%, from .6 to .9. Thus, relieved of the problems of expansion, the firm is again able to increase its professional capability. Increased professional capability builds market interest, and potential demand rises.

By month 96, rising potential demand and decreasing production capacity result in the same type of conditions as in month 60. De-
livery delay and expansion pressure are rising and the firm again attempts rapid expansion.

Between months 96 and 114, employment is more than tripled. But potential demand and professional capability fail to increase -- and actually decline between months 100 and 108 when professional effort is being most rapidly increased. The cause of this decline is apparent in the curve of the professional absorption inefficiency multiplier, which drops to about .4 at month 110. At this point, so many new people are in the organization and the chaos of rapid growth so great that effective professional employees must devote about 60% of their effort to training new employees and solving internal problems. Professional efforts affecting the market suffer, and potential demand declines.

At month 114, the firm again becomes aware of severe problems and again contracts operations. Cycles of rapid growth followed by collapse persist for the remainder of the run. Long-term growth is stifled -- during the growth phase of each cycle, professional capability fails to increase because of absorption problems and inefficiencies; during the cutback phase, reductions in professional effort preclude development of additional professional capability. As a result, potential demand stays at a relatively constant level, making growth impossible. The hypothetical firm of the model stays in business; it is unlikely that a real organization could survive beyond the first or second collapse.

This run clearly shows how growth instabilities occur when a firm attempts expansion at a rate above that at which professional capability can be successfully increased.
4.2 **Conservative Expansion Policies**

The problem in the preceding run resulted from the aggressive expansion activity which precipitated physical growth beyond the firm's ability to correspondingly expand its managerial and engineering resources. Next, we examine the system's behavior when the firm employs more conservative expansion policies.

The model depicting the conservative response is identical to the basic model except that the fractional increase rate of both production capacity and professional effort for any given level of expansion pressure is reduced.

This change requires revising the table functions which relate the fractional increase of production capacity (FIPC, Equation 16A) and the fractional increase of professional effort (FIPR, Equation 43A) to the pressure for expansion (PE, Equation 63L).\(^1\) Figure 4.3 compares the fractional increase rates used in this and in the basic run.

---

\(^1\)In the basic system: \[
\begin{align*}
[FIPC*] &= \begin{bmatrix}
0.007/0.02 & 0.058/0.09 & 0.107/0.11 & 0.115
\end{bmatrix} \\
&16A,C & 43A,C
\end{align*}
\]  

The parameters here: \[
\begin{align*}
[FIPC*] &= \begin{bmatrix}
0.007/0.015/0.02 & 0.025/0.03 & 0.033/0.035
\end{bmatrix}
\end{align*}
\]  

TFIPC--Table for Fractional Increase of Production Capacity  
TFIPR--Table for Fractional Increase of Professional effort
Figure 4.3. Fractional Increase Rates

Figure 4.4 shows the plotted output of a run with the above parameter change. Growth behavior is strikingly different than in the basic run. The firm expands steadily, experiencing no major setbacks.

The flat delivery delay between months 60 and 100 gives an indication of the reasons behind the different system responses of Figure 4.1 and 4.4. The oscillations of delivery delay characteristic of the basic run are eliminated. Examination reveals that this occurs because the firm takes much less aggressive action for any given level of expansion pressure. Although the delays in loops
Figure 4.4. Behavior of System with Conservative Expansion Policies
1 and 2 of Figure 4.2 are the same, now the firm, by responding slowly, does not make major changes during the delay interval. As a result, it observes the effects of actions on operating conditions, and can control the system to operate smoothly.

An example of the improved control occurs between months 112 and 180. During this period the professional absorption delay increases from 7 to 24 months. An increasing fraction of professional effort is in the absorption process. The training burden and inefficiencies cause the professional absorption inefficiency multiplier to drop from 90% to 70%. As a result, less professional effort per unit of production capacity is available to work in areas generating potential demand. Potential demand, which was 85% above the order rate at month 112, is only 61% above it at month 180. The number of potential orders above production capacity declines, so delivery delay falls. The lower delivery delay derives from a reduced order backlog which, in turn, creates reduced pressure for expansion and a slower growth rate. Expansion is here "automatically" curtailed as the growth rate of potential demand decreases. In the basic run, the firm's aggressive expansion activity precluded recognition of market symptoms of the decline in potential demand until capacity was overextended to a point where a major readjustment was necessary.

The less aggressive expansion activity causes a higher average delivery delay than in the basic run. The lower increase rate of professional effort reduces the training burden and inefficiencies of growth for effective professional employees. Also, a smaller
fraction of total effort is in the absorption process for any given value of the training delay. As a result, the ratio of professional capability to production capacity is increased, more potential demand per unit of capacity persists, and a higher delivery delay exists to discourage the excess of potential demand over capacity.

While this run avoids the instabilities and stagnation of the basic run, the performance shown in inferior to that of the basic system in one major respect. At the end of five years, the firm of the basic system had successfully grown to employ 76 workers and 27 professional employees. After the same interval, the more conservative firm is only 51% as large. While conservative policies avoid instabilities resulting from difficulties in absorbing professional effort, they stifle growth rate during the period when professional capability can be expanded rapidly.

4.3 Slower Response to Pressure

This run differs from the basic run only in the rapidity of the firm's response to the pressures for expansion resulting from backlog and inventory conditions. In the basic system the pressure for expansion (PE, Equation 63L) was a three-month smoothed version of the pressure for expansion currently warranted (PECW, Equation 62A). The three-month time constant represented the time for pressure to stimulate action (TPES, Equation 63L,C). Here we increase the time for pressure to stimulate action (TPES) to 18 months.²

²In the basic system: TPES=3 63L,C
Here, this parameter is: TPES =18
TPES--Time for Pressure for Expansion to Stimulate action
This change denotes more conservative management tending to "wait and see" if currently warranted pressures persist before committing the firm to employment and capacity changes.

Figure 4.5 shows the output of a simulation run of the changed system. The firm grows quite smoothly until near month 120, when it begins to experience the increasingly severe fluctuations of employment and production capacity seen in the basic run (Figure 4.1).

The reasons for the improved stability in the early growth stage appear in loop 2 of Figure 4.2. In the basic system, a prime factor creating fluctuations in growth rate, delivery delay, and pressure for expansion was the extent of action taken before the results of previous actions were reflected in market conditions. The fluctuations were not serious as long as potential demand far exceeded capacity, so that the control exerted by delivery delay brought demand in line with capacity. They became disastrous, however, when potential demand failed to rise at about the same rate as capacity.

Here, as with conservative hiring policies, slower action leads to improved stability. At month 90, for example, delivery delay is slightly above three months. Pressure for expansion is rising slowly, stimulating production capacity and professional effort additions. Professional capability, however, remains almost constant, reflecting the difficulty of building an effective professional staff at the same rate as professional effort is rising. The result is a stagnation of potential demand relative to production capacity. Potential demand rises 25% between months 90 and 120, while produc-
Figure 4.5. Behavior of System with Slow Response to Pressure
tion capacity rises 74% in the same period. As the gap between potential demand and production capacity narrows, the firm's backlog and delivery delay fall, pressure for expansion drops, and capacity acquisition ceases. The decline of delivery delay, signifying closure of the gap between capacity and potential demand, takes place more slowly than in the basic system, because the firm expands capacity less rapidly. Thus, even though the response delay has been increased, the slower change in delivery delay and other system variables caused by the firm's less violent response allows recognition of the potential demand stagnation before major overexpansion occurs.

A striking difference between this and the basic run is that growth rate here considerably exceeds the rate sustained in the basic system. At month 60, for example, the firm which responds slowly to pressures has grown to a size 33% larger than the rapidly responding firm. This difference results from the improved stability of early growth; professional capability is not sapped during periods of rapid expansion, but can increase smoothly maintaining a high level of efficiency.

The firm grows much further in this run (relative to the basic run) before it enters the period of stagnation and fluctuation. This, of course, derives also from improved stability, as described above. Ultimately, however, the slowly responding firm does enter this period. At month 150, for example, capacity begins to increase and by month 175 exceeds potential demand. An extended run of this system shows that its growth ends after month 175 when even the slow response is too rapid to maintain stability in the face of the
time interval necessary for building professional capability.

This run and the one preceding it show the importance of
the relationship between the aggressiveness of corporate actions
and the period over which the results of actions can be recognized
and evaluated. In particular, growth stability in our system is
strongly influenced by the firm's ability to recognize that poten-
tial demand has ceased to grow as rapidly as production capacity
and professional employment in time to curtail expansion activity.

4.4 Short Delay for Absorbing Professional Effort

In all of the preceding runs, the delay for absorbing profes-
sional effort (DAPE, Equation 38A) has been related to total pro-
fessional effort (TPE, Equation 39A) as shown in Figure 4.6 Here
we change this delay to a constant value of three months.\(^3\)

It is unlikely that a firm could maintain such a short profes-
sional absorption delay. To do so would require not only hiring
experienced people about whom much is known from previous exper-
ience, but also maintaining an organizational structure that would
allow quick and effective instillation of the proper attitudes and
goals in new employees. The run, however, is still useful, for it
permits examination of the role played by the professional absorp-
tion delay and increases our understanding of system dynamics.

\(^3\)In the basic system: TDAPE*=3/4/5/6/9/12/17/20/22/24

TDAPE--Table for Delay in Absorbing Professional
Effort 38A,C
Figure 4.6. Original Delay for Absorbing Professional Effort

Figure 4.7 shows the plotted results of a simulation of the modified system. A striking change from basic systems behavior appears. Growth is relatively stable and continuing. The firm maintains a constant average growth rate without experiencing the major setbacks and stagnation characteristic of the basic system. To maintain the same plot scales as in other runs, only the first 100 months of growth are shown.

The behavior of Figure 4.7 confirms our analysis of the basic system which pointed to the stagnation of potential demand as a principle factor inducing the firm's major problems. Because professional effort can, in this run, be absorbed as rapidly as production capacity, the firm is able to keep potential demand well above capacity. As a result, the gap between potential demand and capa-
Figure 4.7. Behavior of System with Short Delay for Absorbing Professional Effort
city is maintained; delivery delay continues to control demand to meet capacity; and the concurrent pressure for expansion stimulates continued growth.

Note that here, as in the basic run, delivery delay and pressure for expansion fluctuate with a period of about 35 months. These fluctuations result from interactions between the firm's capacity decision and market response to delivery delay. They create no severe problems when potential demand is far above capacity which, in this run, is always the case.

This run points up the significance of a firm's hiring and training policies to growth performance. A firm hires experienced people and concentrates on bringing them to the point of operating effectively, thereby avoiding the problems resulting from inability to expand professional capability seen in previous runs. The growth rate that can be successfully maintained is strongly influenced by a firm's ability to build an effective managerial and engineering staff.

4.5 Planned Growth

The systems explored in the preceding runs have all based expansion rates on pressure resulting from backlog and inventory conditions. Here we investigate a different type of expansion policy. The firm now plans to expand at a certain rate; and continues expansion at this rate as long as there is no indication of overcapacity in backlog and inventory conditions. In other words, the resource
acquisition policies are insensitive to changes in backlog and inventory conditions unless definite evidence exists that growth should be curtailed.

Two planned growth runs are included. One depicts a firm attempting growth at a rate of about 5% per month. The other depicts planned growth at a rate of about % per month. The model description of planned growth policies entails modifying the curves relating the fractional increase of production capacity (FIPC, Equation 16A) and the fractional increase of professional effort (FIPE, Equation 43A) to the pressure for expansion (PE, Equation 63L).

Figure 4.8 below compares the planned growth curves with those used in the basic system. These curves show that resources are acquired at a constant rate until pressure for expansion goes distinctly negative.

Figure 4.9 shows system behavior when growth is planned at a rate of about 5% per month. The firm successfully expands at the planned rate for 78 months, then enters a period characterized by increasingly wide fluctuations of capacity around a constant level.

During the period of stable, exponential growth the fluctua-

\begin{align*}
\text{In the basic system:} & \quad \frac{\text{TFIPC}}{\text{TFIPR}} = \frac{.007/.02}{.058/.09} / \frac{.107/.11}{.115} \\
\text{For 5%/month planned growth:} & \quad \frac{\text{TFIPC}}{\text{TFIPR}} = \frac{.004/.04}{.05/.05} / \frac{.05/.05}{.05/.05} \\
\text{For 3%/month planned growth:} & \quad \frac{\text{TFIPC}}{\text{TFIPR}} = \frac{.004/.025/.03}{.03/.03} / \frac{.03/.03}{.03/.03}
\end{align*}

TFIPC—Table for Fractional Increase of Production Capacity
TFIPR—Table for Fractional Increase of Professional effort
Figure 4.8. Comparative Fractional Increase Rate Curves

tions of delivery delay and pressure for expansion, evident in the basic system, have been eliminated. These fluctuations occurred primarily because of interactions involving the firm's response to backlog and inventory conditions; now, with resource acquisition taking place at a constant rate, virtually all fluctuations disappear.

Stable growth could be maintained during the first 76 months because professional capability and potential demand could be increased at the planned rate. But as the firm grows, it becomes increasingly difficult to absorb professional effort. As in previous
Figure 4.9. Behavior of System with 5% per month Planned Growth
runs, continued attempts to expand at a rate precluding commensurate growth of professional capability makes further growth impossible and leads to a highly oscillatory performance pattern.

Figure 4.10 shows system behavior when growth is planned at 3% per month. The firm, of course, grows more slowly than in the preceding run. The slower growth rate avoids the problems of trying to grow faster than professional capability can be built. The penalties of more rapid growth are avoided, but at the cost of a lower growth rate.

The planned growth runs show that expansion at a constant rate produces smooth growth as long as the rate chosen does not exceed that at which professional capability can be effectively increased.

4.6 Conclusions

The system behavior seen in the runs presented in this chapter serves to validate the hypothesis of Chapter 2. Typical growth patterns, showing successful and rapid growth for many years followed by a collapse as the firm finds itself oversized relative to its potential market, can indeed arise from the interactions treated in this study. When the firm bases its expansion activity on the perceived opportunity for growth as indicated by backlog and inventory conditions and acts aggressively, it does not recognize, until far overextended, failure of potential demand to increase at a rate commensurate with its own physical growth. Employing conservative expansion policies reduces the risk of overexpansion, but sacrifices
Figure 4.10. Behavior of System with 3% per month Planned Growth
growth rate in the period when successful rapid expansion could be achieved. Planned growth policies succeed in reducing short-term fluctuations in growth rate, but do not avoid the problems of "planning to grow" at a rate exceeding that at which professional capability can be increased.

The policies controlling production capacity and professional resources explored so far have several failings. First, if they dictate an expansion rate at which professional capability can be effectively increased, then growth does occur at this rate. The firm tries to control growth rate on the basis of market demand, but is in fact controlling growth rate by its own expansion policies. Second, the policies explored, by disregarding the role of professional capability in creating the opportunity for growth, neglect to recognize the limitations imposed on growth by the firm's own ability to absorb professional effort. This leads to a sequence of interactions precluding the maintainence of long-term growth.

In the next chapter, we explore different policies for controlling production and professional resources -- policies that allow the firm to both exploit the full potential for growth and avoid the instabilities which are likely to accompany rapid expansion if the policies of the basic system are used.
Chapter 5

Policy Design

5.0 Introduction

This chapter describes the design of resource acquisition policies which differ structurally from those in the basic system. The new policies vastly improve the growth performance of our hypothetical firm. We first describe the general characteristics of the new policies and present the detailed equations for them. Finally, we discuss simulation runs incorporating the revised decision mechanisms.

5.1 General Characteristics of New Policies

In the basic system two types of resource acquisition policies were tested. The first made the resource expansion rate strongly dependent on pressures for expansion generated by observed values of backlog and inventory. The second "planned" growth at a given rate and acquired resources at this rate unless strong evidence of overcapacity appeared. Both of these policies showed the same general characteristics. Aggressive expansion actions led to a period of rapid growth followed by a period of potential demand stagnation and fluctuating operations. Conservative expansion actions led to sustained growth, but at a lower rate than necessary. Parameter changes in the basic system affected general performance characteristics only in degree.
Here we search for policies which could improve growth performance far beyond that possible with parameter changes in the basic system. In this study, we will consider both growth rate and growth stability as criteria for evaluating improvements.

In all of the runs in the preceding chapter, we note that as long as potential demand remains well above the firm's capacity to produce, growth can be maintained. The firm controls potential demand. Potential demand results from activities of professional employees in areas affecting the market. The extent of these activities, in turn, depends on 1) the number of professional employees and 2) the fraction of their effort which is not absorbed by recruiting, training new employees, and inefficiencies resulting from expansion. The second factor above is primarily a function of the rate at which expansion is being undertaken. As seen in the basic system, severe problems result when growth is attempted at a rate which hampers development of professional capability and potential demand causing production capacity to closely approach, or exceed, potential demand.

Given the above, it becomes clear that a possible means of controlling growth performance would be to regulate expansion activity in such a way that potential demand remains well above production capacity. For example, a firm might attempt to keep potential demand 20% above its capacity to produce. If it sees that potential demand exceeded capacity by only 10%, then it could slow down expansion, relieve the professional staff of the burdens of growth, develop professional capability, and increase potential
demand. On the other hand, if it observes potential demand to be 40% above capacity, then it can "afford" more professional effort for internal growth activities and can increase its growth rate. In this chapter we explore policies based on the firm's ability to control the relationship between production capacity and potential demand through its resource acquisition rate.

This policy idea is not without problems. Most critical is that potential demand cannot be known and measured directly in a real situation. There, is, however, a possible way of estimating potential demand. The firm can observe its delivery delay. It can also estimate the effect of delivery delay on the market. For example, if delivery delay is twice the industry normal, the firm may estimate that only 25% as many orders are being received than would be the case if products were immediately available. The result would be an estimate that potential demand is four times the incoming order rate. A key requirement for a usable improved policy based on this kind of information is that it perform desirably even when estimates are far from accurate.

Figure 5.1 shows a simplified outline of the revised production capacity and professional effort acquisition policies.

The company estimates potential demand by using information about its delivery delay and average order rate. Potential demand is desired to exceed production capacity by a wide enough margin to absorb exogenous fluctuations and randomness. By comparing estimated potential demand with production capability the firm
Figure 5.1. Outline of New Policies

determines the expansion rate of both production capacity and professional effort.
5.2 Model Formulation of New Policies

This section describes the model formulation of the policies outlined above. Figure 5.2 is a flow diagram of the variables in the formulation.

The first equation below determines the fractional increase rate of both production capacity and professional effort. The increase rate depends on the ratio of estimated potential demand to production capability as shown in the accompanying graph. The graph shows that when the ratio is one (potential demand equals production capability) expansion is completely suppressed.\(^1\) At this point, the gap between production capability and potential demand has vanished and expansion should be halted until professional capability can be rebuilt and potential demand increased.

At the other end of the scale estimated potential demand far exceeds production capability. In this region, expansion takes place at a maximum rate dictated by physical limitations and other factors not included in the system. We set this rate at 9% per month. Between the two extremes the fractional increase rate rises as the ratio increases. The specific curve shape would depend on factors such as the amount of excess potential demand over production capability desired by the firm.

\(^1\)Actually, this curve should reach zero. Some hiring is always necessary to replace specialized skills lost through normal occurrences. It is anticipated that this conceptually erroneous formulation will have a negligible influence on system behavior.
Figure 5.2. New Policies Flow Diagram
\[ \text{FIR.K} = \text{TABHL(TFIR,RPEP.K,1,1.7,1)} \]

\[ \text{TFIR} = 0 / 0.024 / 0.06 / 0.069 / 0.081 / 0.09 / 0.09 / 0.09 \]

FIR -- Fractional Increase Rate (1/months)
TFIR -- Table for Fractional Increase Rate (1/months)
RPEP -- Ratio Potential demand Estimate to Production Capability (dimensionless)

The ratio of estimated potential demand to production capability appears below. The numerator of the right side of the equation is estimated potential demand. The denominator is total production capacity times the productivity of capacity.

\[ \text{RPEP.K} = \frac{\text{EPD.K}}{\text{TPC.K} \times \text{PROD.K}} \]

RPEP -- Ratio Potential demand Estimate to Production Capability (dimensionless)
EPD -- Estimated Potential Demand (units/month)
TPC -- Total Production Capacity (men)
PROD -- PRODuctivity (units/man-month)
The firm estimates potential demand by evaluating the impact of delivery delay on ordering. An estimate of the delivery delay multiplier is made. This gives the fraction of potential orders actually being placed. Dividing the average order rate by this fraction produces an estimate of potential demand.

\[ \text{EPD}_K = \frac{\text{AOR}_K}{\text{EDDM}_K} \]

**EPD** -- Estimated Potential Demand (units/month)
**AOR** -- Average Order Rate (units/month)
**EDDM** -- Estimated Delivery Delay Multiplier (dim.)

The next equation provides management's estimate of the delivery delay multiplier. It depends on the delivery delay ratio observed at the company as shown in the following graph. Initially, we assume that the company accurately assesses the effect of delivery delay on the market. Thus the table function here is identical to that used in describing the actual effect of delivery delay on the market. (See Equation 5A for Delivery Delay Multiplier, DDM, page 22).
The delivery delay ratio observed by the company appears next as the delivery delay observed by the company divided by the industry normal delivery delay.

\[ \text{DDROC} \cdot K = \frac{\text{DDOC} \cdot K}{\text{DDN}} \]

The next equation gives the delivery delay observed by the company as a smoothed version of the actual delivery delay. The smoothing time, here taken as three months, represents the interval for physical observation and for gaining conviction that changes are not random fluctuations.

\[ \text{DDOC} \cdot K = \text{DDOC} \cdot J + (DT)(1/TDDOC)(\text{DD}\cdot J - \text{DDOC} \cdot J) \]

The final two new policy equations equate the fractional increase rates of production capacity and professional effort to the fractional increase rate (FIR, Equation 65A) calculated at the
beginning of this section. They replace the fractional increase
rates as formulated in the basic model.\(^2\)

\[
\text{FIPC}_K = \text{FIR}_K \\
(\text{Replaces Equation 16A})
\]

\[
\text{FIPR}_K = \text{FIR}_K \\
(\text{Replaces Equation 43A})
\]

FIPC -- Fraction Increase of Production Capacity
(1/months)
FIR -- Fraction Increase Rate (1/months)
FIPR -- Fraction Increase of Professional effort
(1/months)

The formulation of revised policies is now complete. Next
we turn to an examination of system behavior when the new policies
are employed.

5.3 **System Behavior with New Policies**

Before discussing simulation runs of the modified system we
should note that the policies designed in this chapter are cur-
rently undergoing initial experimentation. Further modification
of system structure may be required before policy design can be

\(^2\)Three other minor changes must be made in the basic
model to accommodate the revised policies. They involve formu-
lations based on the pressure for expansion. This pressure is
no longer truly indicative of conditions facing the firm. In
fact, with the parameters chosen above, the new policies attempt
to control potential demand to be close enough to capacity to
create a negative expansion pressure under normal operating con-
ditions. The following three table functions, determining produc-
tion capacity and professional effort reductions and produc-
tivity, have been changed to reflect normal operations with nega-
tive pressure for expansion. This change is an expedient, but
experimentation shows that it has no significant effects on sys-
tem behavior. The new table functions are:

\[
\text{TFDPC}_* = 0.06/0.05/0.03/0.01/0.007/0.005/0.004 \quad (\text{replaces Eq. 18A,C})
\]

\[
\text{TFDPR}_* = 0.06/0.05/0.03/0.01/0.007/0.005/0.004 \quad (\text{replaces Eq. 46A,C})
\]

\[
\text{TPROD}_* = 0.7/0.8/0.93/0.97/1.05/1.12/1.2/1.2 \\
(\text{replaces Eq. 20A,C})
\]
deemed complete. The results presented here are not to be taken as conclusive evidence that the new policies are ideal; rather, the results indicate that great potential for improving growth performance exists in the area of policy design.

Figure 5.3 shows the plotted output of a simulation with the new policies. Growth performance is dramatically different than in the basic system. The firm expands steadily, employing 1067 production workers and 417 professional people at the end of 180 months (15 years). Note that the plot scales on this figure differ from those in Chapter 3 figures. The scale for potential demand, order rate and production capacity, for example, ranges from zero to 1600 rather than zero to 400 as in previous plots.

The new policies have effectively controlled potential demand so that it remains above production capacity. During the first 40 months of operation, when the firm is small and building professional capability rapidly, the fractional increase rate averages over 4% per month. Between months 40 and 80, the fractional increase rate drops from 4% to 2.2% a month. Finally, at month 110, the system stabilizes and grows at a constant rate.

Let us look in detail at the interactions creating the observed behavior. Initially, between months 0 and 16, the results of professional activities cause potential demand to increase; delivery delay rises to discourage the increasing number of excess orders. The rising delivery delay indicates to the firm that potential demand far exceeds production capability. Expansion is undertaken
Figure 5.3. Behavior of System with Revised Policies
at an increasing rate until month 12 when rising production capacity decreases the ratio of estimated potential demand to production capability (not on figure). The fractional expansion rate drops. The new policies have controlled expansion in such a way that no excess capacity is acquired. This control is clearly evident between months 40 and 80. In this interval the delay for absorbing professional effort (not on figure) rises from 6.6 to 24 months because of increasing organizational size. This means that if a constant expansion rate were maintained, professional capability would drop relative to production capacity, both because an increasing fraction of effort would be in the absorption process and because effective employees would be devoting less time to areas affecting the market. Here, however, the new policies do not allow a constant expansion rate. The drop in professional capability relative to production capacity causes, after a delay, a similar decline of potential demand relative to production capability. As the firm notices this decline, it reduces the fractional increase rate of professional effort and production capacity through the action of Equation 65A. Thus, as the delay for absorbing professional effort increases, growth rate is curtailed as seen in the figure.

After month 110, the delay for absorbing professional effort (not of figure) remains constant at 24 months. Now the system can stabilize at a constant fractional increase rate which maintains a gap between potential demand and production capability.
The new policies seem to meet our criteria for improvement. They increase the firm's growth rate and maintain growth stability. The improved performance derives from the policies' ability to control growth rate to the rate at which professional capability can be effectively increased. When the firm is small and can grow rapidly, a high fractional increase rate persists. As organizational size increases and the delay for absorbing professional effort rises, growth is curtailed to the point where stable expansion can be maintained.

This run is not, however, sufficient evidence for adoption of or strong recommendation for the new policies. To be acceptable, a policy should operate satisfactorily independent of the particular assumptions made by the model builder. Thus, a suggested policy should be tested at length to assure acceptable results over a wide range of plausible assumptions.

The following two runs are examples of the kind of experimentation involved in policy design. In the previous run, we assumed management accurately assessed the effect of delivery delay on order rate. The estimated delivery delay multiplier (EDDM, Equation 68A) was exactly the same function of the delivery delay ratio as the actual delivery delay multiplier (DDM, Equation 5A). It is unlikely that such a precise estimate of market characteristics can ever be made. Below we test the system with two erroneous estimates of delivery delay's market impact.

Figure 5.4 below compares the two erroneous estimated delivery delay multipliers with the actual delivery delay multiplier. For
reference the erroneous estimates are labelled estimate 1 and estimate 2.  

*Figure 5.4. Estimated Delivery Delay Multipliers*

Figure 5.5 shows system behavior when estimate 1 is used.

The broad behavioral characteristics of the run with a perfect estimate are retained -- growth is stable, the fractional increase rate declines as the delay for absorbing professional effort (not on figure) rises rapidly between months 60 and 90, and growth rate stabilizes at 1.8% per month from month 90 on.

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3In the initial formulation:

\[ \text{TEDDM} = 1.95/0.6/0.45/0.35/0.30/0.27/0.25 \]

68 A,C

For estimate 1:

\[ \text{TEDDM} = 1.95/0.8/0.5/0.3/0.25/0.22/0.20 \]

For estimate 2:

\[ \text{TEDDM} = 1.95/0.4/0.35/0.28/0.25/0.23/0.21 \]
The noticeable change resulting from the erroneous estimate is that growth has been slowed considerably. At the end of 180 months the firm here is only 55% as large as the firm of the preceding run. The reasons for the reduced growth rate appear in Figure 5.4 which compares the estimated and actual delivery delay multipliers. Throughout the run, the delivery delay ratio never exceeds 1.5. In this region the erroneously estimated delivery delay multiplier is higher than the actual multiplier. This creates an underestimate of potential demand for any given incoming order rate. (See Equation 67A for estimated potential demand, EPD). Believing potential demand to be lower than in fact it is, the firm expands more slowly than were a perfect estimate made.

Figure 5.6 shows system behavior when estimate 2 is used. Again, broad system characteristics are similar to those obtained with an accurate estimate. However, growth rate is noticeably different -- now the firm grows 20% more in 180 months than it did using an accurate estimate.

The reasons for the faster growth derive from the direction of error in estimating the delivery delay multiplier. Now the estimated delivery delay multiplier is always less than the actual multiplier. As a result, estimated potential demand exceeds actual potential demand, stimulating more rapid growth than with an accurate estimate.

Note that this does not imply a firm should estimate optimistically. Excessively optimistic estimates could lead to undesirable
Figure 5.6. Behavior of Revised System -- Erroneous Estimate 2
performance. They would allow the gap between actual potential demand and production capability to close too far before corrective action (reduced expansion activity) would be taken. This might create instabilities much like those seen in the original system.

The above two runs show that system performance does depend on the particular way the firm estimates the effect of delivery delay on the market. This is not, in itself, bad, for both runs perform significantly better than was possible using the original resource acquisition policies. Further experimentation is, however, needed to evaluate the adequacy of the policies given plausible degrees of inaccuracy in other system assumptions.

5.4 Conclusion

The contents of this chapter indicate that a strong potential for radically improving growth performance exists. The new policies were developed out of an understanding of the interactions creating the growth problems of the basic system. This points up the power of the experimental approach employed for treating managerial problems and improving decision making.

The resource acquisition policies designed require only one piece of information often unavailable in actual organizations -- an evaluation of current delivery delay. Delivery delay information is, however, usually calculable from normal operating records. If the need for such information is evident, as this study indicates, it can certainly be obtained and made available for decision making.
Chapter 6

Conclusion

6.0 Review of the Study

The study documented here has passed through four distinct stages. First, we developed a thesis in the form of a dynamic hypothesis for the way that a firm's internal resource policies could influence both its growth rate and growth stability. Second, an industrial dynamics model was constructed to depict the elements of the hypothesis. Third, model experimentation served to validate the hypothesis and allowed detailed study of complex system interactions. Fourth and last, policy design was initiated and shows great potential for improving system behavior.

6.1 Major Conclusions

Next we briefly summarize several key points made in the study. They relate to behavioral characteristics of the system treated.

1. A firm which bases resource acquisition on pressures for expansion generated by order backlog and inventory conditions controls its growth rate through its resource acquisition policies as long as professional capability can grow at a rate commensurate with the physical expansion rate.

2. The limitation placed on growth by the inability to effectively increase professional capability manifests itself in stagnation of potential demand and fluctuations in operations.

3. When expansion is based on order backlog and inventory status, a trade-off between long and short-term growth rate appears. Aggressive resource acquisition policies produce rapid initial growth. Attempting to continue aggressive expansion, however, leads to alternating periods of expansion and cutback which preclude long-term growth. Conservative policies allow continuing, stable growth but at a rate which may be far below potential.
4. Fluctuations in growth rate, even when professional capability imposes no limitation on expansion, can be caused by resource acquisition policies which are sensitive to changes in order backlog and inventory conditions. Improved growth stability can result from responding slowly to perceived changes or by following planned growth policies.

5. It appears that resource acquisition policies based on estimated potential demand can significantly improve growth performance in the system studied. Such policies create stable growth at a rate commensurate with the ability to expand professional capability.

The overriding general conclusion of the study, based on the specific points above, is that a firm's resource acquisition actions can play a predominant role in determining growth patterns. A firm is no passive entity responding to market vagaries; rather it is an active element which, through managerial policies, strongly controls the dynamic performance of a system containing both it and its environment.

6.2 Further Study

This study has probed the nature of the corporate growth process. It has focused on one system of interactions in an attempt to build understanding of some of the fundamental mechanisms creating the diverse growth patterns experienced by industrial enterprises. Many avenues for further study of corporate growth exist, three of which are outlined below.

First, continued research into the system treated here would likely be valuable. Experimentation with the original system may yield insights not yet realized. Further exploration of revised policies is also necessary to reap the benefits of the work already done.
Second, the work to date has suggested other areas for research. For example, we have seen that the way in which professional people are brought to the point of effectively contributing to a firm crucially influences its dynamic behavior. One could fruitfully examine the effects of various methods of professional development in an expanding organization. Other factors affecting professional work, such as effort allocation policies and policies determining the quality of people employed could also be examined.

Third, if a basic understanding of the growth process is to be fully achieved, a body of information about actual growth performance must be developed. Extremely valuable work could proceed in this area, adding substance and relevance to research studies such as this. Accounting reports and normal operating data of real organizations are unlikely to provide the information needed. Much of it will probably come from the descriptive commentary of people who have lived with expanding firms and their problems.

In summary, this study has, perhaps, only scratched the surface of the potential gains to be realized from research into the growth process. Its attempt has been to provide one of the initial steps toward an understanding of corporate growth. Other steps must follow if its full value is to be exploited.