SOURCES OF RISING PRODUCT DEVELOPMENT TIMES

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I.   Introduction

        A number of high technology firms have recently reported increasing
delays in the development of computer-related hardware and software.
Experiencing increasing product development times and schedule overruns,
one such company commissioned a system dynamics study of the management of
its product development group. The purpose of the study has been to
uncover potential sources for rising product development times in the
company and to identify those over which management can exercise some
control.

        The results of the study are interesting to consider in light of
current perceptions of declining industrial productivity in the United
States and increasing question about the efficiency and effectiveness of
research and development efforts. The study has demonstrated that the
symptoms of what is apparently a problem of declining engineering
efficiency can be generated by a pattern of decisions in the firm.   This
paper describes the study that supports this conclusion and analyzes the
decision structures that have the potential to produce rising product
development times.

        Section II of this paper describes in more detail the nature of the
problems addressed by the study and discusses a number of perspectives on
such problems. Section III describes the structure of the computer
simulation model developed in the course of the study. Section IV analyzes
the causes for rising product development times in the model. Section V
discusses implications of these model-based analyses for the management of
a development group in the context of rapid corporate growth.

II.   The Problem

        The company on which this research is based is a developer and
manufacturer of data-communications equipment. Having enjoyed a real rate
of revenue growth in the neighborhood of thirty-to-thirty-five percent per
year for the past ten years, the firm now encompasses six diverse product
lines, including high-speed modems, multiplexers, intelligent terminals,

and diagnostic devices for computer communication systems. The firm projects that the personnel in the product development group will grow over the next five years at more than twenty percent annually.

Since 1977, the company has experienced increases in the time it takes to bring a product from the initiation of development to its first shipments. In this period overruns in product development schedules have increased in frequency and severity. Product development times have risen from a norm of 18-to-24 months to as high as 30 months, and schedule overruns have gone as high as nine months. Because the time it takes to develop a product is essentially the delivery delay of a development group, increases in it can lead to the loss of sales. Thus rising product development times threaten to slow the traditionally rapid growth of the firm. Compounding the problem, from 1977 to 1979 the company lost a number of senior development engineers. The reasons expressed varied considerably, but seemed to center on changes in the character of the firm brought about by its dramatically rapid growth: increasing administrative burdens on senior engineers, a large and growing percentage of new engineers in the development group, and the feeling that the quality and commitment of personnel were not quite what they used to be.
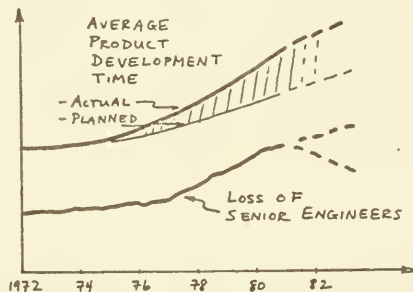

Figure 1: The problem focus: rising product development times and an increase in turnover of senior development engineers

These two dynamic patterns, shown graphically in figure 1, are the focus of this study. It is reasonable to suggest that they are related: a loss of highly productive, senior engineers could easily set development projects back considerably. An influence in the opposite direction is also conceivable: a prolonged pattern of rising product development times could produce such a pressured atmosphere to meet schedule deadlines that engineers eventually opt for more comfortable job situations.

Perspectives on the Problem

Such patterns may be viewed as natural, unavoidable aspects of the dynamics of rapidly growing, high-technology industries. A number of experts in the data-communications industry trace recent overruns in product development schedules to the shift to more sophisticated technology--from LSI (large-scale integrated circuitry) to VLSI (very large-scale integration). "At the heart of the problem," says Business Week [1], "are the complex logic circuits that make up the computer processor. As more and more of this circuitry is squeezed onto a single high-density chip, it becomes tougher to correct design flaws. Once the circuits are cased in silicon, they cannot be changed without redesigning and refabricating the entire chip, a process that takes at least four to six weeks." So product development times are seen to rise for two likely and related reasons: increasingly complex products inherently take longer to design, and undiscovered errors in the new VLSI technology take longer to correct. Fierce competition for development engineers highly skilled and experienced in LSI and VLSI design and manufacture is a natural consequence. Turnover is likely to be increasingly high, as engineers are lured from company to company by ever more attractive job situations. [2]

If the problems are industry-wide and essentially beyond managerial control, no one firm's share of the market is threatened by a pattern of rising product development times. Everyone will reach the market somewhat later than advertised, and no one will be able to capitalize permanently on the development delays of others. If, however, there are aspects of the phenomenon that are potentially within the control of corporate management, then those companies that learn the quickest stand to reap considerable

benefits in market share and revenues. Our client company wished to
investigate the point of view that some aspects of the problem could
actually be exacerbated by its own R&D management policies. It requested a
study focused internally on the operation of its development group.

A wide range of perspectives on the problem can be brought together
by the following simple mathematical model, essentially a definition of the
development time of a product:

$$\text{product development time} = \frac{\text{tasks in product development}}{(\text{engineers/product}) * \text{productivity}}, \quad (1)$$

where a "task" is some arbitrarily defined unit of work and productivity is
measured in tasks per person per unit time. The following equivalent
identity neatly shows how the fractional growth rates of these quantities
consequently must relate:

$$\frac{\dot{PDT}}{PDT} = \frac{\dot{PER}}{PER} - \frac{\dot{ENG}}{ENG} + \frac{\dot{PDEV}}{PDEV} - \frac{\dot{PROD}}{PROD}, \quad (2)$$

where
    PDT = product development time (months),
    PER = product engineering requirement (tasks per product)
    ENG = engineers,
    PDEV = products under development.
    PROD = productivity per engineer (tasks/engineer/month),

and dots denote derivatives with respect to time.

If product development times are rising, then the right-hand side of this
identity (2) must be positive, which is to say the fractional growth rates
of the product engineering requirement, the number of engineers in the
group, the number of products under development, and the average
productivity per engineer are out of balance. To keep product development
times constant in the face of rising technological complexity and rapid
corporate growth, the terms in (2) must net to zero.

All perspectives on the immediate causes of rising product
development times can be found in this identity. Because of the complexity
of the problem and the drive to delve deeply into its underlying causes,
most attention has been focused on single terms in (2). Considerable
research has focused on productivity issues, for example. The identity

shows that if fewer engineering tasks per month per engineer are completed, then even if the complexity of the development effort remains constant product development time can rise. Management experience and the R&D literature suggest numerous factors have the power to influence productivity. Cotiis and Dyer [3], for example, discuss twelve dimensions of project management that correlate significantly with the efficient use of product development resources, including stability of product specifications, coordination and cooperation, clear lines of authority and responsibility, and comprehensive group communication. Stahl and Steger [4] relate an engineer's productivity to characteristics of the individual and his or her development group, including such things as perceptions of pressure to produce, participation in goal-setting, communication with other professionals, length of scientific employment (they found a negative correlation), and perceptions of the project leader's empathy and evaluation of the work. Allen [5] has documented the importance of the role of communication networks. Though not directly addressing the problem of rising product development times, these studies shed light on determinants of the behavior of the productivity term in (2) and thus suggest potential sources of our problem.

Another trend in the literature has focused on the product engineering requirement. Rising technological complexity and the need for rework fall into this category. Sharp increases in technologicial complexity such as those involved in the new VLSI technology invalidate some of the old rules of thumb of project planning and scheduling, making it difficult to estimate accurately the man-months of product development required. In addition the difficulties in debugging the more complex VLSI circuitry, for example, have the power to generate the need for considerable rework. Both can lead to overruns in the the man-months of product engineering required. Rework is especially troublesome. The longer an error goes undetected, the more extensive the necessary rework and the greater the rise in the product engineering requirement. Changing design specifications after development has begun also generates the need for rework. Cooper [6] describes a large system dynamics study of cost overruns in a shipbuilding contract. The study showed that the rework required by frequent design changes imposed by the Navy were the major

contributing factor to a $500 million dollar overrun. (A suit was settled out of court for $447 million.) Undiscovered rework is also the focus of the simple R&D project models in Roberts [7] and Richardson and Pugh [8].

The work described in this paper provides an integrating framework for the perspectives on rising product development times captured in (2). The computer simulation model developed as a basis for the research places the interactions between productivity and technological complexity in the context of a comprehensive manpower planning and product scheduling structure. The whole is designed to look and behave like the product development group of a high technology company. As a result of this integration, the work has illuminated sources of rising product development times that have not been previously acknowledged in the literature -- in particular, sources related to the middle two terms of the identity (2). In the context of rapid corporate growth the coordination of manpower planning and product scheduling is apparently more difficult than assumed. Our work suggests that the lack of adequate coordination is a potentially potent source of rising product development times.

Several characteristics of the system dynamics approach help to explain why this work has resulted in a slightly different view of rising product development times. First, the approach focuses on patterns of behavior over time, and the time frame encompasses both short-term and long-term phenomena. Second, the major modeling effort is focused on creating a very strong correspondence between model structure and what are deemed to be essential features of the real system. Flows and accumulations of people and material in the real system, for example, are carefully conserved in the model. The conservation tendency led naturally to a careful allocation of an engineer's time to various engineering and nonengineering demands. Finally, most importantly, the approach takes a cybernetic view -- the presumption that the behavior of a complex system is a consequence of its "information feedback structure." The following brief discussion of the structure of the model in this study will expand these notions.

III. Modeling the Process of Product Development

A number of system dynamics models relating to the management of R&D
projects have been developed and used for policy analysis. [6] - [11] The
model in this study differs from these in that it does not trace the
lifecycle of a single project; rather, it reproduces the dynamics of a
development group over a ten year period as a continuous stream of products
are developed and placed into production. The model focuses on the number
of products under development, the use of resources required, and an
aggregate average product development time. In addition, the model differs
from past modeling efforts by placing R&D dynamics in the context of rapid
corporate growth. It is intended to replicate the structure and behavior
of a product development group growing initially at thirty percent per
year.

Model Overview

The model contains more than 150 equations representing a complex
structure of interacting variables and interconnected feedback loops
assumed active in a corporate product development group. It was
constructed over the course of a year with the aid of the senior director
of business planning in our reference company in consultation with the vice
president for development and a senior director of development. A complete
description of the model is not possible here. Instead, those pieces of
model structure that support the insights it has helped to generate will be
presented in detail. [12]

As shown in figure 2, the model consists of four major sectors
focusing, respectively, on engineers, managers, product development, and
revenue and budget. These sectors are sufficient to capture the major
dynamics of the terms in the simple identity (2) and to include feedback to
and from the market for the firm's products. The engineer sector (70
equations) traces the flow of engineers as they are hired into the firm, as
they become assimilated and develop into highly productive senior
engineers, and as they are promoted to managers or leave the firm. The
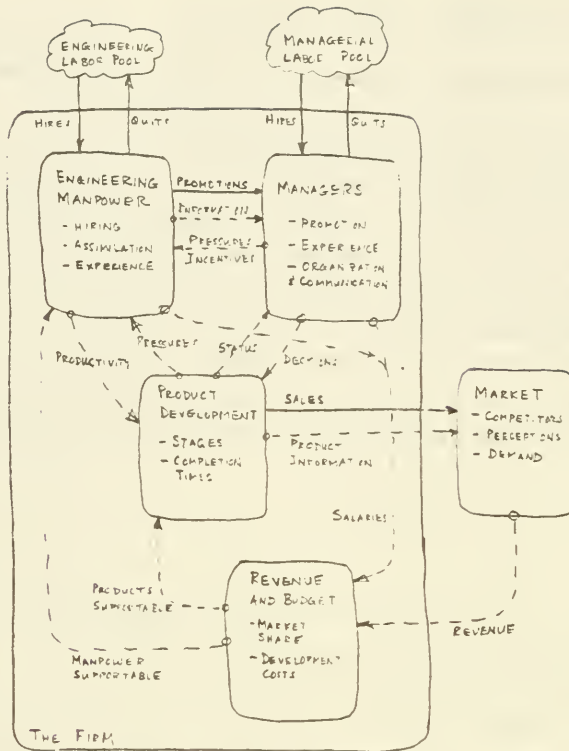sector monitors pressures that have the potential to cause quits of senior

Figure 2: Overview of the structure of the model

engineers and keeps account of competing demands for an engineer's time.
The manager sector (23 equations) hires and promotes people into managerial
and coordinating positions and traces the effects of managerial experience
on the productivity of engineers. In the product development sector (29
equations) products are initiated, developed, completed, passed into
production, and eventually drop out of production as they become obsolete.
This sector computes an engineers' estimated product development time, the
compromise target development time settled on in light of perceptions of
market needs, and the actual product development time that results from the
dynamics of the entire development group. The sales and revenue sector (30

equations) contains a simplified treatment of a growing market. The firm's
market share responds to the quantity and quality of the firm's output,
relative to its competitors. A percentage of the revenues from products in
production is allocated to the development group and used for salaries and
product development. With the market effects assumed in the model a closed
loop of action and information exists: the operations of the development
group affect revenues, and the resulting growth in revenues affects the
growth of people and products in the development group.

The internal operations of the firm are influenced by three exogenous
factors: a gradually growing pool of engineering talent, a growing market
for the firm's products, and increasing competition for the firm's market
share. These exogenous influences can be varied to test different
scenarios. When kept the same in different computer simulations, they
provide a common background against which to test different management
policies within the firm. The dynamics of all of the remaining variables
in the model are determined endogenously, that is, internally, by the
assumed decision structure of the firm.

Influences on Productivity

Six factors in the model directly affect engineering productivity:
the basic quality of the engineering group, average aggregate engineering
experience in the firm, supervisory activities required of engineers, team
size, requirements for nonengineering activities related to organization
and communication, and pressures arising from development schedules. These
influences are used to compute a number of "full-time equivalent
experienced engineers," the fully productive fraction of the total number
of engineers. The concept of an "FTE" is a modeling convenience defined to
represent the mythical senior engineer who spends every minute of every
working day in fully productive engineering activities. Product
development time is then simply the result of dividing the number of
man-months of actual product engineering required by the number of full-
time equivalent engineers per product.

Because declining productivity is one of the most likely sources of
rising product development times, the actual equations assumed in the model
will be presented here. Product development time is computed essentially
as in (1):

$$PDT = PER/FTEPP \qquad\qquad (3)$$

where

      PDT   = product development time (months),
      PER   = product engineering requirement (man-months),
      FTEPP = full-time equivalent engineers per product (people).

To determine the number of full-time equivalent engineers in the
development group, three competing demands for an engineer's time are
recognized in the model: engineering, supervising engineers new to the
firm, and handling a mix of non-engineering activities called the
"organization and communication burden" of the development group (described
in section IV). The computation is

$$FTEPP = ETS * EF * ESPP * EQEP * EIP \qquad\qquad (4)$$

where

      FTEPP = full-time equivalent engineers per product,
      ETS   = effective team size (people/product),
      EF   = engineering fraction (see below),
      ESPP = effect of schedule pressure on productivity,
      EQEP = effect of the quality of engineers on productivity,
      EIP   = effect of incentives on productivity (a policy parameter).

Essentially, the number of full-time equivalent engineers per product is
equal to the actual number of engineers per product, multiplied by the
fraction of these people that are "full-time, experienced equivalent
engineers," and modified further by effects on productivity from short and
long-term schedule pressure, the overall quality of the engineering group
in the firm, and a potential effect of an incentives policy.

The engineering fraction EF translates the number of inexperienced and experienced engineers in the model into an equivalent number of experienced engineers and subtracts out the fraction of time engineers spend in supervisory and organization and communication activities. The equation is

$$EF = EFEP - FEX*FMHS - FEOC \qquad (5)$$

where

EF	= engineering fraction,
EFEP	= effect of fraction experienced on productivity,
FEX	= fraction experienced,
FMHS	= fraction of experienced manhours to supervision,
FEOC	= fraction of an engineer's time in organization and communication activities.

A Development Group as a Feedback System

In the system dynamics approach two fundamental concepts form the focal points for model conceptualization: accumulation processes -- stocks and flows of people and material -- and feedback loops -- closed paths of action and information. Figure 3 shows the principal accumulations (levels) and flows (rates) assumed in the model. (A number of other accumulations that appear in the model as delays or averaging processes are not shown.)

The model separates both engineers and managers into "inexperienced" and "experienced" pools so that a number of productivity effects can be represented. Supervision of new engineers by senior people, for example, creates two opposing effects on engineering productivity: increased supervision speeds the assimilation of new engineers and shortens their period of lower productivity, but it pulls senior engineers away from actual product development work. Both effects are captured in the model.
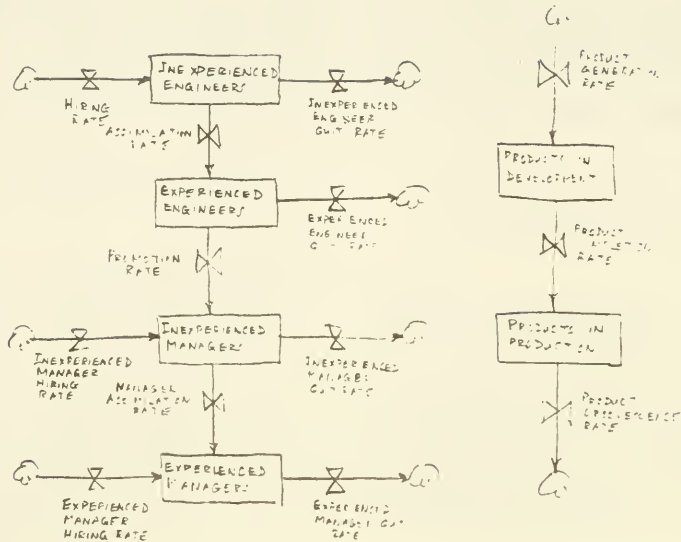
Figure 3: Principal levels (stocks) and rates (flows)
in the model. [Rectangles represent accumulations;
valve symbols represent rates of flow. All rates in
this figure vary over time in response to other
influences not diagrammed.]

The concept of feedback arises naturally in analyzing cause and
effect sequences that appear to be related to the problems of rising
product development times and increasing quits of senior engineers.
Supervision again provides a good example. Suppose the firm experiences an
increase in quits among senior engineers who spend some fraction of their
time providing engineering guidance to others. The loss would mean that
less day-to-day supervisory time would be available to newer engineers. As
a consequence, it should take longer to assimilate new engineers into the
firm -- a longer apprenticeship or development period before a new person
reaches the productivity of a senior engineer. Thus, the rate of flow into
the pool of experienced engineers would tend to slow up. In sum, an
increase in the outflow from the experienced pool tends to decrease (other
things being equal) the inflow to that pool, further exacerbating the drop

in senior engineers caused by the increase in quits. This self-reinforcing
process, called a positive feedback loop, is shown in figure 4 side-by-side
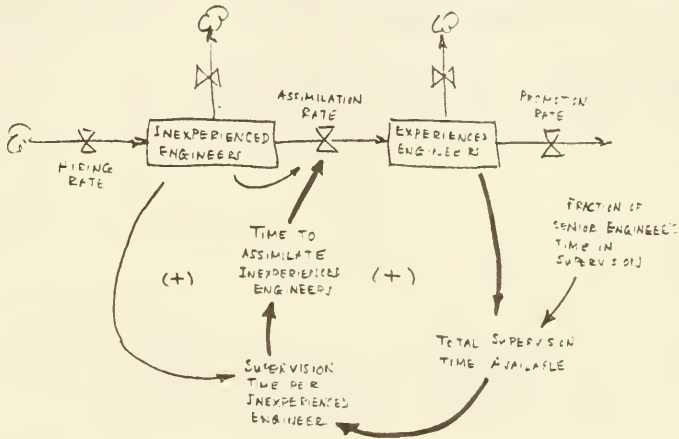with another loop having the same self-reinforcing character.

Figure 4: Self-reinforcing (positive) feedback loops
in the supervision of new engineers by senior
development engineers.

The feedback perspective illuminates two general types of processes
at work in any complex system -- those that are self-regulating and those,
like the supervision loop, that are self-reinforcing. The model in this
study was formulated from the point of view that all decisions are made in
the context of feedback. Some aspect of the system is perceived; change
comes from the desire to move the system closer to some desired state;
decisions are made to bring the actual state of the system closer to the
desired; the actions taken alter the state of the system, giving rise to
new perceptions of the system. Such a closed loop of action and
information is called a feedback loop, because information eventually
"feeds back" to its point of origin, affecting future perceptions and
actions. The model developed in this study contains hundreds of such
loops. The dynamic behavior of the system is a consequence of the complex
interactive structure they form.

The decision to introduce a product for development is embedded in numerous feedback loops, and is an important determinant of the behavior of the system over time. The decision is based upon the current workload in the development group, the availability of resources, project completions, and growth goals. The model equation states:

$$PGEN = (DPDEV-PDEV)/PDEVAT + COMP + GP*PDEV, \qquad (6)$$

where

       PGEN = product generation rate (products/month),
       DPDEV = desired products in development,
       PDEV = products in development,
       PDEVAT= adjustment time for products in development (months),
       COMP = product completion rate (products/month),
       GP   = growth factor for products in development.

Essentially, the equation states that new products are added to the workload of the development group when old ones are completed (COMP) and when additional ones are necessary to keep up with planned growth (GP*PDEV). The term (DPDEV-PDEV)/PDEVAT represents pressures in the decision process that adjust the rate of introduction of new products to the availability of development resources. It pushes the actual introduction of products above or below the base rate (COMP + GP*PDEV) depending upon how PDEV compares to its desired value, DPDEV. The latter is an aggregate concept representing the firm's perception of the number of products in development that is necessary to meet its market needs and that can be supported by the manpower and revenue currently available to the development group. The parameter PDEVAT reflects how closely management monitors the workload in the development group and how rapidly it takes action to bring actual conditions more in line with desired. In the base case in the model PDEVAT is set at 24 months, the average product development time at the start of the simulation.

        A feedback loop is evident in the first term in this formulation.
The current number of products in the development group (PDEV) is compared
to a desired number (DPDEV). Any discrepancy generates countervailing
action in the product generation rate: if PDEV is too small, for example,
the adjustment term will be positive, and more products will be generated
per month until PDEV is brought up to DPDEV. Figure 5 shows the simple
feedback loop represented by this adjustment term. The loop is self-
regulating: it continuously strives to adjust PGEN to keep the number of
products in the development group equal to the number desired. It is
called a negative feedback loop because it tries to negate or counteract
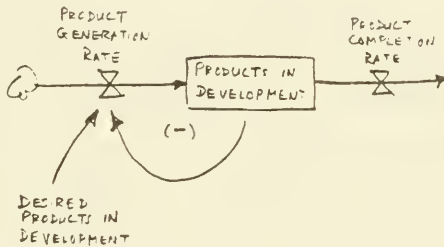any change in PDEV from its goal, DPDEV.

Figure 5: Self-regulating (negative) feedback loop in
the decision to introduce products for development

        The formulation of PGEN also illustrates a positive or self-
reinforcing feedback loop. The positive feedback loop linking products and
revenue is among the most important self-reinforcing feedback loops
associated with a technology-based company. Products in development
eventually become products in production, which are the source of the
company's revenues. Revenues support the budget of the development group.
In our reference company, six-to-eight percent of gross revenues go to R&D.
Thus the more revenues generated, the more engineers, money, and technical
resources are available for expanded product development. In the model,
more revenues thus mean a higher number of products supportable in the
development group, that is, a higher DPDEV, and hence a greater rate of
product generation (other things equal).

This cummulative expansion of products and revenues is the
fundamental growth-producing loop of a technical company: more products in
development lead eventually to more products in production, which produce
more revenue; more revenue means more resources for product development,
which lead to more rapid generation of products and a growing stock of
products in development. The closed sequence of causes and effects appears
as three loops in figure 6. Each is clearly self-reinforcing: by
generating additional revenue, products in development can lead to still
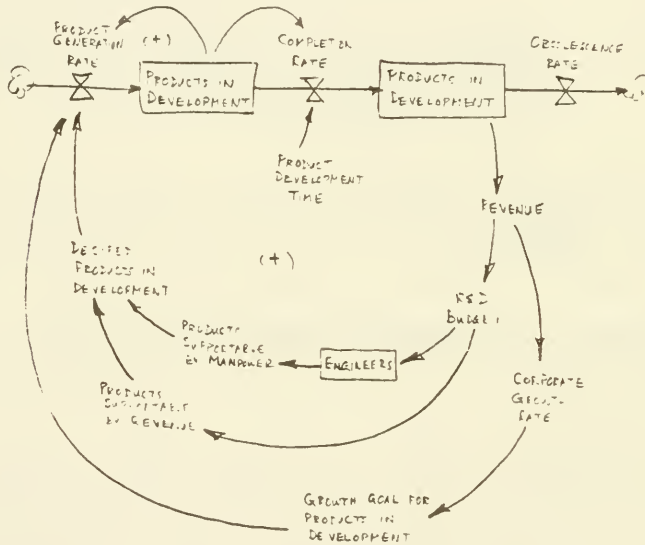more products in development.

Figure 6: Self-reinforcing (positive) feedback loops in
the decision to introduce products for development

The diagram also suggests that these loops can be self-reinforcing in the
opposite direction. In a sustained market decline, for example, products

in production produce declining revenues, leading perhaps to fewer
resources available for product development, leading to a cutback in
products in development, eventually fewer products in production, and
perhaps still greater declines in revenue. (It is likely that other loops
representing more complex corporate decision-making not shown in this
figure would intervene in such a situation, however, perhaps raising the
fraction of revenues going to development.)

Further details of the model structure assumed will be given in
section IV when they help support the analysis of model behavior and policy
implications.

IV.   Analyzing Rising Product Development Times

The goal of a system dynamics modeling effort is to improve
understandings of the relationships between the feedback structure of a
system and its behavior over time. The simulation model is a laboratory
tool. By altering parameters, changing the strengths of assumed effects,
or deactivating pieces of model structure we learn the connections between
model structure and behavior. With care, and a number of iterations of
conceptualization, formulation, testing, and refinement, we try to move
toward understanding the connections between the structure of the real
system and its behavior. Thus the base run of the model is best viewed as
a reference against which to compare other runs that differ in varying
degrees in parameter values and feedback structure. We shall begin by
showing important aspects of the base run. Then various model assumptions
will be alterned in a sequence designed to reveal their relationship to
rising product development times.

Figures 7 and 8 show that the base run of the model reproduces the
problem behaviors of interest. Figure 7 shows a pattern of rising product
development times set against the engineers' projections, management's
desired product development time (assumed constant at 24 months), and the
compromise upon which engineering and management decisions are based. The
average product development time rises from 24 months to 28 months after

48 months of simulated time, declines a bit for the next 24 months, and then resumes its rise for the remainder of the run. Engineer's projections follow a similar pattern, displaced somewhat in time due to delays in perceiving changes in engineering efficiency. The compromise product development time is a balance between the engineers' projections and an unwavering management goal of an average of 24 months per product and thus is precisely in phase with the pattern of the engineers' projections. By itself, figure 7 tells us little except that the model is capable of replicating the problem of periodic increases product development times.

Figure 8 shows the fraction of senior engineers leaving the firm each month, along with the three quit pressures generated endogenously in the course of the simulation. The dominant pattern in the figure is the rise in the quit pressure from the "administrative burden" on senior engineers and the apparently related fifteen percent rise in the fraction of senior engineers leaving the development group. The quit pressure peaks around month 48, declines back to normal by month 90, and then appears to begin another rise as the simulation ends. It represents the tendency of some engineers to move elsewhere if they perceive an unwelcome amount of administrative, managerial work has been falling their way, pulling them away from the engineering tasks they are expected to do and want to do. As the graph of quit pressure from schedule pressure indicates, a small portion of the increase in quits is due to persistent, long-term pressure resulting from the overrun of product development times. A third potential source of inreasing quits, the quit pressure from "experience," reflects the possibility that senior engineers might be moved to transfer if they perceive the experience level or quality of recent hires has changed the traditional character of the firm. Because the relative fractions of inexperienced and experienced engineers change very little in the course of the reference run, the quit pressure from experience changes very little relative to the other quit pressures. It thus appears as a constant equal to 1 throughout the simulation.

Since the peaks in figure 8 occur at nearly the same point in time as the start of the leveling off of productive development time in figure 7, the phenomena in the two plots appear to be related in the model, but the relationship is not clear from these plots alone.
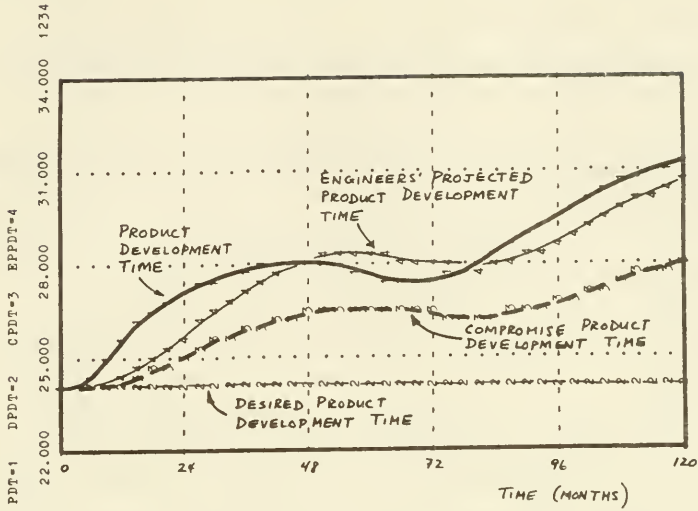
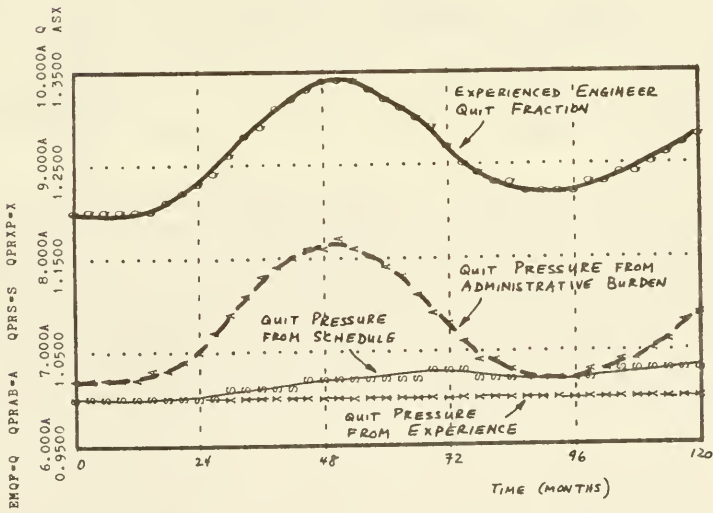Figure 7:   Product development times in the base run

Figure 8:   Quits and quit pressures in the base run

The patterns in figures 7 and 8 were produced by the internal structure and behavior of a product development group in the context of a growing market for the firm's products, a more slowly growing pool of available engineering talent, and a growing competitor sector vying for market share. In addition, in the reference run the firm consciously opts for developing technologically more complex products requiring progressively more man-months of product engineering. However, increasing technological complexity is not a source of the rise in product development time in this run. The pattern of product development time is exactly the same when the product engineering requirement is held strictly constant in the model. That invariance is the result of several optimistic assumptions. The reference run of the model assumes that engineers can correctly perceive the number of man-months of engineering required to develop a product -- no bias, no perception delays, and no intentional under- or over-estimation. If greater product complexity means a proportionally greater need for rework, for example, the model in the reference run assumes the need is anticipated and project teams staffed accordingly. The reference run also assumes that project teams can be made larger without loss of engineering efficiency. As team size varies from 4 at the start of the run to 17 by the end of the ten-year period, this assumption is tantamount to assuming that management at all levels in the development group is very skillful. These optimistic and debatable assumptions were taken in the reference run in order to focus first on other, less obvious, sources of rising product development times.

Figure 9 shows the behavior of product development times in four different simulations representing different management policies within the development group. In each of these runs the growth rates of the market, the engineering labor pool, competitors, and the product engineering requirement are the same as in the base run. The following discussion analyzes the reasons for the successive improvements evident in the runs.
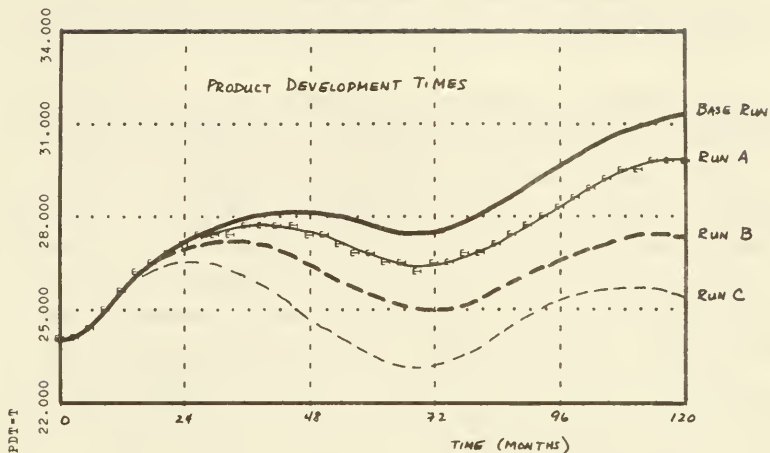
Figure 9:   The behavior of product development time
in the base run and three policy simulations:
   A - Revised promotion policy
   B - Reducing overcommitment
   C - Using estimates of engineering efficiency

Promotion Policy

The difference between run A and the reference run is a single change
in the promotion and hiring policy of the firm. In the reference run the
firm obtains its managers in the development group largely from its own
group of senior engineers. Specifically, throughout the run a constant 90
percent of the managers acquired by the firm are drawn from the firm's own
engineers, and 10 percent are hired from outside the firm. In the policy
run A, the firm begins the run acquiring only 70 percent internally, and
then deliberately lowers that percentage as necessary to keep the growth
rate of the pool of senior engineers near the target growth rate of the
development group. By the end of the run only about 58 percent of the
firm's managers are being acquired by promotion. In the base run the
promotion rate was determined solely by the need for managers. In the

policy run information about the level of senior engineers (its growth
rate) is taken into consideration. The promotion rate depletes the
engineering pool, but the pool now influences the promotion rate, thereby
creating another feedback loop of action and information in the system.

It is probably unrealistic to assume that a firm would acquire a
fixed fraction of its managers by promotion. It may also be unrealistic to
assume a firm takes the growth rate of its engineering pool into
consideration in deciding from where to draw its managers. The value of
the reference run and policy run A is that they highlight a fundamental
aspect of the firm's problem. Skilled development engineers are hard to
come by; every one promoted into a nonengineering, managerial position
must be replaced, and each is likely to be replaced by someone initially
less experienced and productive. A high rate of internal promotion into
managerial ranks in the face of severe competition in the industry for
engineers tends to maintain a relative young, less experienced, and less
productive engineering group. Two pressures lead to the tendency to
promote highly productive senior engineers out of engineering: the
personal desire to advance in the corporate ranks, and the scarcity of
people in the industry skilled in managing high-technology product
development work. Policy run A reinforces the long recognized need for a
technological ladder of advancement as well as a managerial ladder.

Reducing Overcommitment

Run B in figure 9 includes the variable fraction of managers acquired
by promotion from run A, and adds what ammounts to increased attention to
coordination of the number of products under development, their average
engineering requirement, and the number of engineers in the group.

The assumptions in the base run reflect a number of pressures that
can combine to overextend the resources of a development group. Management
experience and the R&D literature [13] show that some amount of pressure is
necessary for efficiency. The general wisdom is that work will expand to
fill the time provided for it, so management wants to provide no more than
what it perceives to be the minimum to do the job well. By itself that

pressure for efficiency is healthy and does not necessarily lead to
overcommitment. But there are potential systemic characteristics that can
push beyond efficiency, to overcommitment. Without accusing any one
specifically as the source, the following combine to create pressure that
is hard to resist:

- o   the belief that the more products initiated in the development
       group, the greater the rate at which they will emerge as revenue-
       generating products in production;
- o   the tendency to remove all slack from estimates of product
       engineering effort required;
- o   no excess engineering capacity to deal with an overrun without
       disrupting other projects;
- o   not planning in excess capacity to handle requests from the
       marketing side of the firm to refine a design of a previously
       developed product to enhance sales;
- o   budget constraints that tend to reduce hiring but not eliminate or
       scale down product development efforts;
- o   the self-image of the corporation as a leading innovator in a
       rapidly growing industry;
- o   the corporate perception or self-image of the development group of
       being capable of doing a lot with limited resources;
- o   depending on extraordinary skill and effort in the engineering group
       to keep to schedules ("its a lot to expect, but Smith and Jones here
       can do it," or at least they can keep the project on schedule until
       the required team is fully assembled.)

        The reference run reflects these pressures in the formulation of the
product generation rate, the decision to introduce a new product into
development. The desired number of products in development is a compromise
between the number supportable by current revenues and the number that can
be handled by the manpower in the group. In the face of constraints on
hiring skilled engineers, the number of products supportable by revenue
tends to be higher than the number supportable by manpower. In the base
run, there is a slight tendency to introduce a product before the necessary
team is on hand: desired products in development is biased slightly above
products supportable by manpower as long as the revenue stream can support
the higher number. Figure 10 shows the growing wedge between products in
development and products supportable by manpower that results from
tendencies to acquiesce to pressures to overextend the development group.
In spite of the increases in productivity that the model assumes as
schedule pressure increases, the tendency to overcommit to too many
products under development, if unchecked, leads inexorably to rising
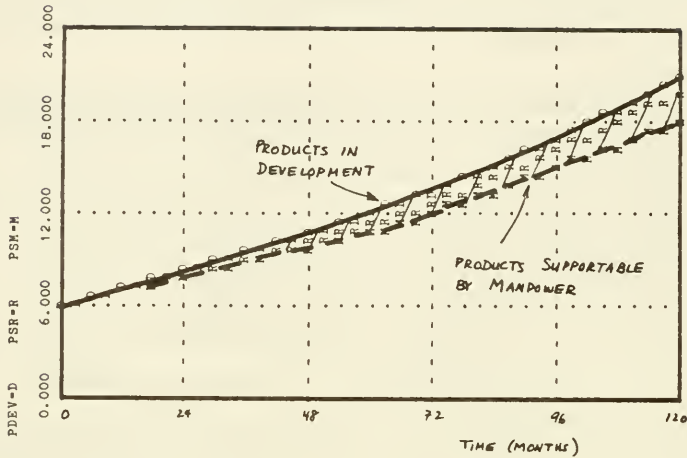product development times.

Figure 10:   The growing wedge between products in
development and products supportable by manpower in the
base run.

    In policy run B in figure 9, desired products in development has been
set to equal to minimum of products supportable by revenue and manpower.
But the improvement in the determination of desired products in development
would have little effect unless management pays close attention to it.
Thus an additional important aspect of the policy change implemented in run
B is a shortening of the time it takes the firm to adjust to discrepancies
between the desired number and the actual number of products in
development [see PDEVAT in equation (6)]. With an adjustment time for
products in development of 6 months instead of the base run's 24 months,
the improved determination of desired products in development essentially
eliminates the growing wedge shown in figure 10. The development group is
corresponding less overextended and product development times decline as
shown in run B in figure 9.

It should be noted that a considerable portion of the improvement
comes just from paying closer attention to the adjustment of products in
development to the number desired, even if the number desired is somewhat
inflated. The reason is that the adjustment term is just one of three
terms in the product generation rate. The fractional growth rate of the
number of products in development establishes the basic increasing pattern
in products in development, and it is also a potential source of
overcommitment of the development group. Growth goals from revenue growth
targets are common, and in the face of a tight labor market for engineers
product growth goals derived from revenue targets can easily exceed the
growth of engineering manpower in the group. The model computes a growth
factor for the total workload in the development group, setting it equal to
the long-term growth trend in revenues. That growth in workload is then
allocated by decisions internal to the model into a growth in the size or
technical complexity of products and a growth factor for the number of
products. The scarcity of engineers tends to pull the fractional growth
rate of people in the development group below the growth target, but the
growth target for products remains. A tendency to overcommit the group
results.

Run B shows that a lack of close attention to matching the number of
products in development with the group's resources is a source of rising
product development times. It seems likely that an accurate match would be
troublesome in the context of the extremely rapid corporate growth rates
exhibited in some high-technology industries.

Using Estimates of Engineering Efficiency

The further reduction in the rise of product development time shown
in run C in figure 9 comes from the use of additional information in the
system, information that may well tend to be ignored or judged impossible
to obtain reliably. That information is an accurate estimate of recent
engineering efficiency per person in the development group. Run C involves
the changes in run B plus an adjustment of desired team size to reflect
perceived changes in the average productivity of an engineer in the group.

In the base run desired team size increases proportionally as the
number of man-months in the product engineering requirement increases, and
also in response to increases in schedule pressure resulting from overruns
in product development times. As the firm tries to grow more rapidly than
its pool of available engineering manpower, it tries to expand the pool by
increasingly attractive salary offers and, reluctantly, by reaching further
into the pool, accepting not just the top ten percent of engineering
graduates, but the top twenty or the top thirty percent. As a result the
basic quality of the engineers in the development group declines slightly
from the start of a run, causing a slight drop in engineering efficiency.
(A more extreme drop in efficiency comes from increases in the time
engineers spend in various nonengineering tasks, which will be discussed
shortly.) In the base run that drop in efficiency is not taken into
account in setting the desired team size. Taking it into account, as in
run C, increases the estimate of the number of people per product needed
and produces still further gains in the battle against rising product
development times.

The improvement in run C comes not from hiring more people, however,
for the available pool of potential hires is still constrained and the firm
is doing as well as it can. Instead, the more accurate estimate of desired
team size reduces still further management's view of the number of products
supportable in the development group. (The equations for products
supportable by revenue and manpower are

        PSR = RDBE/(DTS*AES)
        PSM = TM/DTS

where
        PSR   = products supportable by revenue,
        PSM   = products supportable by manpower,
        RDBE   = R&D budget to engineers' salaries ($/year),
        DTS   = desired team size (people/product),
        AES   = average engineer's salary ($/person/year),
        TM   = total engineering manpower (people).

Thus an increase in desired team size lowers the estimates of the number of
products supportable.) The use of information about engineering efficiency
improves the decision of whether or not to introduce a product into
development. Throughout run C desired products in development is lower

than in the previous runs, with the result that the development group is
not as overcommitted. It is interesting to note that overcommitment of the
development group can result from the lack of a piece of information at a
certain decision point. Whether firms have access to accurate information
about current engineering efficiency is questionable, but if they have it
and do not use it they are inadvertantly creating part of the tendency for
product development times to rise.

(Perception delays or downward bias in engineers' estimates of a
rising product engineering requirement would have essentially the same
effect as the lack of information about efficiency: the desired team size
would be set slightly too low. In the context of a shortage of available
qualified engineers, the resulting tendency for product development times
to rise would come from inflated estimates of the number of products
supportable by the development group's resources. The base run of the
model assumed that the current product engineering requirement is
accurately estimated, so this potential source of rising product
development times was assumed away.)

Incentives

Policies aimed at improving productivity that do not address the
underlying problems exposed by runs A, B, and C may work in the short run
but will fail in the long run. Suppose, for example, that a dramatically
successful incentives program creates a permanent ten percent increase in
engineering productivity. A reasonable expection would be that product
development time should rapidly fall about ten percent, the amount of the
productivity increase. Tracing around the positive feedback loops shown in
figure 6, one sees that products would flow quicker into production,
revenue and revenue growth would rise, profits would rise, leading to an
increase in the R&D budget, and the product generation rate would
eventually rise in response, producing more products in development. With
the higher productivity the firm would enjoy higher revenues and a higher
revenue growth rate, but the tendency to overextend the development group
accordingly would remain, and product development times would rise back up
as a result. The feedback structure of the system compensates naturally

for the increase in productivity that stems from the incentives policy.[14]

The Organization and Communication Burden

        The sources of rising product development times discussed up to this point fail to explain the oscillatory patterns evident in figure 9. The oscillations can be traced to the way the firm handles what we have called the "organization and communication burden" of the growing development group. If each engineer were to spend a greater fraction of his or her time in non-engineering activities, less productive engineering time is available and product development times should rise as a result. Conversely, if less time were spent in non-engineering activities, product development times should fall. The model exhibits a recurring up and down cycle in the fraction of time an engineer spends dealing with the organization and communication burden of the development group. Consequently, there is alternating upward and downward pressure on product development times.

        The organization and communication burden is a highly aggregated concept in the model representing a mix of nonengineering activities assumed to be required in the normal operation of a development group. We intend the concept to include such things as reporting, coordinating members of a team, coordination between teams, budget preparation, scheduling, ordering materials, handling crises, interviewing and hiring, evaluation for salary and promotion decisions, and so on. It is a wide range of tasks, including many usually considered managerial. No attempt was made to model the detailed interactions the concept is intended to represent. The organization and communication burden was formulated simply to rise slightly more rapidly than the total number of engineers in the development group:

$$OCB = k * ENG^{OCBX}$$

where

        OCB = organization communication burden (man-months per month),
        ENG = total engineering manpower (people),

    k   = proportionality constant to set initial conditions,
    OCBX = an exponent slightly larger than 1.

(The exponent OCBX used in the above runs was 1.2.) The final section of
this paper discusses variations on the formulation for OCB.

The Fraction of an Engineer's Time in Nonengineering Activities

        The model assumes that a certain amount of the organization and
communication burden must be handled by engineers. Fifteen percent of an
engineer's time is deemed acceptable, normal, and largely unavoidable.
More than that, however, means an unacceptable loss of engineering
productivity and, if sustained, an increase in the tendency of senior
engineers to quit because of the uncomfortable administrative burden placed
upon them. Therefore, when it is perceived that engineers are forced to
devote more than fifteen percent of their time to nonengineering
activities, pressures build to speed the acquisition of more managerial and
support people. The primary role of managers in the model is to draw off
the burden of organization and communication activities from engineers,
increasing their productivity by leaving them freer to engineer.

        The cyclic pattern in the fraction of an engineer's time in
organization and communication activities can be traced to a set of
negative feedback loops and perception delays involved in the decision to
acquire managers. Figure 11 shows an overview of the structure assumed in
the model. (The equation for the acquisition of managers has exactly the
same basic structure as the equation given above for the product generation
rate: it contains a term to replace quits and retirements, a term for
growth, and a short-term adjustment to keep the number of managers equal to
the number desired.) Essentially, managers are promoted or hired in a
planned ratio to the number of engineers in the development group. As it
is perceived that engineers are spending too great a fraction of their time
in nonengineering activities, the company deliberately changes the planned
ratio of managers to engineers to correct the situation and return the
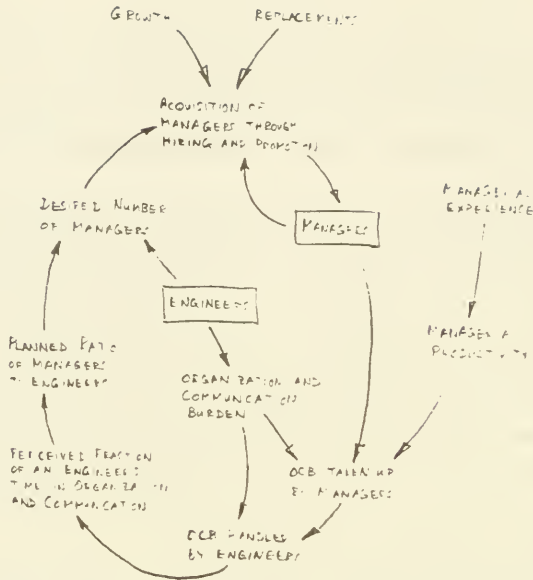development group to full productivity.

Figure 11: Structure underlying the cyclic pattern in
the fraction of an engineer's time in organization and
communication activities

The loop in figure 11 can be thought of as representing some aspects
of organizational change: a change in the ratio of managers to engineers
probably represents in reality a shift to another layer of management, or
to a matrix structure, or from matrix to product line organization. There
are several rather unavoidable delays around the large negative loop shown
in figure 11. It takes the engineers themselves some time to realize that
the time they can devote to engineering has gradually declined. Top
management takes even longer to come to the conclusion that past
orgainzational policy should be changed. Finally, once the decision to
increase managerial capacity has been made, the acquisiton of managers
takes time as well. These various perception and action delays around the
negative feedback loop tend to produce a natural oscillating pattern in the
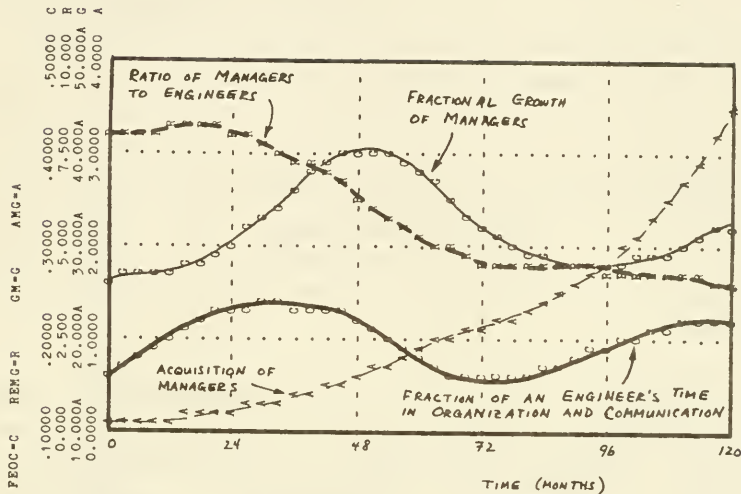fraction of an engineer's time in organization and communication.

Figure 12: Graphs of variables related to
organizational change in the base run, showing the
oscillating pattern of the fraction of and engineer's
time in organization and communication activities.

Figure 12 shows the pattern of the acquisition of managers in the
base run, together with the related behavior of the fractional growth of
the manager pool, the ratio of engineers to managers, and the fraction of
an engineer's time in organization and communication activities.   The
sequence of events these curves reflect is as follows: the burden of
organization and communication activities grows slightly more rapidly than
the development group. Additional managerial structure is acquired in
proportion to the growth of the group, but because the organization and
communication burden grows faster the planned ratio eventually proves to be
too small.   The fraction of an engineer's time in organization and
communication activities grows. When it is finally perceived that
productivity is suffering from having engineers deal with too many

nonengineering activities, steps are taken to increase the planned ratio of managers to engineers and speed the acquisition of managers. The planned ratio (the reciprocal of the quantity graphed in figure 12) continues to increase until it is perceived that the fraction of an engineer's time in managerial and coordinating activities has returned to an acceptable level. Delays in acquiring managers mean that the group has insufficient managerial capacity for a time and engineers have to fill in even more with organization and communication tasks. Perception delays mean that by the time the group believes it has brought the situation back to normal and the push to accelerate the acquisition of managers and support staff ceases, the rapid growth of the company has begun again to increase the fraction of an engineer's time in organization and communication activities, and the cycle repeats.

One result of this ebb and flow of group reorganization is periodic upward and downward pressure on product development times. In the base run it coexists with the insistent upward pressure on product development times that stems from the widening wedge between products in development and products supportable by manpower. The graphs of product development times in figures 7 and 9 are thus the result of two patterns superimposed.

A second result of this cyclic behavior is the pattern of quits of senior engineers shown previously in figure 8. Organization and communication activities interfere with what engineers would rather be doing. The tendency of senior engineers to quit is assumed in the model to increase eventually as the unofficial administrative burden placed upon them increases. More, however, is involved in figure 8 because an increase in quits of senior people has some self-reinforcing tendencies. Fewer people to handle the engineers' organization and communication burden mean that each must absorb that much more. In addition, the positive feedback loops associated with the assimilation of inexperienced engineers (described in figure 4) become active. There is less time available, for example, for the remaining experienced engineers to guide or advise new people, so the development of the less experienced engineers tends to be slowed. At the same time the remaining experienced people probably try to spend a bit more of their time providing such supervision, so the fraction

of time they can devote to their own engineering tasks may decline. Both
tendencies exacerbate problems in the group by lowering productivity,
increasing schedule pressures, and, if persistent, further increasing the
quit pressure on senior engineers.
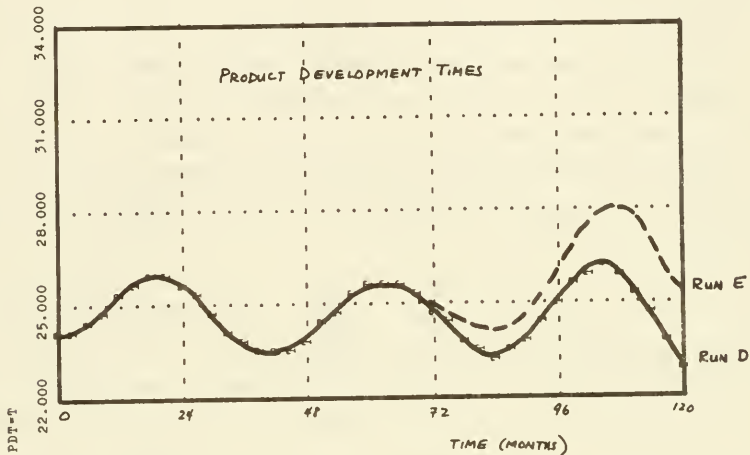

Figure 13:   The patterns of product development times
             with the conditions of run C (figure 9) plus:
             D - faster response to the need for managers, and
             E - the assumptions in D with limitiations on
                 effective team size.

     The pattern of product development times labeled D in figure 13 shows
the influence of the decision structure surrounding the acquisition of
managers. The run was produced with the assumptions of run C in figure 9
plus two parameter changes representing quicker organizational change.
First, the delay in perceiving the fraction of an engineer's time in
organization and communication activities was reduced from 18 months in the
base run to 6 months in run D. Second, given the perceived need for a
adjustment in the traditional ratio of engineers to managers, the
adjustment in run D takes place more rapidly. The quicker perception time

has a beneficial damping effect on the oscillations and shortens their period. The more aggressive fractional change in the traditional ratio of engineers to managers keeps the fraction of an engineer's time in organization and communication activities down more but adds greater instability. The result of the two changes together is a faster oscillation with slightly less amplitude than in run C.

Effective Team Size

A final simulation reveals an effect that has been omitted in these runs, partly to avoid obscuring other effects and partly because it is a matter of some controversy. Run E in figure 13 shows the results of run D in a more pessimistic scenario, in which it is assumed that the productivity per engineer in large teams is smaller than in small teams. Specifically, the effective team size of a product development team is assumed in run D to equal actual team size up to 10 people per product but then fall below actual team size. Because of anticipated increases in the number of man-months in the product engineering requirement, team size reaches 18 to 20 people by the end of these runs. Run D ends with about 21 people per product. With the assumed diminishing returns to team size, these 21 people are as productive as only about 17.5 people. The decline in productivity emerges toward the end of the run as team sizes get large, and productive development times rise accordingly as shown in figure 13.

The rise is not due to the absolute drop in productivity, however, but rather to the delay in perceiving engineering efficiency. Runs C, D, and E all assume that esimates of productivity are being used to plan manpower needs and decide on the number of products supportable in the development group. Placing the pessimistic effective team size assumption in the base run and runs A and B would push up product development times considerably further. Whether large teams can be effectively managed with no loss in productvity per engineer is an unanswered question not addressed in this study.

V.   Policy Implications

     The preceding analyses show that a pattern of rising product
development times can be traced to two relatively independent sources that
have little to do with rising technological complexity. One has the
capability to push up product development times continually; the other
generates fluctuations in engineering productivity that translate into
relatively short-term ups and downs. The cyclic pattern is due to the
structure involved in the planning for and acquisition of managers and
support people. The long-term pressure upward on product development times
comes from the structure of the decision to introduce a product for
development. Both structures involve the organization's attempt to
coordinate a number of people with the extent of the tasks they are
expected to discharge. In terms of the simple identity (2) that initiated
this discussion,

$$\frac{\dot{PDT}}{PDT} = \frac{\dot{PER}}{PER} - \frac{\dot{ENG}}{ENG} + \frac{\dot{PDEV}}{PDEV} - \frac{\dot{PROD}}{PROD}, \tag{2}$$

one structure seeks to match engineers and products in development in such
a way as to hold

$$- \frac{\dot{PER}}{PER} + \frac{\dot{ENG}}{ENG} - \frac{\dot{PDEV}}{PDEV}$$

to zero. The other tries to match managerial and support people to the
organization and communication tasks of the group so that engineering
productivity does not drop and

$$\frac{\dot{PROD}}{PROD}$$

does not become negative.

     Table 1 shows some additional information about the simulations in
section IV that would be necessary to evaluate the policy alternatives
implicit in them.

Table 1: Comparison of the initial and final values of selected
quantities in the base run and five policy simulations.

Run	PDT	MER	PDEV	PGEN	COMP	PIP	MSH	REV $(x10^6)$	PVCGP $(x10^6)$
Initial values -									
All	24.0	.56	6.0	3.9	3.0	6.4	.200	19.9	0.0
Final values -									
Base	31.2	.46	20.9	10.1	8.1	29.4	.227	449.4	668.6
A	29.9	.50	21.7	11.0	8.7	31.2	.239	474.5	687.7
B	27.2	.50	19.8	10.5	8.7	31.5	.240	477.1	689.2
C	25.4	.50	18.6	10.2	8.8	31.9	.242	480.9	717.3
D	22.9	.57	19.0	11.3	10.0	33.1	.250	496.0	709.5
E	25.4	.48	17.5	8.6	8.3	30.9	.239	474.7	701.7

    PDT   = product development time (months)
    MER   = manpower efficiency ratio (dimensionless
            measure of engineering productivity, FTE/ENG)
    PDEV = products in development
    PGEN = product generation rate (products/year)
    COMP = completion rate (products/year)
    PIP   = products in production
    MSH   = average market share
    REV   = current revenue ($/year)
    PVCGP = present value of cumulative gross profit over
            the course of the simulation ($)

Table 1 shows that the policy simulations A, B, and C discussed in
section IV improve a number of indicators of the health of the company and
its product development group. Each successive policy adds more control to
product development times and improves the cumulative gross profit
indicator computed in the model. Run D adds improves the indicators still
further, with the apparent exception of the cumulative gross profit
(computed as a discounted present value over the course of the run).
Profit in this run is less because the development group has significantly
more managerial and support people by the end of the run relative to
engineers (managers = 115, engineers = 384 in D vs. 98 and 386,
respectively, in C). The salary scheme assumed in the model says managers
are paid more, so run D winds up with a more costly organizational
structure and profits are reduced even though revenues and revenue growth
are greater. (The profit figures should be viewed with skepticism,
however, because the model does not assume a technological ladder of
advancement that pays very senior engineers as much as managers.)

It is hardly surprising that policies that do a better job of
matching the size of the engineering group to the tasks they are expected
to accomplish also do a better job holding down product development times.
And it is also not surprising that lower product development times would
tend to improve market share and revenues. More interesting is the
observation that in run C the completion rate of products under development
by the end of the simulation is actually greater than in previous runs,
while the initiation rate (PGEN) is less. Recall that the policy in run C
served to reduce the estimate of the number of products supportable by
revenue and manpower and, consequently, to slow the rate of introduction of
new projects. Less is being put in to the development group, but slightly
more is coming out. The difference is tiny, but the run appears to
contradict the feeling of "more in, more out" that tends to pressure
working groups of all kinds.

The reasons for this behavior are to be found in the feedback nature
of the system. Lower product development times tend to reduce the
pressures that arise from being behind. Less schedule pressure, for
example, means less quit pressure on senior engineers, and that means less
turnover in the engineering group. The engineers at the end of run C are
actually just slightly more productive than those at the end of run A,
although that fact is obscured in the table because the values of MER round
to the same two decimals (MER = .495 in A, .496 in B, and .498 in C). (The
reason they are not significantly more productive is that the model assumes
short term gains in productivity from schedule pressure, and that effect
helps to counter the losses from turnover.) The feedback to and from the
market is more significant, however. The greater revenue stream that
results from lower product development times allows a slightly greater
engineering group to be hired, and as a group they complete slightly more
products per year.

Transferability of Results

The goal of the analyses in section IV is eventually an increased
understanding about the relationships between structure and behavior in a

real product development group. The analyses suggest several potential
sources for rising product development times that have not been previously
acknowledged. In the context of very rapid corporate growth it is
apparently difficult to match accurately the size of the engineering and
manager pools to the size of the jobs they have to perform.

        The critical question for model-based analyses is their
transferability: to what extent should we believe that policies that work
in the model will work in reality? The answer hinges on our confidence in
the degree of match between the real system and the model.

        One might ask, for example, if a company does not acquire managers in
a planned ratio to engineers, are analyses based upon the model not
applicable? The personnel from the company that participated in this
study could not give an aggregated view of the acquisition of managers in
their development group. They accepted the formulation in the model as a
reasonable abstraction and simplification suiting the model's purposes, but
they felt that in reality an additional manager was acquired when it was
perceived that a new job had come to exist in the group. Does that suggest
that the oscillatory pattern observed in the model relating to the
acquisition of managers is likely not to be a contributor to that company's
rising product development times?

        While there is no clear-cut answer, we suggest that the way to pursue
answers is to focus on the essential structure in the model responsible for
the pattern of behavior, and to try to compare it to the corresponding
essentials in the real system. The essential source of the oscillations in
the fraction of an engineer's time in organization and communication
activities in the model is a large negative feedback loop with some
information and acquisition delays (see figure 11). Some such negative
feedback loop must exist in the acquisition of managers in real systems --
there must be a view of the number of people needed and some process of
adjusting actual numbers to that need, and that structure tries to negate
or counteract deviations of actual considitions from desired. The critical
question is are there sufficient perception delays and lags in the
adjustment structure in the real system to produce the sort of oscillations

the model exhibits? And just before a new managerial post is created and filled, how are the components of that job being handled? Does the creation of the new managerial post leave engineers with more time to engineer? Were engineers, in fact, handling some of that administrative burden? Those who wish to apply notions from this study will have to address such questions in their own contexts.

We might agree that transferability or applicability of the results of this modeling study depends on the matching of essentials, not the congruence of all details. Still, the extremely high level of aggregation involved in the formulation of the organization and communication burden, OCB, is a potential source of a lack of confidence in the model-based analyses. Current work is exploring formulations that compute OCB as a function of product team size (people per product) as well as the total size of the development group. Sources in our reference company suggest that team size has a significant effect on OCB; they estimate that a doubling in the average size of a product development team would increase the organization and communication burden more than a doubling in total engineering personnel (other things being equal).

Experiments with model reformulations of OCB involving team size as well as the total group size have raised an intriguing set of questions about the nature of the real system. Management systems must try to match the number of managers with the size of the task they are supposed handle. However, it seems in the nature of real management systems that it is not possible for a company to directly perceive the size of the organization and communication burden. However it is formulated in a model, it must be inferred, probably from the number of people engaged in it and the extent of their effort. The company must try to match the growth of its managerial staff to the growth of an assumed or inferred organization and cummunication burden. The matching is made more difficult if one assumes that managers themselves add to the organization and communication burden they are supposed to discharge.

Although investigations in reformulations of the model relating to the organization and communication burden are incomplete, the behavior of

the model appears to remain much the same as shown above. Again, a
fundamental negative loop with perception and action delays surrounding the
acquisition of managers tends to produce an oscillatory pattern in the time
an engineer spends in these nonengineering activities. While some of the
details differ, the basic structural insight remains unchanged.

Excess Capacity

        Perhaps the single most powerful notion to combat the sources of
rising product development times suggested in this study is excess
capacity. Excess managerial capacity could move in to absorb unforseen
increases in the organization and communication burden of an engineering
group, before engineers were forced to divert some of their time and energy
to more nonengineering tasks. It would be costly, of course, and it would
be difficult to be sure the productivity gains and eventually revenue
returns would justify the additional managerial cost. As the summary
figures in table 1 show, one might conclude that competing goals are
affected differently: in run D, for example, market share improves and the
company has more products on the market, but cumulative profits are down
compared to run C.

        Though perhaps harder to implement, excess engineering capacity could
also be considered. It could take the form of a slight relaxation in the
some of the pressures described in section III that combine to lead to
overcommitment of resources. In judging product development proposals that
are competing for the same resources, for example, management could try
balancing incentives to underestimate the resources necessary with
incentives to bid accurately. Again the critical question is whether the
benefits would outweigh the costs, and the answer would undoubtedly depend
upon circumstances.

        In the final analysis there is the question of whether the benefits
that result from holding down product development times outweigh the costs
of the effort required. How does the relative influence of product
development time on revenue, market share, or other corporate bench marks
compare with the influences of product availability, marketing effort,

service, or responsiveness to consumer demands? If dollars are to be spent
improving the company's competitive position, should they be spent to hold
down product development times, or should they be spent improving
production facilities? In focusing solely on the product development group
and on behavior of product development times this study has not addressed
that question. The leverage commonly attributed to R&D in high-technology
industries suggests (but does not prove) that controlling product
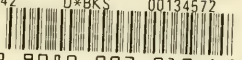development times may be worth the effort.

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