WORKING PAPER
ALFRED P. SLOAN SCHOOL OF MANAGEMENT

RATIONALITY AND STRUCTURE IN BEHAVIORAL MODELS OF BUSINESS SYSTEMS

by

John D. W. Morecroft

WP-1430-83

MASSACHUSETTS
INSTITUTE OF TECHNOLOGY
50 MEMORIAL DRIVE
CAMBRIDGE, MASSACHUSETTS 02139

RATIONALITY AND STRUCTURE IN
BEHAVIORAL MODELS OF BUSINESS SYSTEMS

by

John D. W. Morecroft

WP-1430-83

D-3419-1

RATIONALITY AND STRUCTURE IN

BEHAVIORAL MODELS OF BUSINESS SYSTEMS

By

John D. W. Morecroft
System Dynamics Group
Massachusetts Institute of Technology
Cambridge, Massachusetts

To be presented at the 1983 International System Dynamics Conference, Chestnut Hill, Massachusetts, July 27-30, 1983

February 1983
Revised April 1983

The author received valuable help and suggestions on an earlier draft of this paper from Jay W. Forrester, John M. Richardson, John D. Sterman, George P. Richardson, and Robert L. Eberlein.

ABSTRACT

Rationality is an underutilized concept for creating and analyzing behavioral simulation models of business systems. Much explanatory power and insight can be gained by assuming that business decisionmaking is intendedly rational, examining the factors that limit rational adjustment in business decisions, and exposing in simulation experiments the rationality that underlies even the most counterintuitive total-system behavior.

The paper begins by defining rationality and illustrating the difference between objective rationality, which is common in classical economic models of decisionmaking, and bounded rationality, which is common in behavioral models of decisionmaking.

Two methods of analysis are then proposed for clarifying the theory implicit in a simulation model. The first method is premise description. In describing decision functions and model equations attention should be drawn to the organizational processes of factoring, goal formation, routine and tradition that limit the area of rational adjustment in business decisionmaking. The second method is partial model testing. A sequence of partial model tests should be designed to examine the intended rationality of decisionmaking. The intuitively clear and sensible behavior of partial tests should be contrasted with the more complex and often counterintuitive behavior of the whole model.

The application of these methods is illustrated with a simulation model of a sales organization containing linked decision functions for sales objectives and salesman overtime, and a behavioral function for sales force motivation.

INTRODUCTION

Suppose we learn that a magazine publisher goes out of business and that the circumstances leading up to the collapse are record losses and, at the same time, record revenues and circulation--circumstances that have occurred a number of times in the past.[1] What do we conclude about the rationality of the publisher's strategy? It is clearly unreasonable to assume that the business failure occurred because strategy was deliberately designed to cause major losses. Rather, the separate policies comprising the strategy were intendedly rational, but when linked in a commercial setting they produced an unexpected and undesirable outcome.

The thesis of this paper is that rationality is an underutilized concept for creating and analyzing behavioral simulation models of such business problems. There is a great deal of explanatory power and insight to be gained by assuming that business decisionmaking is intendedly rational, examining the factors that limit rational adjustment in business decisions, and exposing in simulation experiments the rationality that underlies even the most nonrational total-system behavior.

For example, suppose we have a simulation model of the familiar industrial production and distribution system[2]. The model is composed of many interrelated decision functions for ordering, inventory control, forecasting, labor adjustment, and so forth. It is well known that such a system produces costly fluctuations in production, orders and labor force. (Mack 1967) The behavior is at first surprising, because we assume that retailers, manufacturers, and vendors are not intending to create a costly system--in fact, quite the reverse. Simulation analysis by itself is capable of showing that fluctuation is a possibility. But simulation coupled with an analysis of rationality can reveal how such fluctuations arise from intendedly rational decisionmaking and therefore why the behavior is likely to persist.

In the paper we will first explore the concept of rationality in decisionmaking, drawing on the ideas of the Carnegie school. We will then describe two methods of model analysis--premise description and partial model testing--that can clarify and better communicate the theory implicit in a simulation model.

OBJECTIVE AND BOUNDED RATIONALITY

Simon (1982, p. 209-238) has characterized theories of objectively rational behavior as

> ...those that employ as their central concepts the notions of (1) a set of alternative courses of action presented to the individual's choice; (2) knowledge and information that permit the individual to predict the consequences of choosing any alternative; and (3) a criterion for deciding which set of consequences he prefers.

Objectively rational behavior is possible, when the conditions surrounding decisionmaking are very simple. Consider, for example, an individual faced with the choice between wearing and not wearing a raincoat in a violent rainstorm. The consequences are to stay dry or get wet in the rainstorm, and the presumed criterion is that the owner wishes to stay dry. Objectively rational behavior is likely because the choices are very limited (only two), the consequences obvious, and the criterion straightforward to apply and unlikely to change.

By contrast, our magazine business strategy is much more complex. It is very difficult to reliably deduce the consequences of the interacting policies underlying strategy. Consider pricing policy as one element of the overall business strategy (and bear in mind that in the magazine publishing industry subscription prices affect circulation, which in turn affects advertising revenue: advertisers will pay more to advertise in a magazine with high circulation). (Hall 1976) To anticipate the effects of a price change, and therefore to set prices rationally, one must fully understand customer needs, the structure and maturity of the market, competitor prices and price responses, not to mention the circulation requirements of advertisers and the general economics of the publishing business. The consequences of alternative prices are contingent on an enormous chain of linked events. Objectively rational magazine pricing is much more difficult than objectively rational weatherproofing!

It is helpful for our later discussion to picture an objectively rational decisionmaking process. Figure 1 shows information (say, about weather conditions) flowing from the environment into the decisionmaking process. The information prompts the selection of an appropriate course of action from a set of alternatives. Given a criterion--the desire to stay dry--and the exercise of intelligence--the ability to deduce that a raincoat ensures dryness--a rational course of action is selected. In general, a wide range of alternatives may be considered. A course of action is selected that optimizes a criterion function, shown in the figure as f(x,y,z). Adequate intelligence, shown as a memory matrix, is available for the storage of information and the prediction of consequences.

The figure readily allows for considerable complexity in the decision process. It is possible that a course of action will influence the environment (shown by a return flow of information). Objectively rational behavior will have available the mental capacity to factor these interactions into the selection. It is possible that the set of alternatives is very large, and the criteria subtle and interdependent. Objectively rational behavior handles this complexity with ease and precision.

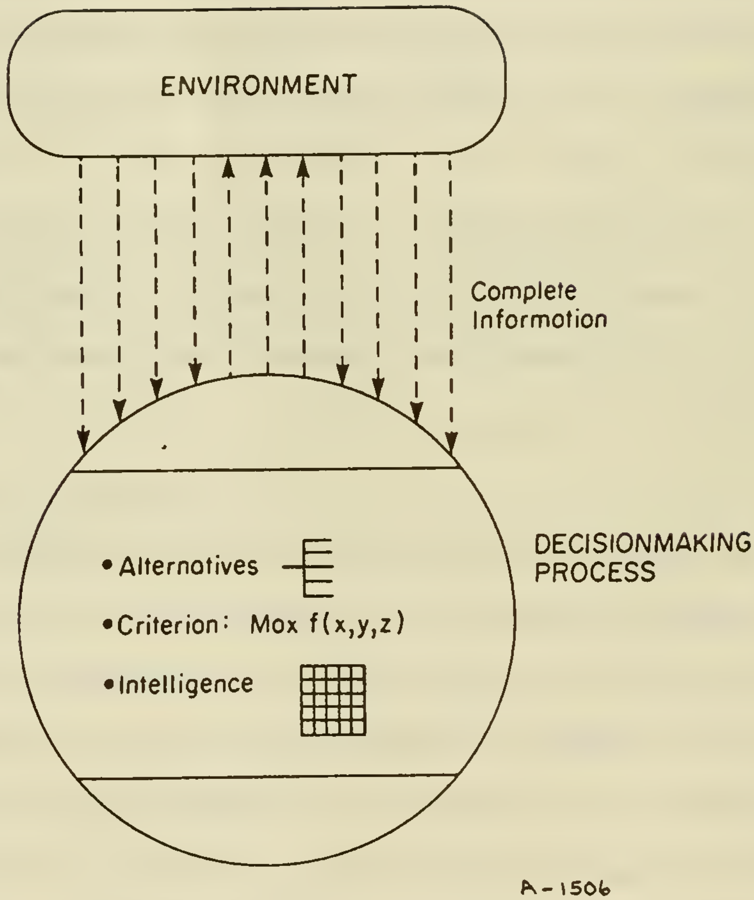

Figure 1. Picture of Objectively
Rational Decisionmaking

Bounded Rationality

Problems of choice in business organizations are very complex. To set an objectively rational production plan in a manufacturing firm, one would want to know the personal circumstances and state of mind of all potential customers, the sales plans of all retailers, the exact status of retail and distribution inventories, the status of manufacturing inventories, the condition and availability of plant and equipment, the willingness to work of the workforce, the production plans of all suppliers, and the capacity, production, and promotion plans of all competitors. In addition, one would need a sound and detailed knowledge of the economics of the industry to compute and compare the financial consequences of alternative production plans.

No individual can possibly hope to solve problems posed in such complex terms. Yet organizations exist, they are managed by ordinary people, often with great success. This seeming paradox is readily explained when we realize that organizations are structured to "transform intractable decision problems into tractable ones." (Simon 1979, p. 501) Individuals in organizations exhibit only bounded rationality--they make rational decisions under conditions of choice that have been deliberately simplified.[3] There is usually a rationale for any business decision. Whether that rationale "makes sense" for the organization as a whole depends on whether the simplified conditions of choice lead to actions that support the goals of other parts of the enterprise.

The challenge to the modeler and theorist is to be sensitive to the many ways in which conditions of decisionmaking can be simplified, and to develop the vocabulary for recognizing and describing such situations. As Simon (1982, p. 215) has pointed out:

> Significant models can be constructed by singling out for attention, and for embodiment in them, the significant limiting conditions that serve as boundaries to the area of rationality in human behavior.

Factored Decisionmaking

One way to simplify a complex decisionmaking process is to factor it into small pieces as shown in figure 2. Within each decision function there are few alternatives, simple criteria to be satisfied, and intelligence matched to the simplified problem. Factored decisionmaking is an inescapable empirical feature of all organizations. (Allison 1971; Cyert and March 1963) There are important structural implications of such an arrangement. Information is distributed among the various decision nodes of the system. Each node receives only part of the available flow of information--an amount sufficiently small to allow timely processing and action. Organizations are clearly a long way from monolithic thinking; they are systems of weakly coupled, distributed thinkers. Models should properly reflect this obvious structural feature of the information network.

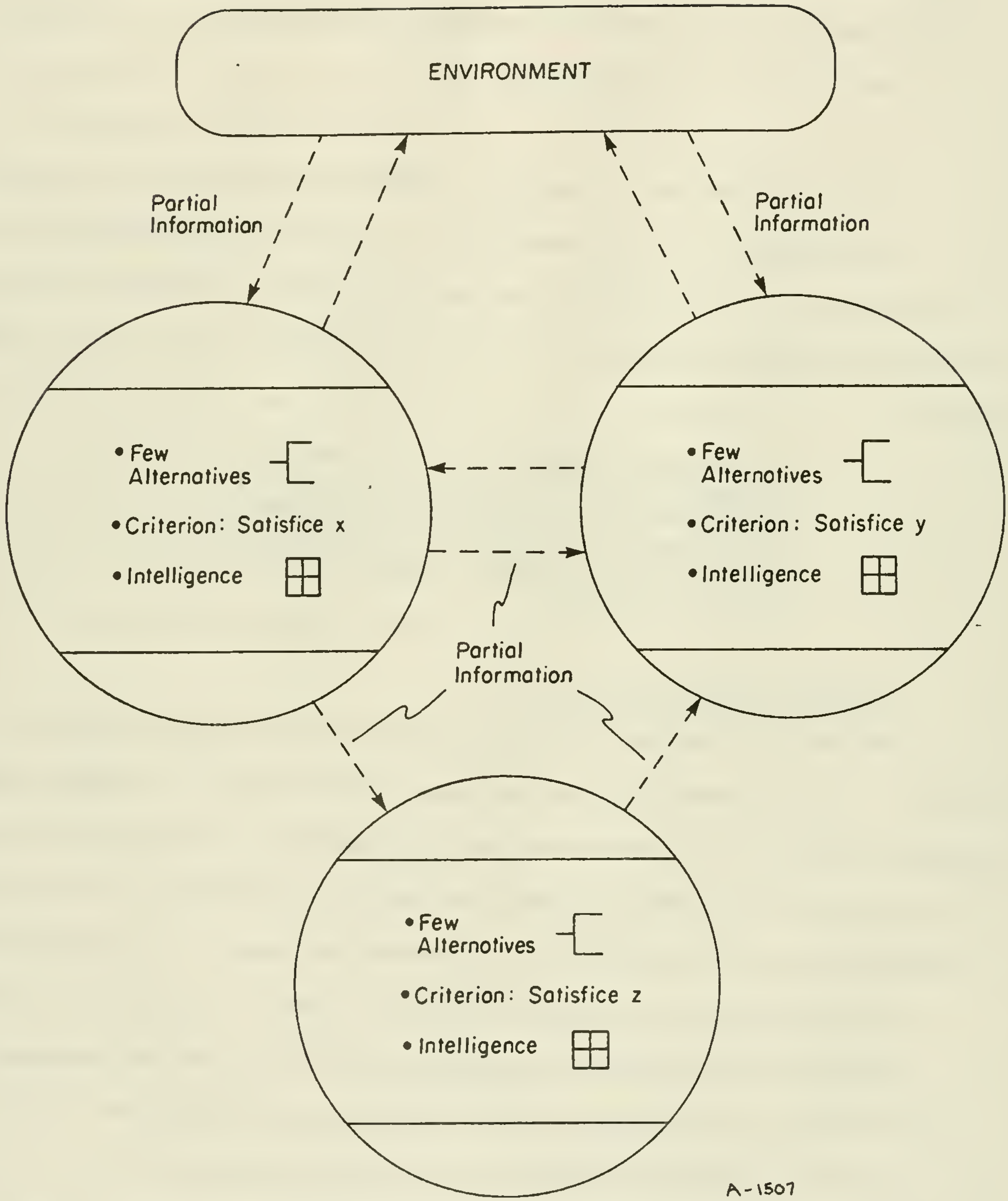

Figure 2. Factored Decisionmaking and Bounded Rationality

Goal Formation and Incentives

Goals and incentives can simplify decisionmaking by focusing the attention of an individual on a small part of the enterprise and making him responsible and accountable for its success. In terms of information flows (and therefore model structure), goals and incentives determine what information is viewed as important, and what is considered irrelevant at different points of the organization.[4]

Authority, Culture and Style

Authority, culture and style also simplify decisionmaking, though often in intangible ways. They serve to transmit basic values and traditions of the organization to all its members. Authority and culture permeate thinking at the decision nodes of the enterprise, altering the premises of decisionmaking and often introducing bias and distortion into the interpretation of information.

For example, in an interesting case modeled by Forrester (1968,1) the president of a company with a fast-growing new product line insisted on maintaining strict personal control over the approval of all capital expenditures. As a result there was a bias in the company's decision process for capital-equipment ordering. Considerable demand pressure, in the form of high order backlogs, had to accumulate to justify expansion. The model that incorporated this conservative facet of executive style showed that the bias in capital-equipment ordering could cause sales to stagnate in a potentially enormous market.

Routine

Organizations are great storehouses of specialized decision processes and routines. (Allison 1971, p. 83; Nelson and Winter 1982, pp. 96-136) Experienced employees carry around in their heads a repertoire of standard responses to recurrent business situations. Routines are yet another way of simplifying decisionmaking. They predetermine the information to be used in decisionmaking and supply rules of thumb for processing the information. Typically, routines use small amounts of information and simple rules of thumb. For example, a pricing policy might be routinized to set prices for this year's product x-percent higher than last year, where the percentage increase is governed, say, by inflation in costs. Routines are important because they introduce momentum into organizational behavior. An organization that encounters rapid change in its environment (say, competitor prices) may find its repertoire of standard responses (cost plus pricing) inappropriate to the new situation.

Basic Cognitive Processes

When the conditions surrounding decisionmaking have been simplified by factoring, by goal formation and incentives, authority, culture, and routine, there still remain limitations on rationality imposed by basic cognitive processes.[5] People take time to collect and transmit information. They take still more time to absorb information, process it, and arrive at a judgment. There are limits on the amount of information they can manipulate and how much they retain in memory. These basic cognitive processes are also a part of bounded rationality--in fact, the basic constraint on rationality once organizational measures to improve it have been exhausted. Cognitive processes can introduce delay, distortion, and bias into information channels which the modeler should try to capture.

Summary

In this section we have explored the two concepts of objective and bounded rationality in some detail. Objective rationality is an ideal of rationality that requires monolithic, highly integrated thought and is rarely exhibited in real choice problems, except perhaps trivial ones. Bounded rationality is the rationality of normal humans in real organizations. To portray and interpret bounded rationality in a model requires a knowledge of features of organization used to simplify decision-making: factoring, goal formation, incentives, authority, culture, style, and routine.

USING RATIONALITY TO PROVIDE STEPPING STONES IN MODEL-BASED THEORY

This section proposes two methods of analysis--premise description and partial model testing--for clarifying the structure of computer simulation models and refining their implicit theories of behavior. Both methods examine the bounded rationality of the model's decisionmaking--first at the level of equations, then at the level of simulation runs. The two methods provide stepping stones to fill the (usually) large gap in logic between the assumptions embodied in single equations of a model and the simulated consequences of the many equations.[6]

Premise Description of Decision Functions

Premise description is similar to a normal equation description (see, for example, Forrester 1981, pp. 215-251). But where a normal equation description reports in a journalistic sense how decisions are made, premise description goes further by focusing on the simplifying conditions/organizational processes that bound the rational adjustment of each decision function.

The modeler starts with a diagram of the model system showing the network of interlinked decision functions. He then presents the equations corresponding to each decision function, drawing attention to the way factoring and local goals simplify rational choice; how authority and culture influence the content and interpretation of information streams; and how routine and cognitive limitations influence the collection, processing, and transmission of information.[7] At the back of his mind the modeler has as a yardstick the notion of objective rationality. This yardstick raises questions of why some information is available in a decision function and other is not, why delay and distortion occur in the transmission and interpretation of information, and why bias is present. The answers to these questions naturally point to empirically observed organizational processes that underlie bounded rationality.

Such a model description alerts the reader to the deficiencies present in the information network and signals the possibility of problem behavior in the system as a whole. The decision functions of the model are seen to be intendedly rational within the bounds set by common organizational practice, yet far removed from the demanding standards set by objective rationality.

No unique way exists of describing the "extent of rationality" of a given decision function or for measuring how much a function departs from objective rationality. The description of premises simply makes the modeler (and reader of the model) conscious of the limitations on decisionmaking embodied in the model.

In cases where substantial insights have been gained into the conditions required for "optimal" decisionmaking, the yardstick of objective rationality may be applied with more precision. For example, in the well-studied area of production planning and control (Bitran and Hax 1977; Holt et al. 1960), there is considerable understanding of how aggregate production rates should be set to minimize inventory carrying, set-up, and overtime costs. The information content of a heuristic production planning decision rule might be judged against the richer and more complex information structure of the "optimal rule."[8] But, more often, it is up to the modeler to decide how best to draw the attention of the reader to the bounded rationality implicit in the simulation model.

Partial Model Tests of Intended Rationality

The second method of model analysis is partial model testing. Partial model testing has long been used in simulation modeling to debug subsystem models prior to whole model simulations. Here we suggest that partial tests have a much more important role to play in model analysis. They should be used to expose the intended rationality of business decisionmaking.

There is a single assumption that justifies the new and important role of partial model tests. It is that decisionmaking is rational within the context of the premises supplied to the decisionmaker and the limits of his mental computing capacity.[9] This assumption enables one to decompose a complex simulation model into small pieces and to expect simulation runs of the pieces to reveal intuitively clear, plausible behavior. The partial tests should show that local decisions are well adapted to achieving local goals provided the organizational setting is sufficiently simple. The assumption of intended rationality does not imply that the behavior of the whole system is well adapted to the many goals of the enterprise. Dysfunctional behavior of the organization is quite possible but is a systemic problem resulting from the coupling of decision functions--in other words, a flaw in the structure and design of the organization as a whole.

The analysis begins with a causal-loop diagram (Richardson and Pugh 1981, pp. 25-30) that shows compactly the feedback loops resulting from organizational, cognitive, behavioral, and physical assumptions of the underlying equations. The causal-loop diagram is then used to design a sequence of simulation experiments to explore the behavior of pieces of the total feedback structure.[10] The tests show how one (or perhaps a few) decision functions work when the premises of rational adjustment for the functions are not seriously violated. Partial tests are then compared with whole model tests to understand the causes of behavior (particularly dysfunctional behavior) in the complete system.

For example, in a model of production planning and labor adjustment containing simple linear inventory control and labor hiring rules (Forrester 1968,2; Holt et al. 1960, pp. 363-388), it is instructive to consider how the inventory control rule performs when the delay in adjusting production (caused by labor hiring) is made small. (Lyneis 1980, pp. 185-205) Under this partial model test aggressive inventory management (meaning rapid correction of inventory imbalances) always has the intuitively correct effect of bringing inventory in line with its goal quickly. The premise of the inventory policy (eliminating inventory discrepancies quickly) is perfectly valid if production can respond instantaneously to requests for inventory replenishment. However, in the complete model, when a labor adjustment delay of say four to six weeks is present, rapid correction of inventory discrepancies leads to the initially counterintuitive result that inventory rebalancing is delayed. The system becomes quite oscillatory and takes a long time to settle into equilibrium.

The great strength of partial model testing is most apparent when the whole model (or some larger configuration of loops) exhibits counterintuitive and highly ineffective behavior.[11] Then it is apparent that the surprise behavior of the whole model is a consequence of the interaction of many intendedly rational parts. In other words, in the coupling of the many decision functions, the premises or conditions for rational adjustment of individual functions are violated. In these situations a system of decision processes fails to integrate in a way that the rationality of the parts is a close approximation to the objective rationality required for success of the total system. The contrast of partial and whole model tests provides a powerful explanatory tool for behavior analysis and theory creation.

A BEHAVIORAL MODEL OF A SALES ORGANIZATION

In this section a simple model of a sales organization is described and analyzed using the methods of premise description and partial model testing. The simple model is based on a much larger model developed to examine marketing strategy for a vendor of advanced office equipment. The larger model contained more than 100 active equations describing some twenty interlinked decision functions, covering customer purchasing and price perceptions in the market, and salesman time allocation, overtime, motivation, and objective setting in the sales organization.[12] The structure of the larger model, in terms of factored decision nodes, information flows, heuristics, routines, biases, and so forth, was derived from the operating knowledge of members of the project team and subject area experts in sales and marketing. The information was gleaned mostly from interviews and roundtable discussions as described in Morecroft (1983,2).

The simple model contains just 14 equations and focuses attention on the decision functions for overtime and objective setting, and the behavioral function for sales force motivation. The structure and parameterization of these functions are virtually unchanged from the larger model. The rationality of the simple model is therefore representative of the larger, empirically derived model. Moreover, its simulated behavior, to be described later, has much in common with the more complex model.

Model Overview - Factored Decisionmaking

Figure 3 shows the policy structure of the simple model containing six functions for sales, sales objective, performance, overtime, motivation, and sales effort.[13] From discussions in the sales organization it was clear that revenues and profitability were a major concern of chief executives. But there was obviously no monolithic, integrated decisionmaking process for maximizing either revenue or profit. Rather, the task of maintaining acceptable rates of revenue and profit was factored within the sales organization among marketing managers, staff analysts, and salesmen. Figure 3 depicts this factoring.

On the right side of the figure, sales are generated by the sales effort of individual salesmen. Market planning managers and their staff have the responsibility for setting challenging sales objectives, which they do largely based on past sales performance. The sales objective is then handed to the field sales force that has the responsibility of deciding how much time must be expended to meet the objective. The major decisionmaking nodes, then, are the setting of the sales objective, which is factored to market planning; assessment of sales performance, which is factored between field sales managers and their salesmen; and finally the overtime decision, which is the personal responsibility of individual salesmen.

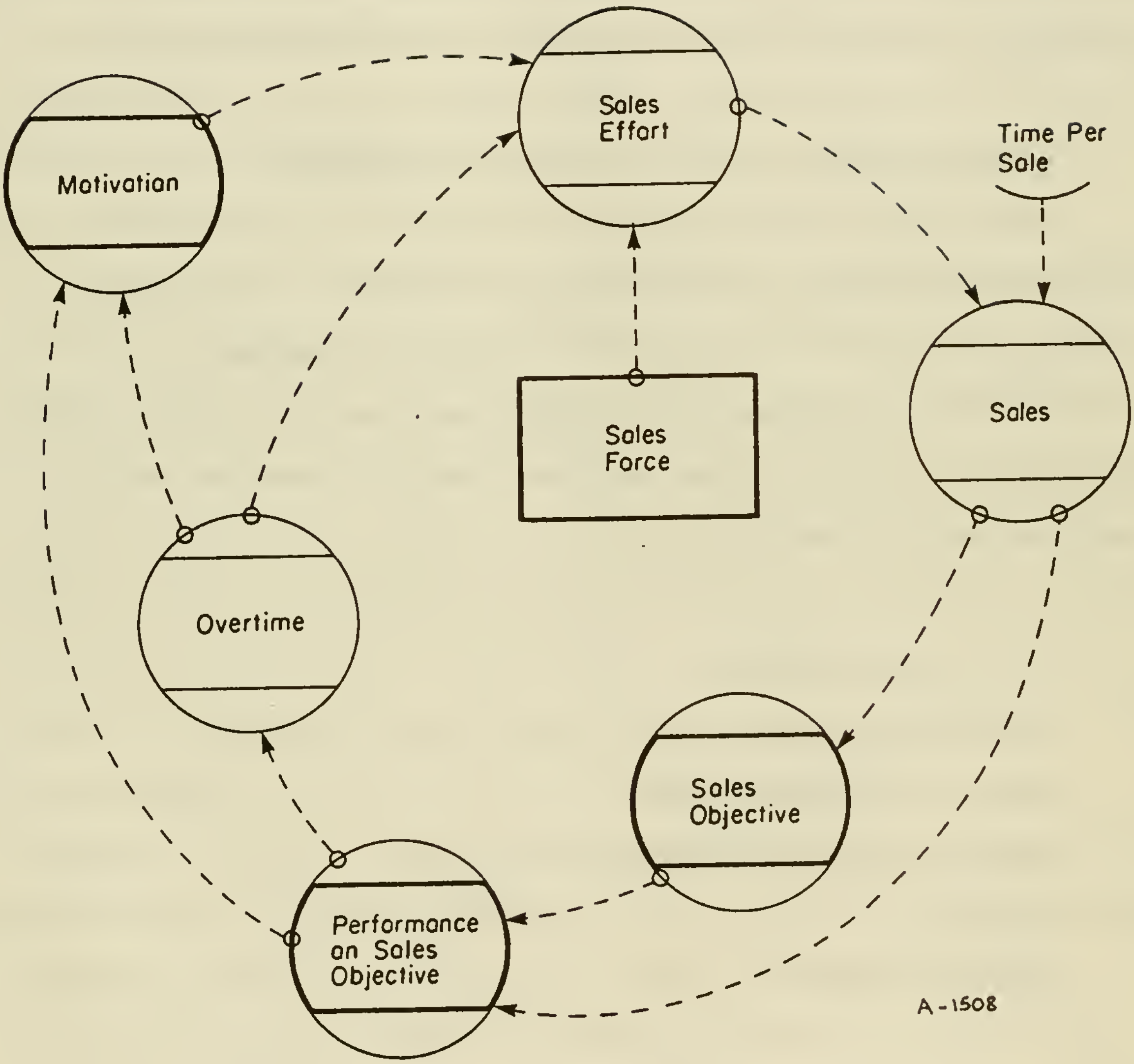

Figure 3. Policy Structure of A Simple
Sales Organization

The figure also shows functions for motivation and sales effort. Motivation is a purely behavioral function that portrays the response of salesmen to varying conditions of workload (measured by overtime) and performance. Sales effort is a behavioral/physical function that computes how much sales effort is available from a given number of salesmen working a given amount of overtime at a particular level of motivation.

Premise Description of Decision Functions

This section describes the premises of decisionmaking for the setting of sales objectives and overtime. The description draws attention to the sources, uses, and interpretation of information in the sales objective and overtime functions.[14] A documented listing of the equations of the complete model is included in the appendix.

a). Sales Objective

$$MSO_t=MSC_t*(1+MASC) \quad (1)$$

$$MASC=0.05 \text{ Dimensionless} \quad (1.1)$$

$$MSC_t=MSC_{t-1}+(1/TESC)(MS_{t-1}-MSC_{t-1}) \quad (2)$$

$$MSC_0=MS_0 \quad (2.1)$$

$$TESC=12 \text{ Months} \quad (2.2)$$

where MSO - Monthly Sales Objective (Units Per Month)

MSC - Monthly Sales Commitment (Units Per Month)

MASC - Margin for Achievement of Sales Commitment (Dimensionless)

MS - Monthly Sales (Units Per Month)

TESC - Time to Establish Sales Commitment (Units Per Month)

The sales objective is set by market planning managers and their staff. The process is a particularly interesting example of bounded rationality that illustrates the role of authority, organizational routine, and cognitive limitations in forming the premises of decision.

Equation 1 states that the monthly sales objective MSO is based on a monthly sales commitment MSC inflated by a fixed margin MASC of 5%. The formulation captures a political goal formation process. Managers make a commitment to higher-level executives to sell a certain number of units in their sales region. Their own performance as managers is judged on their ability to fulfill this commitment. To build in a margin of safety for themselves and a challenge for the sales force, they deliberately inflate the sales objective above their own commitment, in this case by a margin of 5%. The margin provides security for the market manager and, at the same time, pressures the sales force to improve on its past sales performance. It is a remarkably simple device by which executive pressure for cost-effective performance can be transmitted through middle-level managers to affect the efforts of salesmen.

Equation 2 states that the monthly sales commitment MSC is an exponential smooth (Forrester 1961, pp. 406-411) of past monthly sales MS with a time constant TESC of twelve months. At the heart of the sales-commitment process is the routine of commiting to sell in the future the same amount as was sold in the recent past. It is a routine that demands little detailed information--certainly much less than would be required by sophisticated market forecasts or other more formal and more "rational" approaches to commitment and planning. Yet there was wide agreement in the organization that the real process was heavily dependent on recent sales.

b). Overtime

$$MOT_t = f_1(PSO_t) \qquad (3)$$

where MOT - Multiplier From Overtime (Dimensionless)

PSO - Performance on Sales Objective (Dimensionless)

f_1 - Nonlinear Decreasing Function of PSO

Equation 3 for overtime states that salesmen take performance on the sales objective PSO as the premise for their overtime decision. Provided salesmen are meeting or exceeding the sales objective ($PSO \geq 1$), there is no particular incentive to put in overtime. As performance falls below the objective ($PSO < 1$), salesmen feel pressure to work harder--both to look good on the job and to avoid loss of income from sales bonuses.

Overtime rises sharply to a peak 40% greater than the standard 130 hours per month. (See the full equation listing in the appendix for the exact shape of the nonlinear function f_1.)

Two features of rationality deserve comment in this formulation. First, the salesman's decision on how hard to work is tied exclusively to the local sales objectives supplied by market planning managers. The decision function does not contain a revenue-maximizing algorithm for the whole sales organization, which would require much more information. Moreover, the function does not contain any explicit income-maximizing algorithm for individual salesmen. The assumption is that a salesman works overtime to achieve his sales objective, not to maximize his personal income. (An increase in overtime usually prevents income loss but is not precisely calculated to minimize loss.)

c). Performance on Sales Objective

$$PSO_t=PSO_{t-1}+(1/TPSO)((MS_{t-1}/MSO_{t-1})-PSO_{t-1}) \quad (4)$$

$$PSO_0=IPSO \quad (4.1)$$

$$IPSO=1/(1+MAPC) \quad (4.2)$$

$$TPSO=3 \text{ Months} \quad (4.3)$$

where PSO - Performance on Sales Objective (Dimensionless)

MS - Monthly Sales (Units Per Month)

MSO - Monthly Sales Objective (Units Per Month)

IPSO - Initial Performance on Sales Objective (Dimensionless)

TPSO - Time for Performance on Sales Objective (Months)

Performance on the sales objective PSO is formulated in equation 4 as an exponential smooth of current performance, with a time constant TPSO of 3 months. Current performance is the ratio of monthly sales MS to the monthly sales objective MSO. The formulation captures a natural cognitive smoothing process in decisionmaking. A fall in monthly sales relative to the objective does not immediately lead the salesman to conclude his performance has declined. Only a drop in sales sustained for several months will persuade the salesman he is missing target and should take corrective action.

Description of the Behavioral Motivation Functions

This section presents a standard equation description of the model's nonlinear motivation functions that relate the productivity of salesmen to pressures from overtime and performance against sales objective. These functions are not conscious decision functions; they portray behavioral properties of people. It is important to know how the functions are formulated to interpret the simulation runs presented later.

$$EMSE_t = f_2(M_t) \quad (5)$$

$$M_t = M_{t-1} + (1/TEM)(MI_{t-1} - M_{t-1}) \quad (6)$$

$$M_0 = IMI \quad (6.1)$$

$$TEM = 3 \text{ Months} \quad (6.2)$$

$$MI_t = (MIO_t * MIP_t) * SMI + (1 - SMI) * IMI \quad (7)$$

$$SMI = 0 \quad (7.1)$$

$$IMI=MIO_0*MIP_0 \quad (7.2)$$

$$MIO_t=f_3(MOT_t) \quad (8)$$

$$MIP_t=f_4(PSO_t) \quad (9)$$

where EMSE - Effect of Motivation on Sales Effort (Dimensionless)

f_2 - Nonlinear Increasing Function of Motivation

M - Motivation (Dimensionless)

TEM - Time to Establish Motivation (Months)

MI - Motivation Index (Dimensionless)

SMI - Switch for Motivation Index (Dimensionless)

IMI - Initial Motivation Index (Dimensionless)

MIO - Motivation Index From Overtime (Dimensionless)

f_3 - Nonlinear Decreasing Function of MOT

MIP - Motivation Index From Performance (Dimensionless)

f_4 - Nonlinear Increasing Function of MIP

Equation 5 asserts that low motivation will reduce the sales effort of the sales force. Motivation is defined on a dimensionless scale from 0 to 1. Figure 4 shows the shape of the behavioral relationship. When motivation is high (around 1), it has little or no depressing effect on sales effort. As motivation falls below .8, it has an increasingly depressing effect on sales effort, reducing it by fully 35% when motivation reaches a value of .4. It is assumed that no matter how low motivation falls, it will not depress sales effort by more than 60%.

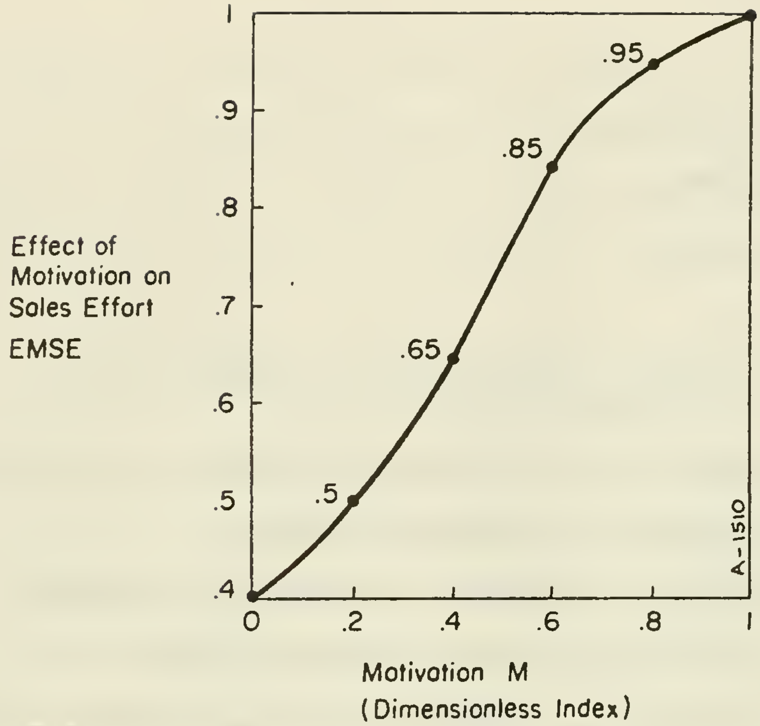

Figure 4. Effect of Motivation on Sales Effort

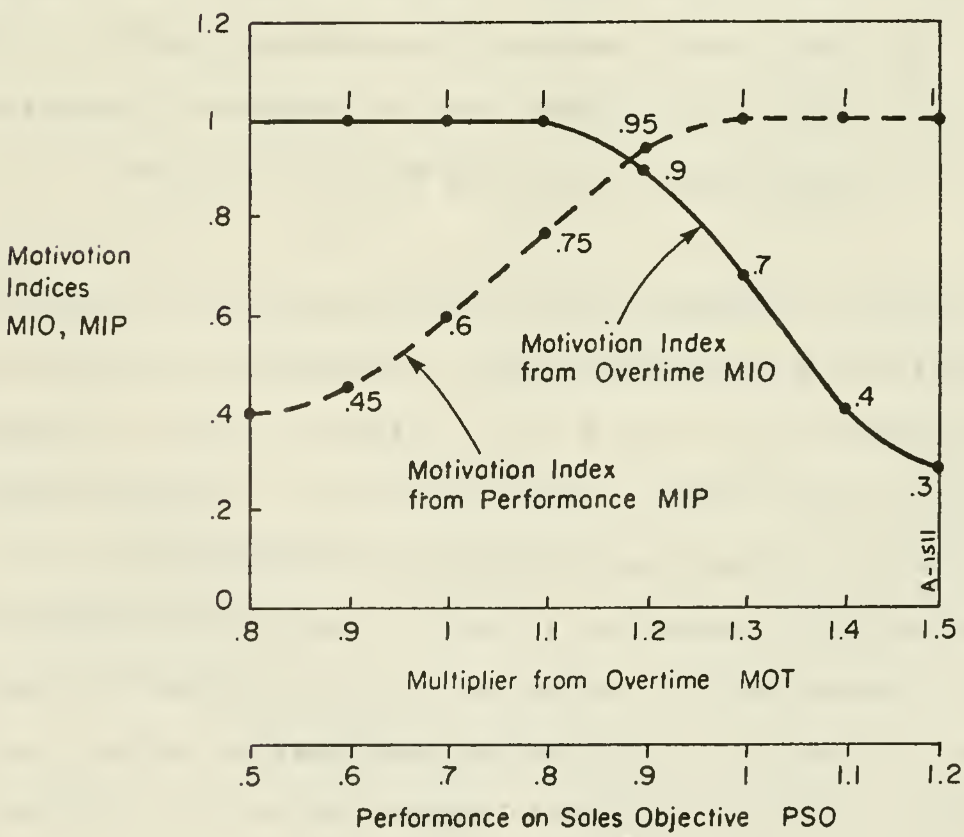

Figure 5. Determinants of the Motivation Index

Equations 6 to 9 assert that sales force motivation depends on working conditions--the level of overtime and performance against sales objective. High levels of overtime and poor performance lower motivation. Equation 6 states that motivation M lags three months behind the motivation index MI--the index of current working conditions. It takes time to become demoralized! In equations 7, 8, and 9 the motivation index MI is defined as the product of nonlinear functions (f_3 and f_4) of overtime MOT and performance on sales objective PSO. The shape of the functions is shown in figure 5.

Partial Model Tests of Intended Rationality

Figure 6 shows the feedback structure of the system which forms the basis for designing partial tests of intended rationality. It is composed of four interlocking loops.

Loop 1 contains the adjustment process of the individual salesman. If sales volume falls, say, because each sale takes more time, then the salesman will see his performance fall and will compensate by putting in overtime, thereby boosting sales. Loop 1 is, in system dynamics terminology, a goal-seeking loop, in which the overtime decisions of salesmen are geared toward meeting the sales objective.

Loop 2 contains the commitment process of market managers. In loop 2, if sales fall, managers will gradually become aware of

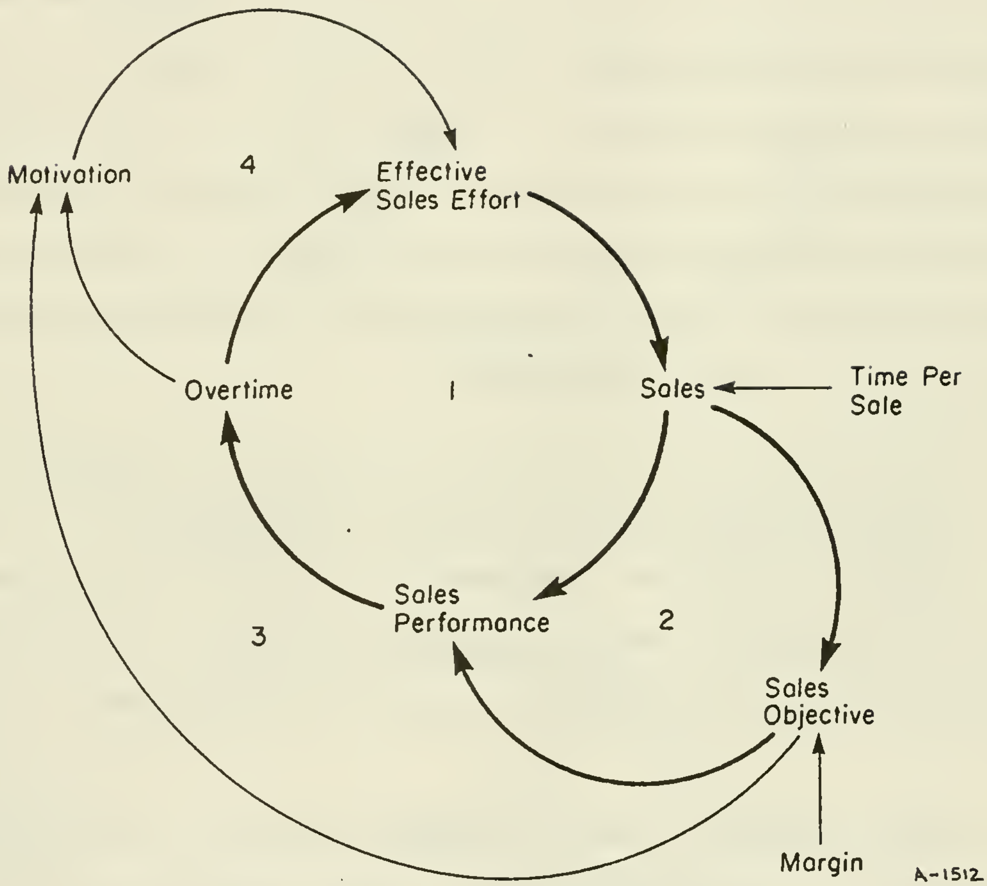

Figure 6. Feedback Structure of the Sales Model

the fall, and factor it into their commitments and objectives. Loop 2 then works in the opposite sense to loop 1, allowing a relaxation of sales objectives when general market conditions tighten.

Loops 3 and 4 are formed by the behavioral motivation function in the model. Because the function itself is highly nonlinear, the loops are not active under most business conditions. However, when they do become active, they tend to undermine the efforts of salesmen to achieve their sales objective. When motivation is low, a salesman who puts in longer hours to achieve his sales objective might end up generating fewer sales due to his decreased sales effectiveness.

Intended Rationality of Salesman Overtime Adjustment

Figure 7 shows the adjustment of the system to a 50% unanticipated increase in the normal time per sale, from 60 hours to 90 hours per unit.[15] The adjustment is made under the assumption that the sales objective does not change and that the motivation function is neutral. We therefore see a test of the overtime adjustment by itself, in other words, loop 1 in isolation.

The adjustment is rapid and intuitively sensible. In month 1, sales fall by 1/3. The resulting large discrepancy between monthly sales and the objective causes salesmen to increase

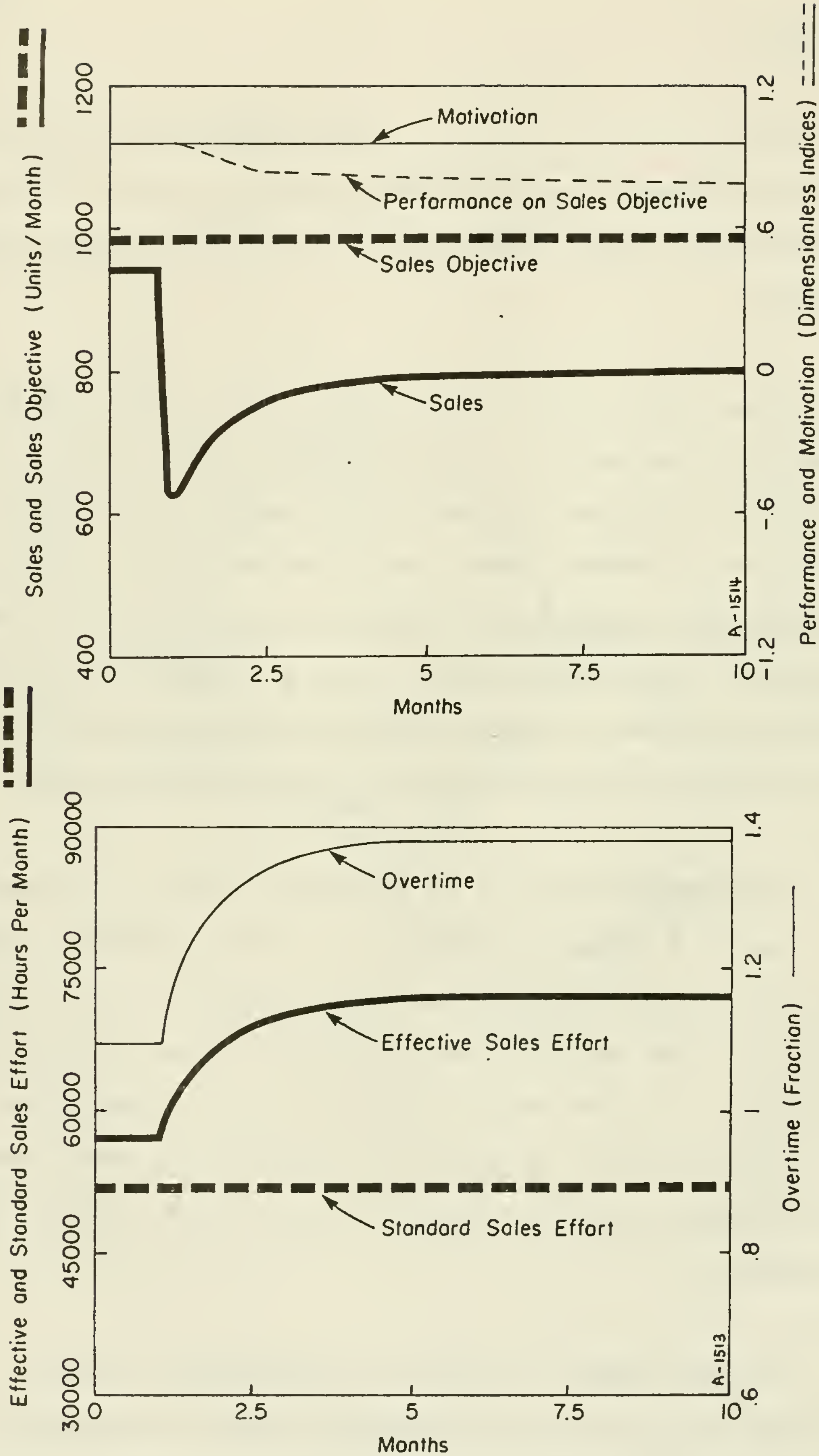

Figure 7. Salesman Overtime Adjustment Loop 1 in Isolation

overtime from an initial value of 10% (of the normal 130 hours per month) to a final value of almost 40%. Most of the adjustment is complete in the first two months of the run. The system settles into a "stressed equilibrium," in which salesmen are working long hours under pressure from an unyielding sales objective.

Intended Rationality of Commitment and Objective Setting

It is clearly unreasonable to assume that market managers will fail to learn about major market changes and factor them into their commitments and objectives. Figure 8 shows the adjustment of the sales objective in response to the same 50% increase in time per sale, under the assumption that overtime cannot rise above 10% and that the behavioral motivation function is neutral. The simulation is a test of the adjustment around loop 2 in isolation. (Readers should note that the time scale in this run has increased to 50 months by comparison with 10 months in the previous run.)

Monthly sales fall by 1/3 in month 4. The sales objective falls as market managers learn of the tightened market conditions and renegotiate their sales commitment with executives. But the fall is gradual. It takes time to be convinced that the decline in sales is permanent and not simply the result of unusual, but temporary, market conditions or reduced effort by salesmen. The market manager must have a convincing story to tell executives in

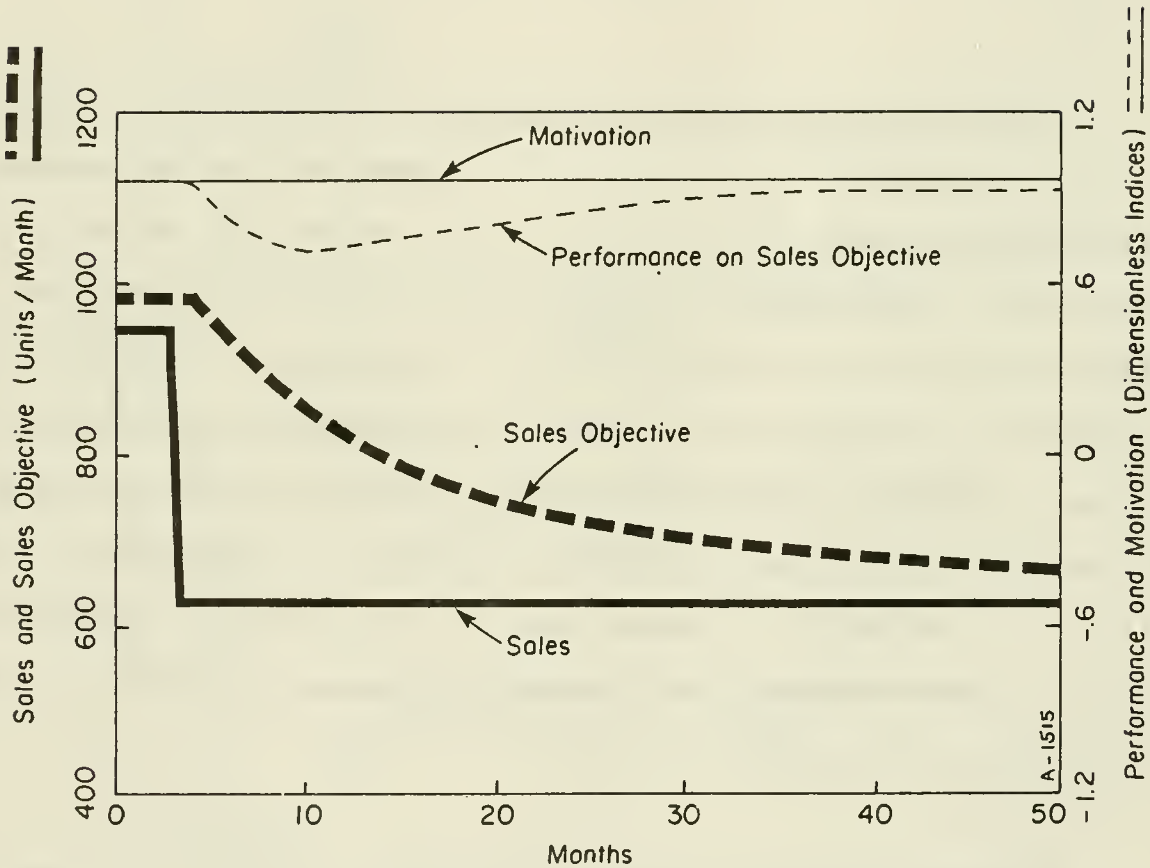

Figure 8. Adjustment of Sales Objective Loop 2 in Isolation

order to negotiate a reduction in his sales commitment without loss of face. Routine and authority therefore result in considerable inertia of the sales objective. Nevertheless, the objective does respond in a rational though cautious way, yielding more than 60% of the sales decline in twelve months.

Bounded Rationality and Inefficiency in the Full System

The two previous simulation experiments show that overtime and the sales objective adjust in a plausible and intuitively obvious way to an unexpected increase in the difficulty of selling.

Figure 9 shows the adjustment of the complete system of four interacting loops--the two loops already examined in partial model tests, and the two new loops (3 and 4 in figure 6) opened by activating the behavioral motivation function.[16] The adjustment is grossly inefficient. The sales organization becomes locked into a trap in which sales are well below potential and effective sales effort falls below the standard that can be achieved with no overtime.

Why should the apparently reasonable decision rules of market managers and salesmen fail so noticeably in the more complex environment? Why is the system incapable of adjusting to the new but lowered market potential without first passing through a phase of more than two years where salesmen are operating well below potential?

A careful scrutiny of figure 9 provides insight into the difficulties of managing the complete system. Monthly sales fall by 1/3 in month 4, thereby opening a large gap between sales and the objective. Salesmen put in more overtime, increasing effective sales effort and so preventing further decline in their sales performance, as shown by the leveling off of performance between months 4 and 6. So far the adjustment makes sense; however, two unforeseen problems are occurring.

First, the high level of overtime coupled with low performance causes a sharp decline in motivation. Compounding this problem, the sales objective itself does not fall as quickly as it did in isolation, because the efforts of salesmen are masking the full decline in the market. (To illustrate this point, the figure shows superimposed the sales objective as it was in isolation.)

By month 10 of the simulation run, motivation has depressed sales effort below the effort available from a well-motivated force working no overtime! Consider now the rationality of the salesman and market manager decisions. The salesman, pressured by the sales objective, continues to work long hours even though his effective effort in the market falls. The result is a further decline in sales. The market managers are now very confused. They have been cautiously lowering their sales objective as they learn about the tighter market conditions.

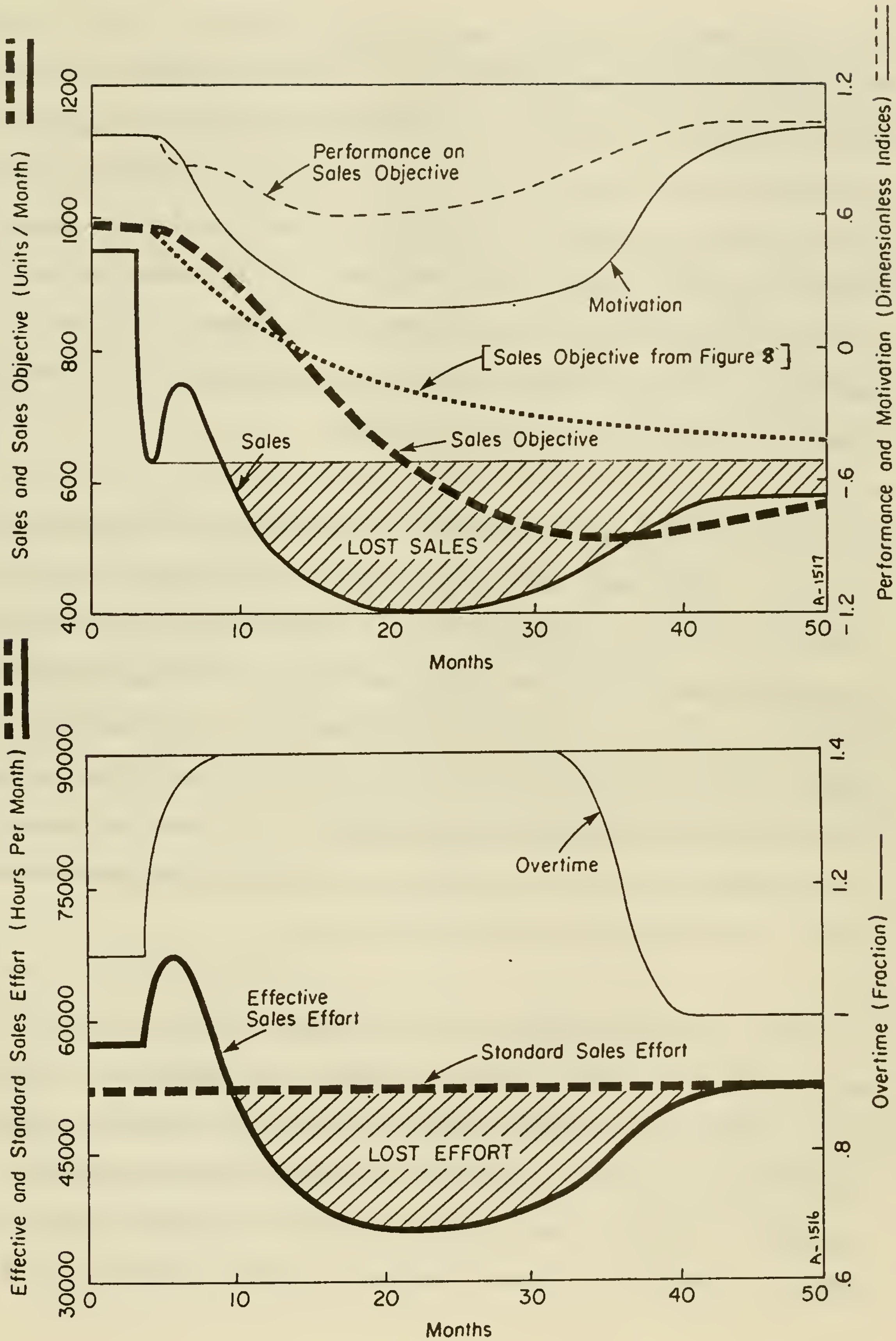

Figure 9. A Productivity and Sales Trap in the Full System

But, starting in month 9, sales begin to decline still further. The objective-setting process cannot distinguish the fall in sales caused by the market from the fall caused by lowered sales force motivation and productivity. Cautious downward adjustment of the objective keeps the pressure on the salesmen--usually a sensible thing to do. But in the prevailing situation continued pressure lowers rather than raises the effective effort of salesmen. There has been a complete breakdown in the logic of sales management and control process.

Sales continue to decline until month 20. The system is in a trap. It has been managed, or rather mismanaged, into a situation where the productivity of each salesman is much lower than normal and sales are below potential. A recovery occurs gradually after month 20, when motivation and productivity have reached rock bottom and the sales objective falls low enough to relieve workload and performance pressure on the salesmen. But, as the shaded areas in the figure show, there has been a major loss of sales and much wasted sales effort.

The feedback structure of the system, the set of four interlocking, nonlinear loops, makes sales management a hazardous task. When only moderate changes in market conditions occur, the overtime and objective-setting functions work effectively together. (A small, say, 20% increase in time per sale causes a temporary increase in overtime and a gradual relaxation of sales objectives--with no hint of a productivity or sales trap.) However, a much larger increase in time per sale activates the nonlinear motivation loops.

When these loops become dominant, they reverse the normal response of salesmen to pressure from the sales objective. Instead of increasing their effort through overtime, salesmen work longer, but much less effectively--a result entirely in violation of the premises of the objective-setting process. Under these circumstances the market managers make dysfunctional decisions. Failing to meet their sales commitment, they (unwittingly) set objectives that guarantee a still larger discrepancy between future sales and commitment. Their decisionmaking, though intendedly rational, is not sufficiently close to objectively rational to account for the large changes in salesman productivity caused by the highly nonlinear motivation loops acting in concert.

SUMMARY AND CONCLUSIONS

The previous section has shown how a description of the premises of decisionmaking followed by partial model testing can aid the interpretation of a system dynamics behavioral simulation model. But what do these methods of analysis provide that normal methods of equation description and simulation analysis cannot?

Clarifying the Theory Implicit in a Model

Normal methods of description and analysis leave a large gap in logic (and therefore in the theory) between the assumptions embodied in individual equations and the simulated behavior that results from combining the equations in a simulation model. Premise description and partial model tests bridge this gap.

Premise description relates the information content of decision functions to factoring, routines, traditions, and biases--in other words, to known and empirically observed organizational processes. Premise description specifies the bounds on rational adjustment in the model and is the first step in exposing the model's theory of behavior. For example, in the sales model the sales objective-setting process of market managers was quite myopic--its "area of adjustment" was bounded by the routine of sales forecasting and by executive bias transmitted through the sales commitment. The myopia of objective setting, which was embodied in several equations, was important in explaining the unnecessary loss of sales following a hardening of the market.

Partial model testing relates the premises of decisionmaking to simulated behavior and is the second step in exposing the model's theory of behavior. If we accept that business decision-making is intendedly rational, then we should expect partial model tests to reveal behavior that is intuitively clear and consistent with respect to the premises of the model's decision functions. So, as we saw in the sales model, when motivation is held constant the overtime function always adjusts so that salesmen put in more effort when sales performance falls below objective--the intuitively correct response. A comparison of partial and whole model tests provides an explanation for why dysfunctional or counterintuitive behavior occurs.[17]

Precision of Formulation and Policy Analysis

The understanding acquired from premise description and partial model testing can be helpful in justifying model formulations and selecting between alternative formulations. For example, awareness of the myopia (and its consequences) in the objective-setting function naturally prompts the question of why a more "intelligent" function is not in use. Why don't market managers learn more quickly about changes in market conditions and integrate them into sales objectives? One possible answer is that perhaps they do learn quickly, but the process has just not been adequately modeled. Another answer is that the information required to improve rationality is simply not available. Yet another is that the information is available but is ignored. Fear of renegotiating a sales commitment may block real knowledge about changing market conditions. In any case, the modeler is prompted to scrutinize his basic assumptions.

Premise description and partial model testing are also helpful in policy design. An understanding of the conditions that cause a breakdown in the rationality of a given decision function and a subsequent problem in the system may well point to the changes necessary to remedy the problem. For example, in the sales model a policy change that assumes market managers know <u>and act</u> on motivation information greatly reduces the likelihood of being caught in the productivity and sales trap. Alternatively, a policy change that assumes market managers have instantaneous and detailed knowledge of market conditions, <u>and</u> use the knowledge to renegotiate their sales commitment, avoids the trap.

In conclusion, premise description and partial model testing provide powerful diagnostic tools for simulation modeling that can improve the quality of model formulation and analysis and help clarify the theory implicit in the model to both academic and managerial audiences.

NOTES

1. A fascinating account of the failure of the Saturday Evening Post is provided in Harvard Business School Case Study 9-373-009 (1972). An interesting model-based theory of the collapse is provided in Hall (1976).

2. See, for example, Forrester (1961) chapters 2 and 15, Lyneis (1980) chapter 7, and Coyle (1977) chapter 10.

3. Much of Simon's Administrative Behavior (1976) is devoted to showing first that actual human rationality departs from objective rationality and, second, that organizations are intended to place their members "in a psychological environment that will adapt their decisions to the organization objectives, and will provide them with the information needed to make these decisions correctly." Chapter 10, "The Anatomy of Organization," provides a useful summary of the central thesis.

4. For a picture of the goal-oriented decision process, see Forrester (1961), p. 95.

5. For a detailed account of cognitive limitations, see Hogarth (1980).

6. For a thoughtful discussion of problems of computer simulation and theory building, see Frijda (1967). The paper discusses the modeling of psychological processes but makes a number of interesting general observations about the strengths and weaknesses of simulation as a tool of theory creation. Bell and Senge (1980), Forrester and Senge (1980), and Mass and Senge (1978) discuss some thought-provoking issues in the validation of model-based theories.

7. This kind of formulation description was used in Morecroft (1983,1), though not as an explicit descriptive aid.

8. Optimal is put in quotes here because the optimality holds only within the bounds set by the simplifying assumptions of the optimizing algorithm. Like any decision function, the algorithm itself has limits to its rationality set in this case by the assumed constraints on the availability of capacity, labor, and overtime.

9. Decisionmaking that is rational given its premises is intendedly rational with respect to its environment. Simon (1976, p. xxviii) has made the following interesting assertion on the assumption of intended rationality and its relationship to theory creation:

> It is precisely in the realm where human behavior is intendedly rational...that there is room for a genuine theory of organization and administration.

10. For another example of partial model testing used to examine rationality, see Morecroft (1983,1).

11. See Mass (1981) for further discussion of the process of diagnosing surprise model behavior.

12. There were in addition 45 accounting equations, which were not part of the feedback structure, and 35 supplementary equations.

13. For a discussion of policy structure diagrams and their relationship to other diagraming methods in system dynamics, see Morecroft (1982).

14. The actual model was written in the DYNAMO simulation language (1976). DYNAMO equations are very similar to discrete difference equations with one important difference: DYNAMO allows independence of the time unit of description in the modeled system from the time unit of computation. The description of the sales model is in terms of months, but the simulation interval is in weeks. When the time units of description and computation are equal, then the DYNAMO and discrete difference equations are identical. Unfortunately, in many situations this restriction causes integration error in numerical computations during simulation (Forrester 1961, pp. 403-406). In other words, the behavior of the system becomes sensitive to the computation interval. Such sensitivity is an undesirable and misleading feature in a system dynamics model (though in pure discrete difference equation models it might be a perfectly acceptable feature). The reader should therefore treat the difference equation format as an approximation of the DYNAMO format, and realize that in all simulation runs to be presented, the time unit of computation is one week, much smaller than the one-month time unit of description.

15. This is a significant hardening of the market, but quite plausible. For example, in the full-scale project model (Morecroft 1983,2) the market was being converted from old to new technology. A sudden hardening could occur when sales had been made to all the easy-to-convince customers, leaving only the die-hards in the old technology. Precisely when such a transition would occur was very difficult to predict.

16. In the model the motivation fuction is activated by setting the switch for motivation index SMI to 1 in equation 7.1 of the text. In the base model SMI is set to 0.

17. For another example of how partial model tests lead to a clarification of model theory, see Sterman's (1983) explanation of the causes of the so-called Kondratieff long-wave economic cycle.

APPENDIX

SALES IS A SIMPLIFIED MODEL BASED ON THE SALMOD SERIES AND USED AS THE EXAMPLE IN THE PAPER 'RATIONALITY AND STRUCTURE IN BEHAVIORAL MODELS OF BUSINESS SYSTEMS' BY JOHN D.W. MORECROFT, FEBRUARY 1983

SALES

```
MS.K=ESE.K/TPS.K                                                  A,1
    MS      - MONTHLY SALES (UNITS PER MONTH) <1>
    ESE     - EFFECTIVE SALES EFFORT (HOURS PER MONTH) <3>
    TPS     - TIME PER SALE (HOURS PER UNIT) <2>

TPS.K=NTPS*(1+STEP(STPS,TSTPS))                                   A,2
NTPS=60                                                           C,2.1
STPS=0                                                            C,2.2
TSTPS=4                                                           C,2.3
    TPS     - TIME PER SALE (HOURS PER UNIT) <2>
    NTPS    - NORMAL TIME PER SALE (HOURS PER UNIT) <2>
    STPS    - STEP IN TIME PER SALE (DIMENSIONLESS) <2>
    TSTPS   - TIME FOR STPS (MONTHS) <2>
```

SALES EFFORT AND OVERTIME

```
ESE.K=SSE.K*MOT.K*EMSE.K                                          A,3
    ESE     - EFFECTIVE SALES EFFORT (HOURS PER MONTH) <3>
    SSE     - STANDARD SALES EFFORT (HOURS PER MONTH) <4>
    MOT     - MULTIPLIER FROM OVERTIME (DIMENSIONLESS) <6>
    EMSE    - EFFECT OF MOTIVATION ON SALES EFFORT
               (DIMENSIONLESS) <10>

SSE.K=SF.K*NHSM                                                   A,4
    SSE     - STANDARD SALES EFFORT (HOURS PER MONTH) <4>
    SF      - SALES FORCE (MEN) <5>
    NHSM    - NORMAL HOURS PER SALESMAN MONTH (HOURS PER
               SALESMAN PER MONTH) <5>

SF.K=ISF                                                          A,5
ISF=400                                                           C,5.1
NHSM=130                                                          C,5.2
    SF      - SALES FORCE (MEN) <5>
    ISF     - INITIAL SALES FORCE (MEN) <5>
    NHSM    - NORMAL HOURS PER SALESMAN MONTH (HOURS PER
               SALESMAN PER MONTH) <5>

MOT.K=TABLE(TMOT,PSO.K,.75,1.1,.05)                               A,6
TMOT=1.4/1.4/1.35/1.25/1.1/1/1/1                                  T,6.1
    MOT     - MULTIPLIER FROM OVERTIME (DIMENSIONLESS) <6>
    TMOT    - TABLE FOR MULTIPLIER FROM OVERTIME <6>
    PSO     - PERFORMANCE ON SALES OBJECTIVE (DIMENSIONLESS)
```

Documented Listing of Sales Model

```
PSO.K=PSO.J+(DT/TPSO)((MS.J/MSO.J)-PSO.J)                          L,7
PSO=IPSO                                                           N,7.1
IPSO=1/(1+MASC)                                                    N,7.2
TPSO=3                                                             C,7.3
    PSO     - PERFORMANCE ON SALES OBJECTIVE (DIMENSIONLESS)
               <7>
    DT      - COMPUTATION INTERVAL OF SIMULATION (MONTHS) <14>
    TPSO    - TIME FOR PERFORMANCE ON SALES OBJECTIVE (MONTHS)
               <7>
    MS      - MONTHLY SALES (UNITS PER MONTH) <1>
    MSO     - MONTHLY SALES OBJECTIVE (UNITS PER MONTH) <8>
    IPSO    - INITIAL PERFORMANCE ON SALES OBJECTIVE
               (DIMENSIONLESS) <7>
    MASC    - MARGIN FOR ACHIEVEMENT OF SALES COMMITMENT
               (DIMENSIONLESS) <8>


      OBJECTIVE SETTING

MSO.K=MSC.K*(1+MASC)                                               A,8
MASC=.05                                                           C,8.1
    MSO     - MONTHLY SALES OBJECTIVE (UNITS PER MONTH) <8>
    MSC     - MONTHLY SALES COMMITMENT (UNITS PER MONTH) <9>
    MASC    - MARGIN FOR ACHIEVEMENT OF SALES COMMITMENT
               (DIMENSIONLESS) <8>

MSC.K=MSC.J+(DT/TESC)(MS.J-MSC.J)                                  L,9
MSC=MS                                                             N,9.1
TESC=12                                                            C,9.2
    MSC     - MONTHLY SALES COMMITMENT (UNITS PER MONTH) <9>
    DT      - COMPUTATION INTERVAL OF SIMULATION (MONTHS) <14>
    TESC    - TIME TO ESTABLISH SALES COMMITMENT (MONTHS) <9>
    MS      - MONTHLY SALES (UNITS PER MONTH) <1>


      MOTIVATION

EMSE.K=TABLE(TEMSE,M.K,0,1,.2)                                     A,10
TEMSE=.4/.5/.65/.85/.95/1                                          T,10.1
    EMSE    - EFFECT OF MOTIVATION ON SALES EFFORT
               (DIMENSIONLESS) <10>
    TEMSE   - TABLE FOR EFFECT OF MOTIVATION ON SALES EFFORT
               <10>
    M       - MOTIVATION (DIMENSIONLESS) <11>

M.K=M.J+(DT/TEM)(MI.J-M.J)                                         L,11
M=IMI                                                              N,11.1
TEM=3                                                              C,11.2
    M       - MOTIVATION (DIMENSIONLESS) <11>
    DT      - COMPUTATION INTERVAL OF SIMULATION (MONTHS) <14>
    TEM     - TIME TO ESTABLISH MOTIVATION (MONTHS) <11>
    MI      - MOTIVATION INDEX (DIMENSIONLESS) <12>
    IMI     - INITIAL MOTIVATION INDEX (DIMENSIONLESS) <12>
```

Documented Listing of Sales Model (cont.)

```
MI.K=(MIO.K*MIP.K)*SMI+(1-SMI)*IMI                                A,12
SMI=0                                                             C,12.1
IMI=MIO*MIP                                                       N,12.2
    MI      - MOTIVATION INDEX (DIMENSIONLESS) <12>
    MIO     - MOTIVATION INDEX FROM OVERTIME (DIMENSIONLESS)
                <13>
    MIP     - MOTIVATION INDEX FROM PERFORMANCE
                (DIMENSIONLESS) <14>
    SMI     - SWITCH FOR MOTIVATION INDEX (DIMENSIONLESS) <12>
    IMI     - INITIAL MOTIVATION INDEX (DIMENSIONLESS) <12>

MIO.K=TABLE(TMIO,MOT.K,.8,1.5,.1)                                 A,13
TMIO=1/1/1/1/.9/.7/.4/.3                                          T,13.1
    MIO     - MOTIVATION INDEX FROM OVERTIME (DIMENSIONLESS)
                <13>
    TMIO    - TABLE FOR MOTIVATION INDEX FROM OVERTIME <13>
    MOT     - MULTIPLIER FROM OVERTIME (DIMENSIONLESS) <6>

MIP.K=TABLE(TMIP,PSO.K,.5,1.2,.1)                                 A,14
TMIP=.4/.45/.6/.75/.95/1/1/1                                      T,14.1
    MIP     - MOTIVATION INDEX FROM PERFORMANCE
                (DIMENSIONLESS) <14>
    TMIP    - TABLE FOR MOTIVATION INDEX FROM PERFORMANCE <14>
    PSO     - PERFORMANCE ON SALES OBJECTIVE (DIMENSIONLESS)
                <7>


SPEC LENGTH=0/DT=.25/PLTPER=1/PRTPER=0                              14.4
    LENGTH - LENGTH OF SIMULATION RUN (MONTHS) <14>
    DT      - COMPUTATION INTERVAL OF SIMULATION (MONTHS) <14>
    PLTPER - PLOT PERIOD (MONTHS) <14>
    PRTPER - PRINT PERIOD (MONTHS) <14>

PRINT ESE,SSE,M,MSO,MS,PSO,MOT,EMSE                                 14.5
PLOT ESE,SSE(30E3,90E3)/MOT(.6,1.4)                                 14.6
PLOT MS,MSO(400,1200)/PSO,M(-1,1)                                   14.7
    ESE     - EFFECTIVE SALES EFFORT (HOURS PER MONTH) <3>
    SSE     - STANDARD SALES EFFORT (HOURS PER MONTH) <4>
    M       - MOTIVATION (DIMENSIONLESS) <11>
    MSO     - MONTHLY SALES OBJECTIVE (UNITS PER MONTH) <8>
    MS      - MONTHLY SALES (UNITS PER MONTH) <1>
    PSO     - PERFORMANCE ON SALES OBJECTIVE (DIMENSIONLESS)
                <7>
    MOT     - MULTIPLIER FROM OVERTIME (DIMENSIONLESS) <6>
    EMSE    - EFFECT OF MOTIVATION ON SALES EFFORT
                (DIMENSIONLESS) <10>
```

Documented Listing of Sales Model (cont.)

```
RUN COMPILE                                                        14.8
LENGTH=50                                                        C,14.9
SMI=1                                                            C,15.1
STPS=.5                                                          C,15.2
    LENGTH - LENGTH OF SIMULATION RUN (MONTHS) <14>
    SMI    - SWITCH FOR MOTIVATION INDEX (DIMENSIONLESS) <12>
    STPS   - STEP IN TIME PER SALE (DIMENSIONLESS) <2>
------------------------------------------------------------
RUN BASE                                                           15.3
TESC=3                                                           C,15.4
    TESC   - TIME TO ESTABLISH SALES COMMITMENT (MONTHS) <9>

RUN FLEX OBJ                                                       15.5
TMOT=1.0952/1.0952/1.0952/1.0952/1.0952/1.0952/1.0952/1.0952     T,15.6
    TMOT   - TABLE FOR MULTIPLIER FROM OVERTIME <6>

RUN OBJ SETTING WITH MOTIVATION                                    15.7
SMI=0                                                            C,15.8
TMOT=1.0952/1.0952/1.0952/1.0952/1.0952/1.0952/1.0952/1.0952     T,15.9
    SMI    - SWITCH FOR MOTIVATION INDEX (DIMENSIONLESS) <12>
    TMOT   - TABLE FOR MULTIPLIER FROM OVERTIME <6>

RUN OBJ SETTING ONLY                                               16.1
TESC=10E6                                                        C,16.2
LENGTH=10                                                        C,16.3
PLTPER=.25                                                       C,16.4
TSTPS=1                                                          C,16.5
    TESC   - TIME TO ESTABLISH SALES COMMITMENT (MONTHS) <9>
    LENGTH - LENGTH OF SIMULATION RUN (MONTHS) <14>
    PLTPER - PLOT PERIOD (MONTHS) <14>
    TSTPS  - TIME FOR STPS (MONTHS) <2>

RUN OVERTIME ADJUSTMENT ONLY                                       16.6
```

REFERENCES

Allison, G. T. (1971), Essence of Decision. Little, Brown and Company, Boston MA, 1971, pp. 79-81.

Bell, J. A. and P. M. Senge (1980), "Methods for Enhancing Refutability in System Dynamics Modeling," System Dynamics (in TIMS Studies in the Management Sciences, Vol. 14, 1980, pp. 61-73).

Bitran, G. R. and A. C. Hax (1977), "On the Design of Hierarchical Production Planning Systems," Decision Sciences, Vol. 8, No. 1, January 1977, pp 28-55.

Coyle, R. G. (1977), Management System Dynamics. John Wiley and Sons, Chichester, England, 1977.

Cyert, R. M. and J. G. March (1983), A Behavioral Theory of the Firm, Prentice-Hall, Englewood Cliffs NJ, 1963.

Forrester, Jay W. (1961), Industrial Dynamics, The MIT Press, Cambridge MA, 1961.

Forrester, Jay W. (1968,1), "Market Growth as Influenced by Capital Investment," Sloan Management Review, Vol. 9, No. 2, pp. 83-105, Winter 1968.

Forrester, Jay W. (1968,2), "Industrial Dynamics--A Response to Ansoff and Slevin," Management Science Vol. 14, No. 9, pp. 601-618, May 1968.

Forrester, Jay W. and P. M. Senge (1980), "Tests for Building Confidence in "System Dynamics Models," System Dynamics (in TIMS Studies in Management Sciences, Vol. 14.) 1980, pp. 209-228.

Hall, R. I. (1976), "A System Pathology of an Organization: The Rise and Fall of the Old Saturday Evening Post," Administrative Science Quarterly, Vol. 21, 1976, pp. 185-211.

HBS Case Services (1972), 'The Saturday Evening Post, Case 9-373-009, Harvard Business School, Boston MA, 1972.

Hogarth, R. M. (1980), Judgement and Choice, John Wiley and Sons, New York, 1980.

Holt, C. C., F. Modigliani, J. F. Muth, and H. A. Simon (1960), Planning Production Inventories and Workforce, Prentice-Hall, Englewood Cliffs NJ, 1960.

Lyneis, J. M. (1980), Corporate Planning and Policy Design, The MIT Press, Cambridge MA, 1980.

Mack, Ruth P. (1967), Information, Expectations and Inventory Fluctuation, National Bureau of Economic Research, 1967.

Mass, N. J. (1981), "Diagnosing Surprise Model Behavior," System Dynamics Group Working Paper D-3323, Sloan School of Management, M.I.T., Cambridge MA, October 1981.

Mass, N. J. and P. M. Senge (1978), "Alternative Tests for the Selection of Model Variables," IEEE Systems, Men and Cybernetics, June 1978.

Morecroft, J. D. W. (1982,3), "A Critical Review of Diagramming Tools for Conceptualizing Feedback System Models," Dynamica, Vol. 8, Part I, Summer 1982, pp. 20-29.

Morecroft, J. D. W. (1983,1), "System Dynamics: Portraying Bounded Rationality," Omega, Vol. 11, No. 2, March 1983, pp. 131-142.

Morecroft, J. D. W. (1983,2), "Strategy Support Models," System Dynamics Group Working Paper D-3365-1, Sloan School of Management, M.I.T., Cambridge MA, March 1983.

Nelson, Richard R. and Sidney G. Winter (1982), An Evolutionary Theory of Economic Change, Belknap Press of Harvard University Press, Cambridge MA, 1982.

Pugh, A. L. (1976), Dynamo Users Manual, Fifth Edition, The MIT Press, Cambridge MA, 1976.

Richardson, G. P. and A. L. Pugh (1981), Introduction to System Dynamics Modeling with DYNAMO, The MIT Press, Cambridge MA, 1981.

Simon, H. A. (1976), Administrative Behavior, Third Edition, The Free Press (A Division of MacMillan Publishing Co.), New York, 1976.

Simon, H. A. (1979), "Rational Decision Making in Business Organizations," The American Economic Review, Vol. 69, No. 4, September 1979.

Simon, H. A. (1982), Models of Bounded Rationality (Vol 2): Behavioral Economics and Business Organization, The MIT Press, Cambridge MA, 1982.

Sterman, J. D. (1983), "A Simple Model of the Economic Long Wave," System Dynamics Group Working Paper D-3410, Sloan School of Management, M.I.T., Cambridge MA 02139, February 1983.

Date Due

DEC. 1 4 1992		
[illegible] 1998		