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A SYSTEMS MODEL OF A CONSTRUCTION FIRM

by

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INTRODUCTION

Construction management includes the management of various resource and management information systems. The resource systems consist of production systems involving direct and indirect labor, and construction equipment, as well as finance and time systems. Common information systems are: estimating, payroll, accounting, labor analysis and project planning, scheduling monitoring and control. Some production and information systems emphasize the general firm operation, and others relate to each individual project. This investigation is concerned with those systems related to general company management and not those concerned with the individual projects. The objective of this study is to develop a dynamic, realistic general systems level representation of the major constraints and major policies of a construction firm such that the effects of various different policy parameters, initial conditions and external influences can be analyzed. The development results in a computer simulation model.

The systems model is recommended as a simulation tool to construction firms which would provide an evaluation of different policies and an analysis of future contingencies.

The approach assumed the policies of a growth-oriented construction firm. This implied the firm attempted to maximize use of its available resources. The management of assets such as construction equipment and long-term investments was not considered.

The basic framework of the systems model is the set of working capital accounts in the typical construction firm cash flow statement.

This research is particularly significant to construction management because it is concerned with the overall systems level. Other research efforts have concentrated on the individual systems, for example, bidding models and project management computer programs.

The system definition of Koenig et al. (1967) is assumed in this investigation; namely, a system is a set of interacting components. The systems model, then, represents a set of interacting systems. The systems included in the model were: working capital cash flow, bidding information and constraints, overhead acquisition, short-term investment and external financing. The conceptual approach utilized was that of Forrester (1968a, 1968c). More specifically, emphasis was placed on information and the feedback characteristics. The model was structured using basically two types of variables; those representing levels or states, and those representing rates of change in the flow between the levels.

The analysis of the results included the use of computer simulation experimental design techniques. Two designs were used and they both involved two factors, each with two levels and two blocks. One model employed analysis of variance whereas the other model used analysis of covariance with a quadratic regression model. One factor consisted of two levels of markup and the other factor had two levels of short-term investment monthly return rates. The two blocks represented two initial starting conditions: one with a strong working capital position and liberalized bonding constraint, and the other initial condition represented a moderate working capital position and moderate bonding constraint.

This thesis begins with a review of literature after which a construction firm's operations, policies and systems are described. This is followed by a detailed explanation of the systems model. The explanation includes a description of the major equations of computer simulation model which was written in DYNAMO II. This chapter also includes a validity check using actual construction data and comparing the model results with actual results. The results and analysis are contained in the next chapter. These are based on simulations of various parameter value combinations of a hypothetical firm. The simulation runs included a number of markup policies, a simulated strike, a simulated poor collection of accounts receivable, and a number of different delay combinations; for example, two different average delays in processing accounts payable and two average delays in holding the retainages. This chapter also includes the experimental design analysis. The last chapter summarizes the investigation and offers conclusions and recommendations.

A detailed flow chart is included in the systems model chapter (Chapter Four) and a complete listing of the computer program is found in the Appendix.

REVIEW OF LITERATURE

Developments in operations research, management science, and the physical science have been concerned with the system level of various processes in contrast to an emphasis in the components of a system. Construction firms have been adapting quantitative management techniques in order to improve decision making. This survey of literature is categorized into the following classifications: construction management, construction management information systems, bidding models, computer simulation techniques and computer simulation models.

Clough (1969) describes the essentials of construction management emphasizing the business aspects. Topics include organization, contract bonds, construction insurance, and business methods as well as estimating, bidding, labor relations and others. Accounting methods employed in construction and relevant financial ratios are described and illustrated within the business methods chapter. The ratios considered important in construction by Clough are: net profits to annual volume, net profits to net worth, net profits to net working capital, annual volume to net worth, annual volume to net working capital, current assets to current liabilities, and fixed assets to net worth. Rubey and Milner (1966) described construction management at the same level as Clough. The examples and general treatment emphasized engineered construction (heavy and highway).

Construction management operates under bonding constraints set by the surety company. The surety business is described by Crist (1950). The description includes the various types of bonds including construction

contract bonds. The considerations relevant to underwriting construction contract bonds are also contained in Surety Unit Book (Insurance Company of North America, 1969). These are divided into two broad categories: (1) the nature and extent of the contract undertaking and the terms of the contract and (2) the qualifications of the contractor who proposes to complete the undertaking. The qualifications of the contractor are further refined into three subcategories: character, capacity, and sufficient capital. Elaboration on sufficient capital includes the consideration of the ratio of net quick assets (working capital) to the volume of the contractor's outstanding work where the volume of outstanding work includes the project about to be bid. As a general rule, a minimum ratio of 0:10 is suggested, but is subject to the judgment of the underwriter. It is also stated that a contractor may be given a blanket line of bonding credit as long as certain conditions are not exceeded. Thus under this provision, the contractor's current net quick asset to volume ratio need not be checked by the underwriter for each project under bidding consideration by the contractor.

Park (1966) approaches construction management with quantitative techniques although sophistication is lacking. The discussion includes ratio analysis and an enumeration of twelve financial ratios considered significant to construction and averages values of each for 39,000 contracting firms. The ratios cited included those listed by Clough (1969) plus net profit to total assets, volume to fixed assets, cash to current liabilities, current liabilities to net worth and total liabilities to net worth. Establishing and analyzing profit objectives, breakeven analysis, relationships between volume, fixed costs, markups,

profit margins, queuing theory, theory of games, the Monte Carlo technique and statistical bidding are topics included by Park (1966). The treatment of operation research techniques is basic but pertinent to construction management.

Ackoff (1967) emphasized the role of the manager in the design of a management information system. Managers should be trained to evaluate the system and to control it. Besides listing common and erroneous assumptions behind the design of management information systems, Ackoff suggests a procedure for designing a system by making an analysis of the firm's decision system through use of flow charts. This procedure would disclose those decisions made by default as well as those made by interdependent decisions. The analysis may suggest changes in organization, measures of performances, and other characteristics. A comprehensive approach to the design of management information systems for large construction firms was the concern of Kawasaki (1968). His approach encompassed a description of factors affecting the design of management information systems, an investigation of existing management information systems in large construction firms (this was accomplished through the analysis of a questionnaire) and the design of the system. The design included a recommended procedure and detailed flow charts for eight construction management subsystems and for the total system. The development of a total management information system rather than segmented individual subsystems was recommended.

Approaches to interfacing various construction management information subsystems were suggested by Kawal (1969) for generating information utilized in project planning. Three forecasting models, moving average,

exponential smoothing, and probability were considered as possible means to project production rates for task duration estimation purposes. The three models were compared. The exponential smoothing model appeared the most promising because (1) the emphasis on past data could be adjusted by changing the exponential smoothing constant, (2) the computer memory required was substantially less than that of the moving average, and (3) the probability model required an additional variable to interpret; i.e., the probability a production rate would be less than or equal to a specified value.

Literature pertinent to bidding models is separated as single bid and sequential bid decisions as classified by Broemser (1968). In a single bid decision model the contractor develops a strategy for each bid situation that develops whereas in a sequential bid decision model a strategy is developed for a series of bid situations. A basic single bid model was published by Friedman (1956). The objective of the model was to maximize expected profit in consideration of past profit to cost ratios, and the probability distribution of the number of competitors to be met. Friedman also described simultaneous bidding on more than one contract. Gates (1960) analyzed historical bidding data and recommended approaches to setting bid security policy, to screening mistakes in a bid, and to determining bidding strategies of providing constant work, of maximizing income, and of maximizing profit. In a later publication Gates (1967) described statistical bidding procedures for balanced and unbalanced bidding. His objective in the balanced bid models was to maximize expected profit. The two bidder confrontation was described as a two person, zero sum game. Park (1966) developed bidding models by applying Friedman's

(1956) model. Rubey and Milner's (1966) treatment of statistical bidding referenced the model of Friedman, the work of Park, and the development by Gates.

The unbalanced bidding procedure was treated as a linear programming problem by Stark (1968). The objective was to allocate unit prices so that the expected present worth of future revenue was maximized. The constraints included a bid amount constraint, upper and lower bounds constraints, and rate payment constraints. The approach developed a strategy for a single bid. An application of Stark's approach was published by Mayer et al. (1967).

Benjamin (1969) extended the single bid problem to one of maximizing expected utility for two types of utility functions, bi-linear and exponential. As Benjamin mentioned, the models maximizing expected profit are maximizing a linear utility function. He developed models for combinations of the two utility functions and for the profit distributions. In addition, he defined the bidding problem as a two-stage lottery and described a regression model for assessing the probability of beating the lowest-bidding competitor.

A sequential bidding model was formulated by Broemser (1968) in a mathematical programming format. The objective was to bid those projects which will maximize the present worth of expected overhead and profit. The constraints defined the availability of bonding capacity each time a potential bidding situation was encountered. Other constraints were mentioned as being possible. The model permits its user to determine how much to bid on each job and what future projects should be estimated.

Broemser also stated the bidding problem as one of capital budgeting where the bonding capacity is the "capital" that is to be budgeted among the various bid opportunities. The model was originally defined as an integer programming problem with the decision variable boolean, however this was relaxed and redefined as a linear programming problem where the decision variable was constrained to be between zero and one. It was believed that this change did not significantly change the problem. Broemser also described a linear regression probability assessment model.

Teichroew and Lubin (1966) classify simulation models into two categories, continuous change models and discrete change models. The continuous change models are used when the real system is assumed to consist of a continuous flow of information or material. The model is usually represented by differential or difference equations. These type systems are often modeled with analog computers. However, as the authors point out, when the models are of management or socio-economic systems, they cannot be easily adapted to analogs because 1) the variables are often stochastic, 2) the large number of variables, 3) some of the variables are discontinuous, and 4) some variables have to be nonnegative while others need not be. As a consequence, if an analytical solution is not known, the equations are converted to finite-difference equations. Teichroew and Lubin symbolically describe these equations by the following:

$$X(t+\Delta t) = g(\bar{X}(t), Z(t), W)$$

where $X(t+\Delta t)$ is a state vector at time $t+\Delta t$, $\bar{X}(t)$ represents the state

vector for all previous values of t , $Z(t)$ represents the vector of values of exogenous variables for all relevant values of t , W represents the vector of parameter values, and g specifies the behavior of the system.

The discrete change model is appropriate when the state of the system being studied can be considered in discrete, noncontinuous steps.

Teichroew and Lubin describe such a system:

Systems are idealized as network flow systems and are characterized by the following:

- the system contains "components" (or "elements" or "subsystems") each of which performs definite and prescribed functions;
- items flow through the system, from one component to another, requiring the performance of a function at a component before the item can move on to the next component;
- components have finite capacity to process the items and therefore items may have to wait in "waiting lines" or "queues" before reaching a particular component.

Note that in the above description emphasis is placed on individual components and associated functions. This is what defines the model as a discrete-change model since the model portrays the flow among these discrete units and the flows are subjected to functions of the units. A network of work stations is clearly a system which could be modeled with a discrete-change model. Management systems can be modeled as continuous and/or discrete models, depending on what elements in the system are being emphasized.

After objectives are defined, the next major step in a computer simulation experiment is to develop a model of the system. This development involves the selection of the most appropriate conceptualization, the

selection of simulation languages, and the selection of a design enabling analysis against the objectives. Naylor et al. (1966) describe aspects of this development. Topics include the generation of pseudo-random numbers, descriptions of various simulation languages, examples of different types of models, and considerations in the design of the computer simulation experiment.

One conceptual approach to the simulation and analysis of systems is that of Forrester (1961). Forrester originally labeled his approach as industrial dynamics which he defines as:

the study of the information-feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decisions and actions) interact to influence the success of the enterprise.

His approach utilizes a continuous model. The basic component of a system is the feedback loop (Forrester, 1968a). The feedback loop consists of two types of variables, levels (states or accumulations) and rates of the changes in the flow between levels. Information channels connect levels to the rates. This approach recognizes that systems can be nonlinear, high order (where order is defined as the number of integrations or levels), and possessing multiple loops. The level equation of Forrester is of the following form:

$$X(t+\Delta t) = X(t) + \Delta t(Y-Z)$$

In the equation $X(t)$ represents the level variable or state at time t , Y represents an input rate, Z an output rate, and Δt is a time increment which approximates the dt of differential calculus. This equation form is of the same finite-difference form described by Teichroew and Lubin (1966).

Forrester (1968c) uses financial accounting variables to illustrate level and rate variables in the following manner. The balance sheet variables are levels portraying the financial condition or state while the profit and loss statement variables are the rates of change occurring during the time interval between balance sheets.

Analytical solutions to some basic models are presented by Forrester (1968c). The systems solved are: third order without feedback, first order with feedback, and second order feedback (without minor loops). Simulation results of various basic single loop, linear feedback systems are described by Weymar (1965).

A comprehensive review and criticism of industrial dynamics was provided by Ansoff and Slevin (1968a, 1968b). They questioned the argument for complete quantification of all relevant behavior, the lack of a formal procedure to abstract data from managers and to provide information validity tests, the supposition that all aspects of a firm are best represented by information feedback systems, the requirement of a considerable amount of information collection, and the lack of specific criteria for analysis.

Koenig et al. (1967) prefer another systems approach. They propose studying system behavior using the state-space representation. For linear systems, the state-space models are in the form of a set of simultaneous first-order differential or difference equations which typically resembles:

$$\frac{dY_i}{dt} = \sum_{j=1}^n P_{ij} Y_j + e_i \quad i = 1, 2, \dots, n$$

and

$$r_l = \sum_{j=1}^m m_{lj} Y_j \quad l = 1, 2, \dots,$$

where P_{ij} and m_{lj} are constants that depend on the identified system structure.

Y_i are the state variables

e_i are the identified inputs

r_l are the identified outputs (Koenig et al., 1967)

The approach includes utilizing a linear graph to portray constraints on the system. The components of the system are independently modeled. The state models can be analytically solved and the response characteristics studied (Koenig et al., 1967). The model is a mathematical model. The computer is used to determine the solution to the system and to furnish calculations for studying the response of the system.

The state-space approach to modeling and analyzing socio-economic systems is illustrated by Koenig (1965) with a simple model.

Hunter and Naylor (1970) describe a simulation model with the following equation and variable definitions.

$$g(y_t) = \sum_{i=1}^k c_i h(x_{it}) + \sum_{j=1}^m b_j w(v_{jt}, \dot{u}_j) + f(e, z)$$

where

y_t is the response variable at time t and $g(y_t)$ is a transformation of the response variables.

x_{it} is the i th factor affecting the response at time t and $h(x_{it})$ is a transformation of the factors.

c_j is a parameter weighting the $h(x_{it})$

v_{jt} is a stochastic variable with weight b_j and distribution W with distribution parameters \dot{u}_j (the dot represents a vector).
 e is a random variable with distribution f and distribution parameters \dot{z} .

In addition, dummy boolean variables of value one or zero could be used to represent the absence or presence of certain variables at certain times and to identify blocks of variables that are used together. Also different constraints could be added, other response variables included, and dynamic feedback mechanism provided by letting y_t be a function of $y_{t-1}, y_{t-2}, \dots, y_{t-n}$.

There is a variety of simulator languages available for computer simulations (Teichroew and Lubin, 1966, Naylor et al., 1966). DYNAMO is the language designed for the industrial dynamics approach (Pugh, 1963, 1968, 1969). A FORTRAN version of DYNAMO, FORDYN, is described by Llewellyn (1965).

The use of experimental design techniques from statistics for the analysis of factors affecting system behavior are described by Hunter and Naylor (1970). The use of full factorial, fractional factorial, rotatable, and response surface designs are discussed. Problems of sample size, multiple responses, nonlinearity in the parameters, and convergence are described. The objectives of the experimental design are stated by the authors as:

1. Find the combination of factor levels at which the response variable is optimized.
2. Explain the relationship between the response variable and the controllable factors in the experiment.

Watts (1969) describes methods of time series analysis techniques. Bonini (1963) utilized a fractional factorial design in his analysis of eight factors each with two levels for six response variables.

Forrester's approach to the analysis of the model involves the interpretation of a graphical output (Forrester, 1961). The graphical output consists of plots of relevant variables against time. The graphical output is also valuable for checking the validity of the model.

. . . a model should be judged by its ability to reproduce or to predict the behavior characteristics of the system—stability, oscillation, growth, average periods between peaks, general time relationships between changing variables, and tendency to amplify or attenuate externally imposed disturbances. (Forrester, 1961)

A comprehensive application of computer simulation was presented by Bonini (1963). The model related organizational, behavioral, and informational factors to economic variables in a hypothetical firm. Bonini studied the effects of changes in the external environment, changes in the information system, and changes in the decision system. The model employed a fractional factorial design for analysis. The model was written in FORTRAN. An example of the state-space approach to a large system is the model reported by Koenig et al. (1967). The system model represented the management, the planning, and the resource allocation processes in institutions of higher education. The objective was to determine the logical structure of the processes as they affect the design of a management information system.

An example of a discrete change simulation model is found in Sorensen and Gilheany (1970). The model simulated sugar cane harvest operations. Other simulation examples are those by Morgan et al. (1970), Dickson et al.

(1970), and Thompson (1970).

The Insurance Company of North America employs a simulation model to project cash flows for contractors.¹ The contractor furnishes the current status of accounts receivable, retainages, accounts payable, overhead estimates and the status of each contract. The model projects the cash flows for each contract and for all contracts in total. The effect of contingencies such as a strike can be visualized.

A systematic contingency planning procedure is recommended by Donaldson (1969) for preparing to face unexpected needs for funds. Three steps are suggested. The first step suggests that management simulate contingencies and financial implications using a cash flow simulation model. The second step involves the preparation of an inventory of the resources of financial mobility while the third step consists of the development of a strategy for dealing with the unknown.

¹Sinclair, Hugh, Insurance Company of North America, Philadelphia, Penn. Information on the Insurance Company of North America's Contractor Financial Analyzer. Private communication. 1970.

THE CONSTRUCTION FIRM

A construction firm is an organizational entity providing the service of constructing a facility for a client, the owner. The firm's major objective is to maximize profit and other objectives may include realizing a certain growth or realizing a certain proportion of a construction market. Basically, the function of the construction firm is to manage the resources necessary to complete the firm's contractual obligations. The resources consist of men, machines, materials, time and money. The firm manages these resources to build a highway, bridge, or twenty story office building. Typically, the contractor accomplishes this with a minimum overhead. The contractor operates in a highly competitive environment. Characteristics of construction firms are quite varied however, many of the variations can be attributed to the type of construction the firm is engaged in. The firms can be classified in the following manner:

Residential - These firms build single and multiple family residences and some light commercial and light industrial buildings. Often these firms own the land on which their improvement is constructed. They could build custom structures or speculative structures after an analysis of the market.

Commercial and Industrial - The product of this type of firm is an apartment building, an office building, a warehouse, or a factory. The firm is very seldom the owner in contrast to the residential firm who often may permanently or temporarily own the land and improvement. Those structures are normally designed by architects and consulting engineers.

Heavy and Highway - These firms build dams, bridges, and highways and other work designed primarily by engineers. It is unusual that the product was designed by an architect.

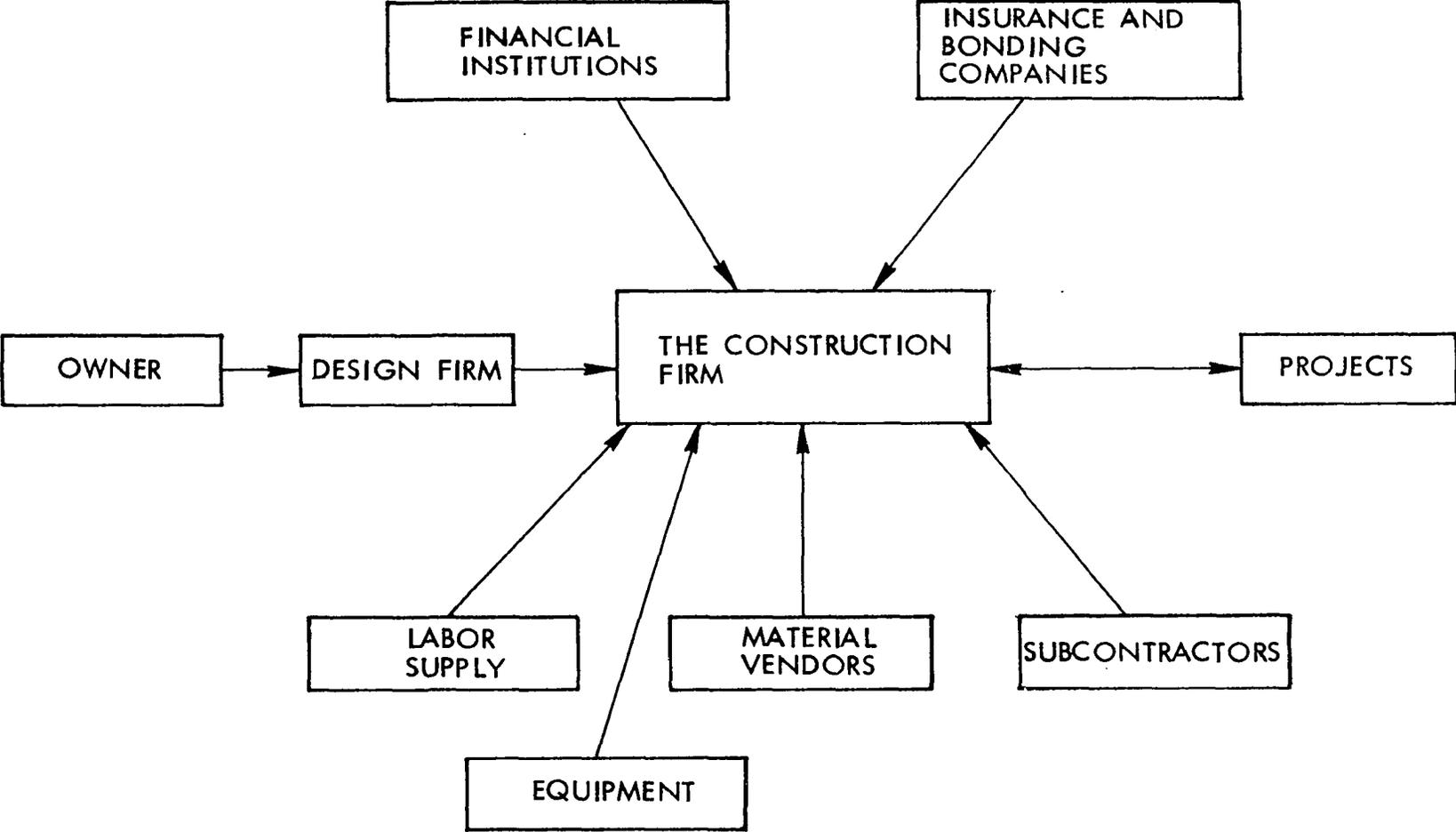
Each of these types has unique management procedures. The residential builder is typically very concerned with financing and market analysis. The building contractor is primarily concerned with the management and support of the field resources utilized in completing the project. The field resources are typically labor intensive, while in the case of the heavy and highway firm the field resources are equipment or capital intensive. The heavy and highway firm often manages a sizable inventory of trucks, scrapers, paving equipment, etc. In addition, their services often require more engineering than the other types of firms.

This chapter will describe the characteristics of a construction firm. The orientation will be toward the commercial and industrial building contractor, however, reference will be made to the other types. The construction firm operates in an environment consisting of the owner, the finance institution, the insurance and bonding companies, the design firms, material vendors, the labor supply, and subcontractors. This is conceptualized in Figure 1. The sections of this chapter consider the relationships between the contractor and his business environment, the firm's operations, and the major decisions confronted by the firm.

Ownership and Organization

Construction firms, as is the case for any firm, can be owned in a number of ways such as a proprietorship, a partnership or a corporation. A common form for construction firm ownership is a closed corporation.

Figure 1. The construction firm and its business environment



The degree of individual ownership is subject to the approval of the board of directors. The board may issue stock in specified amounts to certain individuals who are normally employees of the firm, however the general public is not allowed to acquire stock. Often the venture capital was provided by a few individuals who currently are the board of directors and who desire to retain control of the company.

Profit sharing may be implemented where certain employees are permitted to participate in the profits up to the statutory limit. This participation can be in addition to a bonus plan.

A unique operating form employed in construction is the joint venture. Under this arrangement two or more contractors combine resources for a certain project. The joint venture is a separate business entity and the members of the venture can be participating in a partnership, proprietorship, or corporation. The joint venture permits firms to combine talents, resources such as equipment and assets and to share in the risk (Clough, 1969).

As mentioned earlier, construction firms typically operate at a low overhead level. Construction overhead consists of general overhead and project overhead. Project overhead could consist of superintendent, a project manager, and/or clerk. This could be considered as a direct cost or it could be absorbed into the general overhead. Some firms allocate these costs to the specific contract and these become direct costs. Other firms treat these costs as indirect costs along with the salaries of office personnel. General overhead is that overhead which is not charged to individual projects and includes office management personnel salaries, office heating and cooling expenses, computing expenses, etc. A

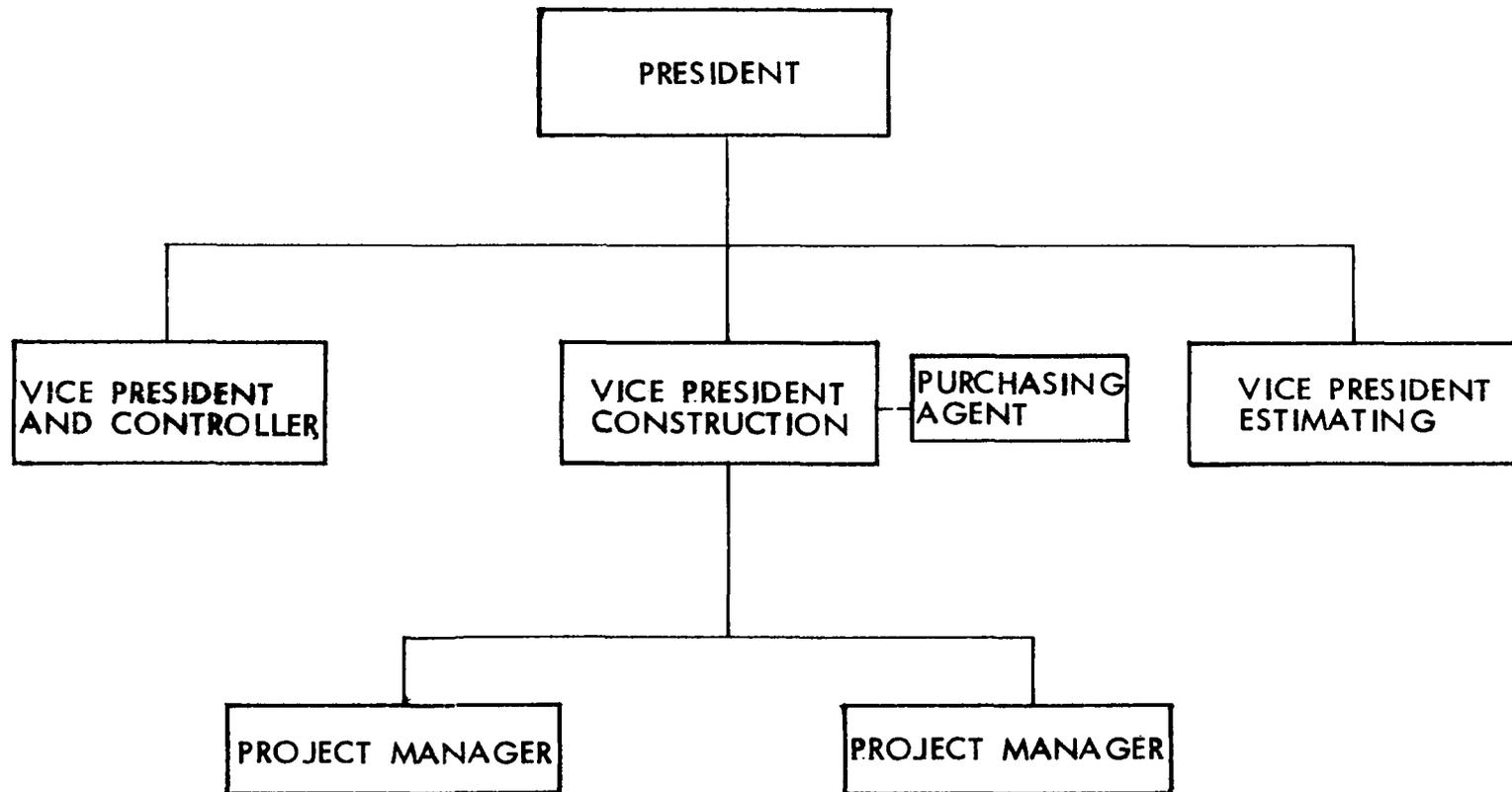
hypothetical organization chart of the key general overhead personnel for a building construction firm doing an annual volume of \$7,000,000 is shown in Figure 2. The board of directors may consist of the president and vice-presidents with the president holding the controlling interest in the stock of the closed corporation. Each project manager would direct a number of superintendents (2, 3 or 4) who manage the field operations for the projects. The project manager would purchase and expedite many of the materials required for each of his projects with assistance given by the purchasing agent. In addition, he would estimate potential projects as well as manage the projects acquired. The vice-president for construction could also manage and estimate projects. Both the controller and vice-president for estimating would require support clerks (the extent of this is determined by the nature of the computing support as well as other factors.) It is possible that all personnel identified on the organization chart and the superintendents participate in profit sharing and bonuses.

Some construction firms may allocate more work to specialists. For example, all cost estimating would be done within the estimating department and all material and equipment acquisition would be accomplished by the purchasing agent. A more vertical organization is also possible.

Owner and Design Firm Relationship

As shown in Figure 1, the owner of the project is linked to the construction firm through the design firm (although there is a direct contract between the owner and the contractor). The indirect link involves all communications regarding the new project. The design firm represents the owner's interests. This extends beyond design to the responsibility

Figure 2. A hypothetical organization chart for a firm with an annual volume of \$7,000,000



of checking the contractor's work against the design and the responsibility of approving payment requests from the contractor.

Details on the payment request approval procedure will be described later in this section.

The owner and the construction firm can enter a variety of different contract agreements. These are divided into two broad categories, competitive bid contracts and negotiated contracts.

Under a competitive bid type contract, the contractor bids for the project against other contractors. The owner usually awards the contract to the lowest qualified bidder. The lump sum contract can be a form of a competitive bid contract in which the owner agrees to pay a fixed amount to the contractor. Thus, the cost of the project to the owner is fixed when the bid is awarded. Another form of the competitive bid type of contract is the unit price contract. The amount paid to the contractor is based on the quantity of items actually completed by the contractor and the contractor's unit price bids. Thus, the total amount is not fixed, only the unit prices are. The items for which the contractor determines unit prices are established prior to bidding. The actual quantities are submitted by the contractor and approved by the design firm. The bid amount submitted by the contractor is equal to the sum of the products formed by multiplying the contractor's unit prices by the respective design firm supplied estimated quantities. A construction firm may take advantage of an error in the estimate provided by the design team by adjusting unit prices so that larger revenues are generated early in the completion of the project.

The second type of contract, the negotiated contract, is the product

of owner-contractor agreements. The negotiated contract could involve lump sum or unit price settlements in cost-plus contracts. In any case the contractor and owner mutually settle on the terms. There are various types of cost-plus contracts (see Clough, 1969) but basically the contractor receives the total cost of the project plus an agreed amount for his general overhead and profit.

Irrespective of the contract details, the design firm must verify the costs incurred by the contractor so that an equitable payment from the owner to the contractor can be made. In competitive bid contracts, retainage is normally withheld from the contractor. This retainage is expressed as a percent of the cost of the work completed since the last payment request. A 10 percent retainage is common. The contractor is not paid in total until he has completed all work to the satisfaction of the design team and in some cases not until the statutory lien period had elapsed. Thus, all retainages are held by the owner until that time. The cost of work completed since the last payment request includes overhead and profit prorated to the cost items. It is possible in some cases for the contractor to moderately disproportionately allocate the overhead and profit such that cost items occurring early in a project are given larger allocations. This unbalancing of payment requests allows the contractor to lessen his initial investment in the project (Clough, 1969).

In some contracts, particularly some cost-plus contracts, the owner may not retain any amount (Clough, 1969). The timing of payments can be very important to the contractor. For example, under a cost-plus contract the payment request requires a considerable amount of verification by the

design firm. This involves time which lengthens the time interval between the request and the payment. The longer time interval may provide a cash hardship on the contractor and the contractor may have lost interest on a potential short term investment.

The above discussion on payment requests relates to lump sum contracts. In unit price contracts, the procedure is similar. The major exception is that periodic calculations of the amount of work accomplished are supplied in the payment request. The resulting calculations must be verified by the design firm. The contractor may unbalance his unit prices so that the items placed early in the project have higher unit prices.

Field Personnel, Equipment, Material Vendors and Subcontractors

Construction firms utilize field crews, equipment, material and subcontractors on the site to construct the project. Each project may use a different proportion of contractor crews, equipment, and materials to the labor, equipment and materials furnished by other firms. The proportion is dictated by cash flow differences, price, competence and financing.

Contractor crews can be union, nonunion, or both. The abilities and pay rates of the labor can vary from one locality to another. A firm operating in a wide geographical area will have to adjust their accounting and estimating accordingly. In some cases a parent construction firm may find it advantageous to hold a nonunion subsidiary which opens or maintains a certain market for them. The coordination, control, and management on the site is the responsibility of the field superintendent. Contractors

are highly dependent on competent superintendents, particularly on projects involving the contractor's crew. In cases when the project is completed strictly by subcontractors, a brokerage operation, the superintendent may be replaced by a project manager who handles the extensive field administrative work common to such jobs.

Construction firms may maintain a material inventory. This is normally a job-to-job inventory not involving a large warehousing effort. On most projects the majority of the material is supplied by material vendors. The material vendor submits a bid price and the contractor awards the material contracts. It is common practice for the material suppliers to offer discounts for early payment.

Contractors often enlist subcontractors to do portions of the work. The subcontractor bids for the work of the contractor. The contractor selects the sub-bids on the basis of the sub-bid amount, the competence of the sub, and past experience with the subcontractor. The construction firm usually retains the same percentage from the subcontractor as the owner retains from him and the retainages are withheld in the same manner as the owner's retainages. On some projects a contractor may act as a broker and build the project strictly through subcontractors. The cash outflow from the contractor is minimized and may be zero. In any situation where the contractor considers utilizing subcontractors, he must investigate the costs of his own crews compared to the price of the subcontractor (which includes the subcontractor's overhead and profit) as well as the cash flow.

Accounting Procedures

In this section accounting practices within a construction firm are described with emphasis on those unique to the construction firm. The accounting system is normally on the accrual basis. As Clough (1969) mentions, there are two types of accrual procedures used in construction for long-term contracts. The percentage-of-completion method periodically recognizes project income as construction progresses. The procedure uses the estimate to distribute the profit on an uncompleted project. Recall that the periodic payments may not reflect actual progress. The alternate method is the completed-contract method. In this case, project income is recognized only when a project is completed or substantially so. No profits are recognized until the project is substantially completed. There are tax and other considerations which influence the contractor in the choice of a particular method on a specific contract (Clough, 1969).

Two basic financial reports utilized by a construction firm are the income statement and the balance sheets. The income statement illustrates the company's income and expenses that have occurred during an interval of time. Table 1 shows a hypothetical income statement prepared by the completed-contract method. For some firms other income would include income from investments and bad debt recovery.

A hypothetical balance sheet showing the assets, liabilities and net worth of a construction firm is exhibited in Table 2. Observe the current assets include retainages due from owners. Current assets could also include an inventory component. The current liabilities includes those liabilities due subcontractors which is the sum of the retainages held by

Table 1. A hypothetical construction firm income statement^a

THE BLANK CONSTRUCTION COMPANY, INC. PORTLAND, OHIO	
<u>INCOME STATEMENT</u>	
For the Year ended December 31, 19__	
ITEM	TOTAL
(a) PROJECT INCOME	\$8,859,138.39
(b) Less Project Costs, including office overhead expense of \$239,757.04	<u>8,705,820.15</u>
(c) Net Project Income	<u>\$ 153,318.24</u>
(d) OTHER INCOME:	
Discounts Earned	\$ 23,064.93
Equipment Rentals	23,758.93
Miscellaneous	<u>12,882.64</u>
Total Other Income	<u>\$ 59,706.50</u>
(e) NET INCOME BEFORE TAXES ON INCOME	\$ 213,024.74
(f) FEDERAL AND STATE TAXES ON INCOME	<u>97,616.66</u>
(g) NET INCOME AFTER TAXES ON INCOME	\$ 115,408.08
RETAINED EARNINGS:	
(h) Balance, January 1, 19__	\$ 75,507.24
(i) Dividends Paid	<u>6,260.00</u>
Total	<u>\$ 69,247.24</u>
(j) BALANCE, December 31, 19__	<u><u>\$ 184,655.32</u></u>

^aSource: (Clough, 1969, p. 169).

Table 2. A hypothetical construction firm balance sheet^a

THE BLANK CONSTRUCTION COMPANY, INC. PORTLAND, OHIO	
<u>BALANCE SHEET</u>	
December 31, 19__	
<u>ASSETS</u>	<u>LIABILITIES</u>
(a) CURRENT ASSETS:	(f) CURRENT LIABILITIES:
Cash on hand and on deposit \$ 389,927.04	Accounts payable \$ 306,820.29
Notes receivable, current 16,629.39	Due subcontractors 713,991.66
Accounts receivable, including retainage of \$265,686.39 1,222,346.26	Accrued expenses and taxes 50,559.69
Deposits and miscellaneous receivables 15,867.80	Equipment contracts, current 2,838.60
Inventory 26,530.14	Provision for income taxes 97,616.66
Prepaid expenses 8,490.68	<u>Total</u> \$1,171,826.90
<u>TOTAL CURRENT ASSETS</u> \$1,679,791.31	(g) DEFERRED CREDITS:
(b) NOTES RECEIVABLE, NON-CURRENT \$ 12,777.97	Income billed on jobs in progress at December 31, 19__ \$2,728,331.36
(c) PROPERTY:	Costs incurred to December 31, 19__ on uncompleted jobs 2,718,738.01
Buildings \$ 5,244.50	<u>Deferred Credits</u> \$ 9,593.35
Construction equipment 188,289.80	<u>TOTAL CURRENT LIABILITIES</u> \$1,181,420.25
Motor vehicles 37,576.04	EQUIPMENT CONTRACTS, NON-CURRENT 7,477.72
Office furniture and equipment 13,596.18	(h) <u>TOTAL LIABILITIES</u> \$1,188,897.97
<u>TOTAL PROPERTY</u> \$ 244,706.52	NET WORTH:
(d) Less accumulated depreciation 102,722.51	(i) Common stock, 4,610 shares \$ 461,000.00
<u>NET PROPERTY</u> \$ 141,984.01	Retained earnings 184,655.32
(e) <u>TOTAL ASSETS</u> \$1,834,553.29	(j) <u>TOTAL NET WORTH</u> \$ 645,655.32
	(k) <u>TOTAL LIABILITIES AND NET WORTH</u> \$1,834,553.29

^aSource: (Clough, 1969, p. 171).

the contractor and the accounts payable to the subcontractor. The balance sheet was prepared under the completed-contract method. Deferred credits represents excess billings over related costs on projects that are currently underway but not completed (Clough, 1969). Current liabilities could also include current installments of a long-term debt. The long-term debt minus the current installment may be included as a noncurrent liability. Accrued expenses may include bonuses and profit sharing.

A funds flow statement may be used by a construction firm to represent the sources and uses of funds. Sources could consist of funds acquired by long-term loans, sale of stock as well as those provided by the operations. The uses of funds may include increases in physical facilities, acquisition of new construction equipment and changes in working capital.

A number of financial ratios are commonly used by construction firms and their financial institutions and bonding companies. Twelve ratios and average values for each taken from a sample of 39,000 contracting firms are presented by Park (1966) and illustrated in Table 3. The averages were developed from corporate income tax returns for firms representing all fields of construction. Therefore, these ratios must be considered with careful interpretation. For example, the ratios using fixed assets for a heavy contractor would be significantly different from those of the building contractor.

The accounting systems usually contain a project cost accounting system. Given source documents originating at the project, commonly, time cards, quantity-placed reports, and equipment time reports, the system provides labor cost distribution reports with projections.

Table 3. Financial ratios significant to contractors^a

Ratio	Average value ^b
Net profit to net sales	3.4%
Net profit to net worth	18.9%
Net profit to working capital	32.1%
Net profit to total assets	7.5%
Sales to net worth	5.6 times
Sales to working capital	9.4 times
Sales to fixed assets	6.0 times
Current assets to current liabilities	1.6 times
Cash to current liabilities	30.3%
Fixed assets to net worth	93.4%
Current liabilities to net worth	68.8%
Total liabilities to net worth	1.5 times

^aSource: Park (1966) p. 29.

^bBased on a sample of 39,000 contracting firms.

Usually the data is arranged by a cost code set at estimating and sorted by project.

Financing and Investments

Construction firms often require external financing to fund long and short term needs. Long term requirements may include capital expansion items such as an addition to the office building while short term loans

may be required to support temporary cash shortages on the projects. In either case, the character and ability of the contractor is analyzed by the lending institution in addition to the firm's financial position before a loan is given. Collateral such as the existing building and investments may be required before the loan is finalized.

Financial institutions are concerned about the liquidity of the construction firm. Two ratios are often carefully checked. The current ratio (current assets to current liabilities) and the sales to working capital ratio. The current ratio represents the ability of the firm to meet short term financial needs. In all cases, the financial institution desires a current ratio greater than one but the target ratio is dependent upon individual circumstances.

The sales to working capital ratio provides an indication of the financial ability of the contractor to meet current sales or volume requirements. The critical value depends on the cash flow management abilities of the contractor, the nature of the financial arrangements with the owner, the material vendors, and the subcontractors. Once a sales to working capital ratio has stabilized to a satisfactory value, the working capital needs for future contracts can be checked. For example, assume an established, appropriate sales to working capital ratio of 30 and that the projection of the funds flow statement indicates that \$500,000 of working capital will be available during the next fiscal period. Thus, a contract volume of \$15,000,000 ($30 \times \$500,000$) could be adequately funded with the working capital. However, if project cash flow problems develop, external financing may be solicited. This should be detected by the current state of the financial ratios involving working capital.

Investment policy in a construction firm may include both long and short term investments. For example, the contractor may invest in land for a future apartment or office building development. The short term investments may include stocks and commercial paper. The contribution of the securities to current assets is an important consideration by the financial institution and the surety company as well as by the contractor. Some securities may be considered lightly in their contribution to current assets. As an illustration, a surety company may consider the current asset worth of stock holdings as only 40 percent of their current trading value.

A good short term investment portfolio usually requires that a competent investment broker be available locally so that prudent short term investments, say in certain 30-day commercial paper, can be arranged. This is often a limitation placed on the construction firm located in a small population center where such services are not available.

Insurance and Bonds

The construction firm requires a vast amount of insurance coverage. The insurance can be classified into three types: project and property insurance, liability insurance, and other insurance. Project and property insurance protects the construction firm from losses on the project under construction. Example coverages include fire, vandalism, lightning, and burglary. Liability insurance protects the contractor against liabilities resulting from items such as injuries to people not in his employ, damage to the property of others, and additional coverage beyond workmen's compensation for personal injury by an employee. The other category

includes vehicle insurance, employee insurance and life insurance (Clough, 1969).

The insurance protects both the owner and the construction firm. It is usual that many insurance coverages are required in the contract documents.

Another type of protection afforded to the owner is that provided by the construction contract bonds. A contract bond is a promise by the surety that guarantees the fulfillment of the terms and conditions of a contract by another party. A bond involves three parties: the obligor, the principal who promises to accomplish something; the obligee, the beneficiary of the bond; and the surety who promises to make restitution to the obligee if the obligor fails to perform satisfactorily (Crist, 1950). In a construction contract bond, a surety company may guarantee to the owner, the obligee, that the contractor, the obligor, will perform the contract.

There are two basic types of construction contract bonds, a performance bond and a payment bond. In a performance bond the surety guarantees the project will be performed by the contractor in accordance with the contract documents while in the payment bond the surety guarantees the contractor will pay for all labor and materials used in performing the project (Clough, 1969). Subcontractor performance and payment bonds may be required.

The basic difference between an insurance company and a surety company is in the way the losses are paid. In the case of the insurance company, the losses are paid by the insurer from its premium fund. However, the

surety company pays only for those losses over and above that furnished by the resources of the obligor (Crist, 1950). Thus, the contractor would be liable to the surety company for all losses covered by the contract bond. Another difference is that a sizeable amount of time may have elapsed before a surety knows the loss whereas an insurance company detects the loss within a short period.

Underwriting construction contract bonds requires considerable subjective judgment as well as analysis of the financial condition of the contractor. The Insurance Company of America (1969) recommends the qualifications of the contractor be judged on the following:

1. Character,
2. Capacity (ability of personnel, experience),
3. Sufficient capital.

Sufficient capital involves the status of the contractor's working capital. A measure of this is the net quick ratio. The net quick ratio equals working capital divided by volume where volume includes the project considered for bidding. The acceptable minimum net quick ratio reflects the experience of the surety with the contractor and the contract provisions. It may be 0.10 for one contractor and for a large successful contractor whom the surety knows well it may be 0.05.

An acceptable minimum net quick ratio equivalent to a minimum current ratio can be determined by considering working capital and volume. The definitions of the two ratios are:

$$\text{NQKRTO} = \frac{\text{CA} - \text{CL}}{\text{VOL}}$$

$$\text{CURRTO} = \frac{\text{CA}}{\text{CL}}$$

NQKRT0 is the acceptable net quick ratio, CA represents current assets and CL the current liabilities, VOL is the current volume plus the potential additional contract, and CURRTO represents the acceptable ratio. As mentioned earlier, NQKRT0 and CURRTO are ratios monitored by the firm's surety and lending institutions. These two restraints are related through VOL. By substitution:

$$\begin{aligned} \text{NQKRT0} &= \frac{(\text{CL})(\text{CURRTO} - 1.0)}{\text{VOL}} \\ \text{or} &= \frac{(\text{CA})(\text{CURRTO} - 1.0)}{(\text{CURRTO})(\text{VOL})} \end{aligned}$$

Thus, for current liabilities of \$1,000,000, a volume (including a new project under consideration) of \$4,000,000, and a current ratio of 1.2, the equivalent net quick ratio is 0.05.

Rather than reviewing each potential project separately, a surety company may give blanket bonding capacity credit to a contractor subject to certain restrictions like project size (Insurance Company of North America, 1969).

Acquisition of a New Project

The purpose of this section is to summarize the processes by which a contractor acquires a new construction contract. A new project can be acquired through negotiation with the owner or through competitive bidding. In either case, prior to the receipt of the contract, a set of procedures common to both are followed. These procedures are enumerated below:

1. Select a potential project and check overhead. The project may be one on which the firm is particularly competitive or it may be

project in a new market. Check the overhead to ascertain whether or not capable personnel and support will be available.

2. Check the firm's financial standing, particularly working capital. This is done by the contractor, his financial institution, and his surety company. The current ratio and net quick ratio are inspected.
3. Estimate the probable direct cost of the project. This involves a quantity survey, pricing the quantities for labor and materials, solicitation of subcontractor bids and material vendor prices, and estimating project overhead. Pricing for labor may be done by using weighted past labor unit prices or by using weighted historical production rates and relevant wage scales. In a negotiated contract the estimate may be less detailed.
4. Assign markup to the direct cost of the potential project. The markup amount represents the general overhead and profit. Frequently the markup is expressed as a percentage of the direct cost, say 10 percent. The bid amount, or total cost of the project, is equal to the direct cost plus the markup. The markup may be adjusted to meet the competition, however, in many cases the competitiveness of the bid is decided by the estimators when they first begin preparing the bid. In the case of a negotiated contract a reasonable fee would cover the markup.

After negotiating with the owner or competing against competitors for the contract, the contractor wins or loses the project. In any one of the above steps, the potential project may be lost and thus the

procedure will begin anew. The initialization of the above procedures is a function of the firm's growth policy, the work available, and the work on hand.

THE SYSTEMS MODEL

This chapter is divided into four sections, the conceptual approach utilized in the development of the model, the simulation language employed, the subsystems of the model, and model validation. The details of the systems model are described within the subsystems.

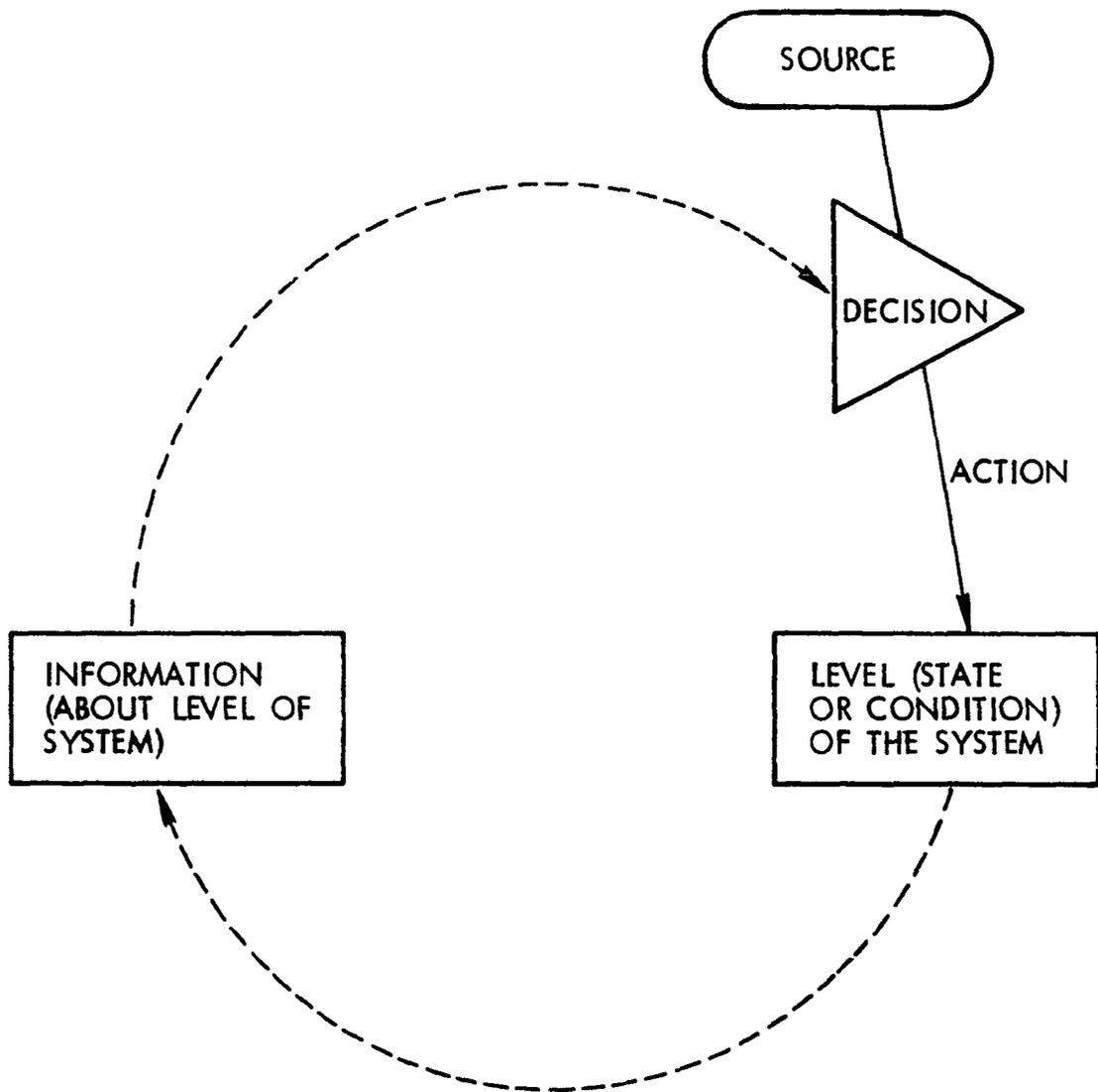
Conceptual Approach

The industrial dynamics or systems conceptualization of Forrester (1961, 1968c) defined the approach utilized in the development of the model. Thus, the construction firm was modeled as a closed system with the basic structural element, the feedback loop. The feedback loop was assumed defined as ". . . a path coupling decision, action, level (or condition) of the system, and information, with the path returning to the decision point" (Forrester, 1968c). This is conceptualized in Figure 3. The level represents the state of the system and is the generator of information about the system. Decisions utilize the information and result in actions.

There are two types of variables in the feedback loop: levels (states) and rates (decisions). The levels are integrations in the system and cannot be changed instantaneously. Rate variables define the rate of change in the levels and do not depend on past values. In essence the rates are the policy statements that describe the action given information about the levels. Forrester (1968c) subdivides the rate into four components:

1. A goal
2. An observed condition of the system
3. A way to express the discrepancy between goal and observed condition.

Figure 3. A conceptualized feedback loop. (Forrester, 1968c, p. 4-3)



4. A statement of how action is to be based on the discrepancy.

The schematic in Figure 4 depicts these components.

A simple first-order system is shown in Figure 5. There is one level, CSNVOL, which represents the construction volume-on-hand. The rate, INPRT, signifies the input rate to the construction volume. It is a policy depending on information about: (1) the competition, (2) the market and (3) the current construction volume. The input rate may be in units of dollars/month. The rate represents an attempt to control the construction volume by comparing the current state of CSNVOL to the desired state, DESVOL. Thus, given the information from the three sources, the rate adjusts so that the CSNVOL is held close to the desired volume, DESVOL. The output rate, PRT, models the production rate for all projects and may be expressed in dollars/month. Hence, PRT indicates the rate at which the construction volume is completed.

The above system is an example of a negative feedback system since it represents a goal seeking process. The other type of feedback system is a positive feedback system which ". . . generates growth processes wherein action builds a result that generates still greater action". (Forrester, 1968c)

The construction firm systems model was structured in the above manner. Two general networks were incorporated, cash and information. These are identified in Figure 6. The cash network consists of the levels and rates and flows (indicated by an oriented solid line). The dashed line portrays the information which connects the rates and levels. The accumulations or levels are represented by a rectangle whereas the rates

Figure 4. Components of a rate variable. (Forrester 1968c, p. 4-15)

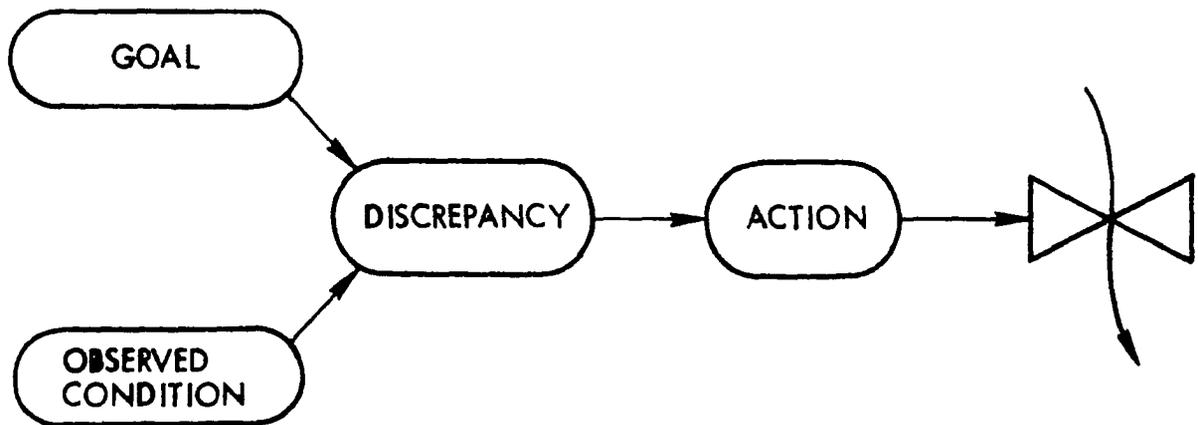
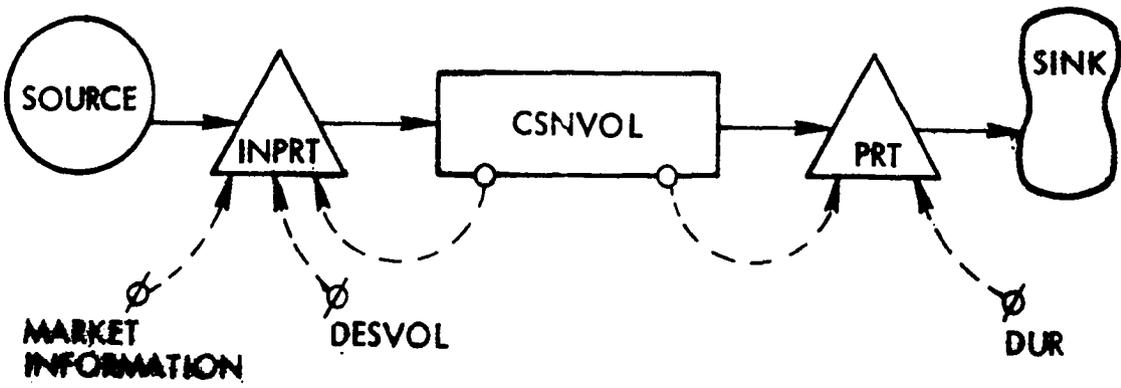


Figure 5. A simple first order system



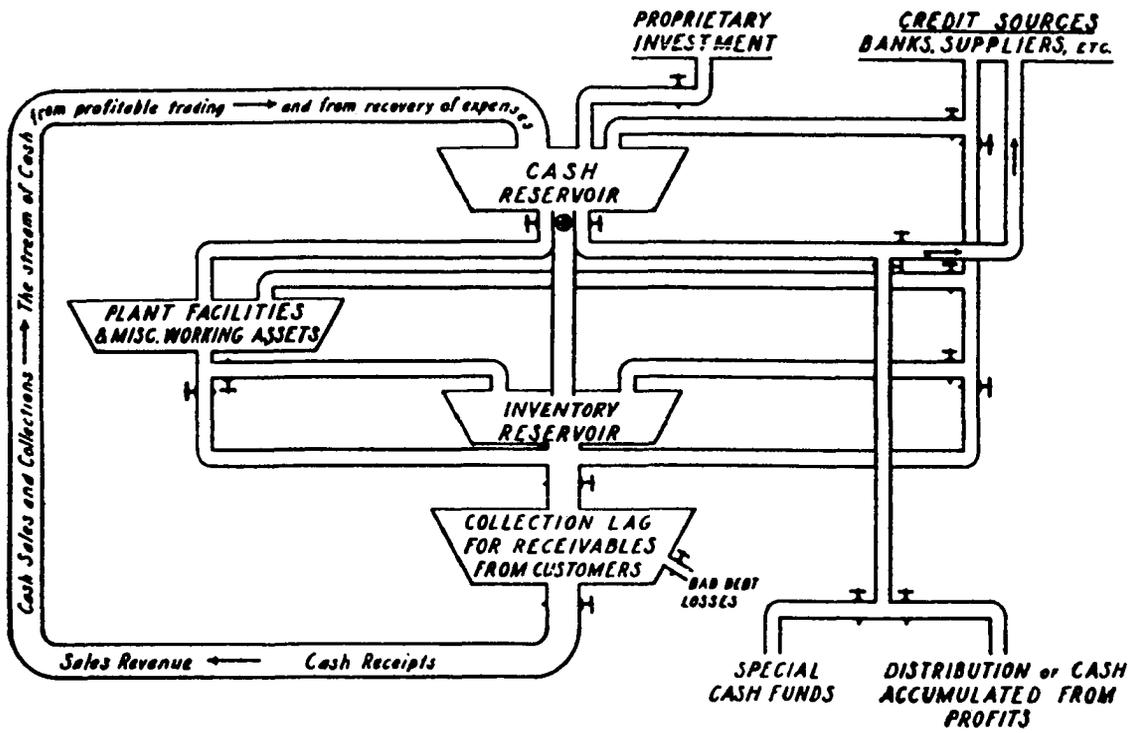
are symbolized by a "peaked" rectangle. The rounded rectangles represent auxiliary transformations of the information which contribute to the rates or decisions. The schematic in Figure 6 is a conceptualized summary of a detailed flow diagram.

The graphic model in Figure 6 is very similar to the cash flow diagram presented by Anthony (1964) and illustrated in Figure 7. The model describes a cash flow statement; a statement which identifies changes in the components of working capital for a hypothetical firm. The basic difference between the two representations is that the cash flow representation by Anthony lacks identification of information channels and feedback loops. However, rates are appropriately shown as valves.

The systems model developed for a construction firm incorporated a number of policies which defined a decision system. Five major policies of concern were included in the decision system: markup, the surety's policy (net quick ratio policy), financing (current ratio policy), overhead, and investment. The policies were assumed consistent with those of a growth oriented firm. These can be seen in Figure 6. Each decision policy was represented by a set of equations. The analysis of the model involved changing the equation form as well as changing the parameters for different simulation runs on the computer. The model can be labeled as a high order, nonlinear, multi-loop representation of a chosen decision system of a construction firm. The component loops were largely negative feedback loops which directed decisions toward an overall growth objective.

Figure 6. Conceptualization of a construction firm

Figure 7. Cash flow diagram. (Anthony, 1964, p. 345)



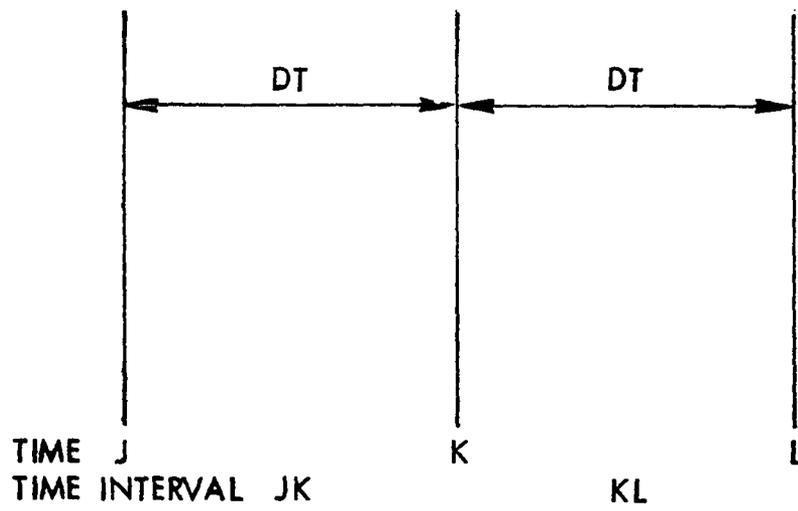
The Model Language

This section describes the computer simulation language used in the model. The model is described in the following section in the terminology of the simulation language and for this reason, a language description is included. Two continuous-change simulation languages were considered, FORDYN and DYNAMO II. Both were designed for processing models conceptualized by the systems approach of Forrester. The FORDYN language has the advantage of being a subroutine and procedural extension of FORTRAN (Llewellyn, 1965) and therefore is available on many computer systems. In addition it allows flexibility in that special routines and algorithms can be programmed. DYNAMO II (Pugh, 1963, 1968, 1969) is a language specific to the notation of Forrester. The language set is small and designed for use by the nonprogrammer. In addition, it provides a good diagnostic capability. The FORDYN language is a FORTRAN extension of DYNAMO (the original version of DYNAMO II) and is designed with the concepts of DYNAMO.

DYNAMO II was selected as the simulation language primarily because of the ease in programming and debugging.

The DYNAMO II language refers to simulated time in two ways. One reference relates to the state or level and the other relates to the time interval, DT , between states. The time representation is illustrated in Figure 8. The time designation follows the variable and is separated from the variable by a period. A level variable, say LEV , is referenced by a single subscript, J or K , or in the notation of the language, $LEV.J$ or $LEV.K$. In a similar manner, rate equations are tagged with an interval of

Figure 8. The simulation language time designation



time, JK or KL. Thus the rate, IN, could be IN.JK or IN.KL.

This simulation time notation sequences the calculations in processing. For example, a level variable at time K can be a function of any other level at time J and any rate during time interval JK. Similarly, a rate during KL can be a function of a level at time K and a rate during JK. The time interval DT represents the dt of differential and integral calculus. It is specified by the user.

The level equations are usually of the form:

$$N \quad \text{STATE} = 50.0$$

$$L \quad \text{STATE.K} = \text{STATE.J} + \text{DT} * (\text{INRT.JK} - \text{OUTRT.JK})$$

The first character defines the statement following it (N signifies an initial value, R a rate, and L a level). In the notation of integral calculus, this level equation represents:

$$\text{STATE}_t = \text{STATE}_o + \int_o^t (\text{INRT} - \text{OUTRT}) dt$$

A common form for a rate equation is:

$$R \quad \text{OUTRT.KL} = \text{STATE.K} / \text{DELAY}$$

Thus the rate discharges 1/DELAY of the level, STATE, each time it calculates. The variable DELAY may represent a production delay in weeks. Constants independent of time are defined in the following manner:

$$C \quad \text{RATIO} = 4.25$$

It is possible that rate equations become complicated and therefore a simplification exists in DYNAMO II for dividing the rate equation into

component equations. This is accomplished by auxiliary equations (identified by A). These equations are written at time K and can be functions of levels and other auxiliaries at time K and rates during JK. Auxiliary equations can be eliminated from the model by direct substitution into the corresponding rate equation. An illustration of a rate equation utilizing an auxiliary equation is given below:

$$A \quad \text{AUX.K} = \text{LEV.K} + 12.0 * \text{RAT.JK}$$

$$R \quad \text{INRT.KL} = \text{AUX.K} / \text{INDEL}$$

Supplementary equations define variables that are desired for output purposes. These are recognized by an S identifier. Supplementary variables are only computed at the time of output and are extraneous to the other equations. A table equation, T, enables the user to define entries in a table. An equation identified by X is a continuation of the statement above it.

A number of functions are available in DYNAMO II. Those used in the systems model of a construction firm are described below. In all cases V represents a quantity name (variable) on the left side of an equation. These definitions are comparable to those of Pugh (1968, 1969).

$$V = \text{SIN}(Q)$$

The sine function of Q where Q is in radians

$$V = \text{TABHL}(\text{TAB}, X, XLOW, XHIGH, XINC)$$

The table function of X where TAB names the table. X is the independent variable. XLOW is lowest X value, XHIGH is highest X value, and XINC is increment in X. In this function the extreme value is used when the range is exceeded. TAB is defined in a T equation where the dependent variables are specified.

V = CLIP(P,Q,R,S)

V = P if $R \geq S$
 V = Q if $R < S$

V = PULSE (P,Q,R)

V is a pulse train where pulses are during DT and at a height (magnitude) of P. The first pulse occurs at time Q and subsequent pulses appear at time = Q+R, Q+2R, etc.

V = STEP(P,Q)

V = 0 if time < Q
 V = P if time \geq Q

V = NOISE ()

V is a pseudo-random number uniformly distributed from -0.5 to 0.5.

V = NORMRN(M,S)

V is a pseudo-random number normally distributed with mean M and standard deviation S. V will not exceed ± 2.4 standard deviations.

V = SMOOTH(IN,DEL)

V is an exponentially smoothed calculation of IN with a delay of DEL. The smoothing is done in the following manner:

$$V_{t+1} = (1/DEL) IN + (1 - \frac{1}{DEL}) V_t$$

Subsystems of the Model

The subsystems of the model are explained using the DYNAMO II simulation language. Only those equations relevant to an understanding of the structure and interactions of the components are enumerated. A complete listing of all equations is found in the Appendix. A detailed flowchart is given in Figure 9. The rectangles represent levels; the triangles, rates; and rounded rectangles, auxiliaries. The solid oriented lines portray the flow of cash and the dashed lines indicate information changes. Each set of equations described in the section is identified by a number enclosed in parenthesis.

Figure 9. Detailed flowchart of the systems model

Project acquisition and production

This subsystem consists of the equations depicting the policies pertinent to securing a new project and the equations related to the preparation and completion of projects. The following equations establish the markup and the characteristics of the competitors.

$$C \quad KMP = 1.10$$

$$C \quad MKVAR = 0.0$$

$$A \quad MARKUP.K = KMP + MKVAR * SIN(4.523 + 6.283 * TIME.k / PERD) \quad (1)$$

$$C \quad AVMKUP = 0.6$$

$$C \quad SDMKUP = 1.0$$

$$C \quad PERD = 48.0$$

The markup, MARKUP, as ratio of the total cost to the direct project cost is expressed as a function of time. The MARKUP varies about KMP according to the phase angle and the ratio of simulation TIME and the period, PERD. The amplitude of the variation is MKVAR. Time is expressed in months. The markup policy is related to the project arrival width of equation set (3) by the difference in the two phase angles. AVMKUP represents the average markup of all bids, the contractor's and his competitors', on past projects while SDMKUP is the standard deviation of the markups.

The following equations generate a potential project's size given the firm's growth rate and average project size for the first fiscal year to be simulated.

C GRWTH = 0.20
 C INPRJ = 500000.0
 A PROJET.K = INPRJ+PRJ1.K+PRJ2.K+PRJ3.K+PRJ4.K (2)
 A SDPRTT.K = PROJET.K/4.0
 A PRJET.K = NORMRN(PROJET.K,SDPRTT.K)

The growth rate is defined by GRWTH. This indicates the firm's planned annual growth increase. The first year's average project size, in dollars, is established by INPRJ. Provision is made through equations supporting PROJET (not contained above) to enable a $1.0+GRWTH$ increase on the past year's expected completed volume. The increase is constant during a year. Thus PROJET.25 (the value of PROJET in the twenty-fifth month) equals $(1+GRWTH)^2 * INPRJ$ and PROJET.36 equals $(1+GRWTH)^3 * INPRJ$. The standard deviation of project size is defined by SDPRTT. The potential project size, PRJET is generated from a normal distribution with a mean of PROJET and standard deviation SDPRTT.

C ARWCHG = 0.0
 C AARWTH = 0.22
 A PRJWTH.K = AARWTH+ARWCHG*SIN(1.571+6.283*TIME.K/PERD) (3)
 A PRJAR.K = PULSE(PRJET.K,0.0,PRJWTH.K)

Equation set (3) determines the width in time, PRJWTH, between projects and then produces a project, PRJAR at PRJWTH intervals. Recall that the markup lags PRJWTH. The statistical expected value of all contracts considered for bidding in a given year is $(12.0/PRJWTH)*PROJET$.

The current year's completed construction volume, YCSNLV is checked against the firm's capacity to manage the growth in the set of equations given below. It is assumed the growth ceiling, GRWCLG, allows for a completed volume increase of GRWTH + ADJGW over and above last year's completed volume, YCSNAX. The constant ADJGW is an estimate of unanticipated extra load which can be maintained with the overhead policy. Thus, the firm's maximum capacity based on overhead capabilities is defined by GRWCLG.

$$C \quad ADJGW = 0.10$$

$$A \quad GRWCLG.K = (1.0+GRWTH+ADJGW)*YCSNAX.K \quad (4)$$

$$A \quad PTBID.K = CLIP(PRJAR.K, 0.0, GRWCLG.K, YCSNLV.K)$$

The constraint offered by the surety company is assumed represented strictly by the lowest acceptable net quick ratio, DNQRTO. Provision is made to allow the net quick ratio constraint to be a function of time. The constraint is implemented in the equations below. If the constraint does not limit the firm, then PRJBIB equals PTBID, the variable representing a project's potential after considering the growth ceiling (see equation set (4)).

$$C \quad CNQRTO = 0.08$$

$$A \quad DNQRTO.K = CNQRTO \quad (5)$$

$$A \quad PRJBID.K = CLIP(PTBID.K, 0.0, DNQRTO.K, DNQRTO.K)$$

The final consideration in determining whether or not a project of a given size is acquired is one of chance. The equations below compute the

probability of winning against the competitor, BIDPRB, by entering a standardized cumulative normal distribution, table BIDTAB, with the transformation represented by ZZ. A uniformly distributed number, ODDS, with values $-0.5 \leq \text{ODDS} \leq 0.5$ is drawn and compared with the bid probability on a common scale, PERCT. The variable PRJWON represents the status of a newly acquired project. It will be zero or PRJBID, approximately a BIDPRD fraction of the simulation cycles.

```

A   ZZ.K = (MARKUP.K-AVMKUP)/SDMKUP
A   BIDPRB.K = TABHL(BIDTAB,ZZ.K,-2.0,2.0,0.25)
T   BIDTAB = 0.98/0.96/0.93/0.89/0.84/0.77/0.69/0.60/0.50/0.40/
        0.31/0.23/0.16/0.11/0.07/0.04/0.02
C   LOWRAN = -0.50
A   PERCT.K = LOWRAN+BIDPRB.K
A   ODDS.K = NOISE()
A   PRJWON.K = CLIP(0.0,PRJBID.K,ODDS.K,PERCT.K)

```

(6)

In order for PRJWON, the value of the acquired project to be >0, the variables PTBID, PRJBID must both be >0, and the project must be won from the competitors given the firm's markup, MARKUP, and the parameters describing a past history of bidding, AVMKUP and SDMKUP. The value of PRJWON equals PRJET when all of the above conditions are met.

The acquired volume can exist in two states; contracts won but not started in the field, CSNPRP, and contracts underway, CSNLV. The value of PRJWON enters CSNPRP. The following equations depict the levels and flows associated with the production on the acquired volume.

N CSNPRP = 800000.0
 L CSNPRP.K = CSNPRP.J+DT*(PRJINR.JK-CSNIN.JK)
 R PRJINR.KL = PRJWON.K/DT
 C PREPDL = 2.0
 R CSNIN.KL = CSNPRP.K/PREPDL (7)
 N CSNLV = 4000000.0
 L CSNLV.K = CSNLV.J+DT*(CSNIN.JK-PRJOT.JK)
 A PRJINC.K = MARKUP.K*PJCST.K*CSNLV.K/CNDUR.K
 R PRJOT.KL = PRJINC.K

The delay, PREPDL, indicates the average length of time a project is in CSNPRP. This delay represents the time between the receipt of the contract and the point in time when sitework begins. The average duration of a project is CNDUR. The duration is a stochastic variable which is determined in the support equations. The production rate, PRJOT, in dollars/month, is a stochastic variable since its calculation utilizes two stochastic variables, CNDUR, and PJCST. PJCST represents a randomly varying cost-to-contract amount ratio. The generation of this is described in the section on support equations. The fluctuations of PJCST represent variations in field production.

Cash inflow subsystem

This subsystem consists of the set of equations which determines two cash inputs within the cash flow structure. The subsystem contains two levels, ACCREC, accounts receivable, and RETHLD, retainages held by the owner from the contractor. The cash input rates then respectively

represent the owner payment rate, PAYRT, and the retainages receipt rate, RETREC. The equations are shown below. The cash inflow due to interest on short term investment is described in a subsequent section.

$$N \quad \text{ACCREC} = 735000.0$$

$$L \quad \text{ACCREC.K} = \text{ACCREC.J} + \text{DT} * (\text{PYREG.JK} - \text{PAYRT.JK})$$

$$R \quad \text{PYREG.KL} = (1.0 - \text{RETRTO}) * \text{PRJINC.K}$$

$$C \quad \text{PYMTDL} = 0.25$$

$$R \quad \text{PAYRT.KL} = (\text{ACCREC.K} / \text{PYMTDL})$$

$$N \quad \text{RETHLD} = 280000.0$$

$$L \quad \text{RETHLD.K} = \text{RETHLD.J} + \text{DT} * (\text{RETRT.JK} - \text{RETREC.JK})$$

(8)

$$C \quad \text{RETRTO} = 0.10$$

$$R \quad \text{RETRT.KL} = \text{RETRTO} * \text{PRJINC.K}$$

$$C \quad \text{RTTMDL} = 2.0$$

$$A \quad \text{RTNDEL.K} = \text{CNDUR.K} + \text{RTTMDL}$$

$$R \quad \text{RETREC.KL} = \text{RETHLD.K} / \text{RTNDEL.K}$$

The variable, RETRTO, defines the fraction of the payment retained by the owner. The respective delays related to the two states significantly influence system behavior. The delay, PYMTDL, is the time interval between the payment request by the contractor and the receipt of the payment. The delay in receiving all retainages on a project, RTNDEL, equals the sum of the project duration, CNDUR, and an additional delay, RTTMDL. The length of RTTMDL can be affected by the statutory mechanic lien period and the average time it takes the contractor to complete the punch list.

Cash outflow subsystem

Equations supporting the simulation of the levels; accounts payable, ACCPAY, the retainages held by the firm from the subcontractors, SUBRTN, and state and federal taxes, TAXLV, are included in this subsystem. These represent the majority of the accounts assumed as current liabilities. However, those variables related to long term loans and bonus and profit sharing are described in subsequent subsystems. The cash outflow subsystem includes those construction direct costs absorbed by the contractor, CPRCT. This variable includes all material costs including those furnished by vendors and all other direct costs.

R $CPRCT.KL = (1.0 - SUBRTO) * PJCST.K * CSNLV.K / CNDUR.K$

N $ACCPAY = 530000.0$

L $ACCPAY.K = ACCPAY.J + DT * (ACPYIN.JK - ACPRT.JK)$

C $SUBRTO = 0.6$

A $SUBPAY.K = (CSNLV.K) * (SUBRTO)$

R $ACPYIN.KL = (1.0 - RETRTO) * SUBPAY.K * PJCST.K / CNDUR.K$

C $ACPDEL = 0.35$

R $ACPRT.KL = ACCPAY.K / ACPDEL$

N $SUBRTN = 230000.0$

L $SUBRTN.K = SUBRTN.J + DT * (SBRTIN.JK - SBRTPD.JK)$

R $SBRTIN.KL = RETRTO * SUBPAY.K * PJCST.K / CNDUR.K$

R $SBRTPD.KL = SUBRTN.K / CNDUR.K$

N $TAXLV = 35000.0$

L $TAXLV.K = TAXLV.J + DT * (TAX.JK - TXPYRT.JK)$

C $TAXRT = 0.5$

(9)

R $TAX.KL = PFBTX.K * TAXRT / DT$

R $TXPYRT.KL = PULSE(TXPAY.K, 2.0, 12.0)$

A $TXPAY.K = TAXLV.K / DT$

A $PFSRTX.K = TAXRT * NPFSHR.K / DT$

R $ADTAX.KL = PULSE(PFSRTX.K, FIRBPS, BPSWTH)$

The ratio, SUBRTO, represents the proportion of the total costs (modeled by PJCST) absorbed by the subcontractor. It is assumed that the retainage fraction withheld by the contractor is the same withheld by the owner, RETRTO. The delay associated with the time required to pay the accounts payable is ACPDEL. The delay for paying the subcontractor retainages is the project duration, CNDUR. Thus, it is assumed the subcontractors are not paid in total until the project is completed.

The state and federal tax rate is indicated by TAXRT. The tax rate is applied against the profits before tax auxiliary variable, PFBTX. The tax liability excepting that due to taxes on the profit sharing "fund", PFSRTX, is represented by the tax level, TAXLV. The taxes are assumed paid every twelve months beginning after two months have elapsed (see the equation for the payment rate, TXPYRT, and that for the auxiliary TXPAY). Note the dependence of many rate equations on the construction project production rate, CSNLV.K/CNDUR.K. This production rate is stochastic because of the stochastic generation of the project duration, CNDUR.

Overhead subsystem

The overhead acquisition policy, bonus and profit sharing plans are the principal components contained in this subsystem (equation set (10)).

C BPSWTH = 12
 C FIRBPS = 1.0
 C BNSRTO = 0.20
 A BNSCST.K = BNSRTO*OVHLV.K
 A BNSDED.K = CLIP(BNSCST.K, INVLV.K, INVLV.K, VNSCST.K)
 A GPRSHR.K = INVLV.K-BNSDED.K
 C MPFSRO = 0.15
 A MAXPFS.K = MPFSRO*(OVHLV.K+BNSDED.K)
 A NPFHR.K = CLIP(MAXPFS.K, GPRSHR.K, GPRSHR.K, MAXPFS.K)
 A TBSPS.K = (BNSDED.K+NPFHR.K)/DT (10)
 A ACRBP.K = TBSPS.K*DT
 N OVHLV = OVHRTO*YCSNAX
 C OVHITV = 12.0
 R OVCST.KL = OVHLV.K/OVHITV
 C OVHRTO = 0.04
 C OVHSMC = 3.0
 A SPRJOT.K = SMOOTH(PRJOT.JK, OVHSMC)
 A DESOVH.K = (SPRJOT.K*12.0*OVHRTO-OVHLV.K)/12.0
 R ADJOVH.KL = CLIP(DESOVH.K, 0.0, DESOVH.K, 0.0)
 L OVHLV.K = OVHLV.J+DT*ADJOVH.JK

Overhead is assumed to contain many of the expenses normally associated with general overhead such as salaries, building depreciation, office supplies, etc. However, it does not include cost of long-term financing and taxes. The systems model does not include account provisions for long-term assets and therefore the overhead expenses consider building and

equipment depreciation as a cash outflow. Thus, the asset acquisition rate is assumed as a continuous expenditure rather than a set of discrete amounts. Also because of this procedure, depreciation expenses are not adjusted to add to the cash flow as is normally done in cash flow statements (Anthony, 1964). As is portrayed in the above equations, the bonuses, BNSCST, and the profit sharing, NPFSHR, are withdrawn from the investment level, INVLV. The bonus ratio is defined by BNSRTO and the maximum permissible profit sharing ratio by MPFSRO. The equations simulate the following procedure:

1. First pay the bonuses up to a maximum of the bonus ratio (BNSRTO) applied against the overhead level (OVHLB).
2. If cash remains in the investment level, INVLV, withdraw up to the permissible maximum of profit sharing, MPFSRO.
3. The net remaining in the INVLV remains as a cash source for short-term investment.

Since the bonus ratio is expressed as a proportion of the assumed overhead, it is not analogous to a bonus-to-salary ratio. The variable ACRBP represents the bonus and profit sharing liability, a current liability. The overhead policy assumes that the overhead can only be acquired and not retired. This is realistic when one considers the small number of general overhead employees in a construction firm and the reluctance of top management to dismiss them because of the personal proximity.

The overhead acquisition policy is based on maintaining an overhead-to-completed volume ratio of OVHRTO. The policy is implemented using exponentially smoothed information about the project completion rate,

PRJOT. The information is weighted by a time smoothing constant, OVHSMC. The input rate to overhead, ADJOVH, then depends upon the difference between the projected overhead need based on the smoothed information, $SPRJOT.K*12.0*OVHRT0$, and the current overhead level, OVHLV. This is indicated in the equations for DESOVH and ADJOVH.

The implemented overhead policy assumes a linear relationship between overhead and completed contract volume. Thus economies of scale are not assumed. This assumption appears realistic under certain assumptions regarding the composition of overhead. The overhead composition appropriate to a linear relation assumes the overhead consists of a high proportion of salaried personnel and the higher salaries are held by project managers. In addition it is assumed that project managers are assigned to projects in proportion to salary; the larger projects receiving a high-salaried project manager.

The salaried personnel not allocated like the project managers above, may be affected by economies of scale, particularly those providing support services like bookkeeping, purchasing, etc. Also the extent of computerization is a factor.

Investment and external financing subsystem

The systems model contains a short-term investment capability. The investment level, INVLV, is the source of funds for annual bonuses and profit sharing as was mentioned earlier. The following equations establish the investment policy.

```

N   INVLV = 300000.0
L   INVLV.K = INVLV.J+DT*(INVDED.JK+LONIN.JK-INVCHG.JK-LONOT.JK)
R   INVCHG.KL = PULSE(TBSPS.K,FIRBPS,BPSWTH)
C   INVWTH = 1.0
C   FIRINV = 0.0
R   INVDED.KL = PULSE(INVAMT.K,FIRINV,INVWTH)
A   SINVLV.K = SMOOTH(INVLV.K,RETWTH)
A   INTST.K = SINVLV.K * INVINT
C   INVINT = 0.0067
C   RETWTH = 1.0
C   FIRRET = 0.0
A   INVRET.K = PULSE(INTST.K,FIRRET,RETWTH)
C   DESBAL = 100000.0
A   DIFBAL.K = CSHBAL.K-DESBAL
A   CSAINV.K = CLIP(DIFBAL.K,0.0,DIFBAL.K,0.0)
C   INVRTO = 1.0
A   INVAMT.K = INVRTO*CSAINV.K/DT
R   INVINC.KL = INVRET.K/DT

```

(11)

The rate inputs to INVLV consist of funds acquired from a long-term loan, LONIN, and those obtained from a cash surplus, INVDED. The loan policy is described later. The rate of cash input to the investment level is determined by a desired cash balance policy. The desired cash balance is set by the constant DESBAL, and if the cash balance, CSHBAL, is greater than DESBAL, then the difference weighted by an investment-to-total potential investment ratio, INVRTO, is inputted into the investment level.

The output rates from the INVLV consist of INVCHG, a rate accounting for the annual bonus and profit sharing deduction, and LONOT, the rate at which the long-term loan is repaid. A monthly interest rate INVINT is applied to the investment. The interest rate is on the exponentially smoothed balance, SINVLV, which emphasizes the balance RETWTH months earlier. If RETWTH is set equal to 1.0 month, then the smoothing approximates an interest return on the INVLV, one month earlier.

The long-term loan policy establishes a source for increasing working capital (since the model does not include provisions for managing noncurrent assets, long-term asset financing is not considered as an application of these funds).

```

N   LONLV = 0.0

L   LONLV.K = LONLV.J+DT*(LONIN.JK-LONOT.JK)

C   CALSMC = 1.0

A   SMCAL.K = SMOOTH(CALRTO.K,CALSMC)

A   DIFCAL.K = (DESCAL-SMCAL.K)*CURLIB.K/DT

C   MINLN = 50000.0

A   DLNAT.K = MINLN/DT

R   LONIN.KL = CLIP(DIFCAL.K,0.0,DIFCAL.K,DLNAT.K)

C   LNPRD = 13.0                                     (12)

R   LONOT.KL = LONLV.K/LNPRD

A   ISLL.K = 0.0

C   LINTR = 0.0075

A   LNITAT.K = LINTR*LONLV.K/DT
C   DESCAL = 1.2
C   FIRLON = 1.0
C   LONWTH = 1.0
R   LONINT.KL= PULSE(LNITAT.K,FIRLON,LONWTH)

```

The long-term loan state, LONLV, is increased by the rate, LONIN. The input rate is a result of a policy considering the firm's desire to maintain at least a specific minimum current ratio, DESCAL. This can also be considered as a finance institution's and/or surety company's constraint(s). In order to avoid over-reaction, the construction firm's actual current ratio, CALRTO, is smoothed with the emphasis on the data CALSMC months earlier. The policy also assumes that a specified minimum loan, MINLN, must be required before a loan is secured. The loan period is specified by LNPRD and the monthly interest rate by LINTR. The loan level output rate, LONOT, assumes the current loan amount is completely repaid in LNPRD months. However, the reduction of the loan state is done continually rather than discretely. The interest cost of the long-term loan is calculated monthly by the rate equation for LONINT which utilizes the auxiliary LINITAT. The variable ISLL represents the current installment of the long-term loan, a current liability. In the above equation set, ISLL is set to zero because the long-term loan is assumed due just after twelve months. This allows the loan to contribute to current assets without incurring a short-term liability and yet be paid just over twelve months. Thus the loan is not considered long-term and will not be carried into the next fiscal period as a long-term liability. If the terms of the long-term loan require a normal long-term period, then the ISLL could be written as:

$$A \quad ISLL.K = LONOT.JK*12.0$$

It is also assumed that assets are available as security for the loan.

Supporting equations

The systems model includes equations supporting the subsystems and the entire system. Each equation in this section is pertinent to the assumptions made in the model. The components of the cash account, CSHBAL, are shown in the following equation.

$$\begin{aligned}
 N \quad & \text{CSHBAL} = 175000.0 \\
 L \quad & \text{CSHBAL.K} = \text{CSHBAL.J} + \text{DT} * (\text{PAYRT.JK} + \text{RETREC.JK} - \text{ACPRT.JK} - \text{CPRCT.JK} - \\
 & \quad \text{OVCST.JK} + \text{INVINC.JK} - \text{TXPYRT.JK} - \text{INVDED.JK} - \text{LONINT.JK} - \text{ADTAX.JK} - \\
 & \quad \text{SBRTPD.JK})
 \end{aligned}$$

The inputs to the cash state are:

1. owner payment rate, PAYRT
2. owner retainage receipt rate, RETREC
3. investment interest income, INVINC.

The cash outputs are:

1. accounts payable payment rate, ACPRT
2. the firm's projects direct cost and material vendor cost rate, CPRCT
3. the overhead cost rate, OVCST
4. the tax payment rate, TXPYRT
5. the cash source for investment rate, INVDED
6. the interest cost of long-term rate, LONINT
7. the tax adjustment for profit sharing rate, ADTAX
8. the subcontractor retainage payment rate, SBRTPD.

The current assets assumed in the model are shown in the equation for CURAST.

$$A \quad \text{CURAST.K} = \text{ACCREC.K} + \text{RETMLD.K} * \text{INVLV.K} + \text{CSHBAL.K}$$

Thus the levels, accounts receivable, ACCREC, retainages receivable, RETHLD, the short-term investment level, INVLV, and cash balance, CSHBAL, are considered as current assets.

The current liabilities, CURLIB, are contained in the following equation.

$$A \quad \text{CURLIB.K} = \text{ACCPAY.K} + \text{TAXLV.K} + \text{ACRBP.K} + \text{ISLL.K} + \text{SUBRTN.K}$$

The accounts payable to subcontractors are represented by ACCPAY, the tax liability by TAXLV, the bonuses and profit sharing payable by ACRBP, the current installment of the long-term loan by ISLL, and the retainages due to subcontractors by SUBRTN.

The owner's equity, OWNEQ, is assumed equal to an initial owner's investment, INSTK, plus retained earnings. The retained earnings input rate is represented by NPFRT, the net profit rate.

$$C \quad \text{INSTK} = 300000.0$$

$$N \quad \text{OWNEQ} = \text{INSTK}$$

$$L \quad \text{OWNEQ.K} = \text{OWNEQ.J} + \text{DT} * \text{NPFRT.JK}$$

It is assumed that the sale of additional stock does not occur during the time period simulated.

The generation of the stochastic variable representing the weighted project duration, CNDUR, is accomplished by the following.

$$C \quad \text{SDDUR} = 3.0$$

$$C \quad \text{AVDUR} = 8.0$$

$$A \quad \text{CNDUR.K} = \text{NORMRN}(\text{AVDUR}, \text{SDDUR})$$

The duration is drawn from a normal distribution with mean AVDUR and standard deviation SDDUR.

In the models processed, three approaches to determining the mean deviation for the aggregated projects were used. In one case the durations of the different projects expected during the simulation period were weighted in proportion to the expected number of each type. An average of the weighted durations was subsequently calculated. The second approach employed data from the most appropriate actual fiscal period. The following proportion was assumed:

$$\frac{\text{Average volume during fiscal period}}{\text{AVDUR}} = \frac{\text{Annual volume completed}}{12 \text{ months}}$$

The average volume was simply the average of the beginning and the end of construction volume on hand. The third approach determined AVDUR after a number of different values were assumed for AVDUR in different simulations. That value which yielded the appropriate annual volume completion provided the estimate. The standard deviation was selected by considering the variation in the expected durations and/or variation observed in the third approach described above.

The auxiliary variable PJCST represents the ratio of cost-to-contract price that occurs at every time point. It is a stochastic variable with mean AVCSRO and standard deviation SDCSRO and is assumed normally distributed.

$$A \quad \text{AVCSRO.K} = 1.0/\text{MARKUP.K}$$

$$C \quad \text{SDCSRO} = 0.040$$

$$A \quad \text{PJCST.K} = (\text{AVCSRO.K} + \text{NORMRN}(0.0, \text{SDCSRO}))$$

Thus fluctuations in the cost ratio such as those resulting from

production changes and weather are simulated. The mean cost ratio equals the reciprocal of the markup. This causes some error when the markup varies with time, because the stochastic cost ratio at time K is assumed dependent on the markup at the same point in time. In reality the average cost ratio would be approximately equal to the reciprocal of the markup at the time the project was awarded which could be many simulation cycles earlier. To simulate this, the markup for each project must be stored. This model, however, aggregates all projects into one large volume.

Model Validation

A model since it is only a representation of a real system cannot be completely validated. However, indications of validity can be determined. The basic indication of validation utilized was the extent to which the actual system behavior was realized. This is the approach recommended by Forrester (1961). Another approach used was the comparison between the model's response and actual results.

Actual data and policy of a construction firm were incorporated in the systems model for validity checks. Two years were simulated. The data included the firm's balance sheets, profit and loss statements, monthly cost reports, and annual overhead expense breakdowns. This information provided the basis for most of the initial conditions and parameters. Once all the initial conditions and parameters were properly implemented, the model was adjusted using simulation runs on the computer. The minimum acceptable net quick ratio had to be adjusted to

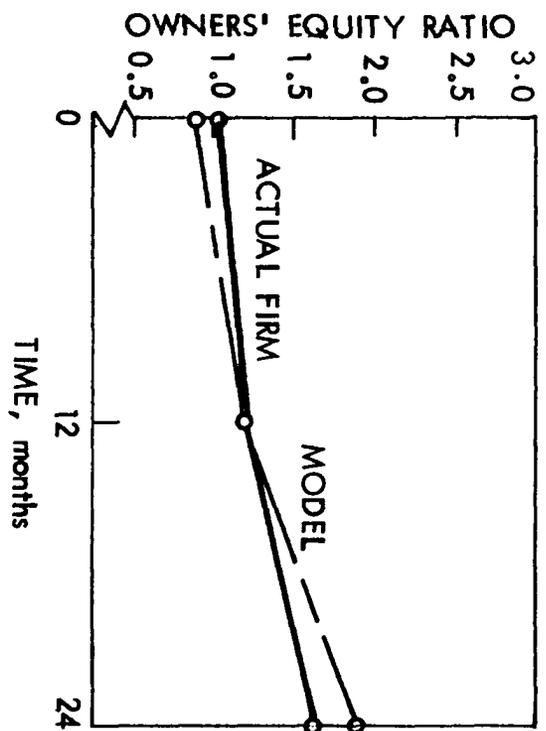
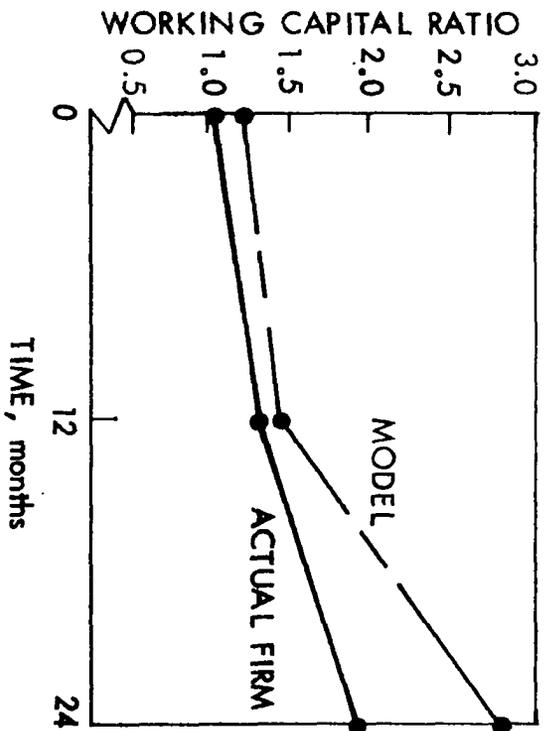
account for the subjective judgment of the surety company. Another adjustment involved selection of the average duration. This parameter influences many variables and was selected considering the simulated project completion rate.

The behavior appeared representative of the firm's performance. Two comparisons are illustrated. In Figure 10 the fiscal year-end working capital balances are compared for each of two years. The points entered on the graph are expressed as ratios of the initial working capital of the firm.

In a similar manner owner's equity is exhibited in Figure 11. The systems model did not duplicate the performance of the actual firm. The model does not account for each individual contract and therefore the cost and time status of volume on hand cannot be exactly stated. For example, one project of \$100,000 may be near completion, whereas another may be only 50 percent complete. This is not acknowledged by the model because all projects are summarized into one aggregate representation. However a long period of simulation time, say five years, would offset this because the original projects would have been completed. This simplification appears to account for most of the error. Nevertheless, the behavior and trends of the simulation were representative of the actual firm. A number of variables were monitored on the simulation run of the firm - in particular the annual project completion amount, the monthly profit amount, the calculated current ratio, the working capital, the volume to equity ratio, the net quick ratio, and the profit sharing. Constraints offered by the overhead capacity and the minimum acceptable

Figure 10. Comparison of model and actual working capital annual balances

Figure 11. Comparison of model and actual owners' equity annual amounts



net quick ratio were checked by inspecting the level of the contracts acquired for which field work has not begun (CSNPRP) along with the level of overhead and the calculated net quick ratio corresponding to the same point in time. Thus if a downward trend in CSNPRP was observed, then the constraint values were studied in order to ascertain the cause. The only other factors affecting the CSNPRP are the pseudo-random project arrival sizes and the pseudo-random winning of contracts by the firm from their simulated competition.

Behavior of the model was also checked in the simulation runs of a hypothetical firm described in the next chapter. The effect of strikes, poor accounts receivable collection, and other factors were simulated and found to be appropriate. In addition, statistical experimental design techniques were also employed to study the effect of including interactions of investment return, markup policy, and initial working capital and net quick ratio policy on the system response. These results were also considered appropriate.

RESULTS AND DISCUSSION

This chapter describes the system behavior of a hypothetical firm under different sets of values for parameters and initial conditions. The analysis deals with the dynamic responses of the model as displayed in the graphical output. Experimental design techniques are employed to explain the main and interaction effects of two factors under two sets of initial conditions.

The Hypothetical Firm

Data were drawn from firms representative of the industry and were cast as those of a hypothetical firm. The data so drawn provided the parameter values necessary for analysis of the systems model. The parameter and initial condition values were those used in the systems model description of the last chapter. All equations and parameters of this firm are listed in the Appendix. The firm's basic plan was to successfully bid an additional twenty percent over the previous years completed volume with the hope of attaining a corresponding increase in profits. Maximum leverage of the working capital was assumed desirable. A medium size firm engaged strictly in contract construction was assumed. The last fiscal years production was \$7,000,000. The policies were set for the next five years.

The firm was initialized with a favorable working capital status (the firm began with a current ratio of 1.653 and \$588,600.00 of working capital). The firm's initial net quick ratio was 0.118 and the beginning volume to equity ratio was 16.0.

The initial working capital accounts are exhibited below.

Current Assets		
Cash	\$175,000	
Short-term investment	300,000	
Accounts Receivable	735,000	
Retainages Receivable	<u>280,000</u>	
Total Current Assets		\$1,490,000
Current Liabilities		
Accounts Payable	530,000	
Profit sharing and bonus payable	106,400	
Taxes Payable	35,000	
Retainages payable to subcontractors	<u>230,000</u>	
Total Current Liabilities		<u>901,400</u>
Working Capital		\$ 588,600

These data represent the beginning balance sheet status. Note the current installment of the long-term debt is zero. The cash to current liability ratio is 0.194, however, if the ratio is redefined to include liquid short-term investment in the numerator, the ratio becomes 0.528.

The base model incorporated the following parameters for establishing the markup policy and for defining the competition. The markup ratio was defined as the ratio of the contract amount to estimated direct cost. The hypothetical firm's markup ratio was set at a constant value of 1.10. The average markup ratio of all competitors (including the markup of the hypothetical firm) on past projects within the firm's market was 0.60 of the hypothetical firm's direct cost. The competitor markup ratios were calculated by dividing the competitor's bid amount by the firm's estimated direct cost. Thus, a low average of 0.60 could be due to the hypothetical firm's high estimate of the direct cost. The standard deviation of competitor markup ratio was 1.0. This low average markup ratio and large standard deviation represented a highly volatile

competitive environment. The above three parameter values yielded a probability of winning of 0.31 (recall the model assumes the markups are normally distributed). The potential project arrival interval was 0.22 months and the first year average size was \$500,000 and the corresponding standard deviation was \$125,000. Thus the expected volume won was: $(0.31) (12 \text{ mos}/(0.22 \text{ mos/project})) (\$500,000/\text{project}) = 8,400,000$ or 120 percent of 7,000,000 (the growth objective).

The growth policy had an upper ceiling for an increase of 30 percent in the completed volume. Hence the firm would discontinue bidding when the actual completion rate exceeded 130 percent of last years completed volume. This represents the maximum capacity of the firm under the assumed policies.

The surety company's constraint on growth was represented by an 0.08 minimal acceptable net quick ratio. A current ratio of 1.2 was set as the finance institution and surety companies' minimal current ratio constraint.

The average duration of the aggregate projects was set at 8.0 months and the standard deviation of the duration at 3.0 months. The length of time a newly acquired project is held by the contractor before field work begins was 2.0 months. The delay in processing payment requests was 0.25 month while time elapsing after the project is completed before the retainages are paid to the firm was 2.0 months. The contractor's delay in processing subcontractor requests for payment was 0.35 months. It was assumed the subcontractor retainages were disbursed immediately after each project was completed.

The firm began the new fiscal period with \$4,000,000 of contracts

underway in the field and \$800,000 of contracts acquired but not started in the field. The direct cost ratio was assumed to be normally distributed with the mean equal to 0.91 and 0.04 standard deviation.

The short-term investment policy was to invest all cash above \$100,000 to yield 0.67 percent per month (8 percent annually). A maximal bonus ratio of 0.20 was incorporated and the maximal profit sharing was 0.15 of the overhead and bonus sum. The overhead acquisition policy was to adjust the overhead in an attempt to maintain it at 0.04 of the current annual completion volume. The information about the actual ratio was experimentally smoothed with a smoothing time constant of 3.0 months.

The company tax rate was assumed to be a constant 0.50. A 0.6 ratio of subcontractor volume to total contract volume was employed.

When the company's current ratio drops below 1.2, a long term loan of at least \$50,000, payable in 13 months at 0.75 percent per month is secured to bolster the current ratio to 1.2 under the assumed long-term loan policy. Thus the current installment due on long-term debt is zero. It was also assumed that assets were always available as collateral for the long-term loan.

The firm's initial owners' equity was set at \$300,000 (this could be considered as the initial book value of the stock).

Systems Behavior

A number of simulations were run using the structure of the hypothetical firm defined above. Parameters and initial conditions were uniquely modified for each run in order to develop an understanding of the systems

model. In each simulation run, the solution interval, DT, was set at 0.05 months in accordance with the recommendations of Forrester (1961, 1968c). The length of the simulation run was 60 months in all cases. Therefore, a total of 1200 simulation cycles were processed in each run. The systems behavior was analyzed by studying the model response in the tabular and graphical output for each set of parameter values and initial conditions. The results and analyses for these runs are presented in this section. To provide a consistent framework, the pseudo-random number sequence was not altered between these runs.

A control simulation run was processed using all of the parameters and initial conditions defined above for the hypothetical firm. This run is labeled the control run. A portion of the tabular output (26 months) is exhibited in Table 4. The headings refer to the model variables. The scale of each variable is printed below each variable. The variables are horizontally aligned to a common simulation time base, TIME. The initial values for each variable are entered at time = 0.

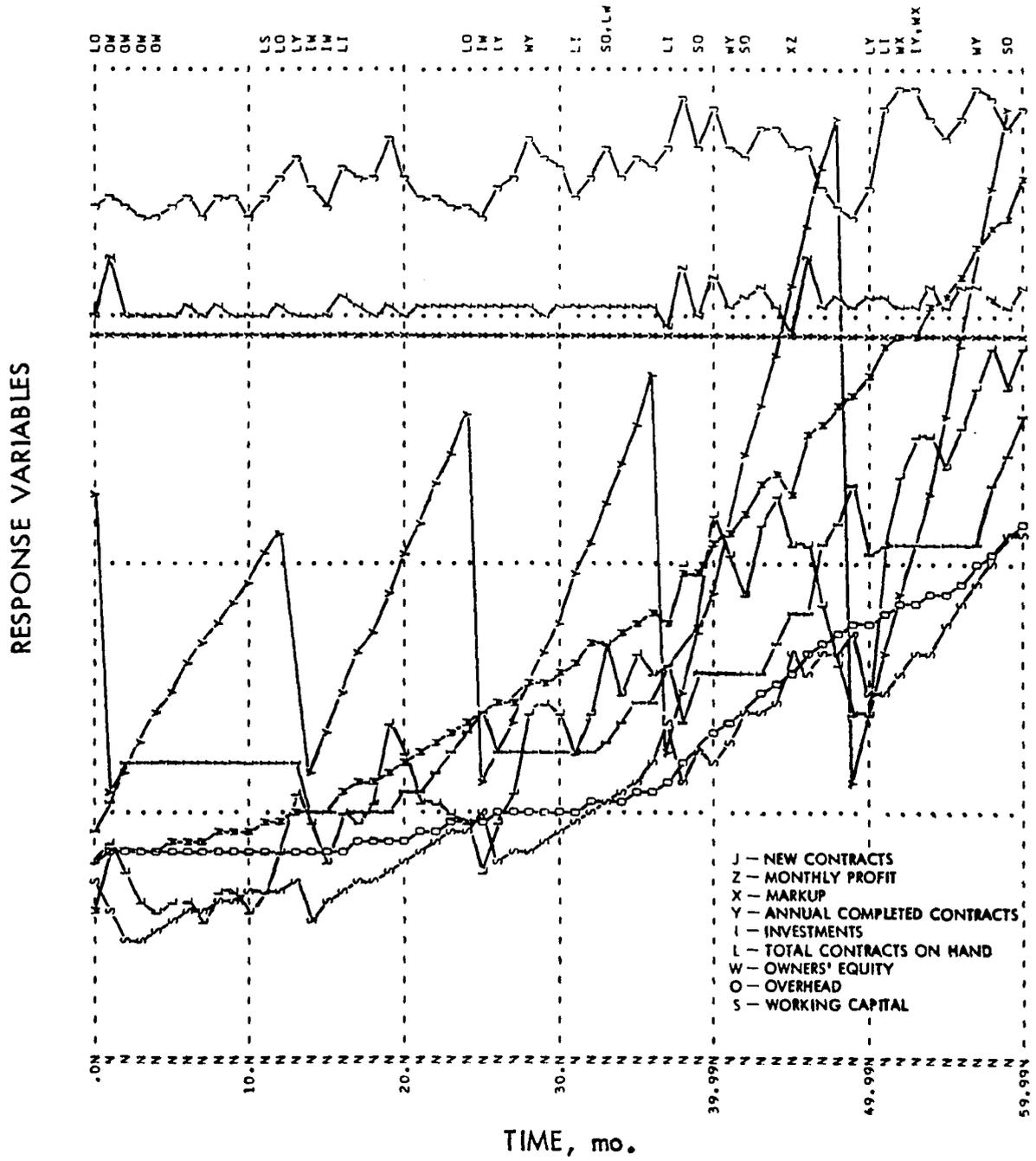
The output variables consist of the total contract amount on hand, the overhead level, the short-term investment level, the long-term loan level, the cash balance state, the owners' equity level, the profit sharing amount, the working capital, the firm's net quick ratio, the volume to equity ratio, the annual project completion amount, the monthly profit amount, the annual profit amount, and the firm's current ratio. The analysis on the systems model behavior is based primarily on the graphical output, however, the tabular output provides some detail and support.

The control run graphical output is shown in Figure 12. Selected

Table 4. A portion of the tabular output for the control run

TIME	TOPRJ	OVHLV	INVLV	LONLV	CSHBAL	OMNEQ	MPFSHR	WKGCAP	NQKRT0	VOLEQ	YCSNAX	MPFLV	YPFLV	CALRTO
E+00	E+06	E+03	E+03	E+00	E+03	E+03	E+03	E+03	E+00	E+00	E+06	E+03	E+03	E+00
.0	4.800	280.00	300.0	0.	175.00	300.0	50.40	588.6	.11767	16.000	7.000	.00	.00	1.6530
1.	5.160	284.77	375.0	0.	301.89	428.4	51.26	493.8	.08766	12.045	7.000	128.39	128.39	1.8035
2.	4.614	288.09	468.7	0.	67.05	425.0	51.86	390.2	.07718	10.858	7.000	-3.43	124.97	1.6769
3.	4.109	289.34	468.7	0.	-85.35	429.2	52.08	410.2	.08936	9.575	7.000	4.21	129.17	1.9962
4.	3.925	289.55	468.7	0.	-86.71	424.1	52.12	448.1	.10168	9.255	7.000	-5.08	124.09	2.0581
5.	4.008	289.55	468.7	0.	-73.41	431.6	52.12	462.7	.10156	9.286	7.000	7.49	131.57	2.1093
6.	4.129	289.55	468.7	0.	-63.81	443.6	52.12	479.9	.10529	9.307	7.000	12.05	143.63	2.1286
7.	3.624	289.55	468.7	0.	-70.49	444.8	52.12	503.5	.12075	8.146	7.000	1.21	144.84	2.1464
8.	4.291	289.55	468.7	0.	-42.52	458.1	52.12	512.9	.10883	9.366	7.000	13.27	158.11	2.1820
9.	4.313	289.55	468.7	0.	-21.16	465.1	52.12	518.9	.10928	9.273	7.000	6.96	165.07	2.2556
10.	3.846	289.55	468.7	0.	-7.22	468.1	52.12	537.3	.12467	8.216	7.000	3.05	168.12	2.2693
11.	4.176	289.55	468.7	0.	3.10	473.8	52.12	556.2	.12386	8.313	7.000	5.70	173.82	2.2584
12.	4.977	289.55	468.7	0.	28.81	486.0	52.12	562.0	.10105	10.240	7.000	12.21	186.03	2.2989
13.	6.074	289.55	468.7	0.	46.85	492.3	52.12	593.5	.08855	12.339	6.053	6.24	6.24	2.2549
14.	5.568	289.55	358.6	0.	35.37	501.5	52.12	473.2	.07383	11.102	6.053	9.25	15.49	1.9931
15.	4.728	289.64	358.6	0.	-34.80	495.9	52.13	533.7	.09578	9.535	6.053	-5.67	9.82	2.1227
16.	5.843	291.69	358.6	0.	24.00	531.9	52.50	546.9	.08503	10.986	6.053	36.02	45.84	2.1845
17.	5.589	294.91	358.6	0.	61.16	552.7	53.08	569.0	.09105	10.112	6.053	20.82	66.66	2.2164
17.999	5.994	296.55	358.6	0.	69.81	562.3	53.38	592.8	.08691	10.660	6.053	9.64	76.30	2.1829
18.999	7.515	300.04	358.6	0.	130.95	589.5	54.01	615.7	.07719	12.747	6.053	27.20	103.50	2.1844
19.999	6.835	302.31	389.6	0.	112.09	591.6	54.42	651.9	.08765	11.553	6.053	2.10	105.60	2.1751
20.999	6.028	305.17	401.7	0.	139.24	613.8	54.93	679.2	.10147	9.819	6.053	22.21	127.81	2.1296
21.998	5.871	309.20	440.9	0.	143.35	632.0	55.66	711.4	.11123	9.290	6.053	18.14	145.95	2.1342
22.998	5.792	312.73	484.3	0.	143.15	656.1	56.29	717.8	.11230	8.829	6.053	24.08	170.02	2.1638
23.998	5.653	315.68	527.4	0.	136.56	674.1	56.82	742.6	.13136	8.387	6.053	18.04	188.07	2.1496
24.998	4.701	320.11	564.0	0.	147.35	696.3	57.62	782.2	.15078	6.751	8.592	22.20	22.20	2.1356
25.997	5.584	322.75	489.7	0.	102.71	713.4	58.09	639.0	.10243	7.827	8.592	17.08	39.28	1.9498

Figure 12. The graphical output for the control run



variables are plotted against time. Each variable is plotted at a different scale which remains constant for all simulation runs (this differs from the tabular output where the scale is determined by the program for each run).

The output of the control run appeared to be reasonable for the firm defined. The annual contract completion amounts, annual profits, and annual profit-to-annual volume percentages are shown in Table 5 for the first, second, third and fourth years. The results for the fifth year are not included because annual completion volume is not

Table 5. Annual results of the control run

Time mos.	Annual completion dollars	Annual profit dollars	<u>Annual profit</u> <u>Annual volume</u> %
12	6,053,000	186,030	3.07
24	8,592,000	188,070	2.19
36	9,481,000	233,040	2.46
48	14,899,000	419,910	2.82

an output until the near year is begun. However, the trend is observable for all five years in the graphical output (Figure 12). The annual profit percentage is similar to that of the building construction industry. The owners' equity at the end of the 60 months was \$1,777,400 and the owners' equity grew nonlinearly over time. The volume to equity ratio oscillated somewhat and became approximately 8.4 toward the end of the simulated five years.

There was some variation in the current ratio. It began at 1.65 but averaged around 2.25 near the end. The current ratio never decreased to its initial value. The net quick ratio averaged 0.10, but the ratio dropped below the lower limit of 0.08 for six of the 60 months. The model did not require external long-term financing.

Overhead acquisition (see Figure 12) appears to follow the completion volume in an appropriate manner. The acquisition of new contracts oscillated considerably over the 60 months, but a general increase over time was noted. The fluctuations are due to the constraints: minimum net quick ratio, overhead capacity, and chance acquisition against the competitors. New contracts decrease to a minimum level at 39 months, probably due to the rapid increase in completion volume which overtaxed the overhead capacity.

The monthly profit varies particularly after 36 months. This may have been caused by the rapid growth after that time. However, an unusually high monthly profit of \$128,390 was observed for the first month.

The short-term investment level showed a general growth with the annual deductions for profit sharing and bonuses visible on the graphical output.

The completed contract-growth is summarized in Table 6. The completed contract amount at 48 months represented an increase of 212 percent over the beginning \$7,000,000. The theoretical increase in new contracts that was successfully estimated at 48 months, assuming the new acquisition growth of 20 percent, is:

$$(1.0+0.2)^4 100\% = 207\%$$

Table 6. Completed contract growth of the control run

Time months	Annual volume dollars	Percentage growth over previous year
0	7,000,000	
12	6,053,000	-13.5%
24	8,592,000	41.9%
36	9,481,000	10.3%
48	14,899,000	57.1%

The firm's growth was not completely consistent with the working capital available. As the results indicated, the firm should have had a greater growth objective. For example, at 48 months the working capital was approximately \$1,250,000, and assuming a minimum net quick ratio of 0.08, the firm could have completed \$15,625,000 rather than \$14,899,000. The somewhat high current ratio developed in the simulation supports the above. The firm could have better utilized its working capital and/or the time delays in the various working capital accounts could have differed.

The graphical results of the payment delay run are shown in Figure 13. In this simulation, the owners' payment delay was increased from 0.25 month to 0.50 month. All other variables remained as those for the control run. This change produced more oscillation in monthly profits particularly in the earlier months. As was expected, the net quick ratio was generally higher than that of the control run. The net quick ratio was less than 0.08 only once in the 60 monthly outputs. The annual

Figure 13. The graphical output for the payment delay run

completion and profit results are shown in Table 7. The owners' equity after five years was \$1,683,300 (\$94,100 less than that of the control run). This simulation run illustrated the oscillations and profit decreases due to the longer processing of contractor payment requests.

Table 7. Annual results of the payment delay run

Time months	Annual completion dollars	Annual profit dollars	<u>Annual profit</u> <u>Annual volume</u> %
12	6,662,000	104,130	1.56
24	9,809,000	196,190	2.00
36	9,940,000	211,260	2.12
48	16,924,000	456,440	2.70

The third simulation run involved the lengthening of the period of time during which the construction firm processes subcontractor accounts payable. This delay was increased from 0.35 month to 0.60 month. All other variables were as defined in the control run. As shown in Figure 14, there was a steeper trend in new contracts acquired. The resulting annual completion and profits are illustrated in Table 8 for the accounts payable delay run. The net quick ratio was generally smaller with 14 months less than 0.08. Also the current ratio was smaller. The owners' equity after five years was \$1,767,400.

In the retainage delay run, the delay by the owner in releasing all retainers held from the contractor was increased from the average project

Figure 14. The graphical output for the accounts payable delay run

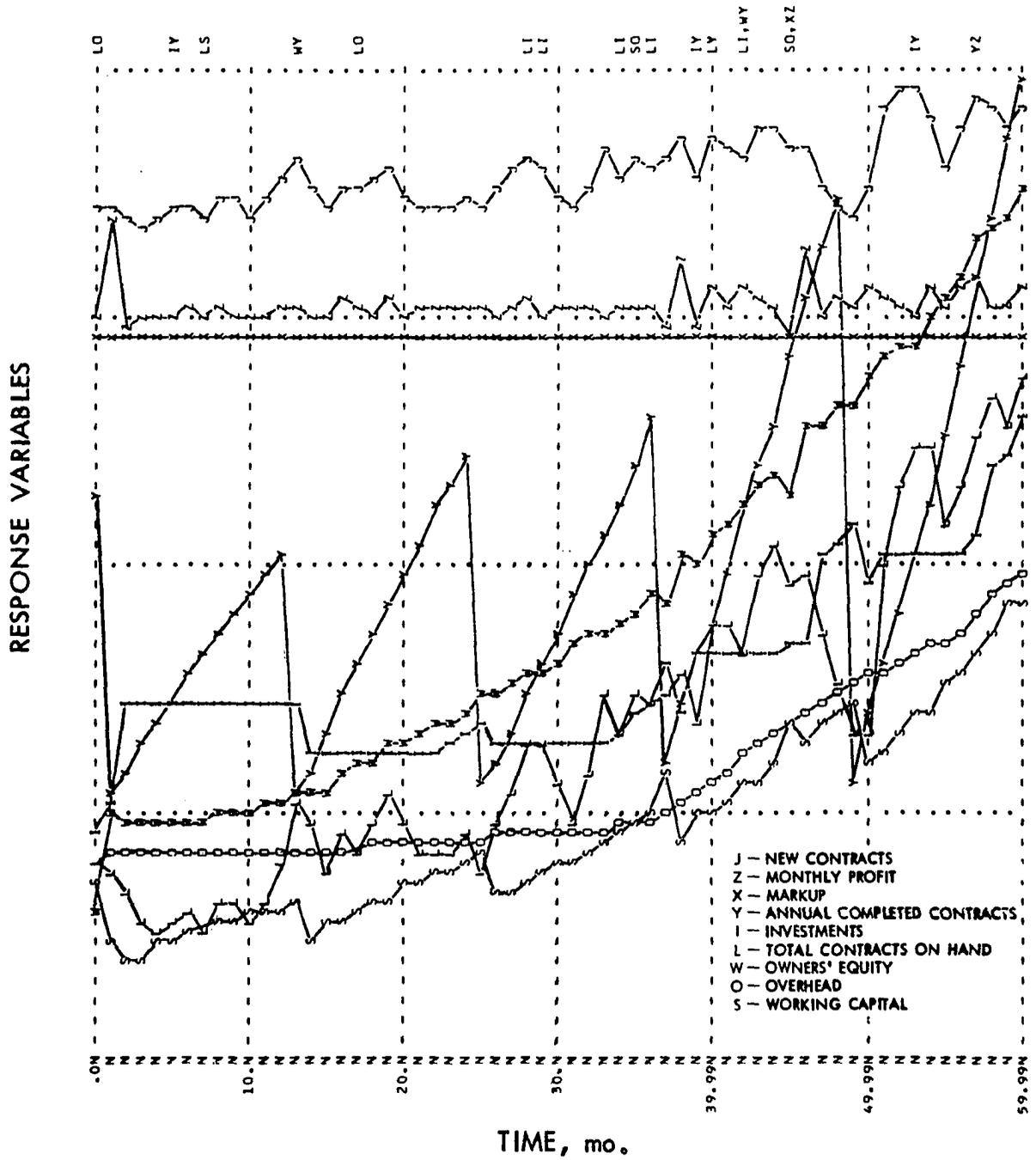


Table 8. Annual results of the accounts payable delay run

Time	Annual completion	Annual profit	<u>Annual profit</u> <u>Annual volume</u>
months	dollars	dollars	%
12	5,704,000	223,090	3.91
24	7,826,000	180,720	2.31
36	8,582,000	226,490	2.64
48	13,214,000	384,100	2.91

duration plus two months to the average duration plus three months. The graphical response was similar to that of the control run. The net quick ratio was generally slightly higher than the control run. Three ratios were less than 0.08. The owners' equity achieved \$1,733,700 after five years. The annual volume and profit results are in Table 9.

Table 9. Annual results of the retainage delay run

Time	Annual completion	Annual profit	<u>Annual profit</u> <u>Annual volume</u>
months	dollars	dollars	%
12	6,053,000	170,070	2.81
24	8,592,000	175,400	2.04
36	9,710,000	228,870	2.36
48	15,666,000	421,950	2.69

The markup run simulated an increase in markup from 1.10 to 1.24. The response is shown in Figure 15. Notice that the short-term investment state climbed very rapidly over time. The owners' equity reached \$4,450,000 in the 60 months. The current ratio was higher than the control run and none of the 60 net quick ratios were less than 0.08. The annual profits were substantially greater than those of the control run (see Table 10), while the annual completions were lower.

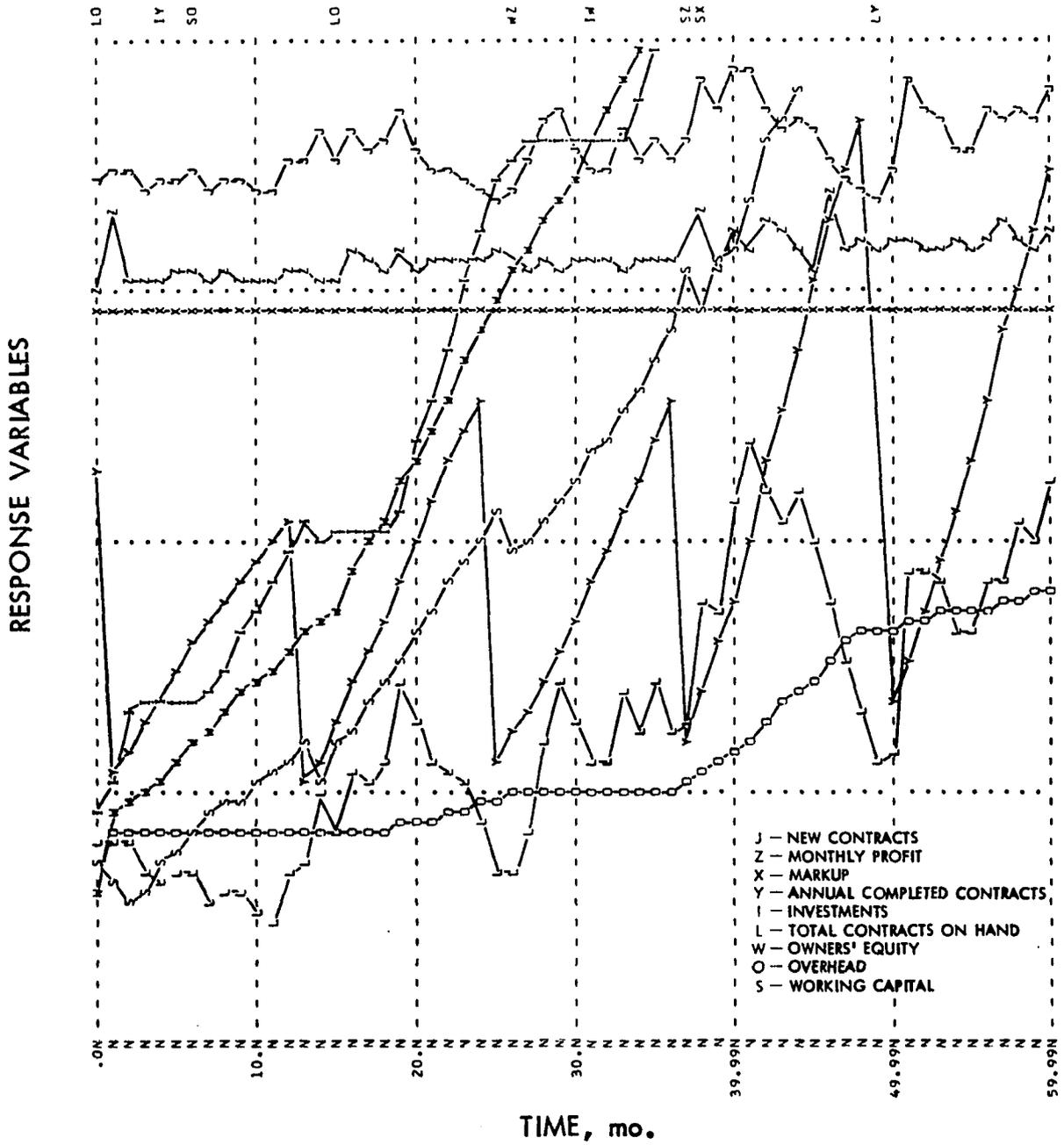
Table 10. Annual results of the markup run

Time months	Annual completion dollars	Annual profit dollars	<u>Annual profit</u> <u>Annual volume</u> %
12	5,916,000	480,500	8.12
24	8,463,000	630,600	7.45
36	8,470,000	689,400	8.14
48	14,235,000	1,196,800	8.41

This run represented the cushion of a healthy working capital situation. Despite a slightly lower probability of winning (0.27 in contrast to 0.31), the return was greater for the assumed distribution of markups. The distribution was quite insensitive to a change in the markup (the sensitivity could have been increased by decreasing the standard deviation).

The probability of winning run simulated a relatively sensitive probability of winning-markup distribution. The mean of the distribution

Figure 15. The graphical output for the markup run



was altered to 1.05 and the standard deviation changed to 0.1. The probability of winning at a markup of 1.10 remained the same as the earlier runs at 0.31. The constant markup was set at 1.20 which resulted in a 0.07 probability of winning. The annual results of this run are shown in Table 11. The owners' equity was \$1,689,400 after five years.

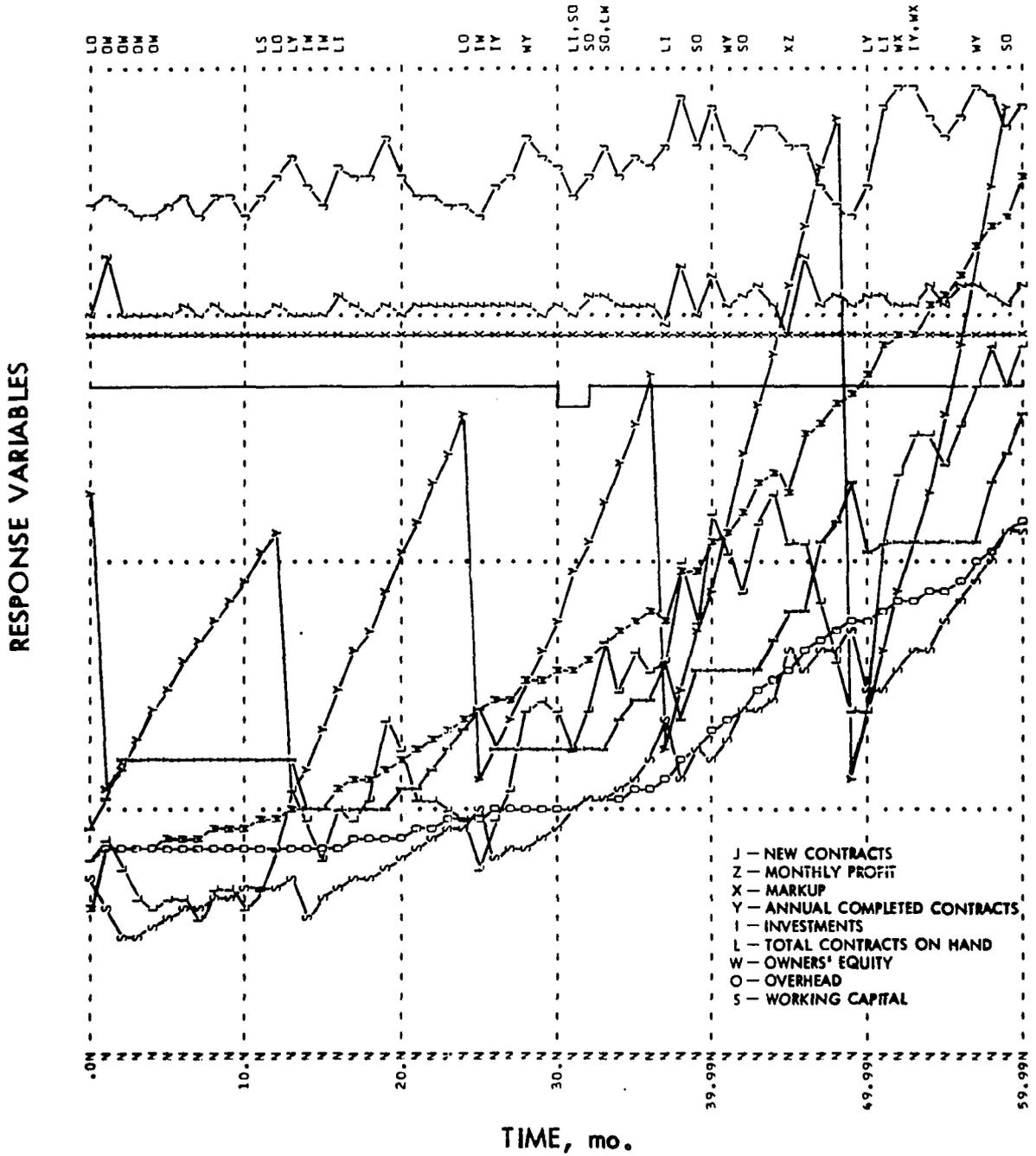
Table 11. Annual results of probability of winning run

Time months	Annual completion dollars	Annual profit dollars	<u>Annual profit</u> <u>Annual volume</u> %
12	2,217,800	333,300	15.03
24	2,915,900	180,490	6.18
36	1,703,700	202,560	11.88
48	3,786,800	296,360	7.82

This was considerably lower than the owners' equity under the insensitive distribution assumed in the markup run. However, the annual profit-to-annual volume was slightly higher for this run; it oscillated more due to completed volume variations.

A simulation run intended to represent a firm having difficulty in collecting account receivables was processed. The run, labeled the receivables run, had the account receivable output rate suppressed to 75 percent of what it normally was. The suppressed rate began at time equal to 30 months and continued as such for two consecutive months (this is graphically shown in Figure 16). This caused the receivables to build up

Figure 16. The graphical output for the receivables run



in the accounts receivable level. The monthly profit amount dipped at 31 months but recovered at 32 and 33 months. The effect on working capital is shown in Table 12.

Table 12. Working capital changes in the receivables run

Time months	Control run	Receivables run
30	736,900	736,900
31	764,900	795,800
32	780,400	807,500
33	813,300	813,700

The annual completion and profit results are exhibited in Table 13. The firm appeared to have recovered from the poor collection of receivables. The owners' equity was \$1,777,400 at the conclusion of the run.

A labor strike was simulated in manner similar to the simulation of

Table 13. Annual results of the receivables run

Time months	Annual completion dollars	Annual profit dollars	<u>Annual profit</u> <u>Annual volume</u> %
12	6,053,000	186,030	3.07
24	8,592,000	188,070	2.19
36	9,481,000	232,970	2.46
46	14,899,000	419,900	2.82

poor receivables. In this case the generation of project direct costs were suppressed to 25 percent of normal for one month beginning at 30 months. The strike run thus simulated a strike affecting 75 percent of the project cash flows. A monthly profit comparison is shown in Table 14.

Table 14. Monthly profit comparison of the strike run

Time months	Monthly profit	
	Control run	Strike run
30	16,500	16,500
31	25,230	30,270
32	26,330	3,870
33	12,480	15,040
34	24,060	25,800

Observe the larger oscillations in monthly profit for the strike run. The owners' equity was \$1,742,200 after 60 months. The comparison of this with the results of the control run attributes a loss of 35,200 over the five years to the simulated strike. Table 15 contains the annual results of the simulation.

The project arrival run represented a firm which was subjected to a sinusoidal variation in project arrivals and which maintained a constant markup policy. The simulation represented a cyclical change with a period of 48 months and maximum amplitude of 0.04 months between project arrivals. Thus the maximum arrival rate was a potential project arriving every 0.18 months (the average arrival interval was 0.22 months) while the minimum was an arrival rate of one every 0.26 months. The project arrival interval

Table 15. Annual results of the strike run

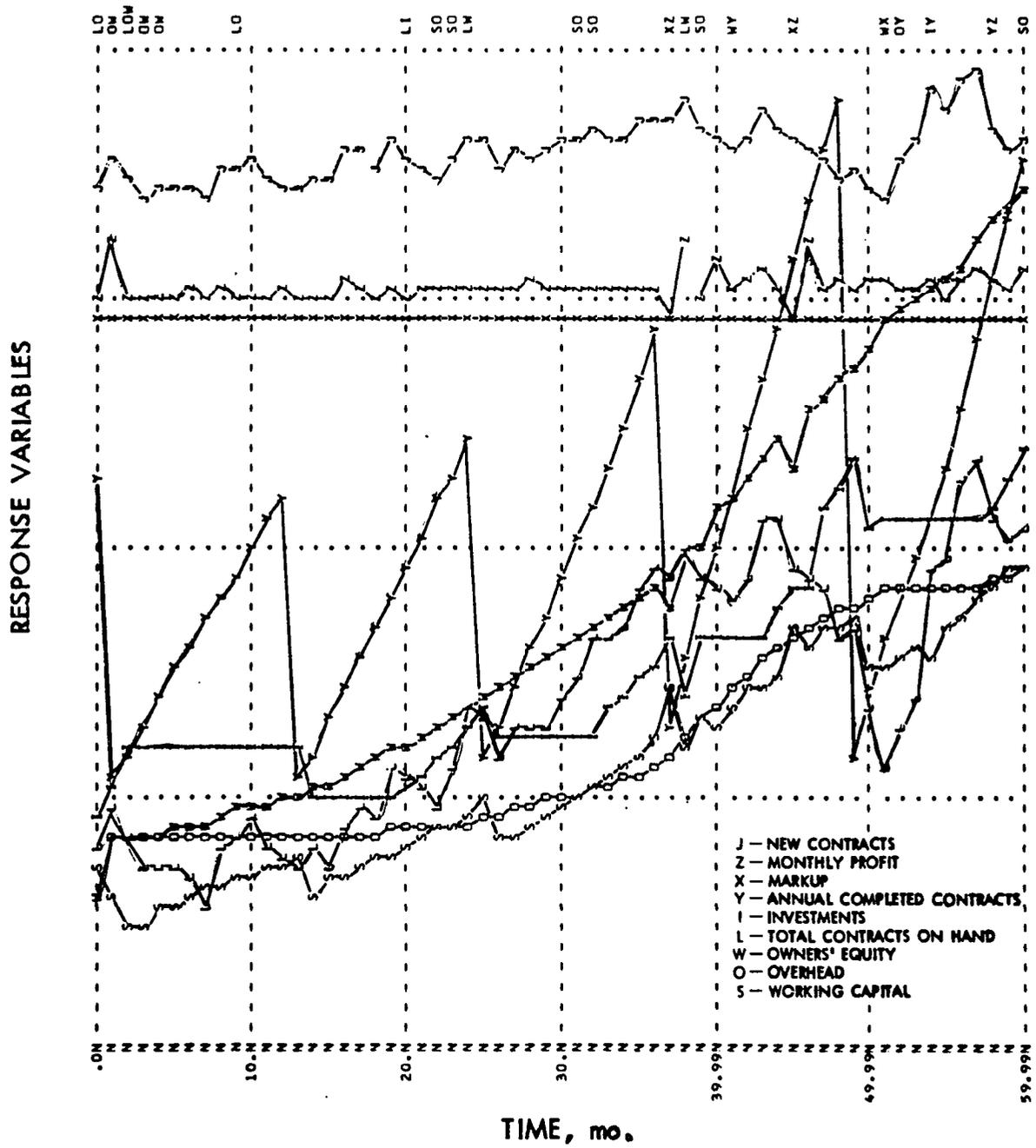
Time months	Annual completion dollars	Annual profit dollars	<u>Annual profit</u> <u>Annual volume</u> %
12	6,053,000	186,030	3.07
24	8,592,000	188,070	2.19
36	9,481,000	232,970	2.46
48	14,899,000	419,900	2.82

started toward a smaller interval until the smallest interval or maximum arrival rate occurred at a time of 12 months. As can be seen in Figure 17, this condition reduced the amplitude of oscillations in the new contracts. The net quick ratio was less than 0.08 at only one month in the 60 months. The overhead restriction on growth occurred as in the case of the control run, however, there was a shift in the minimum of the decreasing new contract trend from a time of 49 months to a time of 51 months. The annual results are illustrated in Table 16. At 60 months the owner's

Table 16. Annual results of the project arrival run

Time months	Annual completion dollars	Annual profit dollars	<u>Annual profit</u> <u>Annual volume</u> %
12	6,571,000	198,980	3.03
24	7,778,000	171,140	2.20
36	10,175,000	247,470	2.43
48	15,008,000	431,270	2.87

Figure 17. The graphical output for the project arrival run



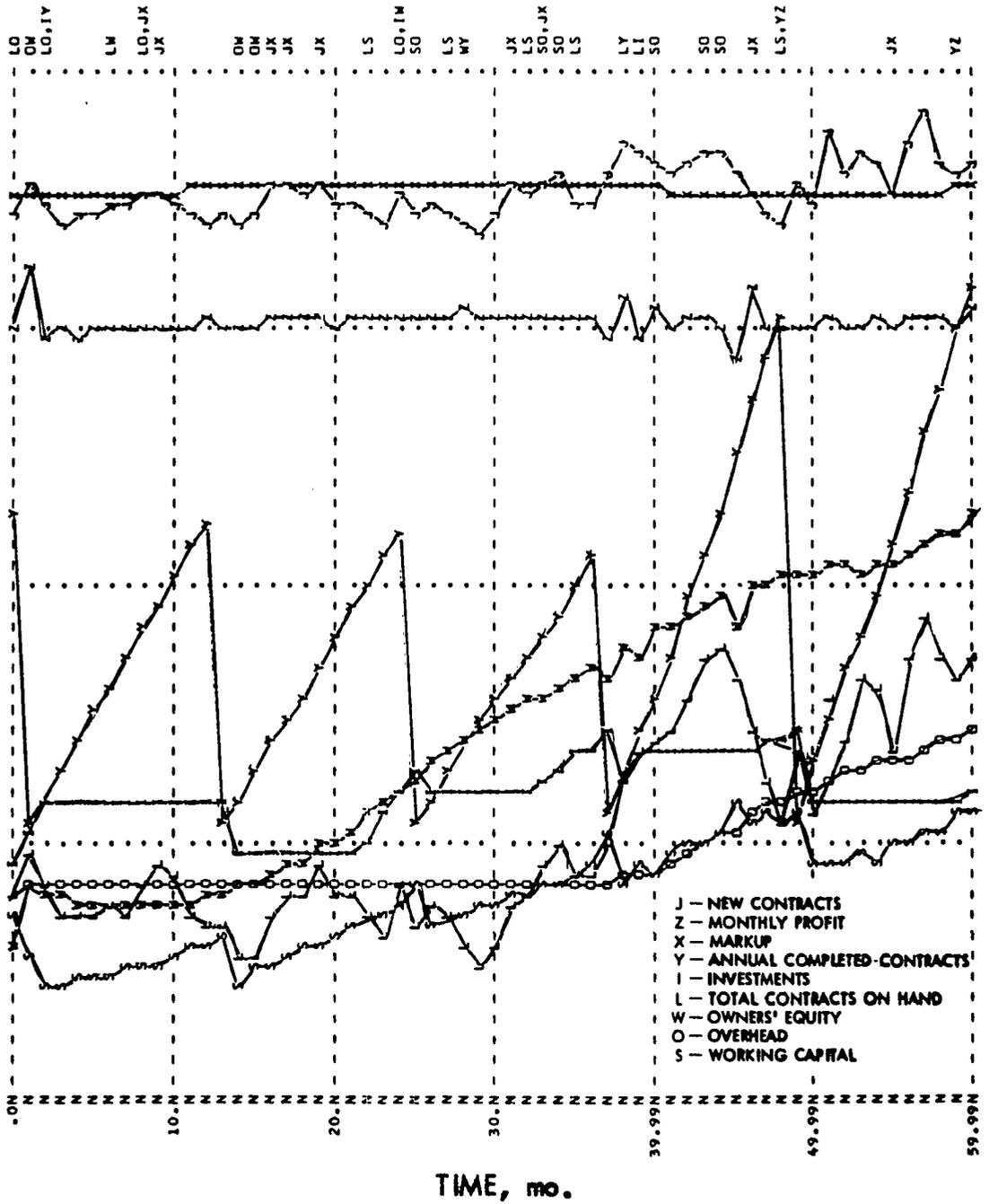
equity was \$1,727,700, a decrease of \$49,700 in comparison to the control run results.

Two runs simulating a markup variation in response to the market variation (the change in potential project arrival widths) were made. In order to better simulate a realistic relation between the probability of winning and the markup, the standard deviation for the markup distribution was decreased from 1.0 to 0.1 and the average past markup was changed to 1.05 from 0.6. This did not alter the probability of winning for a markup of 1.10 (this was 0.31). The markup policy was set such that the markup adjustment lagged the project arrival change by one month. The markup policy became a sinusoidal variation given information about the project arrival interval (in these runs the project arrival variation was the same as that for the project arrival run). The phase relationship between the variations was such that a poor market (poor arrival rate or large arrival interval) generated a decrease in markup. The maximal amplitude in the markup variation was 0.05 in the markup variation at 0.05 run. Thus the largest markup was 1.15 which yielded a probability of winning of 0.16 and the smallest markup was 1.05 with a 0.50 probability of winning. The two variations were approximately 169° out of phase. The second run, the markup variation at 0.10 run, allowed the markup to oscillate from 1.00 to 1.20.

The graphical output for the markup variation at 0.05 is shown in Figure 18. The sinusoidal variation in markup over time is barely detectable at the given response variable scale. A variation in annual completion volume is observed along with a variation in the slope of

Figure 18. The graphical output for the markup variation at 0.05 run

RESPONSE VARIABLES



LO
OM
LO,LY

LW
LO,JX
JX

OM
OM
JX
JX
JX

LS
LO,IM
SO

LS
WY

JX
LS
SO,JX
SO
SO
LS

LY
LI
SO

SO
SO
SO

JX
LS,YZ

JX

YZ

- J - NEW CONTRACTS
- Z - MONTHLY PROFIT
- X - MARKUP
- Y - ANNUAL COMPLETED CONTRACTS
- I - INVESTMENTS
- L - TOTAL CONTRACTS ON HAND
- W - OWNERS' EQUITY
- O - OVERHEAD
- S - WORKING CAPITAL

0.00
10.00
20.00
30.00
39.99
49.99
59.99

TIME, mo.

owners' equity. During the five years the overhead trend was consistent with the project completion rate. The new contract acquisitions were consistent with the corresponding changes in markup.

The net quick ratio remained at approximately 0.10 and none of the monthly outputs were less than the minimum acceptable ratio of 0.08. But there was a drop in working capital during the last ten months. The net quick ratio average dropped to approximately 0.09. The annual results are tabulated below.

Table 17. Annual results of markup variation at 0.05 run

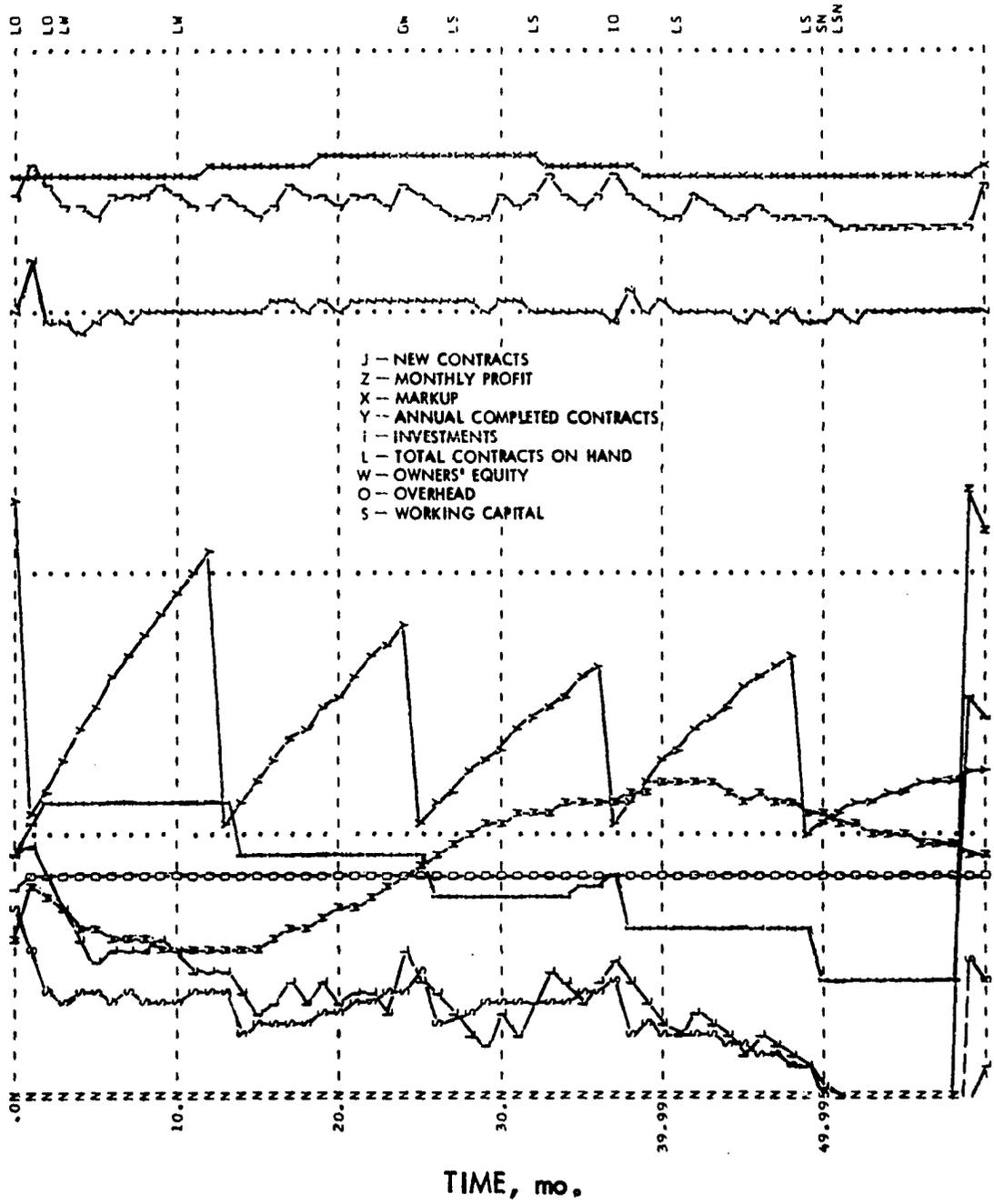
Time months	Annual completion dollars	Annual profit dollars	<u>Annual profit</u> <u>Annual volume</u> %
12	4,312,900	96,970	2.25
24	4,921,600	201,840	4.10
36	5,236,900	235,100	4.49
48	6,108,200	181,110	2.96

After five years, the owners' equity was \$1,131,600.

In the run entitled "Markup variation at 0.10", a markup variation of 0.10 produced a depressed situation in the simulated firm. This is shown in Figure 19. As can be seen, the overhead level remained constant at the original initially adjusted level over a five year period of decreasing annual volume completion rates. Owners' equity exhibited a sinusoidal variation, working capital progressed downward until the last

Figure 19. The graphical output for the markup variation at 0.10 run

RESPONSE VARIABLES



two months where a loan of \$583,670 produced additional capital, and overhead remained constant. The trend in owners' equity appeared to follow the markup; i.e., as the markup increased, owners' equity increased. The owners' equity ended at \$458,740.

Experimental Design Analysis

Analysis of the systems model included analysis derived from statistical experimental designs. This analysis was based upon the variable definitions and initial conditions associated with the hypothetical firm described earlier in this chapter. Two experimental designs were utilized. In each case, two levels within two factors were tested along with two blocks. The interaction effects were included in the analyses. It was the objective of this analysis to carefully examine the main and interaction effects of two factors, markup and short-term investment monthly return rate, and two initial working capital conditions represented by two blocks.

The first factor, factor A, consisted of two levels, a constant markup of 1.16 and a constant markup of 1.08. The two interest rate levels of the second factor, factor B, were a monthly interest rate of 0.75 percent (9 percent annual) and a rate of 0.33 percent (4 percent annual). The four different combinations of these two factors were randomly assigned to two blocks representing two different working capital initial conditions. One block represented a strong working capital position with a current ratio of 2.20. An equivalent minimum net quick ratio would be 0.16, however, the ratio was set at 60 percent of that,

0.076 for this block. The second block represented a weaker working capital initial condition with the current ratio set to 1.2. The minimum net quick ratio was established at 80 percent of the equivalent net quick, 0.05 and was 0.04. Thus the stronger working capital initial condition was given a relatively less stringent net quick ratio constraint. This was done to deliberately establish very favorable and moderately favorable initial conditions.

The following changes in the initial conditions and a constant from the control run were made for initial condition N_1 :

N ACCPAY = 760,000
 N SUBRTN = 330,000
 N TAXLV = 44,000
 C CNQRTO = 0.04

The changes relative to the control run for the N_2 were:

N ACCREC = 1,373,000
 N RETHCD = 580,000
 N INVLV = 600,000
 C CNQRTO = 0.076

The eight combinations are summarized in a two factor randomized design exhibited in Table 18.

Table 18. Definition of the two factor randomized block design

Initial condition N_1		Initial condition N_2	
Current ratio = 1.2		Current ratio = 2.2	
Minimum net quick ratio = 0.04		Minimum net quick ratio = 0.096	
Factor A	Factor B	Factor A	Factor B
A_1 :markup=1.16	B_1 :interest=0.75%	A_1 :markup=1.16	B_1 :interest=0.75%
A_1 :markup=1.16	B_2 :interest=0.33%	A_1 :markup=1.16	B_2 :interest=0.33%
A_2 :markup=1.08	B_1 :interest=0.75%	A_2 :markup=1.08	B_1 :interest=0.75%
A_2 :markup=1.08	B_2 :interest=0.33%	A_2 :markup=1.08	B_2 :interest=0.33%

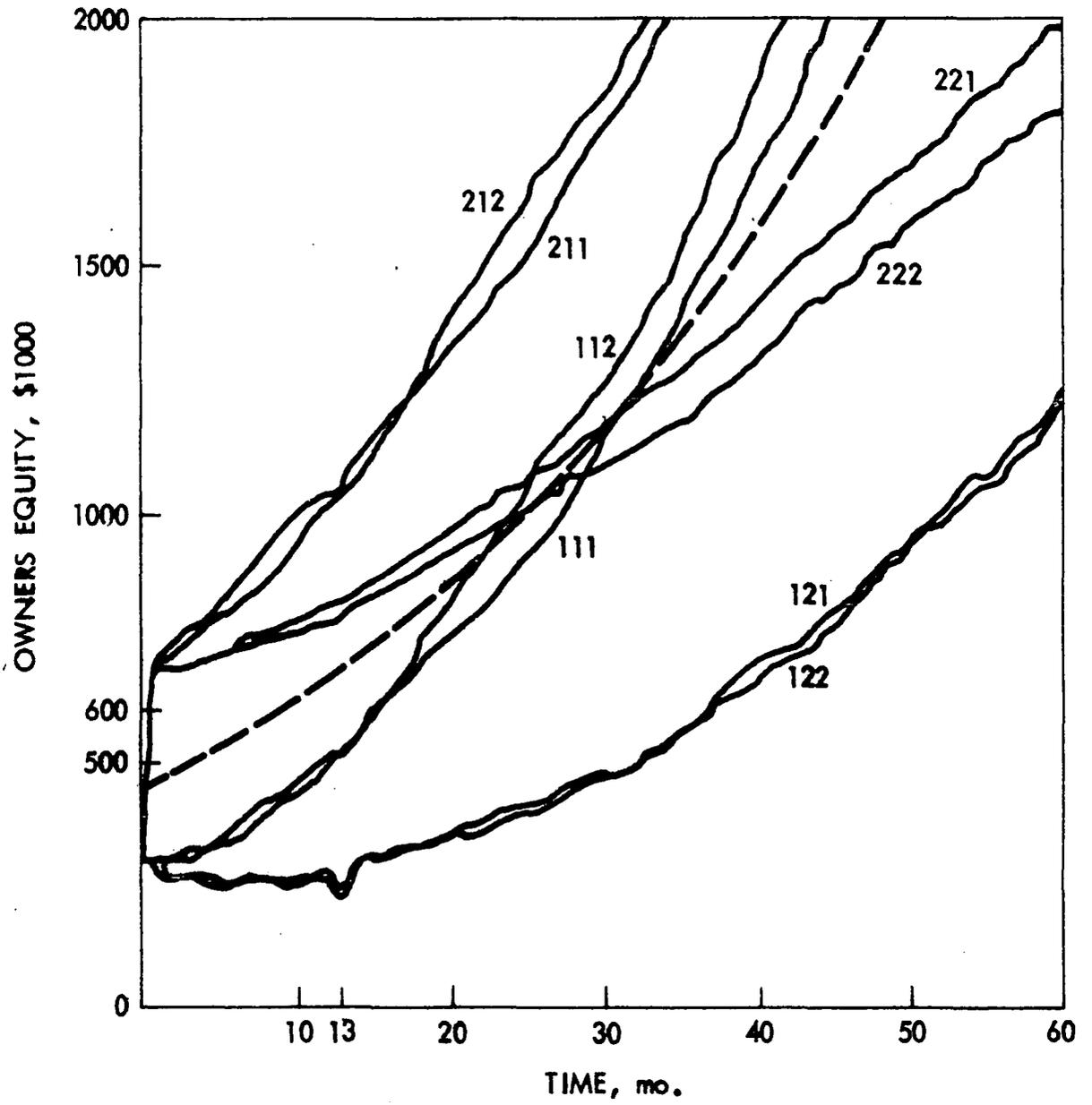
The combinations of the two factors with the two blocks were represented by a three digit numerical code, IJK. A J of 1 symbolized the use of Factor A_1 and 2 the Factor A_2 . The K code represented the two levels of Factor B, 1 indicated B_1 , and 2, B_2 . The two blocks were identified by I, 1 for N_1 and 2 for N_2 . As an example 121 represented the combination $N_1 A_2 B_1$.

One response variable was employed in this analysis, owners' equity. Each combination of factors and blocks represented a simulation run of 60 months. In order to randomize the error as much as possible, the pseudo-random number sequence in each of the eight runs was unique. This was accomplished by introducing equations which altered the generation sequence without affecting other variables in the systems model. Therefore, each stochastic variable in the systems model utilized a unique pseudo-random number sequence over the 60 months for each combination of factors and blocks.

The simulation results for the eight combinations of factors and initial conditions are illustrated in Figure 20. In the figure, the response variable, owners' equity (dollars) is plotted against time (months). Each simulation run represented five years and the owners' equity was outputted every month. Each combination is identified by the numerical code defined above.

The first model used in the experimental design analysis assumed a fixed-model two factor factorial experiment in a randomized block design. The model equation was:

Figure 20. Simulation results for the eight factor and block combinations



$$Y_{ijkl} = \mu + A_j + B_k + N_i + (AB)_{jk} + (AN)_{ji} + (BN)_{ki} + (ABN)_{jki} + e_{ijkl}$$

$$(i = 1, 2)$$

$$(j = 1, 2)$$

$$(k = 1, 2)$$

$$(l = 1, 60)$$

It was assumed the 2x2 treatment combinations were randomly assigned to each of the two blocks. Furthermore, it was assumed the response errors, e_{ijkl} were normally and independently distributed with a mean zero and common variance. The analysis also assumed that all effects were fixed, thus, it was assumed:

$$\sum_{i=1}^2 N_i = 0$$

$$\sum_{j=1}^2 A_j = 0$$

$$\sum_{k=1}^2 B_k = 0$$

$$\sum_{i=1}^2 (NA)_{ij} = 0$$

$$(j = 1, 2)$$

$$\sum_{j=1}^2 (NA)_{ij} = 0$$

$$(i = 1, 2)$$

$$\sum_{k=1}^2 (NB)_{ik} = 0$$

$$(i = 1, 2)$$

$$\sum_{i=1}^2 (NAB)_{ijk} = 0$$

$$\begin{matrix} (j = 1, 2) \\ (k = 1, 2) \end{matrix}$$

The mean responses for each level in each factor for the two blocks, and for the combinations are tabulated in Table 19. The entries are in thousands of dollars of owners' equity. Notice the sizeable difference between the mean for current ratio = 1.2 initial condition, $\bar{Y}_{1\dots}$, and that for the current ratio = 2.2 initial condition, $\bar{Y}_{2\dots}$. There is also an appreciable difference between the two markup ratio levels indicated by $\bar{Y}_{.1\dots}$, the markup ratio of 1.16, and $\bar{Y}_{.2\dots}$, the markup ratio of 1.08. However the two levels of short-term interest rate are very similar, 1308.8 and 1311.7. The differences between higher order combinations are varied in magnitude. The main and interaction effects presented in Table 20 emphasize the differences. The difference in the block effects is large; for example, the effect of block one, N_1 , is 301.1 thousand dollars less than the overall mean. The markup level effects are also large; i.e., +423.9 thousand dollars. However, the short-term interest rate effects are relatively small at +1.5 thousand dollars. All the higher order effects are small compared with the block and markup ratio effects.

An analysis of variance for this design is exhibited in Table 21. The block treatment, initial condition, was statistically significant at 0.01, as was the markup ratio treatment, A. The remaining treatment combinations were not statistically significant under the assumptions of the model.

The above analysis portioned the variance about the overall mean. The curves in Figure 20, however, indicated that a considerable amount of the variance was due to the relationship between the response variable,

Table 19. Means for the two factor randomized block design

\bar{Y}_{\dots}	= 1310.2						
$\bar{Y}_{1\dots}$	= 1009.1		$\bar{Y}_{2\dots}$	= 1611.3			
$\bar{Y}_{.1\dots}$	= 1734.1		$\bar{Y}_{.2\dots}$	= 886.4			
$\bar{Y}_{\dots 1}$	= 1308.8		$\bar{Y}_{\dots 2}$	= 1311.7			
$\bar{Y}_{11\dots}$	= 1442.9	$\bar{Y}_{12\dots}$	= 575.4	$\bar{Y}_{21\dots}$	= 2025.3	$\bar{Y}_{22\dots}$	= 1197.4
$\bar{Y}_{1.1.}$	= 992.6	$\bar{Y}_{1.2.}$	= 1025.6	$\bar{Y}_{2.1.}$	= 1625.0	$\bar{Y}_{2.2.}$	= 1597.7
$\bar{Y}_{.11.}$	= 1709.3	$\bar{Y}_{.12.}$	= 1758.8	$\bar{Y}_{.21.}$	= 908.3	$\bar{Y}_{.22.}$	= 864.5
$\bar{Y}_{111.}$	= 1402.2	$\bar{Y}_{112.}$	= 1483.6	$\bar{Y}_{121.}$	= 583.1	$\bar{Y}_{122.}$	= 567.6
$\bar{Y}_{211.}$	= 2016.4	$\bar{Y}_{212.}$	= 2034.1	$\bar{Y}_{221.}$	= 1233.5	$\bar{Y}_{222.}$	= 1161.3

Table 20. Effects for the two factor randomized block design

N_1	= -301.1		N_2	= 301.1			
A_1	= 423.9		A_2	= -423.8			
B_1	= -1.4		B_2	= 1.5			
$(NA)_{11}$	= 9.9	$(NA)_{12}$	= -9.9	$(NA)_{21}$	= -9.9	$(NA)_{22}$	= 9.9
$(NB)_{11}$	= -15.1	$(NB)_{12}$	= 15.0	$(NB)_{21}$	= 15.1	$(NB)_{22}$	= -15.1
$(AB)_{11}$	= -23.4	$(AB)_{12}$	= 23.2	$(AB)_{21}$	= 23.4	$(AB)_{22}$	= -23.4
$(NAB)_{111}$	= -0.8	$(NAB)_{112}$	= 1.0	$(NAB)_{121}$	= 1.0	$(NAB)_{122}$	= -0.9
$(NAB)_{211}$	= 0.8	$(NAB)_{212}$	= -0.8	$(NAB)_{221}$	= -0.9	$(NAB)_{222}$	= 0.9

Table 21. Analysis of variance for the two factor randomized block design

Source	Sum of squares	d.f.	F ratio
N	43,518,288.	1	85.815**
A	86,229,168.	1	170.038**
B	983.	1	0.002
NA	47,163.	1	0.093
NB	108,826.	1	0.215
AB	261,452	1	0.516
NAB	382.	1	0.001
Error	239,359,552.	472	
Total	369,526,016.	479	

**Significant at 0.01.

owners' equity, and time. Because of this, a second design was constructed and analyzed. The model was similar to the two factor randomized block model described above, however, the variance was also assumed due to the following regression in a covariance model.

$$a + bt_{ijkl} + ct_{ijkl}^2$$

(i = 1,2)
(j = 1,2)
(k = 1,2)
91 = 1,60)

The data were analyzed by partitioning the variance into the regression component and the main and interactive effects. The analysis of the factors and blocks thus considered the deviation about the overall least squares fit of the quadratic equation. The resulting F ratios are shown in Table 22. The results exhibited a sizeable gain in the F ratios of block and markup ratios while the other ratios improved slightly.

Table 22. Analysis of covariance F ratios

<u>Source</u>	<u>F ratio</u>
N	458.377**
A	908.251**
B	0.010
NA	0.497
NB	1.146
AB	2.754
NAB	0.004

** Significant at 0.01.

The regression coefficients derived from the covariance analysis are contained in the quadratic equation below:

$$Y_{ijkl} = 440.37 + 12.79 t_{ijkl} + 0.39 t_{ijkl}^2$$

(i = 1,2)

(j = 1,2)

(k = 1,2)

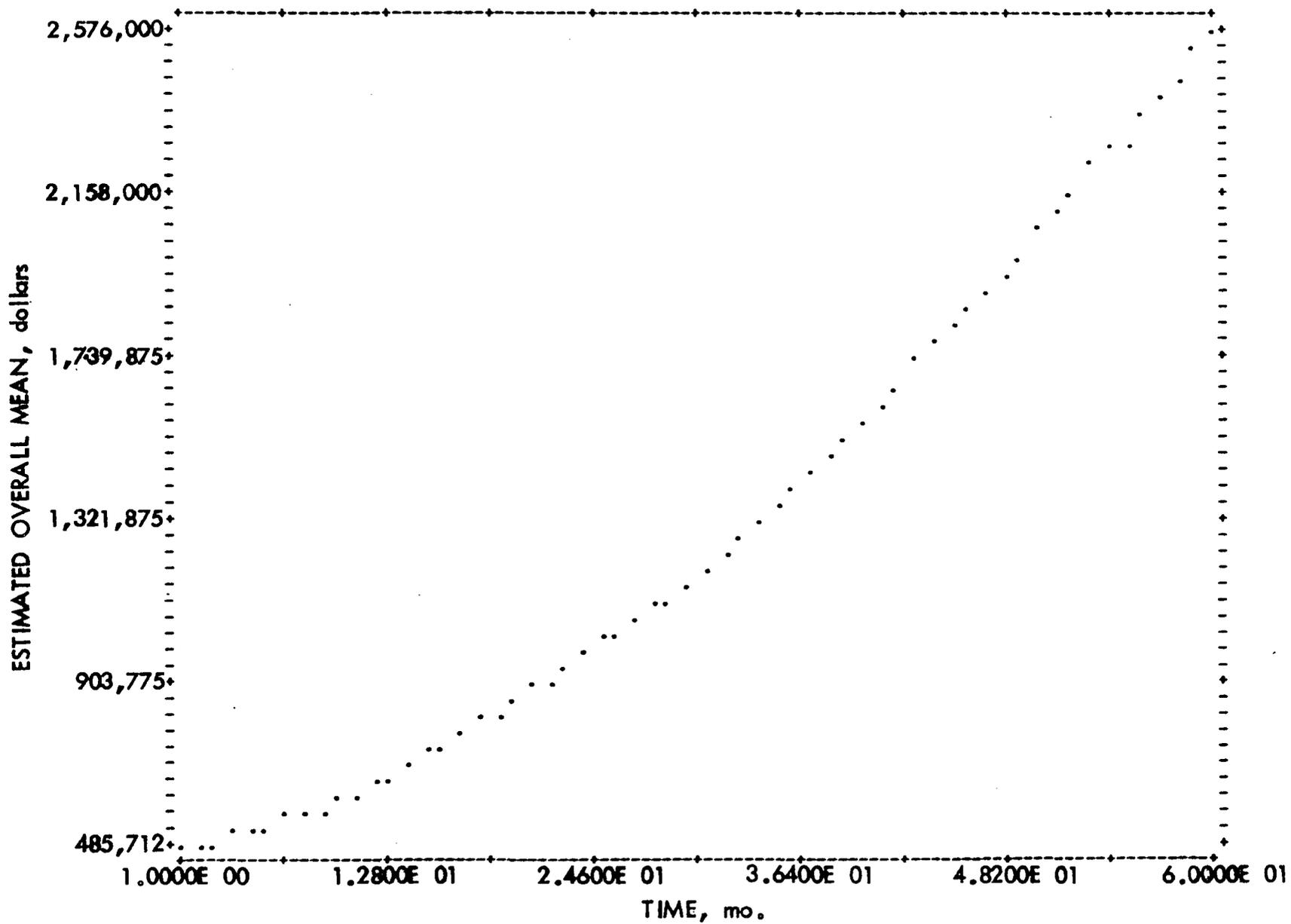
(l = 1,60)

This equation is represented by a dashed line in Figure 20. The equation appears to be good representation of the response trends.

A check on the error assumptions was made. The two models assumed the error was normally independently distributed with mean zero and common variance. The check was accomplished by inspection of estimates of the overall mean and all effects made at each point in time. Thus an estimate of the overall mean was computed from eight observations at each point in time. The monthly estimates of the overall mean are exhibited in Figure 21. The estimates support the quadratic fit used in the analysis of covariance. The randomness of the points about the quadratic trend support the normal distribution with mean zero error assumption. In a similar manner, estimates of the main and interaction effects were plotted against time. The assumption of independence between errors appeared appropriate. The above analysis indicated that the error assumptions for the models were met.

The curves in Figure 20 depict the behavior of model under the two initial working capital conditions, two markups, and two returns. The two runs subjected to the better working capital initial condition and higher markup (runs 212 and 211) have the best owners' equity trends (this agrees with the interactive effects described earlier). Within those two runs,

Figure 21. Monthly estimates of the overall mean response



the run subject to the lower investment return had a slightly larger response over time. The two runs, 111 and 112, were noticeably better than two other sets. These two runs had the poor initial working capital position (current ratio) and the higher markup (1.16). As was the case in the first set, the run with the smaller monthly investment return, 0.33 percent, looked slightly better over time.

The two runs with the higher initial working capital and lower markup, 221 and 222, showed a poor response compared to the high markup counterparts, but nevertheless were better than the similar runs beginning with the poor working capital (121 and 122). The run corresponding to the higher investment return, 221, exhibited a moderately better response than the lower return counterpart, 221. The worst response was given by the two runs which started with the poor working capital condition and which utilized the lower markup. These two results, runs 121 and 122, were very similar. The superiority of the better initial condition which had a current ratio of 2.2 and a more favorable minimum net quick ratio over the other initial condition, noted in the analysis of variance, was most likely due to the good responses of runs 221 and 211 and the poor response of runs 121 and 122. The slight to moderate differences associated with short-term investment return can be explained by considering the bonus and profit sharing plans. These plans initially grow when cash flow surpluses develop and continue to grow under a higher investment return. As this fund grows particularly early in time, more profits are channeled to the employees under this plan.

As can be seen in Figure 20, all runs with the initial current ratio

of 2.2, exhibited a sharp jump in owners' equity at one month. This occurred because of the resulting strong initial net quick ratio position which was approximately 0.30 while the four runs beginning with a net quick of 1.2 began with a net quick of approximately 0.05. The overhead level for all eight runs was very close to \$284,000. Thus the four runs, 211, 212, 221, and 222 generated more income from the acquisition of new projects while the general overhead did not change. In addition these four runs began with an investment level of \$600,000 compared to \$300,000 which generated more interest over the first month.

The higher markup always resulted in the better owners' equity response. In the hypothetical firm assumed in these eight runs, the markup probability distribution was somewhat insensitive; i.e., the markup 1.08 had a probability of winning of 0.32 and the 1.16 markup probability was 0.29. Therefore, acquired volume was little affected by the markup and the increased markup provided a greater surplus on the acquired volume.

SUMMARY AND CONCLUSIONS

A systems model of a construction firm was developed within the information feedback conceptual approach of Forrester. The model simulated overhead, growth, bidding, short-term investment, and external financing policies under realistic bonding, financial, and overhead capacity constraints. The flows in the model were primarily cash within the working capital accounts of a cash flow statement. The model was based primarily on the management systems of a building construction firm. It did not include provision for the asset management common in heavy construction.

The model was validated by comparing results with historical data of an actual construction firm and by analysis of the systems behavior. The simulated response of the actual firm's data was close to that which actually occurred over two years. The systems behavior was described through the use of a hypothetical, realistic firm in the model. Dynamic responses and trends were observed. Parameters were varied so as to simulate the effect of owner's payment processing delay, a construction firm's delay in paying accounts payable, two owner retainage time periods, a high markup, a dynamic markup policy, poor collection of accounts receivable, a dynamic market environment, and a labor strike. The responses under these various conditions appeared representative of construction firm behavior.

The model aggregated all project cash flows into one composite representation. This caused some discrepancy in the actual firm simulation because the actual status of all projects could not be initialized or

computed. If this detail is considered necessary, it is recommended that new contract level and contracts underway be incorporated for each major contract (perhaps five sets would be a practical upper limit) and the net contracts remaining summarized as is currently done in the model.

It was shown that changes in the time delays of the systems had, in general, considerable effect on the response. For example, an extended owners' delay in processing payment requests resulted in \$94,100 less in owners' equity after five years as compared to the control. A constant markup policy over a cyclical market appeared to be a good strategy. Poor accounts receivable and a labor strike were shown to have a noticeable effect on the systems. The simulated poor accounts receivable caused a temporary depression in monthly profits while the simulated labor strike produced oscillations in monthly profit and a loss of \$35,200 over the five years in owners' equity relative to the control run. The model was found to be sensitive to the probability of winning markup distribution. It is recommended that care be exercised in selecting the distribution type and the distribution parameters.

The analysis included the use of statistical experimental design tools. The results of the analysis of variance and analysis of covariance indicated the initial financial condition had a major influence in owners' equity as did the level of the markup ratio. Error assumptions were satisfied. Both experimental designs considered two levels of markup, two levels of short-term monthly return, and two initial working capital minimum net quick ratio blocks. The analysis of covariance model reduced the error by eliminating some of the time dependent error through a

quadratic regression fit of the response owners' equity over time. The results indicated a greater influence of the initial financial condition and the static markup ratio policy on owners' equity.

The best combination of factors and blocks was found to be: A high initial working capital condition with a liberal minimum net quick ratio constraint and a high markup. The probability of winning - markup distribution assumed, however, was quite insensitive so that the higher markup did not appreciably lower the firm's probability of winning.

The systems studied appeared sensitive to the amplitude of the sinusoidal variation in the markup as it lagged the market by one month. A large amplitude caused severe financial problems in the model.

One response variable, owners' equity, was studied in the experimental design analysis. It is suggested that other responses be included. Analyses of the profit sharing level is an example. This response variable could be considered a measure of employee satisfaction.

The simulation model was found to be very helpful in revealing the structure of a construction firm. The basic feedback loops within a construction firm were identified and the behavior observed. It is recommended that the systems model be employed by a firm to study the structure and behavior of their policies. Various parameter values can be substituted and the best policy such as markup or overhead deduced from the simulation runs. In addition it is recommended the model be used in contingency analysis, for example in studying policy in anticipation of labor strikes and different markup situations.

BIBLIOGRAPHY

- Ackoff, Russell L. 1967. Management misinformation systems. *Management Science* 14:B147-B156.
- Anderson, R. L. and Bancroft, T. A. 1952. *Statistical theory in research*. New York, New York, McGraw-Hill Book Co., Inc.
- Ansoff, H. I. and Slevin, Dennis P. 1968a. An appreciation of industrial dynamics. *Management Science* 14:383-397.
- Ansoff, H. I. and Slevin, Dennis P. 1968b. Comments on professor Forrester's "Industrial dynamics - after the first decade". *Management Science* 14:600.
- Anthony, Robert N. 1964. *Management accounting*. 3rd edition. Homewood, Illinois, Richard D. Irwin, Inc.
- Benjamin, Neal B. H. 1969. Competitive bidding for building construction projects. Stanford University Department of Civil Engineering Technical Report No. 106.
- Bonini, Charles P. 1963. Simulation of information and decision systems in the firm. Englewood Cliffs, New Jersey, Prentice-Hall, Inc.
- Brealey, Richard A. 1969. An introduction to risk and return from common stocks. Cambridge, Massachusetts, The MIT Press.
- Broemser, Gary M. 1968. Competitive bidding in the construction industry. Unpublished Ph.D. thesis. Palo Alto, California, Library, Stanford University. (Microfilm copy No. 68-15031. Ann Arbor, Mich., University Microfilms).
- Brown, R. G. 1963. Smoothing, forecasting, and prediction of discrete time series. Englewood Cliffs, New Jersey, Prentice-Hall, Inc.
- Burdick, Donald S. and Naylor, Thomas H. 1969. Response surface design of computer simulation experiments. Durham, North Carolina, Duke University Press.
- Clough, Richard H. 1969. *Construction contracting*. Second edition. New York, New York, Wiley-Interscience.
- Crist, G. W., Jr. 1950. *Corporate suretyship*. Second edition. New York, New York, McGraw-Hill Book Co., Inc.
- Davies, Owen L., ed. 1954. *The design and analysis of industrial experiments*. New York, New York, Hafner Publishing Co.

- Dickson, G. W., Mauriel, J. J. and Anderson, J. C. 1970. Computer assisted planning models: a functional analysis. In Schrieber, Albert N., ed. Corporate simulation models. Pp. 43-70. Seattle, Washington, University of Washington Printing Plant.
- Donaldson, Gordon. 1969. Strategy for financial emergencies. Harvard Business Review 47, No. 6:67-79. November-December.
- Forrester, Jay W. 1961. Industrial dynamics. Students' ed. Cambridge, Massachusetts, The MIT Press.
- Forrester, Jay W. 1968a. Industrial dynamics - after the first decade. Management Science 14:398-415.
- Forrester, Jay W. 1968b. Industrial dynamics - a response to Ansoff and Slevin. Management Science 14:601-618.
- Forrester, Jay W. 1968c. Principles of systems. Second preliminary ed. Cambridge, Massachusetts, Wright-Allen Press.
- Friedman, Lawrence. 1956. Competitive bidding strategy. Operations Research 4:104-112.
- Gates, Marvin. 1960. Statistical and economic analysis of a bidding trend. Journal of the Construction Division, Proceedings of the American Society of Civil Engineers 86:13-35.
- Gates, Marvin. 1967. Bidding strategies and probabilities. Journal of the Construction Division, Proceedings of the American Society of Civil Engineers 93:75-105.
- Gershefski, George W. 1970. Corporate models - the state of the art. In Schrieber, Albert N., ed. Corporate simulation models. Pp. 26-42. Seattle, Washington, University of Washington Printing Plant.
- Grant, E. L. and Ireson, W. G. 1964. Principles of engineering economy. Fourth edition. New York, New York, The Ronald Press Co.
- Hadley, George. 1967. Introduction to probability and statistical decision theory. San Francisco, California, Holden-Day, Inc.
- Hillier, Frederick S. and Lieberman, Gerald J. 1967. Introduction to operations research. San Francisco, California, Holden-Day, Inc.
- Hunter, J. S. and Naylor, Thomas H. 1970. Experimental designs for computer simulation experiments. Management Science, Theory Series 16:422-434.

- Johnston, J. 1963. *Econometric methods*. New York, New York, McGraw-Hill Book Co., Inc.
- Kawal, Donald E. 1969. Information utilization in project planning. ASCE Annual and Environmental Meeting, Preprint 1055. Ames, Iowa, Department of Civil Engineering, Iowa State University.
- Kawasaki, Nobuo. 1968. Design of management information systems for large construction firms. Unpublished Master of Architecture thesis. Ames, Iowa, Library, Iowa State University.
- Koenig, H. E. 1965. Mathematical models of socio-economic systems: an example. *IEEE Transactions on Systems Science and Cybernetics* SSC-1:41-45.
- Koenig, H. E., Yilmaz, T., Keasaven, H. K. and Hedges, H. G. 1967. *Analysis of discrete physical systems*. New York, New York, McGraw-Hill, Inc.
- Koenig, H. E., Keeney, M. G. and Zemach, R. 1968. A systems model for management, planning, and resource allocation in institutions of higher education. National Science Foundation Final Report, Project C-518.
- Little, John D. C. 1970. Models and managers: the concept of a decision calculus. *Management Science*, Application Series 16: B466-B485.
- Llewellyn, Robert W. 1965. *FORDYN: an industrial dynamics simulator*. Raleigh, North Carolina, Privately printed by Typing Service.
- Mayer, Robert H., Fitzgerald, William E. and Stark, Robert M. 1967. Unbalanced bidding models - application. Newark, Delaware, Department of civil Engineering, University of Delaware.
- McMillan, Claude and Gonzalez, R. F. 1968. *Systems analysis: a computer approach to decision models*. Revised edition. Homewood, Illinois, Richard D. Irwin, Inc.
- Morgan, James I., Lawless, Robert M. and Yehle, Eugene C. 1970. The Dow Chemical corporate financial planning model. In Schrieber, Albert N., ed. *Corporate simulation models*. Pp. 374-395. Seattle, Washington, University of Washington Printing Plant.
- Naylor, Thomas H., Balintfy, Joseph L., Burdick, Donald S., and Chu Kong. 1966. *Computer simulation techniques*. New York, New York, John Wiley and Sons, Inc.

- Naylor, Thomas H., Balintfy, Joseph L., Burdick, Donald S., and Chu Kong. 1970. Corporate simulation models and the economic theory of the firm. In Schrieber, Albert N., ed. Corporate simulation models. Pp. 1-25. Seattle, Washington, The University of Washington Printing Plant.
- Park, William R. 1966. The strategy of contracting for profit. Englewood Cliffs, New Jersey, Prentice-Hall, Inc.
- Pritsker, A. Alan B. and Kiviat, P. J. 1969. Simulation with GASP II; a FORTRAN based simulation language. Englewood Cliffs, New Jersey, Prentice-Hall, Inc.
- Pugh, Alexander L. 1963. Dynamo user's manual. Second edition. Cambridge, Massachusetts, The MIT Press.
- Pugh, Alexander L. 1968. (Dynamo II user's manual revision). Mimeographed notes D-1000-2. Cambridge, Massachusetts, Alfred P. Sloan School of Management, Massachusetts Institute of Technology.
- Pugh, Alexander L. 1969. (Revision draft of Chapter 2 of Dynamo user's manual). Mimeographed notes D-1000-3. Cambridge, Massachusetts, Alfred P. Sloan School of Management, Massachusetts Institute of Technology.
- Radcliffe, B. M., Kawal, D. E. and Stephenson, R. J. 1967. Critical path method. Chicago, Illinois, Cahners Publishing Co., Inc.
- Rubey, Harry and Milner, Walker W. 1966. Construction and professional management. New York, New York, The Macmillan Co.
- Sorensen, Eric E. and Gilheany, James F. 1970. A simulation model for harvest operations under stochastic conditions. Management Science, Application Series 16:B549-B565.
- Stark, Robert M. 1968. Unbalanced bidding models-theory. Journal of the Construction Division, Proceedings of the American Society of Civil Engineers 94:197-209.
- Surety Unit Book. 1969. Philadelphia, Pennsylvania, Insurance Company of North America.
- Teichroew, Daniel and Lubin, John F. 1966. Computer simulation - discussion of the technique and comparison of languages. Communications of the ACM 9:723-741.

- Thompson, Robert K. 1970. Higher education administration: an operating system study utilizing a dynamic simulation model. In Schrieber, Albert N., ed. Corporate simulation models. Pp. 43-70. Seattle, Washington, University of Washington Printing Plant.
- Watts, Donald. 1969. Time series analysis. In Naylor, Thomas H., ed. The design of computer simulation experiments. Pp. 165-179. Durham, North Carolina, Duke University Press.
- Weymar, F. Helmut. 1965. Behavior of single loop feedback systems (linear). Excerpts from feedback in single loop systems (an unpublished memorandum, 1961). Cambridge, Massachusetts, Alfred P. Sloan School of Management, Massachusetts Institute of Technology.
- Wine, Lowell R. 1964. Statistics for scientists and engineers. Englewood Cliffs, New Jersey, Prentice-Hall, Inc.

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APPENDIX: THE SYSTEMS MODEL COMPUTER PROGRAM

```

//C261A37 JOB 'U3167,TIME=3,LINES=6K,REGION=256K',KAWAL
//RUN EXEC PGM=DYN2X,REGION=256K,TIME=1
//STEPLIB DD DSN=PROG.U3048DYN,DISP=SHR
//SYSPRINT DD SYSOUT=A,SPACE=(3192,(80))
//SYSIN DD *
* EXPER CONST CD
NOTE CA/CL=1.65
A BEGIN.K=NOISE()
C KMP=1.10
C MKVAR=0.0
A MARKUP.K=KMP+MKVAR*SIN(4.523+6.283*TIME.K/PERD)
C AVMKUP=0.6
C SDMKUP=1.0
A ZZ.K=(MARKUP.K-AVMKUP)/SDMKUP
C INPRJ=500000.0
A PRJI1.K=INPRJ*GRWTH
A PRJI2.K=PRJI1.K*(1.0+GRWTH)
A PRJI3.K=PRJI2.K*(1.0+GRWTH)
A PRJI4.K=PRJI3.K*(1.0+GRWTH)
A PRJ1.K=STEP(PRJI1.K,12.0)
A PRJ2.K=STEP(PRJI2.K,24.0)
A PRJ3.K=STEP(PRJI3.K,36.0)
A PRJ4.K=STEP(PRJI4.K,48.0)
A PROJET.K=INPRJ+PRJ1.K+PRJ2.K+PRJ3.K+PRJ4.K
A SDPRTT.K=PROJET.K/4.0
A PRJET.K=NORMRN(PROJET.K,SDPRTT.K)
NOTE
C ARWCHG=0.0
C AARWTH=0.22
C PERD=48.0
A PRJWTH.K=AARWTH+ARWCHG*SIN(1.571+6.283*TIME.K/PERD)
NOTE
A PRJAR.K=PULSE(PRJET.K,0.0,PRJWTH.K)
C GRWTH=0.20
C ADJGW=0.10
A GRWCLG.K=(1.0+GRWTH+ADJGW)*YCSNAX.K
A PTBID.K=CLIP(PRJAR.K,0.0,GRWCLG.K,YCSNLV.K)

```

```

DYNMA01X
DYNMA02X
DYNMAC3X
DYNMA04X

```

```

C  CNQRTO=0.08
A  DNQRTO.K=CNQRTO
A  PRJBID.K=CLIP(PTBID.K,0.0,NQKRTO.K, DNQRTO.K)
A  BIDPRB.K=TABHL(BIDTAB,ZZ.K,-2.0,2.0,0.25)
T  BIDTAB=0.98/0.96/0.93/0.89/0.84/0.77/0.69/0.60/0.50/0.40/0.31/0.23/0.
X  16/0.11/0.07/0.04/0.02
C  LOWRAN=-0.50
A  PERCT.K=LOWRAN+BIDPRB.K
A  ODDS.K=NOISE()
A  PRJWON.K=CLIP(0.0,PRJBID.K,ODDS.K,PERCT.K)
NOTE
C  SDDUR=3.0
C  AVDUR=8.0
A  CNDUR.K=NORMRN(AVDUR,SDDUR)
NOTE
N  CSNPRP=800000.0
L  CSNPRP.K=CSNPRP.J+DT*(PRJINR.JK-CSNIN.JK)
R  PRJINR.KL=PRJWON.K/DT
C  PREPDL=2.0
R  CSNIN.KL=CSNPRP.K/PREPDL
N  CSNLV=4000000.0
L  CSNLV.K=CSNLV.J+DT*(CSNIN.JK-PRJOT.JK)
A  PRJINC.K=MARKUP.K*PJCST.K*CSNLV.K/CNDUR.K
R  PRJOT.KL=PRJINC.K
NOTE
NOTE
N  ACCREC=735000.0
L  ACCREC.K=ACCREC.J+DT*(PYREG.JK-PAYRT.JK)
R  PYREG.KL=(1.0-RETRTD)*PRJINC.K
C  PYMTDL=0.25
NOTE
R  PAYRT.KL=(ACCREC.K/PYMTDL)*(1.0+D1.K+D2.K)
C  NTITV=1.0
A  RTME.K=30.0+NTITV
C  DEDRT=0.0
A  NDEDRT.K=-1.0*DEDRT
A  D1.K=STEP(NDEDRT.K,30.0)

```

```

A D2.K=STEP(DEDRT,RTME.K)
NOTE
NOTE
N RETHLD=280000.0
L RETHLD.K=RETHLD.J+DT*(RETRT.JK-RETREC.JK)
C RETRTO=0.10
R RETRT.KL=RETRTO*PRJINC.K
C RTTMDL=2.0
A RTNDEL.K=CNDUR.K+RTTMDL
R RETREC.KL=RETHLD.K/RTNDEL.K
NOTE
NOTE
N CSHBAL=175000.0
L CSHBAL.K=CSHBAL.J+DT*(PAYRT.JK+RETREC.JK-ACPRT.JK-CPRCT.JK-OVCST.JK+I
X NVINC.JK-TXPYRT.JK-INVDED.JK-LONINT.JK-ADTAX.JK-SBRTPD.JK)
A PFBTX.K=DT*(PAYRT.JK+RETREC.JK-ACPRT.JK-CPRCT.JK-OVCST.JK+INVINC.JK-LO
X NINT.JK-SBRTPD.JK)
N ACNPF=0.0
L ACNPF.K=ACNPF.J+DT*NPFRJ.K
R NPFRJ.KL=PFBTX.K*(1.0-TAXRT)/DT
NOTE
NOTE
N INVLV=300000.0
L INVLV.K=INVLV.J+DT*(INVDED.JK+LONIN.JK-INVCHG.JK-LONOT.JK)
R INVCHG.KL=PULSE(TRSPS.K,FIRBPS,BPSWTH)
C INVWTH=1.0
C FIRINV=0.0
R INVDED.KL=PULSE(INVAMT.K,FIRINV,INVWTH)
A SINVLV.K=SMOOTH(INVLV.K,RETWTH)
A INTST.K=SINVLV.K*INVINT
C INVINT=0.0067
C RETWTH=1.0
C FIRRET=0.0
A INVRET.K=PULSE(INTST.K,FIRRET,RETWTH)
C DESBAL=100000.0
A DIFBAL.K=CSHBAL.K-DESBAL
A CSAINV.K=CLIP(DIFBAL.K,0.0,DIFBAL.K,0.0)

```

C INVRTO=1.0
A INVAMT.K=INVRTO*CSAINV.K/DT
R INVINC.KL=INVRET.K/DT

NOTE

NOTE

C BPSWTH=12
C FIRBPS=1.0
C BNSRTO=0.20
A BNSCST.K=BNSRTO*OVHLV.K
A BNSDED.K=CLIP(BNSCST.K, INVLV.K, INVLV.K, BNSCST.K)
A GPRSHR.K=INVLV.K-BNSDED.K
C MPFSRO=0.15
A MAXPFS.K=MPFSRO*(OVHLV.K+BNSDED.K)
A NPFshr.K=CLIP(MAXPFS.K, GPRSHR.K, GPRSHR.K, MAXPFS.K)
A TBSPS.K=(BNSDED.K+NPFshr.K)/DT
A ACRBP.K=TBSPS.K*DT

NOTE

NOTE

N OVHLV=OVHRTO*YCSNAX
C OVHITV=12.0
R OVCST.KL=OVHLV.K/OVHITV
C OVHRTO=0.04

NOTE

C OVHSMC=3.0
A SPRJOT.K=SMOOTH(PRJOT.JK, OVHSMC)
A DESOVH.K=(SPRJOT.K*12.0*OVHRTO-OVHLV.K)/12.0
R ADJOVH.KL=CLIP(DESOVH.K, 0.0, DESOVH.K, C.0)
L OVHLV.K=OVHLV.J+DT*ADJOVH.JK

NOTE

A AVCSRO.K=1.0/MARKUP.K
C SDCSRO=0.040

NOTE

A PJCST.K=(AVCSRO.K+NORMRN(0.0, SDCSRO))*(1.0+C1.K+C2.K)
C NETRT=0.0
C NETDUR=1.0
A RDUR.K=30.0+NETDUR
A NNETRT.K=-1.0*NETRT

```

A C1.K=STEP(NNETRT.K,30.0)
A C2.K=STEP(NETRT,RDUR.K)
NOTE
R CPRCT.KL=(1.0-SUBRTO)*PJCST.K*CSNLV.K/CNDUR.K
NOTE
N ACCPAY=530000.0
L ACCPAY.K=ACCPAY.J+DT*(ACPYIN.JK-ACPRT.JK)
C SUBRTO=0.6
A SUBPAY.K=(CSNLV.K)*(SUBRTO)
R ACPYIN.KL=(1.0-RETRTO)*SUBPAY.K*PJCST.K/CNDUR.K
C ACPDEL=0.35
R ACPRT.KL=ACCPAY.K/ACPDEL
N SUBRTN=230000.0
L SUBRTN.K=SUBRTN.J+DT*(SBRTIN.JK-SBRTPD.JK)
R SBRTIN.KL=RETRTO*SUBPAY.K*PJCST.K/CNDUR.K
R SBRTPD.KL=SUBRTN.K/CNDUR.K
NOTE
N TAXLV=35000.0
L TAXLV.K=TAXLV.J+DT*(TAX.JK-TXPYRT.JK)
C TAXRT=0.5
R TAX.KL=PFBTX.K*TAXRT/DT
R TXPYRT.KL=PULSE(TXPAY.K,2.0,12.0)
A TXPAY.K=TAXLV.K/DT
A PFSRTX.K=TAXRT*NPFshr.K/DT
R ADTAX.KL=PULSE(PFSRTX.K,FIRBPS,BPSWTH)
NOTE
N LONLV=0.0
L LONLV.K=LONLV.J+DT*(LONIN.JK-LONOT.JK)
C DESCAL=1.2
C CALSMC=1.0
A SMCAL.K=SMOOTH(CALRTO.K,CALSMC)
A DIFCAL.K=(DESCAL-SMCAL.K)*CURLIB.K/DT
C MINLN=50000.0
A DLNAT.K=MINLN/DT
R LONIN.KL=CLIP(DIFCAL.K,0.0,DIFCAL.K,DLNAT.K)
C LNPRD=13.0
R LONOT.KL=LONLV.K/LNPRD

```

```

A ISLL.K=0.0
C LINTR=0.0075
A LNITAT.K=LINTR*LONLV.K/DT
C FIRLON=1.0
C LONWTH=1.0
R LONINT.KL=PULSE(LNITAT.K,FIRLON,LONWTH)
NOTE
NOTE
C INSTK=300000.0
N OWNEQ=INSTK
L OWNEQ.K=OWNEQ.J+DT*NPFRT.JK
A CURLIB.K=ACCPAY.K+TAXLV.K+ACRBP.K+ISLL.K+SUBRTN.K
A CURAST.K=ACCREC.K+RETHLD.K+INVLV.K+CSHBAL.K
A CALRTO.K=CURAST.K/CURLIB.K
A WKGCAP.K=CURAST.K-CURLIB.K
A VOLM.K=CSNLV.K+CSNPRP.K+PTBID.K
A NQKRTO.K=WKGCAP.K/VOLM.K
S VOLEQ.K=TOPRJ.K/OWNEQ.K
A TOPRJ.K=CSNPRP.K+CSNLV.K
NOTE
NOTE
A MPFAMT.K=PULSE(MPFLV.K,1.0,1.0)
R MPFOT.KL=MPFAMT.K/DT
L MPFLV.K=MPFLV.J+DT*(NPFRT.JK-MPFOT.JK)
N MPFLV=0.0
NOTE
NOTE
NOTE
NOTE
NOTE
NOTE
NOTE
A YPFAMT.K=PULSE(YPFLV.K,12.0,12.0)
R YPFOT.KL=YPFAMT.K/DT
L YPFLV.K=YPFLV.J+DT*(NPFRT.JK-YPFOT.JK)
N YPFLV=0.0
A YCSNAT.K=PULSE(YCSNLV.K,0.0,12.0)
R YCSNOT.KL=YCSNAT.K/DT

```

```

N  YCSNLV=7000000.0
L  YCSNLV.K=YCSNLV.J+DT*(PRJOT.JK-YCSNOT.JK)
N  YCSNAX=YCSNLV
L  YCSNAX.K=YCSNAX.J+DT*(YCSNOT.JK-AXOTRT.JK)
A  YCAXOT.K=PULSE(YCSNAX.K,0.0,12.0)
R  AXOTRT.KL=YCAXOT.K/DT
NOTE
NOTE
NOTE
PRINT TOPRJ,OVHLV,INVLV,LONLV,CSHBAL,OWNEQ,NPFSHR,WKGCAP,NQKRTO,VOLEQ,YC
X  SNAX,MPFLV,YPFLV,CALRTO
PLOT TOPRJ=L(1E6,20E6)/WKGCAP=S(5E4,3E6)/INVLV=I(-2E5,2E6)/OVHLV=O(1E5,1
X  E6)/LONLV=N(0,1E6)/OWNEQ=W(0,2E6)/YCSNLV=Y(-5E6,16E6)/CSNPRP=J(-25E6,
X  5E6)/MARKUP=X(-50,20)/MPFLV=Z(-1.5E6,5E5)
SPEC DT=0.05/LENGTH=60/PRTPER=1/PLTPER=1
RUN CA/CL=1.65
C  DEDRT=0.1
RUN ACREC
C  NETRT=0.5
RUN STRIKE
C  ARWCHG=0.04
C  MKVAR=4.0
RUN MARKUP=1.06,1.14
C  ARWCHG=0.04
C  MKVAR=2.0
RUN MARKUP=1.08,1.12

```