U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-295 099

A Quantitative Method for Analyzing the Allocation of Risks in Transportation Construction

Massachusetts Inst of Tech, Cambridge

Prepared for

Transportation Systems Center, Cambridge, MA

Apr 79

UMTA-MA-06-0100-79-1

PB 295099

REPORT NO. UMTA-MA-06-0100-79-1

A QUANTITATIVE METHOD FOR ANALYZING THE ALLOCATION OF RISKS IN TRANSPORTATION CONSTRUCTION

Raymond E. Levitt
David B. Ashley
Robert D. Logcher
Michael W. Dziekan

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DEPARTMENT OF CIVIL ENGINEERING
Construction Engineering and
Project Management Program
Cambridge MA 02139

APRIL 1979

FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
URBAN MASS TRANSPORTATION ADMINISTRATION
Office of Technology Development and Deployment
Washington DC 20590

Technical Report Documentation Page

1. Report No. UMTA-MA-06-0100-79-1	2. Government Accession No.	3. Recipient's Catalog No. PB295099

4. Title and Subtitle

A QUANTITATIVE METHOD FOR ANALYZING THE ALLOCATION OF RISKS IN TRANSPORTATION CONSTRUCTION

5. Report Date
April 1979

6. Performing Organization Code

7. Author(s)
Raymond E. Levitt, et al.

8. Performing Organization Report No.
DOT-TSC-UMTA-79-14

9. Performing Organization Name and Address
Massachusetts Institute of Technology*
Department of Civil Engineering
Construction Engineering & Project Management Program
Cambridge, Massachusetts 02139

10. Work Unit No. (TRAIS)
MA-06-0100

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Urban Mass Transportation Administration
400 Seventh Street, S.W.
Washington, D. C. 20590

13. Type of Report and Period Covered
Final Report
Sept. 1977 - Jan. 1979

14. Sponsoring Agency Code

15. Supplementary Notes

*Under contract to:
U.S. Department of Transportation
Research and Special Programs Administration
Transportation Systems Center
Cambridge, MA 02142

16. Abstract

This report presents a conceptual model of risk that was developed to analyze the impact on owner's cost of alternate allocations of risk among owner and contractor in mass transit construction. A model and analysis procedure are developed, based on decision analysis but extending the standard methodology to include: 1) explicit consideration of risk as an incentive to perform, and 2) the interaction between two decision-makers (owner and contractor) trading risk for price.

The model is pilot tested on the decision of how to purchase insurance for a mass transit project. Analysis of this problem, using the owner and a contractor on the Baltimore subway system as subjects, reveals an alternative to the usual "wrap-up" insurance arrangement that produces $8 million in expected savings to the owner. Directions for future development of this work are suggested herein.

Although the example risk category, discussed herein, involved insurance, the authors stated that the technique was broadly applicable to all categories of construction risk. In fact, the authors intend to use this model to analyze the allocation of such risks as site geological uncertainty, where the model's "value of information" capability can be used. In such a case, the model will yield the amount of site investigation that should be conducted by an owner before soliciting bids, to minimize his total cost.

17. Key Words

Risk Analysis	Contracting
Subway	Models
Insurance	Construction
Decision Analysis	
Negotiation	

18. Distribution Statement
Available to the public through the
National Technical Information Service
Springfield, Virginia 22161

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages [illegible]	22. Price PC A08 MF A01

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

Contract research has traditionally been a difficult vehicle for the development of new concepts and ideas. The associated time pressures and prespecified objectives usually preclude the unhurried contemplation and interaction so necessary for the conduct of basic research. The M.I.T. research team on this project was, therefore, extremely fortunate to have Mr. Robert Thibodeau as technical monitor on this project. He permitted and even encouraged us, within the project's time limits, to engage in the conceptual model development with a minimum of methodological constraints. The result, we feel, was a significant breakthrough in the field of risk analysis, and opens the field for further development.

We are particularly indebted to officials of the Baltimore Regional Rapid Transit System, notably Herb Priluck, Frank Hoppe and Robert Murray; their insurance consultant, James Murphy; and George Williamson and Keith Shelnutt of the Fruin-Colnin construction company in Baltimore. Their participation as knowledgeable subjects in our field test was indispensable to the project.

We were privileged to have, as technical advisors, a group of experts from all areas of the construction industry. This project advisory board consisted of: Norman A. Burgoon, Bonding Expert; Herbert H. Einstein, Professor of Underground Construction; George Fox, Tunnel Contractor; George Jenkins, Bridge, Highway & Airport Designer; Frank Neville, Transit Authority Project Manager; Thomas Liu, Geotechnical Engineer; Boyd C. Paulson, Professor of Construction Management; Robert Rubin, Construction Legal Expert; Harry Suttcliffe, Mass Transit Designer; and David Thompson, Geotechnical Engineer. They participated in a review of the conceptual model, and commented on the draft of this report, lending ideas and informed criticism, to keep us within the realm of reality. Their assistance is gratefully acknowledged.

Two M.I.T. graduate research assistants--Gary Atkinson and Michael Dziekan--were actively involved in this research project; they participated in the conceptual model development, carried out the field testing of the model, and contributed to the analysis of results and conclusions. Mike Dziekan wrote sections of the final report, and Gary Atkinson is currently working on the rationale for formalization of the conceptual model in the future. The research results achieved are, in large part, a result of their labors over the past year. They have my warmest appreciation and thanks.

Professor David Ashley contributed his ideas to the model and supervised its field test. Professor Robert Logcher provided continuous input and critique from proposal through to final report.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

EXECUTIVE SUMMARY

In September 1977, M.I.T.'s Department of Civil Engineering was awarded a contract by the U.S. Department of Transportation's Transportation Systems Center on behalf of the Urban Mass Transportation Administration, to develop a conceptual model of risks in transportation construction. This conceptual model should incorporate the interaction of risks with one another, and should be capable of quantifying the impact on owner's total cost of allocating these risks in different ways among a project's participants. In addition, the contract called for a pilot test of the model with a sample category of risk on an actual transportation project.

A conceptual model of risk allocation was successfully developed by the research team, and was verified by the technical advisory board for the project in early December 1977. The model was subsequently field tested using the owner and a contractor on the new Baltimore mass transit project as subjects, and analyzing the owner's decision of how to purchase insurance for the construction of the system. The technique and the results of the pilot test will be briefly described in the following paragraphs.

The conceptual model is based upon Decision Analysis techniques, with a significant extension of the standard Decision Analysis procedure used by many analysts. The standard Decision Analysis model creates a decision tree with "chance nodes" and "decision nodes" to disaggregate the variables that impact a single decision-maker in a decision situation. The tree is then used to determine the decision (or sequence of decisions) that maximizes the expected value of the decision maker. In the case of a risk-averse decision-maker, the analyst measures his risk preference ("utility") and maximizes expected utility rather than expected value. The model used in this study adopts the basic tenets of Decision Analysis--subjective probability, value of information, risk-aversion, and the same set of axioms--but develops the model as a two-party, interactive decision process, where risk share is traded for contract price. In addition, considerable use is made of graphic presentations of each risk submodel in the form of "Interaction Diagrams" (circles and arrows) to illustrate the relationships between risks and to verify the submodel with each decision maker.

These changes permit the model to capture two important aspects of the problem not considered in a standard Decision Analysis approach:

- Differences between the contractor's and owner's perception of a given category of risk could be identified and exploited to the owner's advantage in the allocation of risk.
- The value of risk as an incentive for performance could be explicitly considered.

To recapitulate, the conceptual model contains decision analysis submodels for each party. These submodels incorporate the notion of risk as an incentive for performance, and are illustrated and verified through Interaction Diagrams. The submodels interact as follows: (1) An owner determines a particular allocation of risk through contract clauses and other decisions. (2) A contractor responds to the risk share he must accept by pricing the risk into his bid. (3) The sensitivity of the contractor's bid price to different risk allocations can be tested by the model. (4) An owner can then decide how much risk he (the owner) will accept in exchange for a lower bid price.

The model was tested on the owner decision (actually a sequence of decisions) relating to the purchase of insurance for the construction of a hypothetical urban mass transit project. The owner of Baltimore's MTA project and a contractor currently working on that project were the subjects for our test. All of the mass transit systems recently built in the U.S. have been insured under owner coordinated or "wrap-up" programs. Three major categories of insurance are involved: Workers' Compensation, General Liability and Builder's Risk. To date these have all been included in the owners' wrap-up coverage. After disaggregating these risks, our analysis indicated an alternative arrangement; by excluding builder's risk from the wrap-up package, and by accepting more risk (in the form of higher deductibles) the owner could lower his expected cost--<u>including</u> the expected payout of deductibles--by some 20% of total insurance cost, or 1% of total project cost!

It should be noted that whereas our example risk category involved insurance, the technique is broadly applicable to all categories of construction risk. We intend, in the future, to use this model to analyze the allocation of such risks as <u>site geological uncertainty</u>, where the model's "value of information" capability can be used. In the case of site geological risks, the model will yield the amount of site investigation that should be conducted by an owner before soliciting bids, to minimize his total cost.

In addition, future research should look at incorporating the designer as a third party to the process, and at formalizing the models that are developed into a large matrix model which can be computerized. Repetitive use of such a model may make it possible to apply classical statistical analysis methods and human behavior models to identify "typical" decision-makers whose perceptions could be substituted for subjective assessments. Thereby the amount of input information required could be limited to assessments of only those variables to which the final output of the model was extremely sensitive. Such a "standardized" model would not require a detailed analysis for each problem investigated, and would thus save substantial time and money.

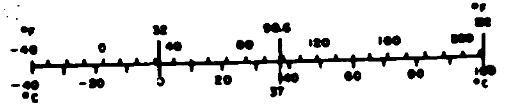
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



1. INTRODUCTION

1.1 PROBLEM STATEMENT

The total cost of constructing major transportation construction projects within the United States is rapidly becoming prohibitively high. U.S. construction costs are continually escalating faster than the U.S. Consumer Price Index. Subway construction costs typically run three to five times as high as those for comparable European systems. Allowance for different financing arrangements and industry and project characteristics in European systems does not significantly change the observation. [Pedrelli and Levitt, unpublished research report, 1978]. As a result the subway system is quickly becoming an unaffordable mode of transportation for U.S. cities, rather than a basic component of urban infrastructure. A recent issue of ASCE's Civil Engineering magazine states the problem very well:

> Subways and subway stations cost far too much to build. For instance, the 100-mile-long Washington Metro subway system, now under construction, is costing $50-60 million per mile (including stations). With costs like these, the U.S. simply cannot afford to build many miles of subways. Costs, believes U.S. Department of Transportation construction expert, Russell McFarland, of the Office of the Secretary, must come down dramatically if the subway is to be a viable transportation mode. [Dallaire, 1976, p. 37].

Further, cost overruns frequently occur on other major transportation construction projects, such as highways and pipelines. The Alaska Pipeline is a case in point, with the final cost of $9 billion about ten times the original estimate.

The same article, referred to above, suggests an answer and echoes the conclusions reached in a recent report, "Better Contracting for Underground Construction." [National Research Council, 1974]. Simply stated, misallocation of risk is the substance of the problem. U.S. public and private construction projects are planned, designed and constructed under conditions that place enormous risks upon planners, designers, their consultants, and construction contractors. Consequently, these parties, who are usually very undercapitalized and underpaid relative to the size of the risks imposed upon them by contract, adopt defensive strategies including:

- charging of contingency amounts (either explicitly, or hidden in inflated unit prices) by contractors to cover risks, frequently uncontrollable, such as changed underground conditions and materials price escalation;
- conservatism in product design and construction methodology;
- reluctance of designers to utilize alternatives involving new technology, because of the potential liability in the event of undue cost or failure to perform; and
- willingness to litigate or send to arbitration any possible type of dispute whether warranted or not.

At the same time, owners would like to be able to receive a predictable final cost and ensure a stated performance standard by placing these risks contractually upon their contractors and designers. Moreover, the responsibility for certain risks (e.g., labor productivity) serves to motivate efficient performance on the part of designers and contractors, resulting in lower costs.

As long as the costs associated with owners' shedding of risk remain obscure, ill-defined, and not quantified, owners will naturally adopt those strategies designed to minimize their susceptibility to variations in cost. Contractors and designers will naturally charge premiums for their increased susceptibility to these risks. This is the problem!

1.2 SUPPORT FOR THIS STUDY

In the summer of 1977, the U.S. Department of Transportation solicited proposals to develop a quantitative model of risk allocation in transportation construction. M.I.T.'s proposal was selected, and the work was performed between September 1977 and August 1978.

1.3 APPROACH

This study explores the cost implications of risk and their assignment to the various parties in transportation construction. To achieve this, it seeks to understand, interrelate, and quantify these risks.

1.3.1 Definition of Risk

To develop an understanding of the entire problem, a clear, concise definition of "risk" must be determined. A "risk" is a variable in the process of constructing a transportation project whose variance results in uncertainty in the final cost to the owner. There are two types of risks, controllable and uncontrollable. Uncontrollable risks are pure random variables within the domain of the parties involved in sharing risks, such as: material price escalation, weather, and variation in underground conditions. Controllable risks reflect variations in human performance, such as: number of design omissions, worker productivity, and material wastage rates. Some categories of risk can be thought of as a combination of controllable and uncontrollable risk (e.g., worker accident rates). However, if the magnitude of the cost implications of risk can be influenced by any of the participants, it will be considered controllable.

1.3.2 Rational Assignment of Risk

Controllable risks may serve to motivate better performance by the party sharing in the risk; and therefore, provide an incentive value. In the case of uncontrollable risk, the risk is a pure lottery to the party bearing it, and has no incentive value.

The costs associated with carrying of risk take the form of contingency amounts over and above the expected cost of the risk to the risk-averse decision-maker. The degree of risk-aversion exhibited by a decision-maker increases as his ability to absorb losses decreases. With contractors and designers undercapitalized relative to the size of the risks they face, the cost to the designer or contractor of accepting such risks would be higher than to the owner, who is typically less risk-averse.

A balancing of the risk should result between an owner and his contractor or designer to utilize the incentive value of bearing risk, while minimizing the contingency charged for accepting the risk. There will be a particular allocation of risk between those parties which will be optimum in terms of final project cost to an owner.

1.4 OUTLINE OF THIS REPORT

To attack the problem, a conceptual model was developed to understand the basic structure of construction risks. The types of risk were ennumerated and interrelated to develop the necessary understanding of the scope of the problem. Decision analysis provided the methodology for the quantification of the model.

Chapter 3 develops in detail the methodology employed. The theoretical foundations of Chapter 2 lead to a normative model of risk allocation. The conceptual framework of the structural model is presented and discussed. The decision analysis methodology is described as a sequence of activities capturing the risks, their implications, and their allocation, to yield a minimum total project cost. The relevance and feasibility of the methodology, thereby, become evident.

Chapter 4 applies the methodology presented in Chapter 3 to an example owner decision--whether to use a coordinated insurance program for an urban subway project. The study was undertaken in a real project situation to enhance the practicality of the methodology. The model is structured and quantified to provide insight to the risks involved, as perceived by the two parties--owner and contractor. The analysis is performed, and the results presented.

Chapter 5 presents the major conclusions of the study. The capabilities of the conceptual model and the decision analysis methodology as used in this study are evaluated. The use of the method to study other specific categories of risk, such as site geology, is then discussed, along with the feasibility of extending the technique toward inclusion of the designer/engineer into the model. Finally, it is suggested that future research should attempt to incorporate all parties and categories of risk into one general model through an extension of the methodology (proximal decision analysis).

Appendix A presents a pilot test of the model on the owner decision of whether or not to purchase construction materials, specifically steel tunnel liners. Additional insight into the risks within the construction process is provided by this example.

2. THEORETICAL FOUNDATIONS

2.1 INTRODUCTION

The comparatively high costs of urban mass transit systems in the United States versus those of Europe requires a study to discover the underlying causes of such costs. As noted previously, the manner in which risks are allocated among the parties involved in the planning, design, and construction of these systems is believed to be a compelling factor behind these extraordinary costs. The mere identification and acknowledgement of the problem, however, neither provides nor dictates the solution. The objective of this research is to find a rational basis for allocating risk, using an engineering approach that will provide a quantitative solution to this problem. In order to provide a method of solution that will be widely accepted and utilized by the interested parties, it is necessary to develop a method with substantial theoretical bases. This chapter reviews some of the pertinent concepts which underly techniques for the analysis of problems involving uncertainty.

2.2 QUALITATIVE MODELS

The first step in any rational approach is to define exactly what it is that is to be analyzed. In this case, the objective is to examine the effects of risk on the final, total project cost. Risk must be defined and then the types of risk must be enumerated. A discussion of the relative importance of each type of risk and its effect on the project cost must ensue. This type of analysis can be designated as a descriptive model. Obviously, it is very qualitative in nature and is intended to "describe" the boundaries of the problem and interrelate the effects in a characteristic fashion only. It provides a tool for developing a conceptual framework of the point at issue, often relying on experience combined with intuition.

2.3 OVERVIEW OF QUANTITATIVE TECHNIQUES TO MODEL UNCERTAINTY

To extend the analysis further, a quantitative approach must be followed. The mathematical formulation or modelling of the problem captures the conceptual insights previously developed and seeks to interrelate them in a mathematical or functional manner. This process of analysis allows a value or quantity to be placed upon each variable within the system.

2.3.1 Operations Research

Operations research encompasses a set of deterministic and probability-based optimization techniques to aid decision-making in a quantitative way. The analysis techniques employed by these methods include both analytical and simulation techniques. The former require rigorous mathematical formulations and provide an explicit, unique solution for each problem. Techniques include linear and dynamic programming, network analysis, queuing theory, inventory theory, and Markov chain analysis. Simulation is covered in 2.3.4.

2.3.2 Systems Analysis

Systems analysis is another form of mathematical analysis brought to the forefront by the computer. Systems analysis considers the interactions and dynamic behavior of complex problems. It is a quantitative study utilizing a number of analytic tools such as production functions (which represent the combination of resources), marginal analysis concepts and optimization techniques to determine preferable alternatives, and sensitivity analyses to determine the reliability of the results. Systems analysis identifies the important issues and alternatives and relates the corresponding costs and benefits in mathematical form. [deNeufville and Stafford, 1971, p.2]. The computer enables the process to incorporate a large number of variables and data to describe complex problems.

2.3.3 Decision Analysis

Decision analysis combines the aspects of systems analysis and statistical decision theory. This combination produces a method that is logical in complex, dynamic, and uncertain situations. It captures the conceptual framework of a problem and quantifies it with the decision-maker's knowledge about uncertain variables, regardless of how sketchy this knowledge may be. The impact of uncertainty can then be measured and interpreted, resulting in a preference ranking between alternatives available to the decision-maker.

2.3.4 Simulation Techniques

The use of a simulation as a research approach is indicated when total systems problems become too large and intricate to handle with linear and dynamic programming models or standard probabilistic models. Such problems often combine the effects of

- uncertainty,

- dynamic interactions between decisions and subsequent events,
- complex interdependencies among the variables in the system, and
- the need to use finely divided time intervals. [Wagner, 1969, p.889].

Computer simulation analysis is accomplished in three steps: one, formulating the model; two, designing the experiment; and three, developing the computer program. In the first step, the level of detail of the problem is developed to guard against extraordinary and unnecessary complexity. The second step involves the design of the operating characteristics of the system being measured and consideration of the statistical tools to be applied. The final step is to program the computer to perform the "simulation." [Wagner, 1969, pp. 892-893].

The formulas stored in the computer characterize the complex interdependencies, dynamic interactions, and the uncertainties. A simulation begins at a specified starting state. The system proceeds to another state at a future instant in time reflecting the combined effects of decisions, and of controllable and uncontrollable events, which may be random. This process of "stepping" occurs until the end of the horizon is reached. Simulation is often thought of as a "method of last resort." The reasons for this are: the results are characterized as estimates subject to statistical error, thus, conclusions must account for accompanying random variations; and the complexity of the model building and subsequent analysis approaches that of the real world problem being addressed. [Wagner, 1969, pp. 890-891]. However, as computer capabilities expand, while costs of processing data decrease, simulation will become an increasingly attractive alternative.

2.3.5 Requirements for This Research

The capabilities of the method of analysis that is sought to optimize the allocation of risk are:

- formal structuring of the interrelationships among all the relevant variables;
- handling disaggregation of components of cost;
- accounting for the different perceptions about the significance of the risks by each party;
- incorporating the risk preference of the decision-maker
- measuring the incentives of accepting risk;
- testing the sensitivity of the output to variable uncertainty;

- quantifying the categories of risk; and,
- allowing for negotiation between the parties, trading risk shares for contract prices.

An examination of research performed to date will be undertaken, before discussing theoretical aspects of the modelling methodology used in the study.

2.4 RESEARCH TO DATE ON RISKS IN CONSTRUCTION

There have been a considerable number of efforts to address the problem of handling construction risk. Most of these works are qualitative in nature. hitting at the problem of increased cost in a descriptive manner. [Dallaire, 1977, pp. 153-163; Immel, 1977, p.1; Smith et al., 1975, pp. 907-921; Abrahamson, 1973, pp. 588-598]. A few efforts have been directed at developing quantitative evaluations of the effects of risk upon cost. [Ashley, 1977; Carr, 1977, pp. 153-165; Mason, 1973; Pouliquen, 1970]. Three salient articles are described below.

2.4.1 Qualitative Modelling

The report Better Contracting for Underground Construction, by the U.S. National Committee on Tunneling Technology, National Academy of Sciences, began to address the problem of U.S. high underground construction costs. The Committee, whose membership includes many prominent tunneling industry figures, examined existing (1974) U.S. and European contracting practices. From their comparison, they concluded that in many respects the U.S. would do well to utilize many of the European contracting practices to ameliorate the great risks placed upon contractors, which lead to a corresponding high cost. The aim was to create a cooperative atmosphere among the parties involved in underground construction. The new, improved contracting methods would provide an equitable sharing of the risks where the owner would receive the complete system at a lower cost and the contractor would receive a just profit. [National Academy of Sciences, 1974, p.6]. The recommendations about U.S. practices made by the Committee are the result of the considerable experience of the members. Their recommendations, however, are qualitative in nature, and rely on their broad experience and professional judgement. There is no quantitative analysis of the recommendations that can indicate a ranking of them according to their impact on reductions in cost. The report does, however, provide an excellent guide for the items that should undergo a quantitative analysis.

2.4.2 Aggregate Quantitative Modelling

Robert Carr [1977, pp. 153-161] demonstrated in a quantitative manner the cost an owner must pay for placing construction risks upon a contractor. Using measured utility functions for both the contractor and the owner, he calculated the percentage difference in cost to the owner for alternative allocations of risk on a project with some uncertainty in cost. The conclusion is that the owner pays extra for a lump sum contract versus a cost plus 5% fee contract with a "typical" risk averse contractor. Based on such analysis, the owner is asked to accept the entire risk of the contract since he is typically less risk averse than the contractor. This clearly is an oversimplification, and one that no owner will accept. The problem is that this analysis does not attempt to address to positive, incentive aspects of handling risk, but only the negative, risk aversion consequences. In addition, it addresses the entire problem of risks in the aggregate; i.e., it makes no account of the different categories of risk, their individual differences and their inherent interrelationships.

2.4.3 Simulation Modelling of Risk

Finally, a paper done under the auspices of the World Bank examines the use of risk analysis in the appraisal of projects. The methodology uses subjective probability distributions of the variables to obtain, as an output, the aggregation of these distributions or, simply, the final variable has a distribution which is some combination of the individual variables with their distributions. A Monte Carlo simulation technique is used to perform the aggregation. [Pouliquen, 1970, pp. 2-3]. The paper discusses the problem of disaggregation, which is how to deal with the correlation of these variables. The difficulty in the determination of the correlations is handled by attempting to define variables that are perfectly correlated. Then, an analysis is performed for the case of complete dependence and for complete independence. The output of the model is compared under each case to study the effects of correlation. [Pouliquen, 1970, pp. 49-50]. The general methodology presented by Pouliquen included several of the capabilities of the method sought for our research. However, it does not have all of the capabilities that are sought as outlined previously. In particular, it does not satisfy the following criteria:

- accounting for different perceptions about the significance of the risks by different parties;

- incorporating the risk preferences of all decision-makers;
- measuring the incentive value of accepting risk; and,
- modeling the negotiation process of the allocation of risk to the parties.

2.5 DECISION ANALYSIS REVISITED

Decision analysis turns out to be the methodology that best models the problems of decision-making under uncertainty for our purposes. It reduces problems to their elemental form by capturing the structure of the interactions of the variables of risk into a formalized framework. Further, it provides conceptually based, and practical, methods for quantifying the uncertainty inherent in the individual variables. It also allows for the determination of the values and preferences of the outcomes of the analysis. The sensitivity of the outcome to each variable in the model can be tested by explicitly utilizing the known uncertainty of that variable.

Decision analysis is a normative approach to the problems it seeks to solve. It illustrates a logical succession of rules that a decision-maker should employ to maximize his objective function. [Matheson & Howard, 1977, pp. 9-13]. However, it has also gained acceptance as a descriptive technique, useful in predicting the outcome of decisions under uncertainty. [Howard, 1977, pp. 45-81].

2.5.1 Subjective Information

The distribution of the uncertainty of a variable is considered in classical statistics to be a physical parameter or a state of nature, and classical statistics postulate that a probability distribution describes the variation of some physical phenomenon. There exists, however, an alternative view of uncertainty. This is that the uncertainty or risk inherent in a variable arises solely from the decision-maker's perception of, or state of information about, the variable. As an example, site geology on a tunneling project is a highly uncertain variable or risk to be faced. In nature, there exists one, and only one, soil or rock formation underground at any given point. The uncertainty or risk associated with it is determined solely by our state of information about what actually exists underground. Decision analysis uses this second view of uncertainty, and captures the uncertainty of a variable by utilizing subjective probability or information. This allows the decision-maker to use his logic, intuition, and experience to assess a probability distribution based upon any amount of data available to him. This notion, it should be pointed out, is often difficult for classical statisticians to accept.

Considering the site geology example again, usually borings are taken to give some indication of the existing conditions. Basic upon such information a design is carried out and a construction method is decided. Whether one considers the residual uncertainty at any point to be a state of nature or of information, the decision is made based upon the information available to the decision-maker. In using the decision analysis technique, the uncertainty of the variables can be captured through encoding of the subjective information available to the decision-maker. This incorporates into the methodology a rational process to make accurate, replicable, probabilistic statements about quantities that are otherwise considered vague.

2.5.2 Statistical Information with Updating

The decision analysis approach often pertains to the one of a kind problem. This study will attempt to structure a model that will be utilized as a continuing system. It may be desirable, therefore, to quantify the uncertainty of some of the risk variables in a statistical manner; i.e., measuring the observed occurrences and deriving a distribution from those observations. This information could be permanently installed in the model. To keep the information current, periodic observations would have to occur. It may be desirable to update the information by correlating it to some easily measured datum. For example, the uncertainty in the price of steel may be calculated from a base distribution and an inflation rate. Obviously, such a technique should be utilized when the repetitive nature of the use of the model could support the data base necessary.

2.5.3 Risk Preference

Risk preference (or risk aversion) describes the behavior of people when faced with an uncertain proposition. The characteristic behavior displayed by most people and organizations under the prospect of uncertainty is risk aversion. The risk averse decision-maker is willing to discount expected winnings and overvalue expected losses. Other types of behavior do exist such as: risk neutral, where the individual is indifferent to a gamble with an expected value of zero, and, risk prone or risk preferring, i.e., willing to gamble in a situation with negative expected value, e.g. at a casino in Las Vegas, or, some believe, in a construction contract. [Matheson, Howard, 1977, pp. 30-31]. A method to easily measure the risk preference of a decision-maker is to utilize a lottery as illustrated in Figure 2-1. The decision-maker must satisfy a number of axioms in order for the theory to hold true. These are:

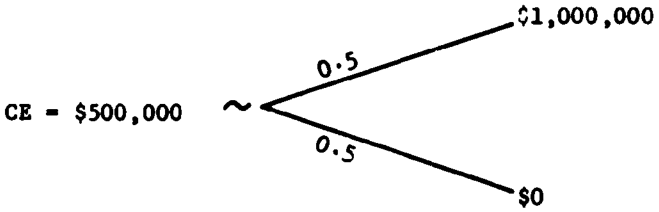
- the decision-maker must be able to state his preferences among the possible outcomes of a lottery (orderability) and exhibit the transitive property (i.e., if he prefers A to B, and B to C, he must prefer A to C);
- if the decision-maker exhibits the transitive property a lottery can be constructed with two outcomes A and C, a probability p of winning A, and a probability (1-p) of winning C, such that he is indifferent between the lottery and the certainty equivalent (substitutability);
- given two lotteries with the same prizes, he will prefer the lottery which has the preferred prize with higher probability (monotonicity); and,
- in a complex form of the uncertain proposition, where a lottery may have another lottery as a prize, the decision-maker will consider the final prize and compute the probabilities of winning each prize and reduce the compound lottery to a simple lottery (decomposability). [Howard, 1977, pp. 438-440].[1]

Refer again, to Figure 2-1. The first lottery illustrates the expected value ($500,000) of an uncertain proposition, in this case a 50-50 chance (toss of a fair coin) of winning one million dollars ($\$1^M$) or nothing ($0). Further, risk averse behavior is illustrated in the second decision-maker's perception of the same lottery where the certainty equivalent of the lottery is $250,000. A measure of the risk aversion is the risk premium the decision-maker places upon the uncertainty or risk. It is the difference between the expected value and the certainty equivalent (risk premium = expected value -

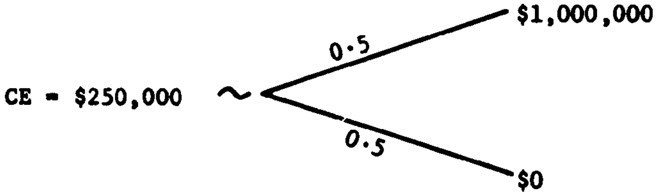
---

[1] Several of the axioms of risk preference (utility theory) are challenged in an article by Kahneman and Tversky [<u>Econometrica</u>, in press, 1978, pp. 1-51]. They conclude that decision-makers undervalue outcomes that are probable in comparison with outcomes that are obtained with certainty and discard components that are shared by all prospects under consideration leading to inconsistent preferences. The encoding of utility curves can capture the decision-makers' preference for risk in such a nonlinear fashion. Willenbrock [1973, pp. 133-153] measured utility functions of contractors that exhibited these characteristics.

EXPECTED VALUE LOTTERY



EXPECTED UTILITY LOTTERY
(RISK AVERSE BEHAVIOR)



UTILITY FUNCTION

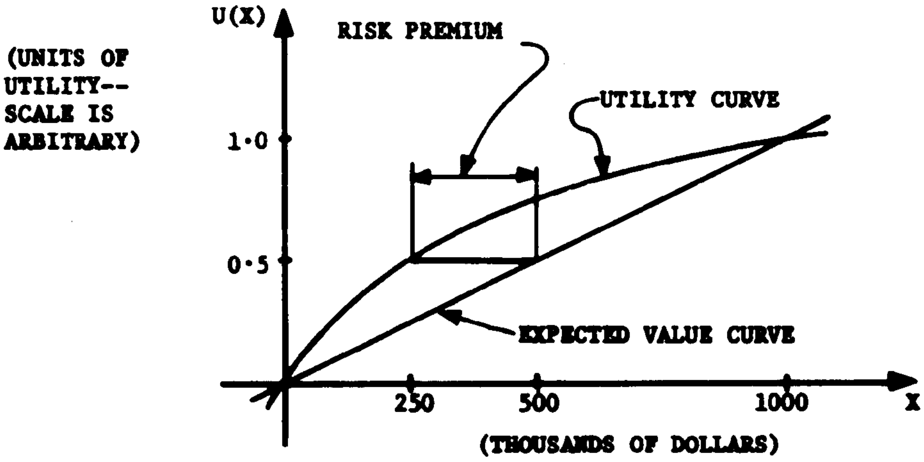


FIGURE 2-1 RISK PREFERENCE

rtainty equivalent). In this case, the risk premium is $250,000.

Mathematically, a function called a utility function can be developed in terms of the probabilities and outcomes of a series of lotteries (refer to Figure 2-1). Utility has two important properties: first, that the utility of a lottery is the expected utility of its prizes; second, that if one lottery is preferred over another, its utility will be higher. The utility function, which provides a graphic picture of the decision-maker's risk preferences, is a method for ranking lotteries according to the risk preference of the individual. Since it is a mere ranking, the results of such an analysis cannot be changed by multiplication by a positive constant or by addition of any constant. Thus, the scale for utility is arbitrary. The curve can show utility to be assigned to any commodity. [Howard, 1977, p. 396]. The cost or value of an outcome in money terms, e.g. profit, value of project's output, or contract price, is the commodity most often used.

2.5.4 Risk as Incentive

So far, the presence of uncertainty has been treated for its negative effect--risk aversion. However, it can have the effect of inducing better performance. In the case of a controllable risk, the risk may serve to motivate good performance by the party bearing the risk, hence, the incentive value. Obviously, an uncontrollable risk involves a pure gamble ("lottery") and, thus, it has no incentive value. For example, the contractor on a lump sum tunnel project faces an uncertainty in advance rate at the face of the tunnel. Therefore, the contractor will strive for maintaining a higher level of worker productivity to ensure the necessary advance rate, since his profit is being affected. The incentive value of the risk can be incorporated into the structural model by directly measuring its influence upon the categories of risk.

2.5.5 Value of Information

One of the benefits of the decision analysis approach is an output appropriately termed "value of information." The term applies to the worth to the decision-maker of obtaining information on one or more of the variables of a problem. This worth is measured in hard dollars and cents.

To calculate the upper bound on any information gathering process that can be employed, a clairvoyant is postulated who is hypothesized to have perfect information. This value of perfect information is easily calculated once the decision-tree structure is established. The procedure is to change the order of the nodes in the tree, placing the state variable representing the resolution of uncertainty before any decision node with the rest of the tree remaining the same. The terminal node values are calculated using the appropriate values. The tree is folded back by placing at the decision nodes the values of the tree that represent the "best" decision. The remainder of the folding back process is carried out by multiplication by the appropriate probabilities.[2] The difference between this expected value with perfect information, and the value obtained by choosing the best option without information, yields the desired result--the "expected value of perfect information." [von Holstein, 1977, pp. 138-139].

The method of calculation will be demonstrated using an example. Referring to Figure 2-2, the first decision tree shows an evaluation of the decision to visit the dentist because of a suspected cavity. The values at the terminal nodes are arrived at in the following manner:

- not visiting the dentist and no cavity, costs nothing ($0);
- not visiting the dentist, but having a cavity, costs one hundred dollars ($100) for the pain, extraction, and partial plate;
- visiting the dentist and having no cavity, costs fifteen dollars ($15) for the visit; and,
- visiting the dentist and having the cavity, costs twenty-fice dollars ($25) for the visit and filling.

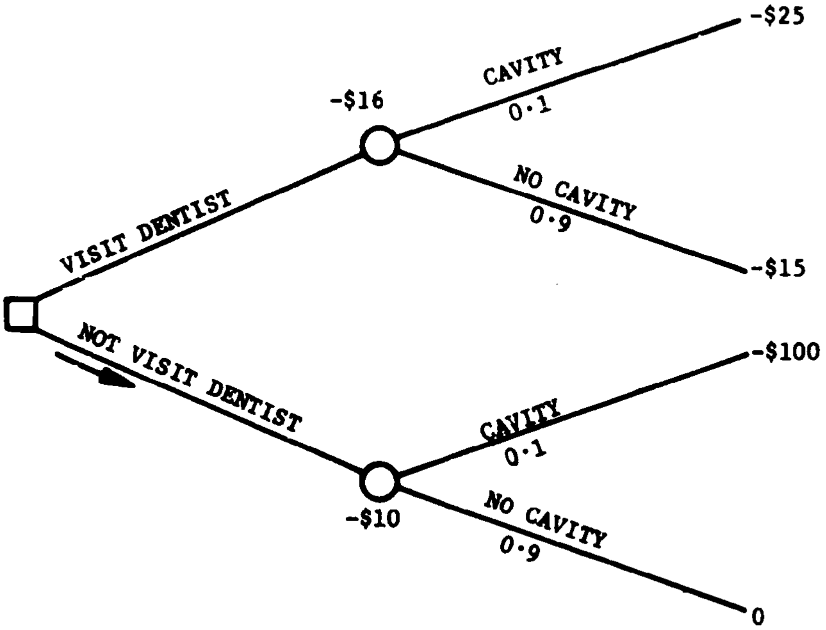
The analysis shows that the individual should not visit the dentist given the values at the different terminal nodes. The second evaluation shows the value of the tree with perfect information (clairvoyance). A comparison of the two evaluations results in a value of information of $7.50 (-$2.50 - (-$10)). The individual would be willing to spend $7.50 to find out whether he actually has a cavity. Since it costs $15 for a visit, he should not go to the dentist for this information.

This analysis can be easily extended to the case of a risk averse decision-maker. All that is required is to substitute expected utility for expected value in each case. The calculation is then identical to the one

---

[2] This method applies for risk neutral decision makers or those with an exponential utility function. Other cases are handled by a trial and error method that equates the expected utilities of the best alternatives with or without information.

DECISION TREE



VALUE OF INFORMATION

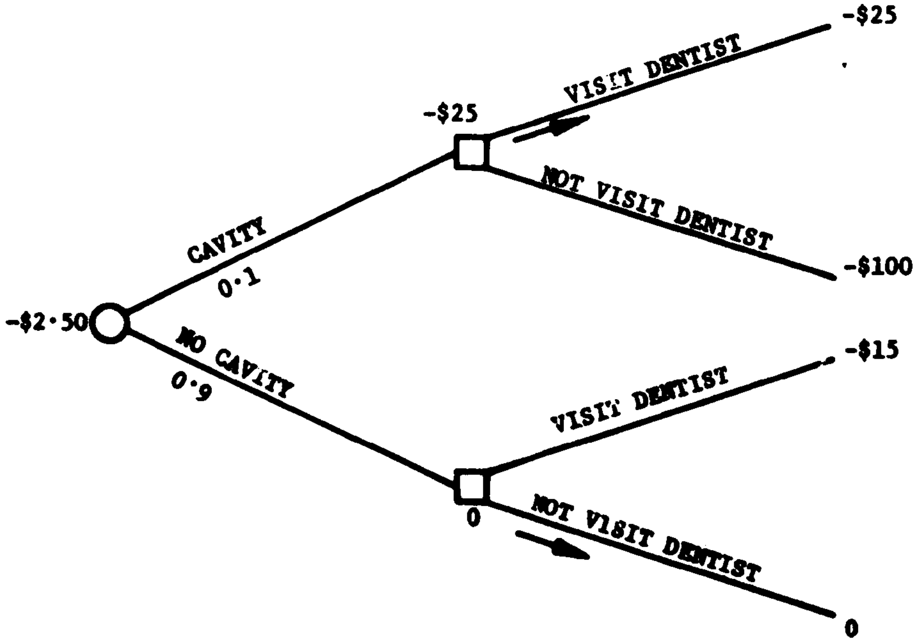


FIGURE 2-2 VALUE OF INFORMATION

above. The power of this analysis can be appreciated, if one considers the uncertainty inherent in site geology and the costs associated with this risk. The "*value of perfect information*" calculation would provide a determination of the *upper limit on the cost of site investigation* that should be performed to reduce this uncertainty, since any real information will be less than perfect.

2.5.6 Proximal Decision Analysis

The extreme complexity of the problem of risks in transportation construction projects presents an overwhelming, conventional modelling process. Consequently, it would be desirable to use a simplified technique to study the model in its entirety, and the conventional process to study the individual risks in detail. Ronald Howard presents the procedure for this simplified technique in his paper "Proximal Decision Analysis." [Howard, 1977, p. 567]. Briefly, this technique reduces the number of subjective probability assessments of variables, estimates the effect of uncertainty and risk aversion in the preliminary analysis stage, and permits compensating decision variable changes corresponding to state variable changes. The above refinements on the decision analysis process provide a useful approximation of the desired output of the model.

2.5.6.1 *Correlations*. The critical improvement in this technique is in the method of assessing variables that are conditional upon other state variables within the model. The decision-maker is required to provide information of how the mean of a state variable changes as a function of the state variable upon which it is conditional. With this information, the analyst is able to calculate the covariance (the degree to which the variance of one state or uncertain variable depends upon the variance of another). The result is that the output of the model is approximated by the value at the mean plus a correction factor involving the covariance. [Howard, 1977, pp. 570-571].

This result enables the construction of a complicated model with a manageable amount of required information. Further, the model can be constructed in parts. The parts will be interrelated by the correlation coefficients.[3]

---

[3] $\rho_{X,Y} = \frac{COV\ (X,Y)}{\rho_X\ \rho_Y}$; the correlation coefficient of joint (uncertain) variables is a normalized version of their covariance. It is the ratio of

2.5.6.2 Matrix Modelling. Building the model in this manner, allows for structuring the entire model into a matrix format. The model will include a number of matrices: the list of risks, the impact of decisions modifying the risks, the impact of the modified risk upon cost, the correlation of the risk variables, and the allocation of the cost to the separate parties given a set of contract clauses. Putting these matrices together in a logical fashion will yield the desired output--final cost to the owner. By manipulation of the elements within the matrices affected by the decision variables and the contract clauses the minimum of the final project cost can be found. This will point out the optimal contract and owner decisions to be followed.

2.5.7 Negotiation

The output of the formalized model represents a final cost to the owner for a given set of contract clauses which allocate the risks among the parties. The minimization of this cost is achieved through the optimal allocation of these risks. This optimal allocation involves, for each party, a trade-off between the risk share and the contract amount. This trade-off is accomplished by the negotiation of these amounts between the parties involved (owner-contractor, owner-designer). This process can take on two forms: competitive bidding/proposal or continuous negotiation where the parties negotiate until an agreed combination of price and risk share is reached.

2.5.7.1 "Negotiation" Through Competitive Bidding. The marketplace of the construction industry is the competitive bidding process. In this process, the contractor (or designer) responds to an owner proposal; a set of plans, specifications, and contract documents with his bid for the completion of the work. This competitive, free-market process results, in the long run, in an efficient measure of the relationship between risk allocation and contract amount. In essence, the contractors' response to the owner proposal is a one-step negotiation process.

2.5.7.2 Economic Model Negotiation. The Edgeworth Box Model is an economic model for a two-person, two commodity bargaining process. Using this theory,

---

the covariance over the product of the standard deviations. [Benjamin and Cornell, 1970, p. 161].

Ashley [1977, pp. 91-133] modelled negotiations between owners and contractors, where risk share and contract amount were traded.

Figure 2-3 presents a graphical representation of the model and process. The bid amount by the contractor in response to the owner s contract terms, plans, and specifications, is the starting point (A) for the negotiation process. The indifference curves for each party are mapped from their preferences for risk, in terms of price. The owner will accept an increase in contract amount with a decrease of risk share. The contractor will require an increase in contract amount with an increase in risk share. Assuming that the parties start at point A, in Figure 2-3, the shaded area represents their negotiation space--i.e. both parties prefer this region to their starting point. The contract curve, which is the loci of tangencies of the indifference curves, is the end point of the negotiation process; this is known as the set of "Pareto Optimal" solutions. A point (B) is reached when under the process, the parties trade-off contract clauses and, consequently, a portion of the risk share according to the strength of their relative bargaining positions until a double tangent point is reached where there is no negotiating space. This point can lie anywhere on the line b-b, and is not predicted by the model.

An owner who received the bid represented by A could, however, be much better off, without any loss of utility to the contractor. The strength of this model is in showing the negotiation space so that the owner can request bids with risk share (and hence expected price) at C, rather than at A.

2.6 SUMMARY

This chapter presented a synopsis of three mathematical modelling techniques applicable to the analysis of uncertainty: operations research, systems analysis, and decision analysis. Subsequently, it outlined the capabilities sought within the method of analysis to be used for this research. A review of the contributions of previous work in the analysis of risks followed.

Next, a detailed discussion of the decision analysis methodology was undertaken. The major facets of the method--subjective information, risk preference, and value of information--were presented. Included in the discussion of the modelling process were the notions of risk as an incentive, statistical data gathering, and an approximate decision analysis technique.

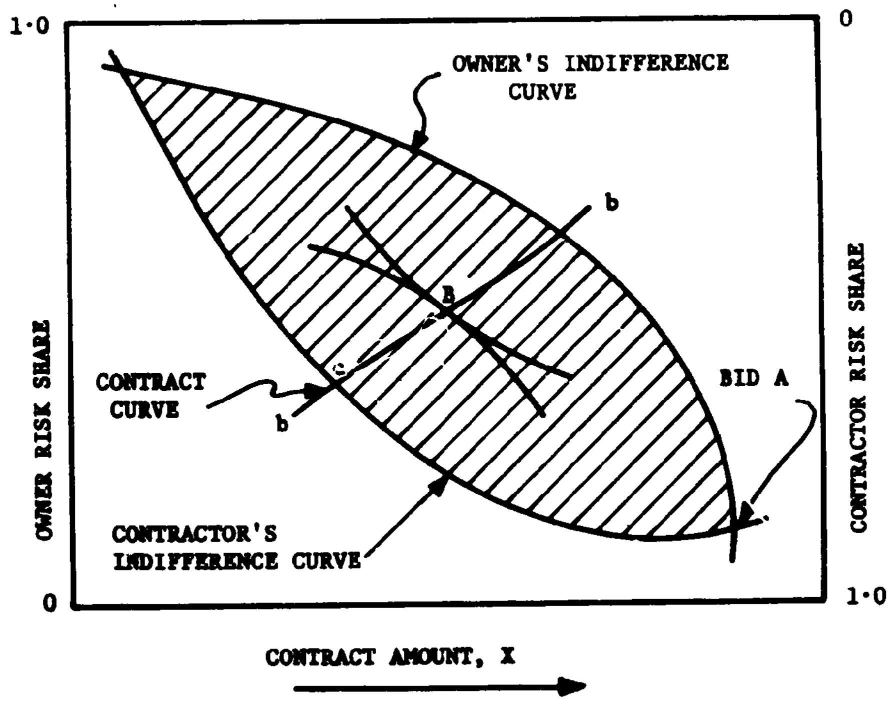


FIGURE 2-3 EDGEWORTH BOX NEGOTIATION

Finally, negotiation models of risk allocation were presented and discussed.

The theoretical bases for the analysis of risks have been explored. The decision analysis technique was chosen for its robustness and efficacy in modelling the problem.

3. METHODOLOGY

3.1 INTRODUCTION

The efficacy and robustness of decision analysis as a normative and descriptive model was established in the previous chapter. A graphic description of the decision analysis cycle is shown in Figure 3-1. [von Holstein, 1977, p. 120]. The process has four major stages: model building, deterministic phase, probabilistic phase, and the informational phase. At three points in the process of the analysis, the possibility exists for the gathering of new information: at the end of the model building stage, deterministic phase, and after obtaining a set of results. The cycle is repeated until further analysis or information gathering is no longer profitable. This chapter will explore in detail each of the phases presented in Figure 3-1, as they were developed in this study.

3.2 MODEL BUILDING

The first and most important phase of the process is the construction of the model. The initial step is to focus in on the exact decision and the outcome (final cost to the owner) that are the subjects of the analysis. A set of project characteristics must be defined to limit the influence on uncertainty that is due to size, environment, and other physical attributes of a mass transit project. Similarly, a general set of contract clauses must be chosen to set the standard for the allocation of risks, costs, and revenues. Of course, in the case of the analysis of a particular contract clause, it may be subject to variation as any other variable. These "project standards" must be clearly understood by both the decision-maker and the analyst to make the analysis effective.

3.2.1 Define Risks

With a basic understanding of the project characteristics and the problem and output well-defined, the decision maker is questioned to describe the significant risks and their impacts on the defined outputs of the model. The process refines these impacts into specific variables. The level of disaggregation of these variables is established by their contribution and significance to the output. There are two types of variables: "decision variables" and "state" variables (actually "state of information" variables). Decision variables are totally under the control of the decision maker. State

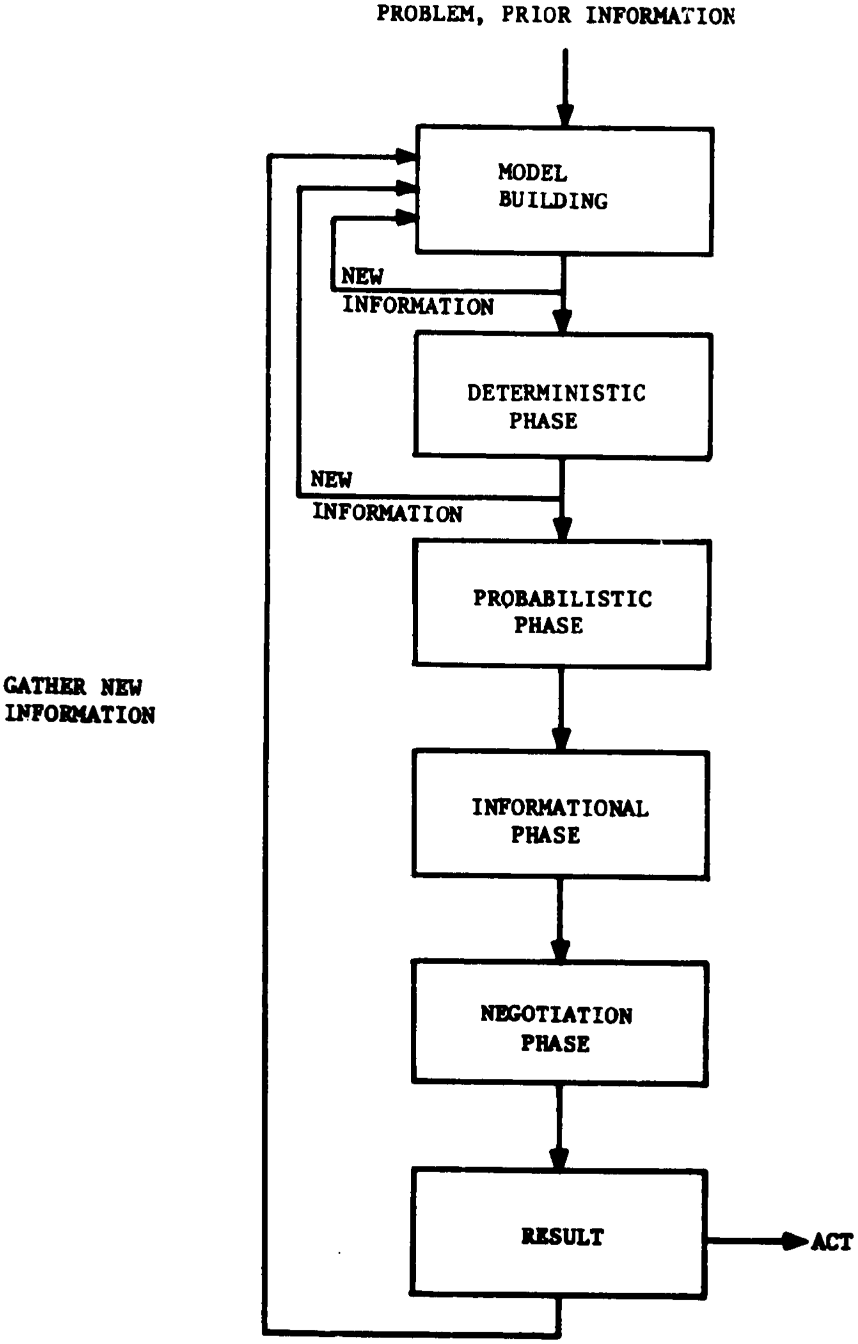


FIGURE 3-1 DECISION ANALYSIS CYCLE

variables are of two types: controllable and uncontrollable. Controllable state variables are a new notion developed in this research; they arise from the idea of risk as an incentive. The variables are defined and disaggregated until they account for all of the major sources of uncertainty in the model's output variable. It is critical that each variable be defined so that it can be quantified in later stages. At this point it is, therefore, appropriate to determine a unit of measure for each variable.

3.2.2 Interaction Diagram

At the same time the risks and impacts are defined, their interactions are sought in order to develop the structure of the model. The cost and revenue sources are integrated into the model. At this point, the analyst independently develops a graphical representation of all the variables pertinent to the problem in the form of an interaction diagram. A general form of the interaction diagram developed for this study by the research team is portrayed in Figure 3-2. Note the hierarchy of the model: the owner decisions impact the perceived risks which lead to a consequence of risk (usually cost); the contract clauses allocate the consequences of risk (revenue and cost), which lead to a net value to the party; and a negotiation of contract clauses optimally allocates the net value and the risks assumed.

3.2.3 Verification

With the model structured in an interaction diagram the decision-maker examines the diagram to see if it essentially and correctly indicates the problem, in his mind. Corrections to the basic structure, redefinition of variables, introduction of new variables, and fine-tuning of the structure occur until the model is verified as correctly representing the problem. New information may be brought in during this stage. At this juncture, the structural equations are determined with their result being the model output. A final schematic is drawn, and named the deterministic model.

3.3 DETERMINISTIC PHASE

The purpose of this phase of the analysis is the preliminary quantification of the model. This quantification leads to the winnowing out through further analysis of those variables which do not significantly effect the model output.

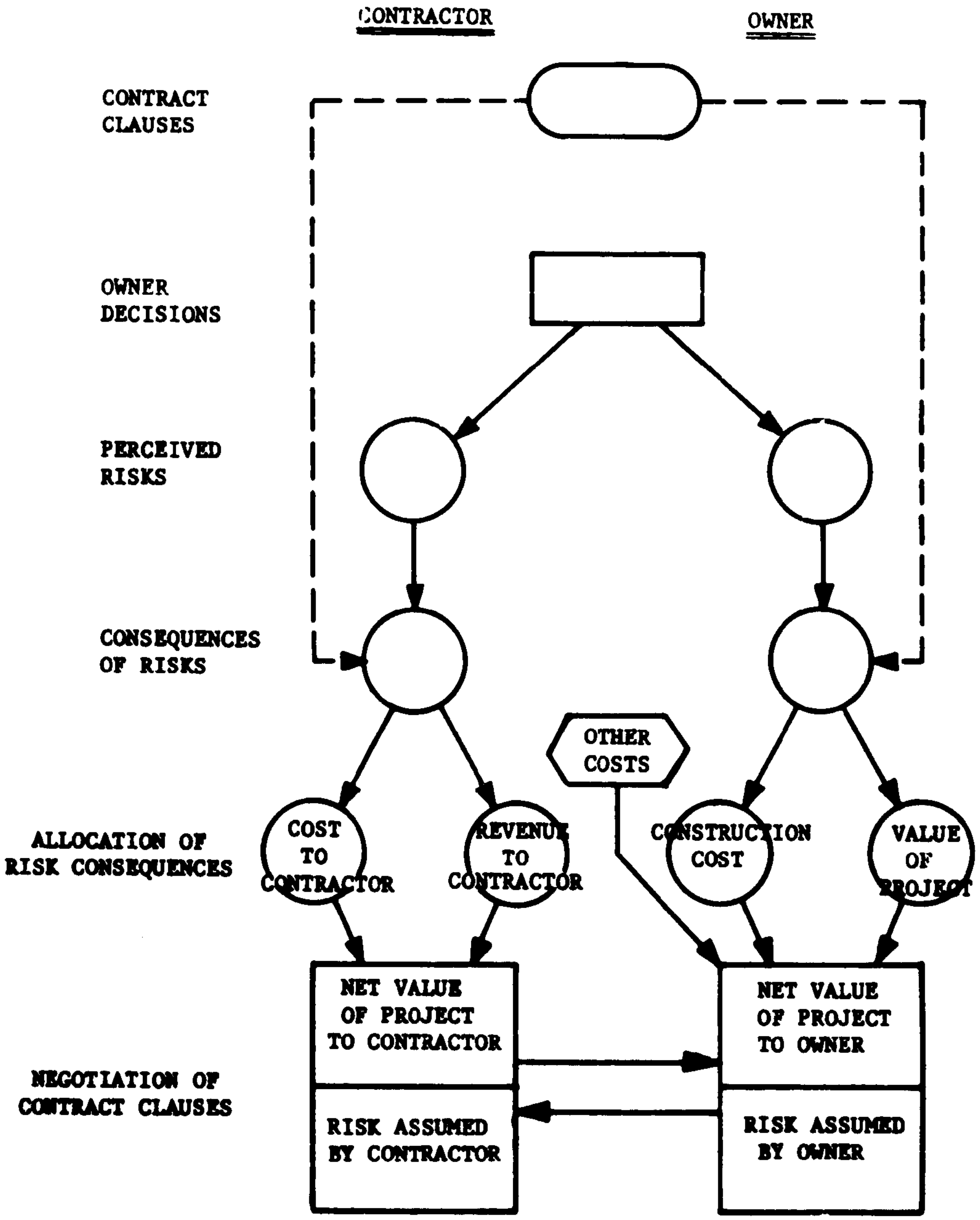


FIGURE 3-2 CONCEPTUAL MODEL OF RISK

3.3.1 Establish Ranges

For every variable within the deterministic model, the decision-maker must specify a nominal or most likely value and two extreme values, high and low, to establish the range. For those variables dependent upon another, the range is established when the initial variable is held at its nominal value; and, when the initial variable is at the extremes, the nominal value is sought for the conditional variable. In the case of the decision variables, the replies reflect the decision-maker's conception of the options available to him. For the state variables, the range signifies the uncertainty assigned to the variable. Mathematically, the nominal value can be thought of as the most likely value and the extremes as roughly equivalent to the tenth (10th) and ninetieth (90th) percentile of a probability distribution. It is crucial that the decision-maker accounts for all the possible uncertainty inherent in any variable. To aid him, it may be beneficial to present scenarios for which extreme values may exist.

3.3.2 Sensitivity Analysis

Utilizing the deterministic ranges, the model is manipulated to determine those variables that contribute the most variation to the model output. Using the structural equations developed above, the model is run with every variable set at its nominal value. Then each variable is swept through its range and a percentage change in the output is noted. After every variable undergoes this process, a ranking of their sensitivity is constructed to delimit those variables with the greatest significance. For practical purposes (questioning of the decision-maker), a limit of approximately six variables was set. The variables determined by this analysis will be further examined to gain a greater appreciation for their uncertainty. The remaining are left at their nominal values. This is reflected as the deterministic model is redrawn into the refined stochastic model. During this deterministic phase, the analysis may indicate a need for restructuring the model or gathering of new information, thus requiring a return to the model building phase.

3.4 PROBABILISTIC PHASE

This phase endeavors to determine in greater detail the uncertainty inherent in the state variables deemed significant by the sensitivity analysis. Probability distributions are assigned to the sensitive variables. The risk preference of each party is also encoded at this time.

3.4.1 Encoding Probability Distributions

The encoding of probability distributions is often a difficult process, since decision-makers are usually uncomfortable in dealing with probability. The other difficulty arises out of the biases encountered when attempting to encode the probability distributions. The biases experienced are motivational or cognitive. Motivational biases occur when the subject's personal reward system influences his response. Cognitive biases adjust his perceptions based on his internal, intellectual process. These biases can be alleviated by careful questioning and pushing the subject into developing scenarios for values of the variable. The analyst should be wary of "anchoring," a behavior whereby the decision-maker narrows his probability distribution around a value indicated by him.

The actual process of encoding probability can occur in two modes: direct and indirect. The direct response mode requires numbers as solutions (probabilities or odds). In the indirect response mode, the decision-maker chooses between two bets or alternatives. The bets are adjusted until an indifferent point is reached. The indifferent point can be translated into probability. Because of the frequent difficulty encountered, a reference process is often used, where one bet is defined with respect to the uncertain quantity and the other to the reference process. Two methods using this process are the probability wheel and the betting cloth. The use of these methods is described by Carl-Axel von Holstein in "Probability Encoding in Decision Analysis" (1977, pp. 416-419).

The actual encoding begins by asking for the extreme values for the uncertain quantity. Once they are established, intermediate values are chosen and encoded. The analyst should steer clear of a value that might be near the most likely value during the early phases of the encoding because of the possibility of developing an anchoring problem. The responses are plotted as points on a cumulative distribution. A curve is fitted to the points after enough points have been encoded. To maintain the subject's attention, the number of points encoded on any one variable should be minimized (five points usually give a good indication of the distribution). The distribution should be verified to see if it is a true indication of the decision-maker's beliefs about the uncertainty. The distributions are then discretized into three levels of value by an approximate method. The method is illustrated in Appendix B. Basically, the number of squares bounded by the straight lines is equalized above and below the curve.

Those variables which are conditional upon other significant variables have to be encoded after the discretization of the initial variable. The distribution of the conditional variable is encoded conditional upon one discretized value at a time, then each distribution is discretized itself.

3.4.2 Encoding Risk Preference

Risk preference and the utility function were discussed in the previous chapter. The encoding of risk preference will be achieved by using a sequence of lotteries. First two arbitrary points must be established. Typically, a reasonable upper bound is at a utility of one (1) and zero is given the utility zero (0). The commodity, money, is the one most often encoded. The equiprobable lottery will be used.[1] The design of the lottery sequence is undertaken to establish a smooth curve between the arbitrary points chosen. Subsequently, the curve is extrapolated downward (for negative values) and upward (increase range) until the range is sufficient to utilize for the model output. Subsequently, the function is checked for consistency and is plotted. It is important to attempt to place the subject into a "real environment" to obtain valid utility functions. The detailed design of the sequence of lotteries to determine a utility function is described by Ronald Howard in "Risk Preference" [1977, pp. 452-457].

3.4.3 Decision Tree

The completion of the previous steps allows us to develop the final model. A decision tree is built incorporating the significant variables determined by the sensitivity analysis as the state variable nodes (see Figure 3-3). The terminal nodes are calculated from the structural equations, using the values along the proper branch of the tree, in conjunction with the nominal values for the other variables in the equation. The utility function is applied to these values to find the certainty equivalent, hence incorporating the decision-maker's risk preference. This phase of the analysis is termed "averaging out." Folding back the tree yields a value for each

---

[1] A lottery where each outcome has a 50-50 chance of occurring.

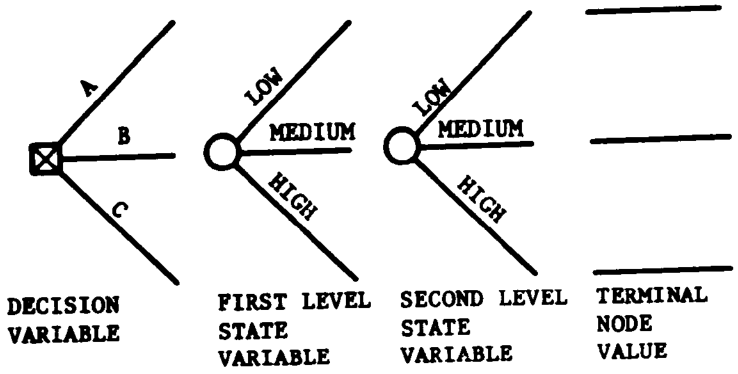


FIGURE 3-3 GENERAL FORM OF DECISION TREE

decision option for all decision variables in the model. This is accomplished by multiplying the certainty equivalents at the terminal node by the probabilities along that branch and summing over all branches of the decision option.

3.5 INFORMATIONAL PHASE

The purpose behind the informational phase of the analysis is placing a ceiling on the possible monetary value of seeking new information about the uncertainty. It is entirely possible that the result of this phase will be that there is no value for additional information.

This process has two steps: measuring the economic value of eliminating uncertainty in the significant variables and exploring the feasibility of gathering the information. By using the procedure developed in Chapter 2, the value of perfect information (clairvoyance) can be calculated. This value represents the upper bound on any expenditure for a program of seeking information on the variable.

The variables that show the greatest economic sensitivity[2] are the chief candidates for an information-gathering program. The information that results from such a program is often less than "perfect." The value of the new sample information is calculated to determine the economic feasibility of the program. [Matheson and Howard, 1977, p.23]. When the gathering program is performed, the probability assignments will be updated to reflect the new information. The basic structure of the model may be changed. Incorporating these changes into the structure of the model requires cycling through the entire methodology again to check new sensitivities. The informational phase again indicates the value to any further information. This process repeats until further information costs more than it is worth and the optimum selection from among alternatives will be completed with available information. [Matheson and Howard, 1977, p.24].

3.6 NEGOTIATION PHASE

Up to this point, all operations have taken place with each model independently (owner, contractor, and designer). This phase assembles the models together to produce the result of final project cost to the owner. The two

---

[2] These variables account for a significant portion of the variation in the project cost output of the models.

methods available to achieve this are the competitive bid negotiation and the Edgeworth Box Model negotiation.

The competitive bidding negotiation produces a single result and the contract clauses cannot be explicitly traded. However, by enumeration of the different contract clauses pertinent to the risk category explored, an optimum allocation can be reached.

The Edgeworth Box Model of negotiation uses, as a starting point, the output of the model from previous phases. The contract amount and risk share are negotiated between the two parties until an optimum allocation is reached. Implicit in the negotiation is the manipulation of contract clauses that apportion the risk, and the contract amount, until the optimal point is achieved within the negotiation space.

This phase yields the solution of the problem. A category of risk has been examined and its impact on cost has been studied. The analysis yields a minimization of the final project cost due to that risk by the allocation of its consequence in an optimum way among the parties.

3.7 SUMMARY

This chapter has explored the decision analysis methodology, and extended it to deal with multiple parties, and negotiation processes.

The model building phase defines the problem, and the risks involved. It structures the impacts into an interaction diagram that, when verified by the decision-maker, structures the problem. The deterministic phase quantifies the model and tests the sensitivity of the model output to the uncertainty in the variables. The probabilistic phase encodes a distribution on those significant variables and provides a measure of the decision-maker's risk preference. The informational phase provides a monetary ceiling on the gathering of new information to reduce the uncertainty. The negotiation phase optimally allocates the risk share and contract amount to yield the desired result--minimum project cost to the owner.

The adequacy of the decision analysis methodology along with the suggested extensions has been proven. The ability of the analysis to be structured, quantified, and manipulated was illustrated. The next chapter will elaborate this further in an example application.

4. APPLICATION OF THE MODEL

4.1 INTRODUCTION

The validity of the conceptual model developed above will be tested by its quantitative application to a sample project containing one or more categories of risk. The sample project was chosen to minimize the number of categories of risk. This enables the research team to develop a clear test of the conceptual model and to promote better understanding of its quantitative application and the ramifications of the particular risks studied. The general methodology has the capability to handle several categories of risks at any one time culminating in the same result, i.e. total cost.

The criteria for the choice of a sample risk category were:

- There should be a displayed interest in the problem by the parties (contractor and owner);

- The complexity of the problem should be such that it could be tackled within an amount of time not burdensome to the contractor and owner;

- There should be an immediate interest within the industry at seeing the problem quantified and yielding a feasible solution, or some insight as to a range of feasible solutions;

- The dollar amount of the risk should be a significant part of the total project cost.

The topics that met these criteria were: "damage to adjacent buildings of the construction site" and the "coordinated insurance program of the project." The one chosen was the coordinated insurance program analysis. Every major U.S. subway system built recently has had some form of an owner coordinated or "wrap-up" insurance program.

4.2 BACKGROUND ON WRAP-UP INSURANCE

A recent D.O.T. report, entitled Better Contracting for Underground Construction [National Research Council, 1974, pp. 35-39], discussed the issue of wrap-up insurance. The conclusion it reached was that even if the insurance program were properly designed and administered, the owners' costs would be increased for a project compared to the insurance costs that contractors would price into their bids. Another, more recent D.O.T. report, Insurance for Urban Transportation Construction [Barrett, 1977], reaches the opposite conclusion. The author presents a convincing case for the use of wrap-up insurance for urban transportation construction. He states further that there are definite cost savings associated with such an insurance program over a conventional insurance program.

Both studies provide a list of the advantages of an owner furnished, coordinated insurance program. Among the advantages cited are:

- single point responsibility for the processing and payment of claims;
- prompt settlement of claims;
- minimization of disputes between different insurance carriers;
- promotion of a coordinated safety program;
- a uniform and usually high level of insurance expertise--often a separate consultant;
- adequate coverage in all types of insurance markets;
- coverage for some potential bidders, including minority business enterprises, who might have difficulty in placing coverage conventionally;
- an effective and controlled preconstruction survey;
- dividends, as a result of a good loss experience, which rebound to the owners, rather than to the individual contractors; and
- reduced cost due to massive purchasing power.

Both studies also cite some of the disadvantages of wrap-up insurance:

- the lack of incentive for the contractor to enforce a safety program and to minimize losses;
- "double-counting" of insurance premiums (the contractors and/or subcontractors place insurance costs in their bids anyway);
- delay in prompt payment of claims;
- risk cancellation of the program by the carrier, mitigating the effect of lower bid prices by those contractors with a good experience modifiers (resulting in lower insurance costs);
- excessive coverage; and
- the administrative complexity in setting up such a program.

One can readily perceive a disagreement over the merits of wrap-up insurance programs. In the course of this study, one person referred to the insurance program with an eye to the above arguments "It's a lot of smoke!" Another commented when asked about the wrap-up insurance program, "It's a flaky philosophy at best!" Those remarks provide an excellent introduction to the analysis to follow.

The analysis that follows, in no way attempts to review or "second-guess" the decision to use the coordinated or wrap-up insurance program in Baltimore. Our aim is to formulate a test of the methodology described in detail previously. An after-the-fact analysis would violate a basic tenet of decision analysis, the inadequacy of a post-decision analysis. The project characteristics are only similar to the Baltimore system environment and in fact are general enough to reflect many downtown urban environments. The quantification of the model also mirrors and stresses this fact.

4.3 DETERMINISTIC MODEL

4.3.1 Introduction

It has been found to be extremely important at the onset of the interviewing process to have a specific set of project characteristics, contract type, and a clear understanding among the participants of all pertinent regulations. For this problem, we utilized a subway system in a downtown urban environment with a length of nine miles. The system is split, about evenly, between subway and aerial lines. The tunnel sections are driven in a compressed air environment. Each contract amount is assumed to be forty million dollars with the total construction cost for the system reaching $580 million, thereby resulting in the presence of fourteen and one-half contracts of a similar amount.

As the interviewing process proceeded, it became apparent that the contractor model and the owner model would each have to be divided, for convenience, into three submodels. The three submodels would represent complete descriptions of those variables important for workers' compensation, builders' risk, and comprehensive general liability insurance coverage respectively. The complete models involve a simple addition of the submodel plus any exogenous variables of the total process.

4.3.2 Contractor Model

The development of each contractor submodel was accomplished through an informal interviewing process with the decision-maker. To gain an understanding of the important variables and input into the process for each submodel, the interview was of a three-hour duration. An interaction diagram was constructed for each submodel, requiring an additional five hours each. Verification of these diagrams was coupled with the assessing of the deterministic ranges for all state variables; this required another four hours. Subsequently, the sensitivity analysis was performed requiring approximately eighteen hours.

4.3.2.1 Workers' Compensation Submodel. The workers' compensation submodel is portrayed in Figure 4-1. (The symbol key is portrayed in Figure 4-2). The significant inputs to the submodel are the project characteristics and the labor payroll dollars for the project. The wrap-up decision is a state variable to the contractor, since he has no control over its outcome. One can see that the significant state variables (uncertain values) are the insurance premiums, the contractor's markup, and the owner enforcement program which affects the dollar amoung spent by the contractor on his safety program. The variable brokers' fee is a nominal or a flat percentage commission of the premiums. It is important to note that in a wrap-up case the contractor's only expenditure will be for the safety program, while a conventional program will incorporate all expenditures. In any workers' compensation insurance program, the governing regulations, whether they be federal and/or state, have a major impact through the prescribed benefit levels. However, for any given project these benefits are set by local legislative action and are well known to the concerned parties. This impact is realized in the insurance premium quotations by the insurance carrier.

The next step of the process involved eliciting from the contractor three values for each state variable (two extremes and a nominal value. See Appendix B for a list). A sensitivity analysis was performed on these values to determine the relative sensitivity, in percentage, of the model output (total coverage cost) to these uncertainties in the state variables. The structural equations used to perform this analysis are presented in Table 4-1. The results of the analysis are summarized in Table 4-2. The criterion for determination of appropriate sensitivity is to select variables whose range results in a variation of approximately twenty percent of total coverage cost for the particular submodel for each extreme, high and low, on the deterministic range. The important variables yielded by this analysis are the contractor safety program costs and the insurance premiums. The reduced model is shown in Figure 4-3. This criterion was used for each submodel of the contractor model. It is significant to note that this analysis shows that, while the contractor believes his incentive to carry an expensive safety program is removed with wrap-up insurance, he does not alter his safety program an appreciable amount. In either case, even given variations

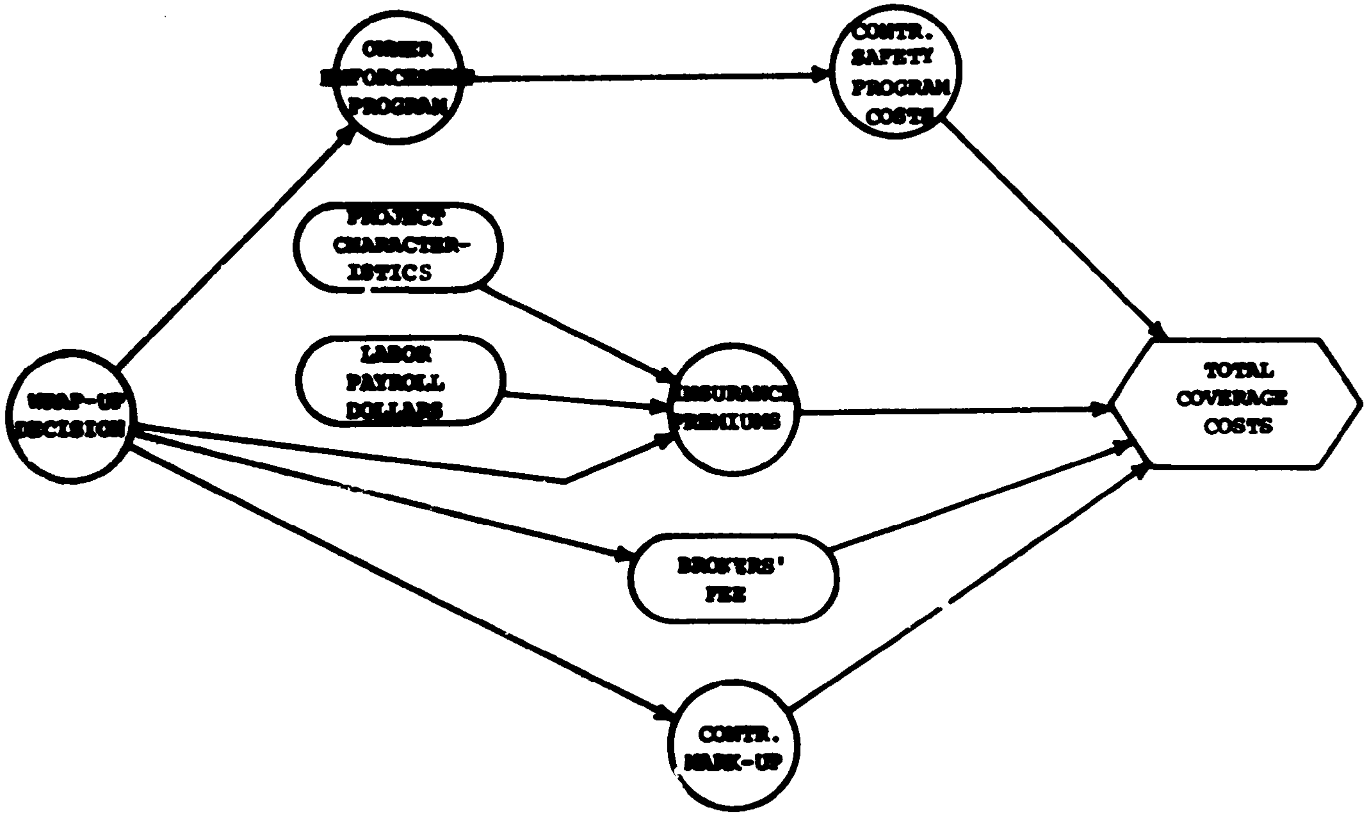


FIGURE 4-1 CONTRACTOR'S WORKERS' COMPENSATION DETERMINISTIC SUBMODEL

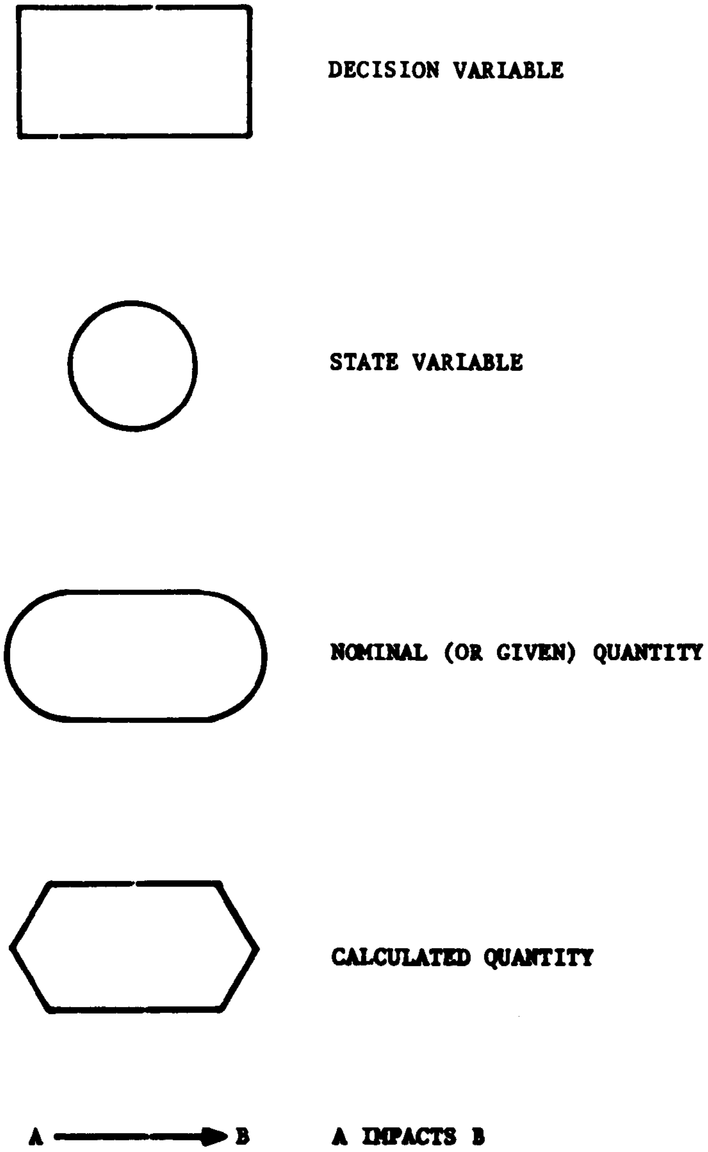


FIGURE 4-2 SYMBOL KEY FOR INTERACTION DIAGRAMS

TABLE 4-1 CONTRACTOR'S WORKERS' COMPENSATION STRUCTURAL EQUATIONS

VARIABLES

T.C.C. = TOTAL COVERAGE COSTS

C.S.P.C. = CONTRACTOR SAFETY PROGRAM COSTS

C.M.U. = CONTRACTOR'S MARK-UP

B.F. = BROKERS' FEE

I.P. = INSURANCE PREMIUMS

O.E. = OWNER ENFORCEMENT

EQUATIONS

WRAP-UP $T.C.C.=C.S.P.C.\,|\,O.E.$

CONVENTIONAL $T.C.C.=C.S.P.C.\,|\,O.E.+(1+C.M.U.)(1+B.F)(I.P.)$

TABLE 4-2 CONTRACTOR'S WORKERS' COMPENSATION VARIABLE SENSITIVITIES

W.U. = WRAP-UP

CONV. = CONVENTIONAL

VARIABLE	SENSITIVITY
CONV., C.S.P.C.	X
CONV., I.P.	X
CONV., C.M.U.	
W.U., C.S.P.C.	
W.U., O.E.	
CONV., O.E.	

KEY: X - SENSITIVE

BLANK - NOT SENSITIVE

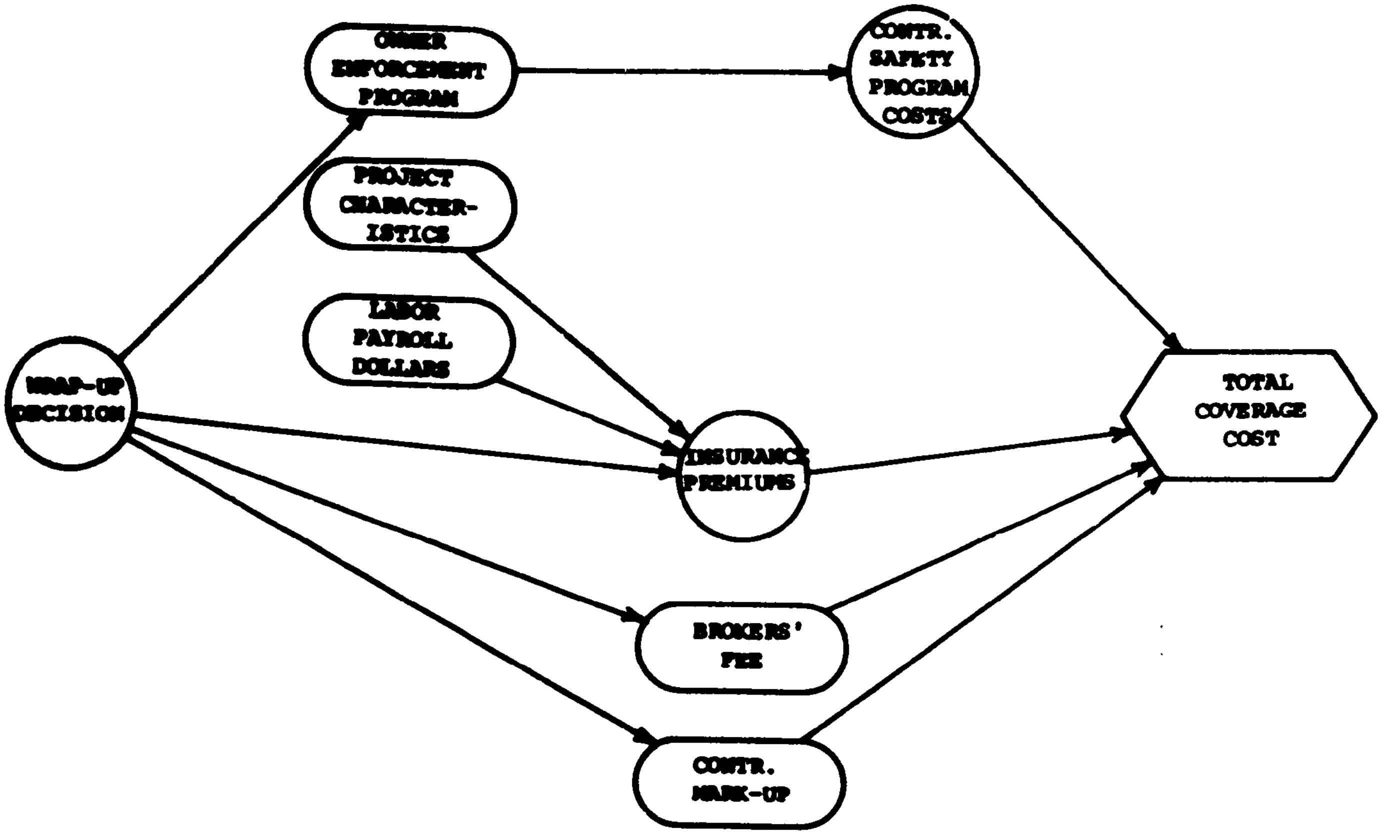


FIGURE 4-3 CONTRACTOR'S WORKERS' COMPENSATION STOCHASTIC SUBMODEL

in the owner enforcement of such a safety program, the contractor maintains the same level of expenditure. This may be somewhat mitigated by the fact that the particular contractor interviewed had considerable pride in the extent of his safety program, which has resulted in a very low loss experience in recent years.

4.3.2.2 Comprehensive General Liability Submodel. The next submodel under consideration is the comprehensive general liability coverage illustrated on Figure 4-4. This submodel incorporates another decision, "amount deductible," that is a state variable to the contractor. The significant state variables verified by the contractor include: one, the amount of owner required coverage resulting in a contractor evaluation of his exposure; two, the contractor's exposure to deductible based upon the deductible amount; three, the combination of one and two influences the contractor loss-control program; four, the number of losses, the number of claims, and average amount of loss are dependent upon the level of contractor loss-control program; five, the cost of the contractor loss-control program affected by its level; six, the insurance premiums; and seven, uninsurable losses and absorbed losses. The model output is, again, total coverage costs.

Using this model, a deterministic sensitivity analysis was performed to yield the most significant variables in terms of their variation of the model's output. (See Appendix B for a list of values.) A summary of the results is shown in Table 4-3, along with the structural equations of the particular submodel in Table 4-4.

As part of the deterministic sensitivity analysis, the amount of deductible was varied through its perceived, possible range. The result illustrated that the coverage cost was significantly affected by this variation. Consequently, at this juncture, it was decided to maintain this decision/state variable as part of every submodel to increase the amount and significance of the output and power of the model.

As shown in Table 4-3, the other significant variables are the insurance premiums, the number of claims, the number of losses, and the average amount of losses. It was observed that the last three variables were a vehicle for the calculation of the amount of losses absorbed by the contractor. Thus, this variable was incorporated into the final valude model of Figure 4-5, which also reflects the results of the sensitivity analysis.

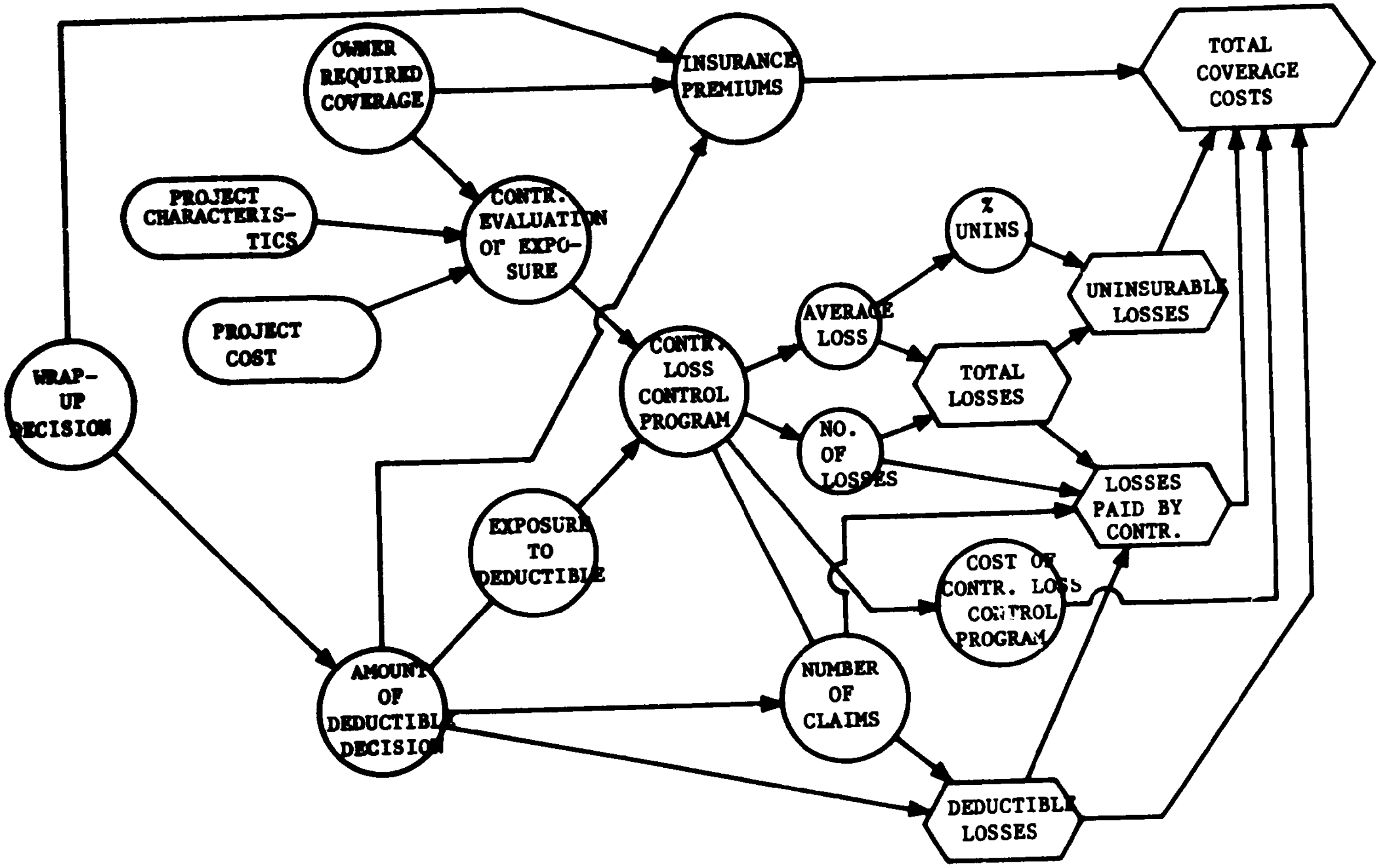


FIGURE 4-4 CONTRACTOR'S COMPREHENSIVE GENERAL LIABILITY DETERMINISTIC SUBMODEL

TABLE 4-3 CONTRACTOR'S COMPREHENSIVE GENERAL LIABILITY VARIABLE SENSITIVITIES

W.U. = WRAP-UP

CONV. = CONVENTIONAL

VARIABLE	SENSITIVITY
W.U., NO. OF CLAIMS	X
W.U., AVE. AMOUNT OF LOSS	X
W.U., TOTAL NO. OF LOSSES	X
CONV., INSURANCE PREMIUMS	X
W.U., OWNER REQUIRED COVERAGE	
W.U., CONTRACTOR LOSS CONTROL PROGRAM	
W.U., PERCENT UNINSURABLE	
CONV., OWNER REQUIRED COVERAGE	
CONV., EXPOSURE TO DEDUCTIBLE	
CONV., CONTRACTOR LOSS CONTROL PROGRAM	
CONV., NO. OF CLAIMS	
CONV., AVE. AMOUNT OF LOSS	
CONV., NO. OF LOSSES	

KEY: X - SENSITIVE

BLANK - NOT SENSITIVE

TABLE 4-4 CONTRACTOR'S COMPREHENSIVE GENERAL LIABILITY STRUCTURAL EQUATIONS

VARIABLES

T.C.C. = TOTAL COVERAGE COSTS

C.C.L.C.P. = COST OF CONTRACTOR LOSS CONTROL PROGRAM

C.L.C.P. = EXTENT OF CONTRACTOR LOSS CONTROL PROGRAM

U.L. = UNINSURABLE LOSSES

D.L. = DEDUCTIBLE LOSSES

L.P.C. = LOSSES PAID BY CONTRACTOR

I.P. = INSURANCE PREMIUMS (ANNUAL)

B.F. = BROKERS' FEE

2 = PROJECT DURATION IN YEARS

EQUATIONS

WRAP-UP $\text{T.C.C.} = \text{C.C.L.C.P.} + \text{U.L.} + \text{D.L.} + \text{L.P.C.}$

CONVENTIONAL $\text{T.C.C.} = 2(\text{I.P.})(1+\text{B.F.}) + \text{L.P.C.} + \text{U.L.} + \text{D.L.} + \text{C.C.L.C.P.}$

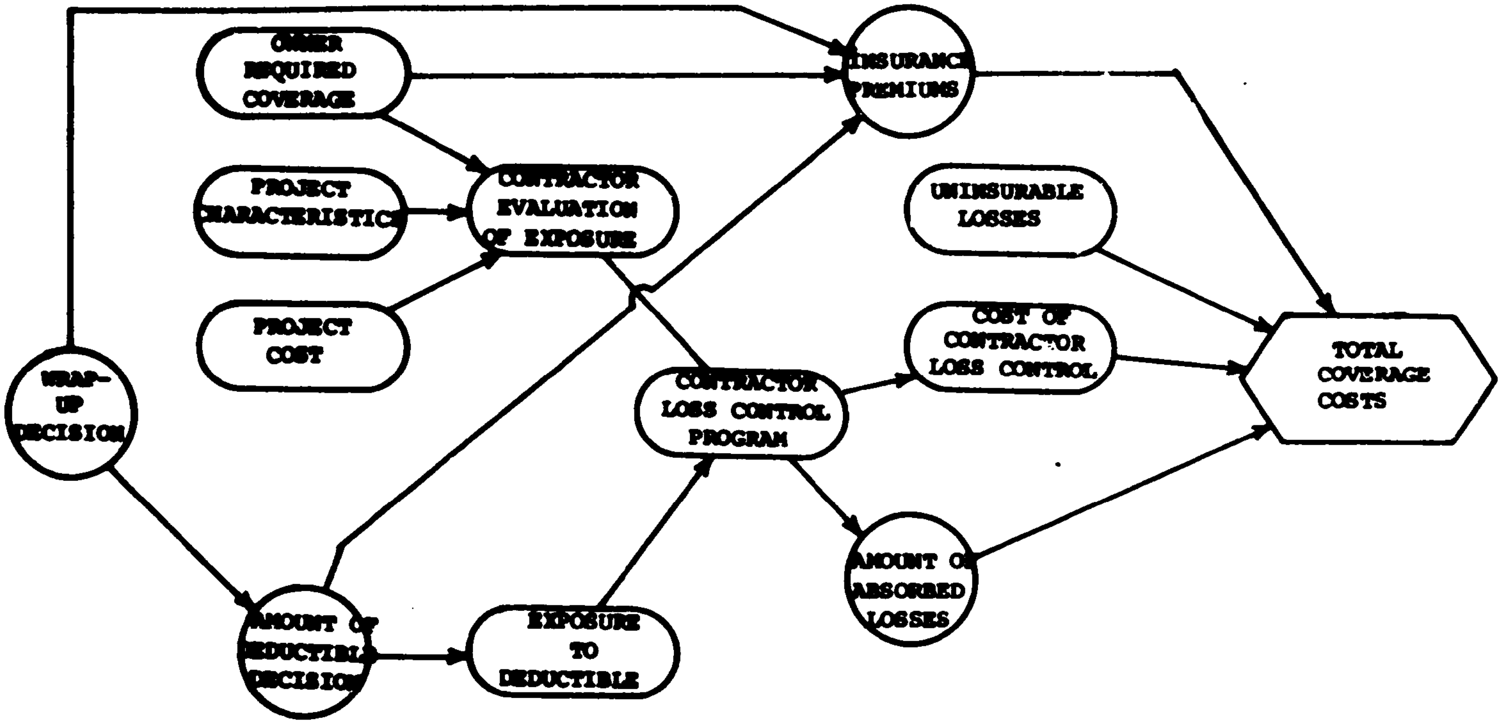


FIGURE 4-5 CONTRACTOR'S COMPREHENSIVE GENERAL LIABILITY STOCHASTIC SUBMODEL

4.3.2.3 Builders' Risk Submodel. The final submodel of the complete contractor model reveals those state variables important to his evaluation of the builders' risk coverage and its appurtenant costs (see Figure 4-6). One immediately notices the complexity of this submodel. To alleviate this problem, the model will be described, tracing the manner in which the state variables impinge on the individual cost components of the model output--total cost.

Total premiums and fees arise from the amount of deductible and the owner required coverage, which affect the premium rate. The premium rate, brokers' fee, and project cost combine to result in the premium cost. The amount of losses absorbed by the contractor are calculated based on total losses, total claims, and the percent of uninsurable claims. The variable "amount of losses" is conditional upon the contractor loss-control program which itself is dependent upon owner required coverage, the amount of deductible, and the given project characteristics and cost. The amount of claims is influenced by the loss-control program and the amount of deductible. The percent of claims that are uninsurable is contingent upon the owner's wrap-up insurance decision.

Another cost variable is the processing delay financing cost which is contingent upon three variables: the opportunity cost of funds; the total amount of claims; and the claim processing delay which is, in turn, dependent upon the wrap-up decision. The cost is the amount of money the contractor uses in financing the delay in payment of a claim to him. For example, imagine that a claim is put in by the contractor resulting from a tunnel collapse due to flood. In the meantime, the contractor proceeds with the work, financing the extra costs with his own money until his claim is processed.

The cost of the contractor loss-control program is influenced, solely, by the extent of the contractor's loss-control program. The final part of the total cost is the delay cost or the cost to the contractor of remaining idle due to a builder's risk loss occurrence, for which he is not compensated. This cost is influenced by the variables project delay, claims as a percentage of losses, and his fixed overhead rate. The first two are conditional upon the total number of claims and losses, which are dependent on the extent of the contractor loss-control program.

Upon verification of this diagram as the model of his thought process, the

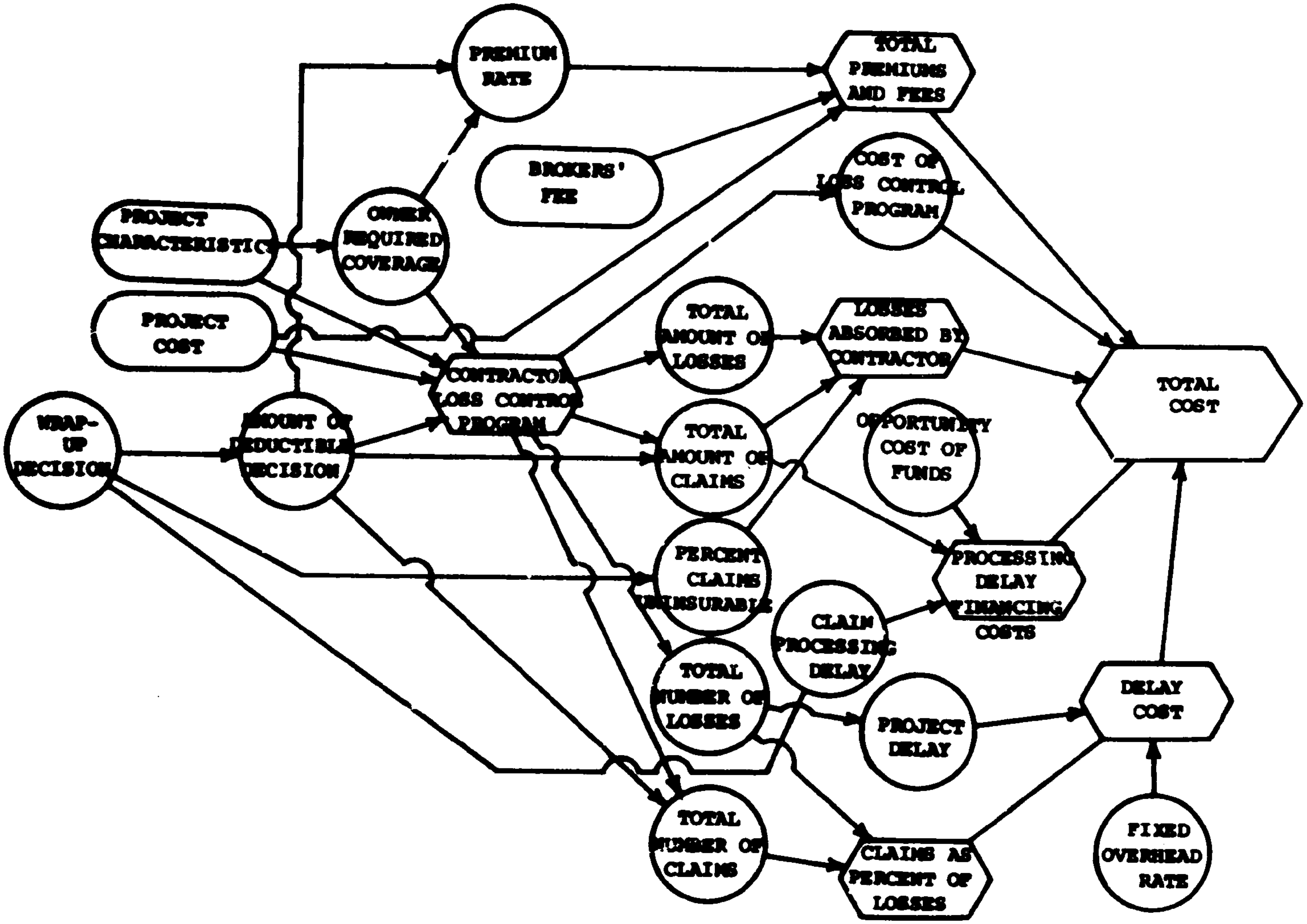


FIGURE 4-6 CONTRACTOR'S BUILDERS' RISK DETERMINISTIC SUBMODEL

contractor provided the deterministic ranges to initiate the sensitivity analysis of this submodel. (See Appendix B for a list of ranges.) The results of this analysis are shown in Table 4-5. The structural equations of this submodel are in Table 4-6. The significant variables produced by the analysis are as expected: the premium rate, the total amount of losses, and the total amount of claims. The reduced model is shown in Figure 4-7.

At this point, it would be appropriate to review the previous two submodels. During the course of the interview process, the contractor perceived an appreciable delay in processing of claims in a wrap-up insurance program comparative to their experience with their own carrier. Supposedly, a significant cost could be correspondingly attached to such a delay. However, given the dollar amounts the contractor could place on this variable, the result showed it to be rather small. Another problem the contractor perceived with the wrap-up program would be that a considerable number of claims would be declared uninsurable relative to the conventional experience. The contractor felt that the insurance carrier would be more responsive to the owner (their client with "wrap-up" coverage), rather than himself, and thus the above scenario would result. The numbers did not bear this out.

4.3.3 Owner Model

In a similar fashion to the contractor model, a corresponding owner's model was constructed in three parts: workers' compensation, comprehensive general liability, and builders' risk. The interview process to gain insight into the important variables and their relationships required four hours. The construction of these relationships into the interaction diagram utilized approximately twelve hours, total. The verification of the model with the owner and the determination of the variable ranges consumed five hours.

4.3.3.1 Structural Models. The workers' compensation submodel is represented in Figure 4-8. The critical inputs to the consideration of this model are the federal and/or state regulations, the statutory coverages (the benefit levels), and the project characteristics. There are three items of cost to the owner in this type of coverage: premiums, safety program costs, and dividends that redound to the owner through favorable loss experience. Referring to Figure 4-8, one can discern the significant state variables that produce these costs. The premiums are calculated from the labor dollars, the premium rate, and the effective experience modifier for the project. The final variable is conditional upon the cost of the owner safety program and the average modifier of

TABLE 4-5 CONTRACTOR'S BUILDERS' RISK
VARIABLE SENSITIVITIES

W.U. = WRAP-UP

CONV. = CONVENTIONAL

VARIABLE	SENSITIVITY
CONV., PREMIUM RATE	X
W.U. AND CONV., TOTAL AMOUNT OF LOSSES	X
W.U. AND CONV., TOTAL AMOUNT OF CLAIMS	X
CONV., OWNER REQUIRED COVERAGE	
W.U. AND CONV., PERCENT UNINSURABLE	
W.U. AND CONV., COST OF LOSS CONTROL PROGRAM	
W.U. AND CONV., CLAIM PROCESSING DELAY	
W.U. AND CONV., PROJECT DELAY	
W.U. AND CONV., TOTAL NO. OF LOSSES	
W.U. AND CONV., TOTAL NO. OF CLAIMS	

KEY: X - SENSITIVE

BLANK - NOT SENSITIVE

TABLE 4-6 CONTRACTOR'S BUILDERS' RISK STRUCTURAL EQUATIONS

VARIABLES

T.C.C. = TOTAL COVERAGE COST

COLCP = COST OF LOSS CONTROL PROGRAM

TAOL = TOTAL AMOUNT OF LOSSES

TAOC = TOTAL AMOUNT OF CLAIMS

AOD = AMOUNT OF DEDUCTIBLE

CPD = CLAIM PROCESSING DELAY

OCOF = OPPORTUNITY COST OF FUNDS

PD = PROJECT DELAY

CPCL = CLAIMS AS PERCENT OF LOSSES

FOHR = FIXED OVERHEAD RATE

P = PERCENT OF CLAIMS UNINSURABLE

PR = PREMIUM RATE

PC = PROJECT COST

BF = BROKERS' FEES

2 = PROJECT DURATION IN YEARS

EQUATIONS

WRAP-UP

$$\text{T.C.C.} = [\text{TAOL}-(1-\text{P})(\text{TAOC})]+[(1+\text{OCOF})^{\text{CPD}}-1](1-\text{P})(\text{TAOC})+(\text{PD})(1-\text{CPCL})(\text{FOHR})+\text{COLCP}$$

CONVENTIONAL

$$\text{T.C.C.} = [\text{TAOL}-(1-\text{P})(\text{TAOC})]+\text{COLCP}+[(1+\text{OCOF})^{\text{CPD}}-1](\text{TAOC})(1-\text{P})+2(\text{PR})(\text{PC})(1+\text{BF})+\text{PD}(1-\text{CPCL})(\text{FOHR})$$

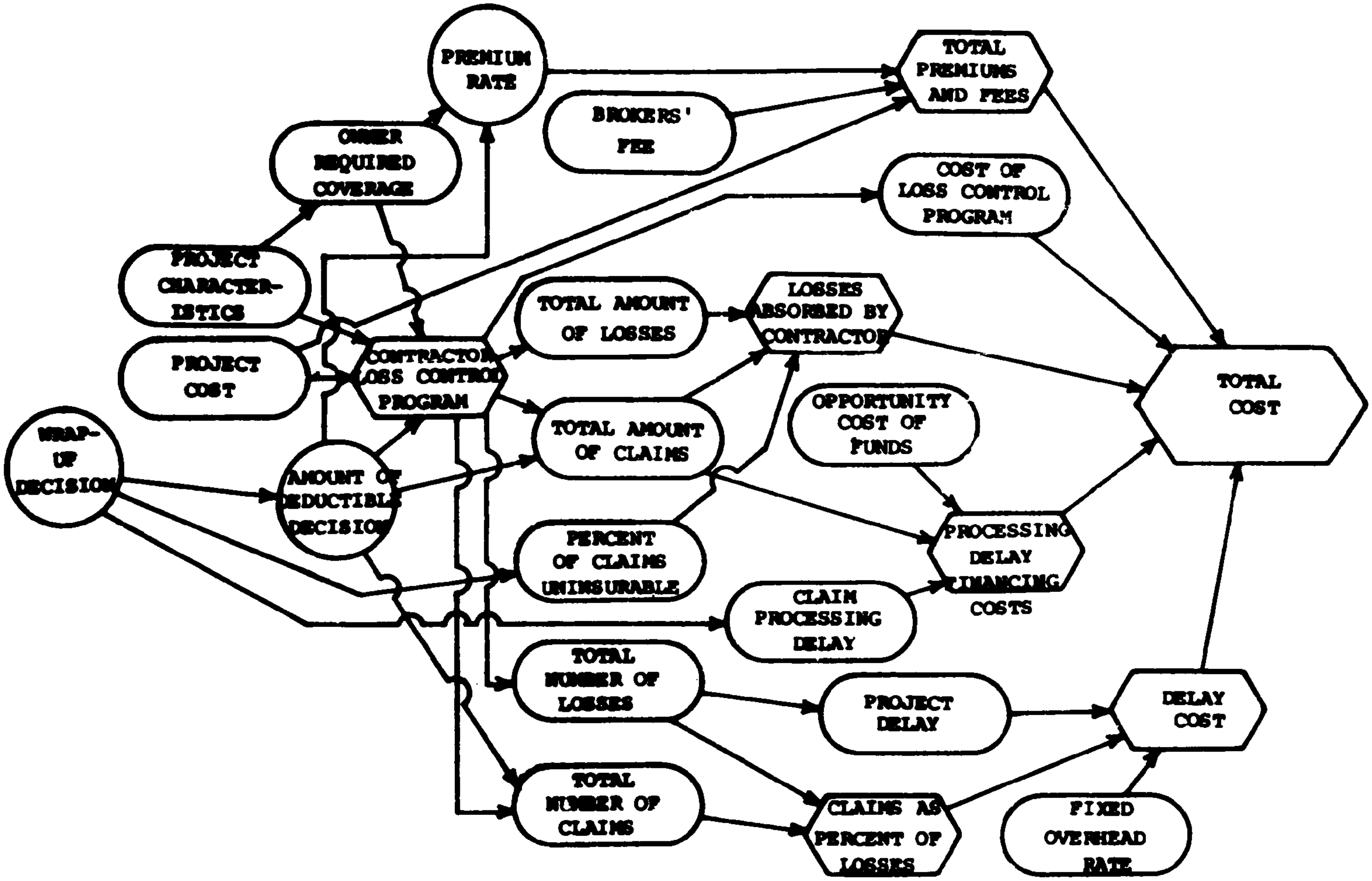


FIGURE 4-7 CONTRACTOR'S BUILDERS' RISK STOCHASTIC SUBMODEL

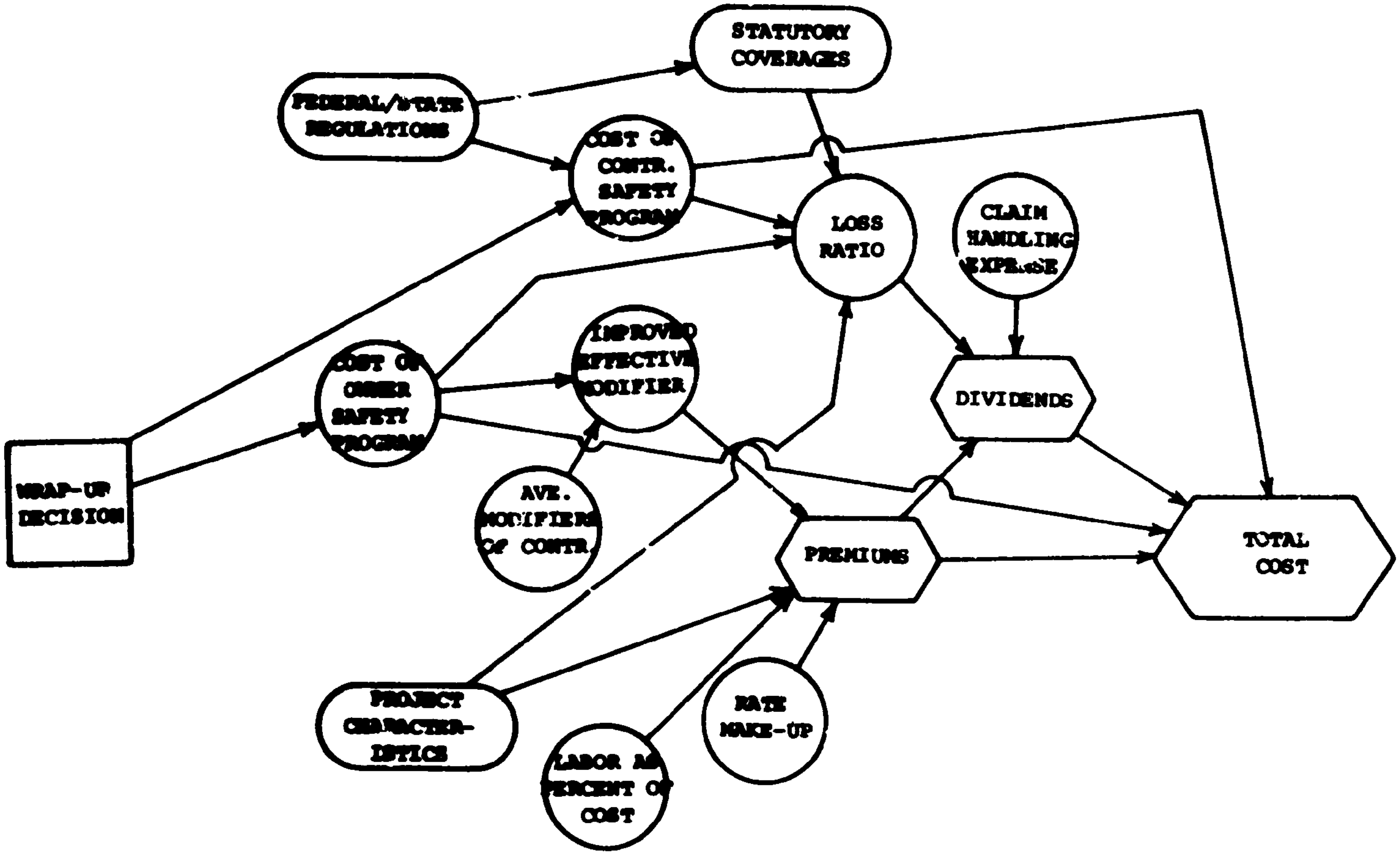


FIGURE 4-8 OWNER'S WORKERS' COMPENSATION DETERMINISTIC SUBMODEL

the contractors expected to bid out the project. It is important to note that the owner perceives that the extent of his safety program can affect contractor behavior and performance enough to effect a reduced experience modifier. The safety program costs are the next item of expenditure. The owner safety program cost is dependent upon the decision about the use of a coordinated insurance program. The contractor safety program depends on that decision, also, but it is impacted heavily by the federal and/or state regulations in force on the job. The dividends are calculated based upon the loss ratio (the percent of claims against the premiums), and the claim handling expense. The loss ratio is affected by the costs of the two safety programs in force. It is interesting to note that, in this type of retrospective rating flow, the owner essentially pays all expected losses and is really purchasing the claims handling expertise of the insurance carrier.

The comprehensive general liability submodel is explained by Figure 4-9. The owner feels the cost impact of this coverage from six sources. The first two items are his means of controlling the amount of his losses and exposure. The state variables, loss-control program cost and the cost of preconstruction survey represent those means. The former is influenced by his wrap-up decision, while the latter is dictated by the size of the project itself. The premium cost is the major cost and is influenced by many variables. The cost is directly conditional upon the premium rates, primary and umbrella. Those rates are contingent upon market conditions, the owner deductible decision, and the levels of coverage. The other major costs arise from his losses. The amount of losses that the owner absorbs is dependent upon the extent of his loss-control program and the deductibles he sets for himself. The claim handling costs that he faces are calculated from the amount of claims, and the claim handling expense is charged by the primary level insurance carrier. The amount of claims are influenced by his spendings for the preconstruction survey and the loss-control program. The amount of dividends rounds out the list of items that lead to the total cost. In this insurance situation as well as in the builders' risk coverage to follow, the owner is facing a two-level decision. His primary decision is whether to go with wrap-up or not, and the secondary decision deals with the deductibles he will impose upon himself and the contractor. It is also interesting to find that the loss-control program and the preconstruction survey were separable, since they are part of the same process of controlling the loss experience on the job.

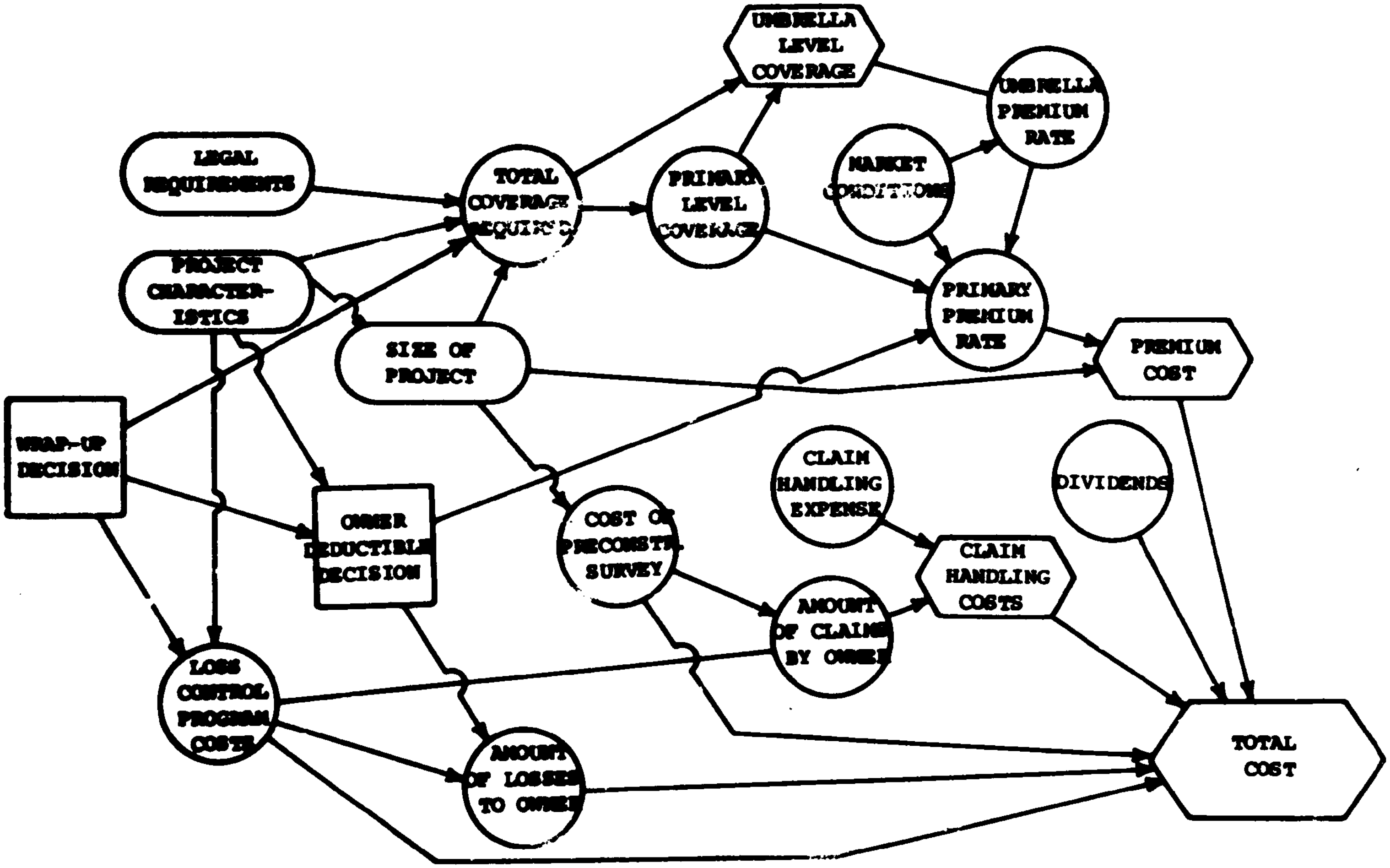


FIGURE 4-9 OWNER'S COMPREHENSIVE GENERAL LIABILITY DETERMINISTIC SUBMODEL

The final submodel within the owner's model is the builder's risk submodel, which is illustrated in Figure 4-10. As mentioned above, the owner has a two-level decision process to undergo. There are four major components of cost in the builder's risk coverage. The premium costs are calculated in a similar fashion to the general liability submodel. They are influenced by the premium rates, primary and umbrella, which, in turn, are influenced by the level of coverage, market conditions, and the amount of deductible. The next item of cost is the amount of losses absorbed by the owner which is directly conditional upon the deductible. Following is the loss-control program cost which is conditional upon the wrap-up decision. The final item of cost is the claim handling cost. This item is dependent upon the claim handling expense charged by the carrier and the amount of claims by the owner (dependent upon the loss-control program). Conspicuously absent from this submodel is any concern about delay costs or damages due to a claim in the builders' risk coverage, which the contractor felt could be considerable if such an occurrence happened. With this analysis technique, however, such disparate information can be accommodated in the separate models and used to advantage.

This completes the description of the owner's model featuring his impressions of the important inputs, decision variables, and state variables, resulting in the total cost of insurance coverage.

4.3.3.2 Deterministic Sensitivity Analysis. The next phase involves testing the relative importance of those variables above. Utilizing the deterministic ranges on the state variables (see Appendix B for list of the variables and ranges), a deterministic sensitivity analysis was performed. In contrast to the analyses undertaken in the contractor's submodels, this analysis will be performed by combining the owner's submodels into a complete model to illustrate the overall importance of each state variable. The structural equations used for this sensitivity test are indicated in Table 4-7. Addition of the corresponding equations from each submodel will produce the desired result. The results of this analysis are shown in Table 4-8.

4.3.3.3 Reduced Models. The sensitivity analysis produced a total of six significant variables, grouped according to the submodel in which they are situated. In the workers' compensation submodel, there is a loss ratio, labor payroll, rate make-up, and owner safety program. The builders' risk submodel

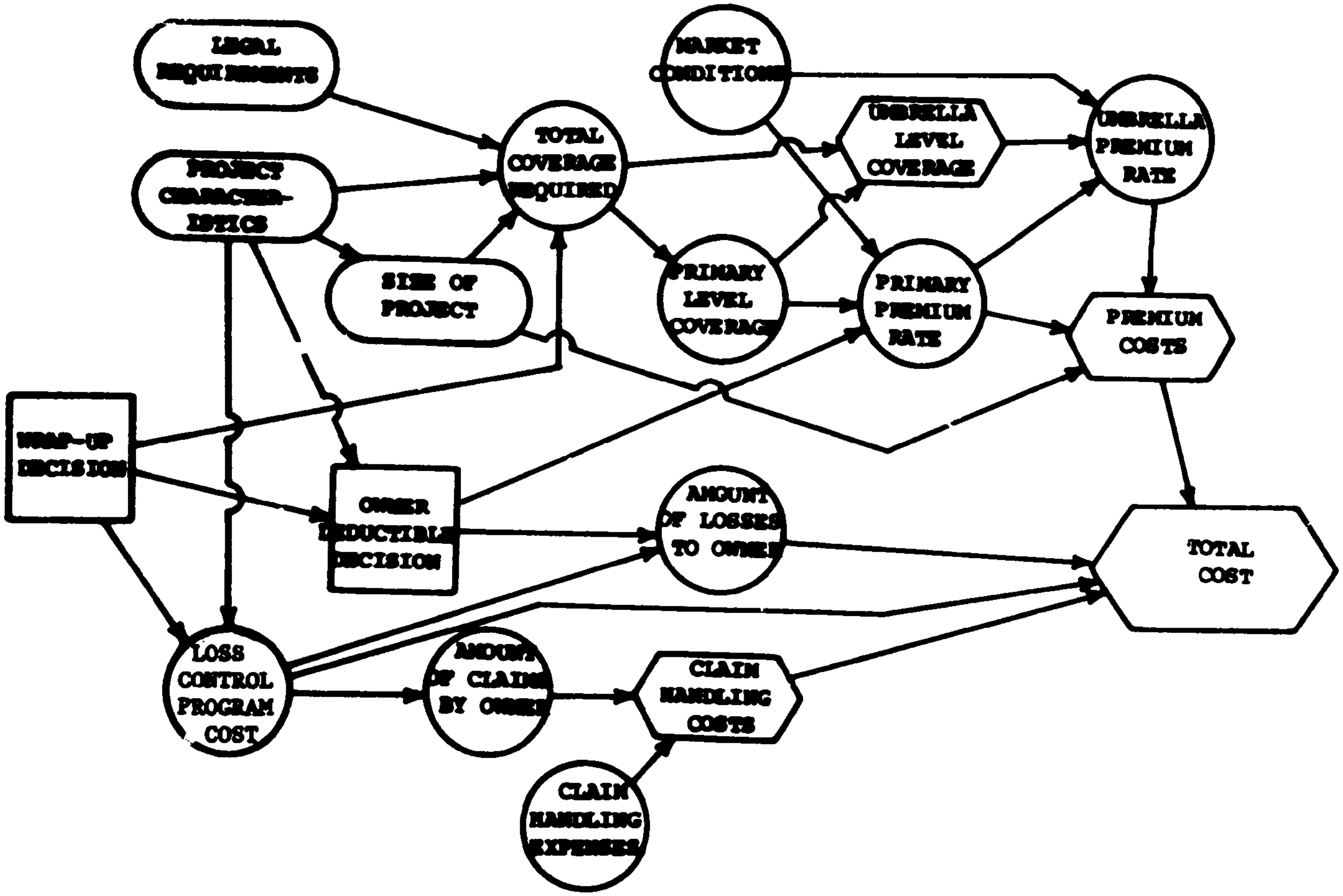


FIGURE 4-10 OWNER'S BUILDERS' RISK DETERMINISTIC SUBMODEL

TABLE 4-7 OWNER'S MODEL STRUCTURAL EQUATIONS

WORKERS' COMPENSATION SUBMODEL FOR OWNER

VARIABLES

T.C.C. = TOTAL COVERAGE COST

COSP = COST OF OWNER SAFETY PROGRAM

CCSP = COST OF CONTRACTOR SAFETY PROGRAM

LAPC = LABOR AS A PERCENT OF TOTAL PROJECT COST

PC = PROJECT COST

RMU = RATE MAKE-UP

PREM. = PREMIUM COST

LR = LOSS RATIO

CHE = CLAIM HANDLING EXPENSE

EQUATIONS

CONVENTIONAL T.C.C.=COSP

WRAP-UP T.C.C.=COSP+CCSP+LAPC(PC)(RMU)-PREM.(1-LR(1+CHE))

COMPREHENSIVE GENERAL LIABILITY SUBMODEL FOR OWNER

VARIABLES

T.C.C = TOTAL COVERAGE COST

LCPC = LOSS CONTROL PROGRAM COSTS

PPR = PRIMARY PREMIUM RATE

UPR = UMBRELLA PREMIUM RATE

PC = PROJECT COST

CPS = COST OF PRECONSTRUCTION SURVEY

ALTO = AMOUNT OF LOSSES TO OWNER

(continued on next page)

TABLE 4-7 OWNER'S MODEL STRUCTURAL EQUATIONS (continued)

ACBO = AMOUNT OF CLAIMS BY OWNER

CHE = CLAIM HANDLING EXPENSE

DIV = DIVIDENDS

2 = PROJECT DURATION IN YEARS

EQUATIONS

CONVENTIONAL T.C.C.=LCPC

WRAP-UP T.C.C.=LCPC+2(PPR+UPR)(PC)+CPS+ALTO+CHE(ACBO)-DIV

BUILDERS' RISK SUBMODEL FOR OWNER

VARIABLES

T.C.C. = TOTAL COVERAGE COST

LCPC = LOSS CONTROL PROGRAM COST

ACBO = AMOUNT OF CLAIMS BY OWNER

CHE = CLAIM HANDLING EXPENSE

ALTO = AMOUNT OF LOSSES TO OWNER

PPR = PRIMARY PREMIUM RATE

UPR = UMBRELLA PREMIUM RATE

2 = PROJECT DURATION IN YEARS

EQUATIONS

CONVENTIONAL T.C.C.=LCPC

WRAP-UP T.C.C.=LCPC+ACBO(CHE)+ALTO+2(PPR+UPR)(PC)

TABLE 4-8 OWNER'S MODEL VARIABLE SENSITIVITIES

WORKERS' COMPENSATION SUBMODEL FOR OWNER	
VARIABLE	SENSITIVITY
W.U., LOSS RATIO	X
W.U., RATE MAKE-UP	X
CONV., OWNER SAFETY PROGRAM	X
W.U., LABOR PAYROLL	X
W.U., COST OF OWNER SAFETY PROGRAM	
W.U., AVERAGE MODIFIER	
W.U., IMPROVED EFFECTIVE MODIFIER	
W.U., COST OF CONTRACTOR SAFETY PROGRAM	
W.U., CLAIM HANDLING EXPENSE	
COMPREHENSIVE GENERAL LIABILITY SUBMODEL FOR OWNER	
W.U., MARKET CONDITIONS	X
W.U., TOTAL COVERAGE REQUIRED	
W.U., PRIMARY LEVEL COVERAGE	
W.U., PRIMARY PREMIUM RATE	
W.U., UMBRELLA PREMIUM RATE	
W.U., LOSS CONTROL PROGRAM COST	
W.U., AMOUNT OF LOSSES ABSORBED	
W.U., DIVIDENDS	
W.U., COST OF PRECONSTRUCTION SURVEY	
CONV., LOSS CONTROL PROGRAM COSTS	

(continued on next page)

TABLE 4-8 OWNER'S MODEL VARIABLE SENSITIVITIES (continued)

BUILDERS' RISK SUBMODEL FOR OWNER	
VARIABLE	SENSITIVITY
W.U., MARKET CONDITIONS	X
CONV., LOSS CONTROL PROGRAM COSTS	X
W.U., TOTAL COVERAGE REQUIRED	
W.U., PRIMARY LEVEL COVERAGE	
W.U., PRIMARY PREMIUM RATE	
W.U., UMBRELLA PREMIUM RATE	
W.U., LOSS CONTROL PROGRAM COSTS	
W.U., AMOUNT OF LOSSES TO OWNER	
W.U., AMOUNT OF CLAIMS BY OWNER	
W.U., CLAIM HANDLING EXPENSE	

KEY: X - SENSITIVE

BLANK - NOT SENSITIVE

contains two: market conditions and the loss-control program costs. Finally, in the comprehensive general liability submodel there is market conditions. The variable "market conditions" therefore appears in two of the submodels.

It is interesting to note that the owner perceives a real cost of the contractor's safety program in the workers' compensation submodel; however, in the remaining submodels there are no associated loss-control program costs for the contractor. This illustrates the relative importance of using and forcing a safety program upon the contractor which will in the end produce reduced losses and corresponding substantial increase in the premium handbacks that redound to the owner. Curiously, in the builders' risk and comprehensive general liability submodels, the premium rates are not significant state variables. However, the state variables that influence these rates are the contributing factor to the variation of total cost. This confirms the opinion of the owner's representative who felt, for the given levels of exposure, that the most significant uncertainty they faced in going to the insurance market was the status or condition of the insurance market itself.

The output of the sensitivity analysis is illustrated in the reduced interaction diagrams of Figures 4-11, 4-12 and 4-13. Refer to Figures 4-8, 4-9 and 4-10 for a comparative study.

4.4 PROBABILISTIC ENCODING

The deterministic sensitivity analysis identifies the significant state variables that impact the owner's total cost. This directs one to seek further information about the nature of these state variables. Using the methods outlined previously, a cumulative probability distribution for each of the state variables is established by constructing a smooth curve through the points given in response to the questions posed to the particular expert. These distributions are then discretized into three levels of the individual variable.

4.4.1 Contractor Model

The encoding process for the variables within the contractor's submodels consumed approximately four hours. Recalling the variables to be encoded from the sensitivity analysis performed previously, they will be categorized according to those variables that are conditional upon other state variables and those that can be classified independent of other influences, i.e., their uncertainty arises from their own basic uncertainty only. The state variables

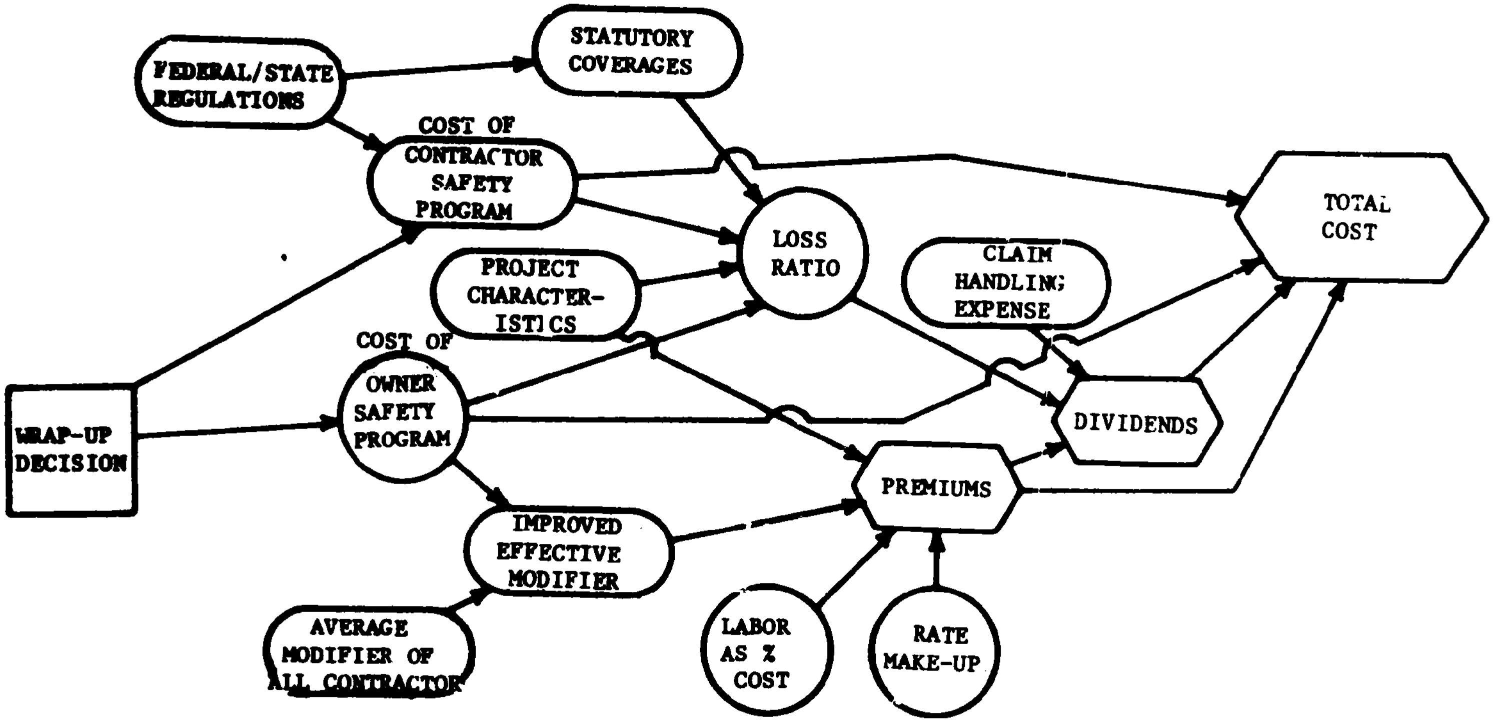


FIGURE 4-11 OWNER'S WORKERS' COMPENSATION STOCHASTIC SUBMODEL

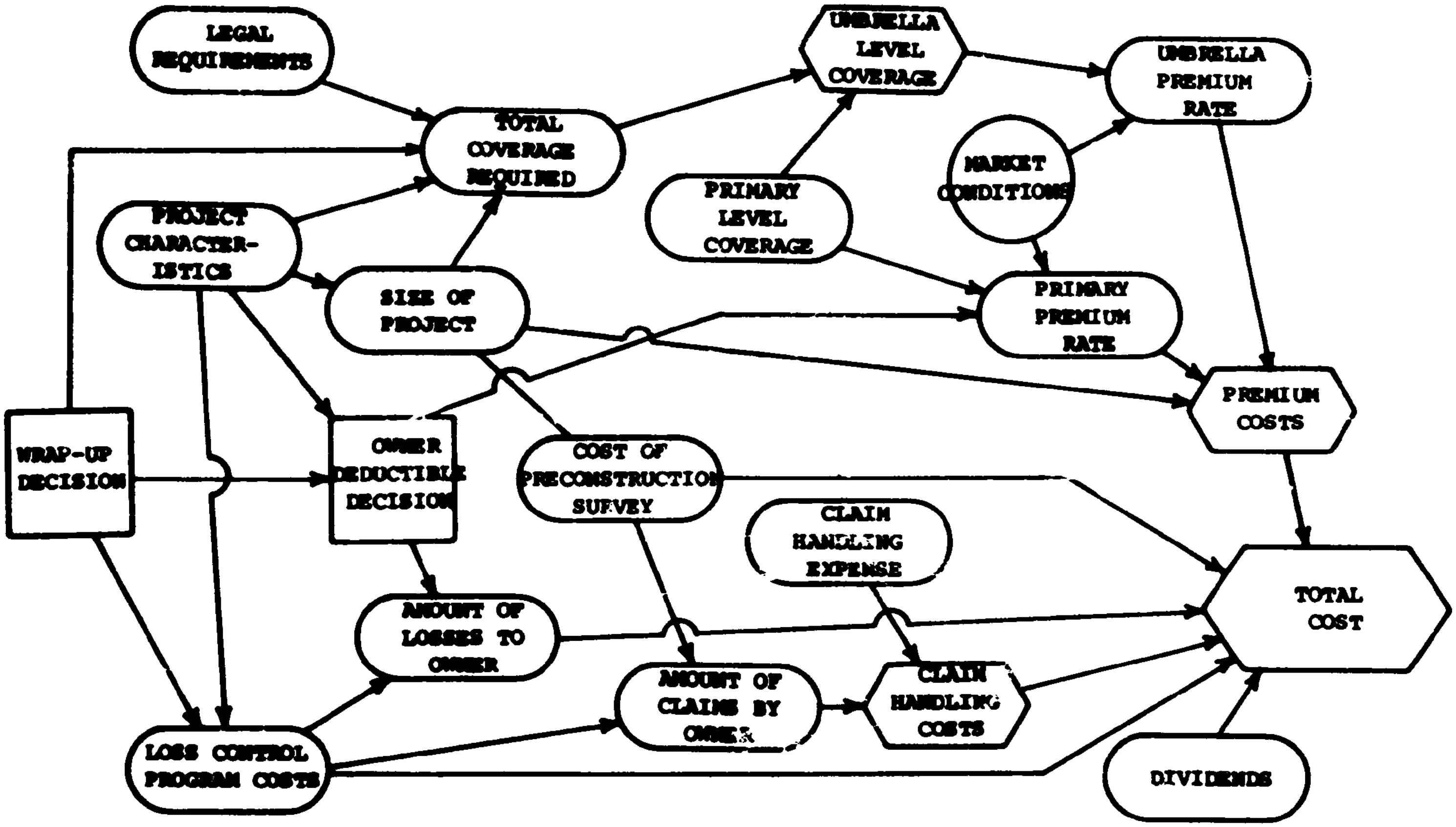


FIGURE 4-12 OWNER'S COMPREHENSIVE GENERAL LIABILITY STOCHASTIC SUBMODEL

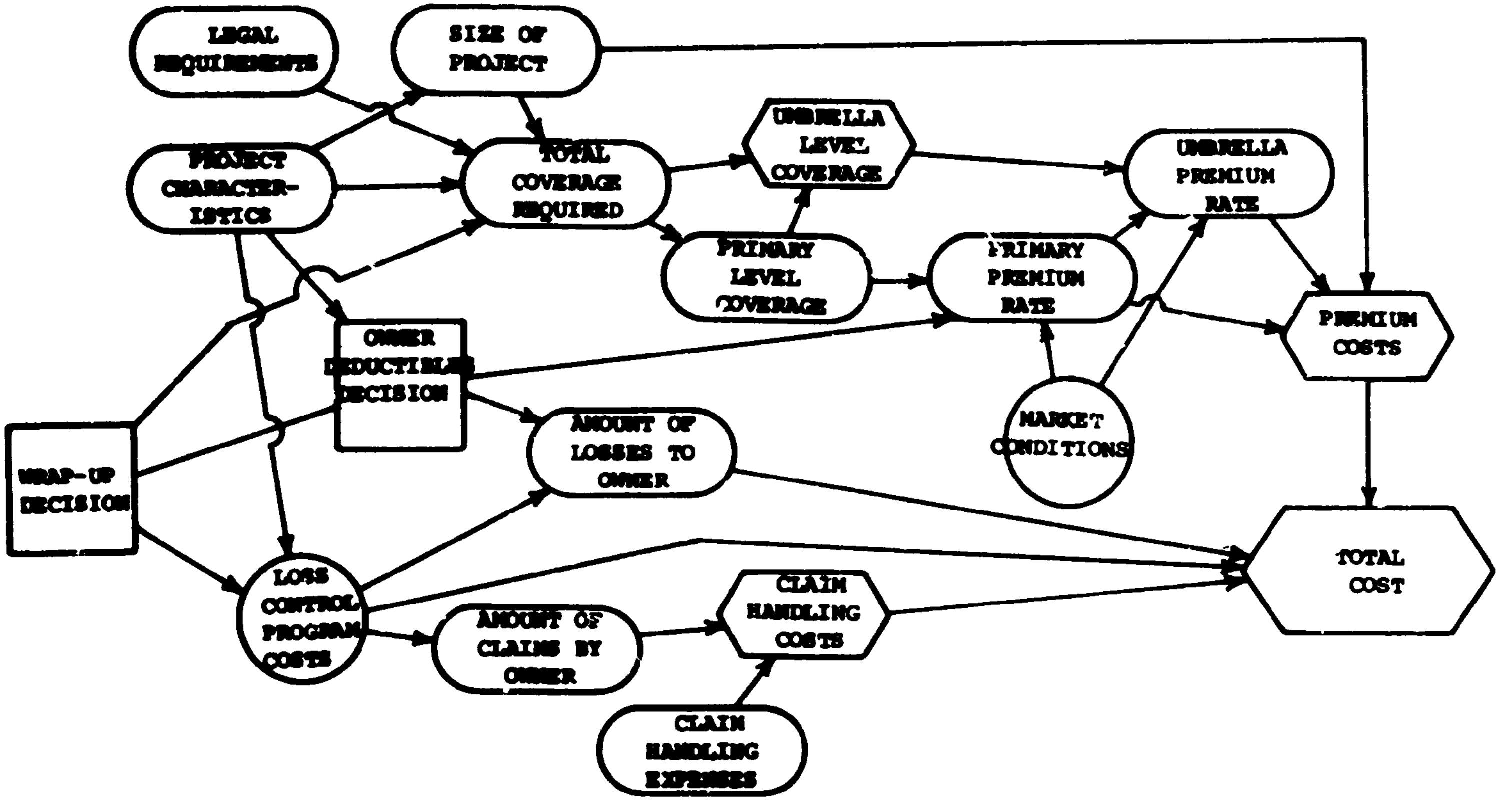


FIGURE 4-13 OWNER'S BUILDERS' RISK STOCHASTIC SUBMODEL

that are conditional upon others are:

WORKERS' COMPENSATION SUBMODEL

- contractor safety program costs conditioned upon a high level of owner enforcement program

COMPREHENSIVE GENERAL LIABILITY SUBMODEL

- amount of losses absorbed by the contractor conditional upon an amount of deductible and the level of a loss control program
- comprehensive general liability premiums given a level of deductible

BUILDERS' RISK SUBMODEL

- total amount of claims contingent upon a level of deductible and the level of loss control program
- total amount of losses conditional upon a level of loss control program
- builders' risk primary level premiums given a level of deductible.

The state variable classified as independent is:

WORKERS' COMPENSATION SUBMODEL

- workers compensation insurance premiums.

The cumulative graphs of these distributions can be found in Appendix B. Table 4-9 shows the results of the discretization of the above variables.

4.4.2 Owner Model

The encoding process for the state variables within the owner's submodels used approximately two hours. The variables will again be categorized into groups with one having those that are conditional upon others; and those that are independent. Referring to the sensitivity analysis previously, the state variables conditional upon others are:

WORKERS' COMPENSATION SUBMODEL

- loss ratio given owner safety program $\$3000^{K}$ and contractor safety program $\$1500^{K}$
- owner safety program given conventional insurance program

BUILDERS' RISK SUBMODEL

- loss control program costs given conventional insurance program.

TABLE 4-9 DISCRETIZATION OF SIGNIFICANT VARIABLES IN THE CONTRACTOR MODEL

(dollar amounts with ,000's omitted)

VARIABLE NAME	LOW	PROB.	MED.	PROB.	HIGH	PROB.
CONTRACTOR SAFETY PROGRAM COSTS	$262	0.32	$300	0.38	$355	0.30
WORKERS' COMP. INS. PREMIUMS	$1375	0.35	$1875	0.36	$2800	0.29
AMOUNT OF LOSSES TO CONTR.						
GIVEN 1^K DED, LOW LOSS CONTROL	$16	0.30	$28	0.46	$62	0.24
GIVEN 5^K DED, MED LOSS CONTROL	$25	0.42	$40	0.37	$67	0.21
GIVEN 10^K DED, MED LOSS CONTROL	$90	0.31	$110	0.42	$142	0.27
GIVEN 20^K DED, HIGH LOSS CONTROL	$150	0.35	$180	0.40	$220	0.25
GENERAL LIABILITY PREMIUMS						
GIVEN 5^K DED, 25^M TOTAL	$550	0.25	$800	0.36	$1280	0.39
GIVEN 10^K DED, 25^M TOTAL	$430	0.30	$600	0.32	$760	0.38
GIVEN 20^K DED, 25^M TOTAL	$225	0.39	$350	0.37	$505	0.24
TOTAL AMOUNT OF LOSSES	DISCRETIZED TO ONE VALUE WITH PROB. 1.0					
GIVEN LOW LOSS CONTROL	$1100					
GIVEN MED LOSS CONTROL	$1000					
GIVEN HIGH LOSS CONTROL	$1050					
TOTAL AMOUNT OF CLAIMS	DISCRETIZED TO ONE VALUE WITH PROB. 1.0					
GIVEN 1^K DED, LOW LOSS CONTROL	$1050					
GIVEN 10^K DED, LOW LOSS CONTROL	$1030					
GIVEN 25^K DED, MED LOSS CONTROL	$900					
GIVEN 100^K DED, HIGH LOSS CONTROL	$750					

(continued on next page)

TABLE 4-9 DISCRETIZATION OF SIGNIFICANT VARIABLES IN THE CONTRACTOR MODEL (continued)

(dollar amount with ,000's omitted)

VARIABLE NAME	LOW	PROB.	MED	PROB.	HIGH	PROB.
*BUILDERS' RISK PREMIUMS						
GIVEN 1^K DED, 5^M BASIC LEVEL	.30/100	0.25	.37/100	0.46	.42/100	0.29
" 10^K DED, 5^M BASIC LEVEL	.26/100	0.24	.33/100	0.31	.36/100	0.35
" 25^K DED, 5^M BASIC LEVEL	.16/100	0.20	.22/100	0.62	.25/100	0.18
" 100^K DED, 5^M BASIC LEVEL	.13/100	0.36	.155/100	0.48	.175/100	0.16

*premium rate quoted in $/$100 of contract value

The state variables categorized independent are:

WORKERS' COMPENSATION SUBMODEL

- workers' compensation premium rate
- labor payroll as percent of project cost

COMPREHENSIVE GENERAL LIABILITY AND BUILDERS' RISK SUBMODELS

- market conditions

The graphs of the cumulative distributions of the above variables is in Appendix B. The variable market conditions are described as being "good," "fair," "poor" and requires direct assessment. The results of the discretization are found in Table 4-10.

4.4.3 Decision Trees

A decision tree for each respective submodel is created using the output of the encoding phase, as summarized in Tables 4-10 and 4-11. The general form that is employed is illustrated in Figure 4-14. The number of levels of state variables is dictated by the number of significant state variables for each submodel. The terminal node values are calculated using the structural equations for each submodel (as found at deterministic sensitivity stage) and employing the values located along that portion of the tree. Upon calculation of the terminal nodes, the tree is folded back to yield the result for each submodel. This process is performed for each of the submodels (6) and for each case (wrap-up and conventional programs). Consequently, there will be a final dollar value within each submodel for each type of program and for each deductible. Table 4-11 gives a summary of the results for an expected value decision model.

4.5 INTEGRATED MODEL

Up to this point, all the operations have been performed upon individual submodels. The submodels have become complete with the results of decision trees. The output becomes an input to the final model which has as its output the total insurance cost for the major insurance packages for the project. The schematic diagram for the integrated model is shown in Figure 4-15. The model has as its variables the three submodels, for the contractor and owner, covering the three major forms of insurance coverage, and the administration costs for placement and management of the insurance by the owner's insurance

TABLE 4-10 DISCRETIZATION OF THE DISTRIBUTIONS OF SIGNIFICANT VARIABLES IN THE OWNER MODEL

VARIABLE NAME	(dollar amounts, with ,000's omitted)					
	LOW	PROB.	MEDIUM	PROB.	HIGH	PROB.
LOSS RATIO GIVEN $3000 AND $1500 SAFETY PROGRAMS	0.39	0.33	0.45	0.35	0.56	0.32
OWNER SAFETY PROGRAM GIVEN A CONVENTIONAL INS. PROGRAM	$1625	0.28	$2050	0.47	$2675	0.25
*WORKERS' COMPENSATION PREMIUM RATE	9.70/100	0.32	11.00/100	0.33	14.00/100	0.35
LABOR PAYROLL AS PERCENT OF PROJECT COST	29%	0.25	32%	0.48	34.5%	0.27
LOSS CONTROL PROGRAM COSTS GIVEN CONVENTIONAL CASE	$75	0.35	$140	0.44	$290	0.21
MARKET CONDITIONS	POOR	0.30	FAIR	0.20	GOOD	0.50

*premium rate quoted in $/$100 of payroll dollars

TABLE 4-11 RESULTS OF EXPECTED VALUE DECISION FOR CONTRACTOR AND OWNER MODELS

(dollar amounts with ,000's omitted)

BUILDERS' RISK, CONTRACTOR		
CONVENTIONAL		
$1 DED.	$700(14.5)	= $10,150
$10 DED.	$644(14.5)	= $ 9,338
$25 DED.	$522(14.5)	= $ 7,569
$100 DED.	$749(14.5)	= $10,860
WRAP-UP		
$1 DED.	$137(14.5)	= $ 1,986
$25 DED.	$195(14.5)	= $ 2,828
$100 DED.	$520(14.5)	= $ 7,540

GENERAL LIABILITY, CONTRACTOR		
CONVENTIONAL		
$5 DED.	$2258(14.5)	= $32,886
$10 DED.	$1617(14.5)	= $23,446
$20 DED.	$1160(14.5)	= $16,820
WRAP-UP		
$1 DED.	$85(14.5)	= $ 1,232
$5 DED.	$141(14.5)	= $ 2,044
$10 DED.	$214(14.5)	= $ 3,102

WORKERS' COMPENSATION, CONTRACTOR	
CONVENTIONAL	
$2991(14.5)	= $43,370
WRAP-UP	
$301(14.5)	= $ 4,364

NOTE: The multiplication factor 14.5 is used to equate the contractor model with the owner model.

$\$40^{M}$	Contract price
14.5	Factor
$\$580^{M}$	Project value

BUILDERS' RISK, OWNER		
CONVENTIONAL		
$149		
WRAP-UP		
OWNER	CONTRACTOR	
	0	$10,139
$1 DED.	$1 DED.	$10,119
	0	$ 7,939
$25 DED.	$1 DED.	$ 7,909
	$25 DED.	$ 7,709
	$1	$ 8,838
$100 DED.	$25	$ 8,638
	$100	$ 6,638

GENERAL LIABILITY, OWNER	
CONVENTIONAL	
$690	
WRAP-UP	
$50 DED.	$19,706
$100 DED.	$15,396
$1000 DED.	$ 7,160

WORKERS' COMPENSATION, OWNER
CONVENTIONAL
$2087
WRAP-UP
$15,528

Administration costs = cost of consultant

Admin. costs = $743

includes fees and reimbursable costs

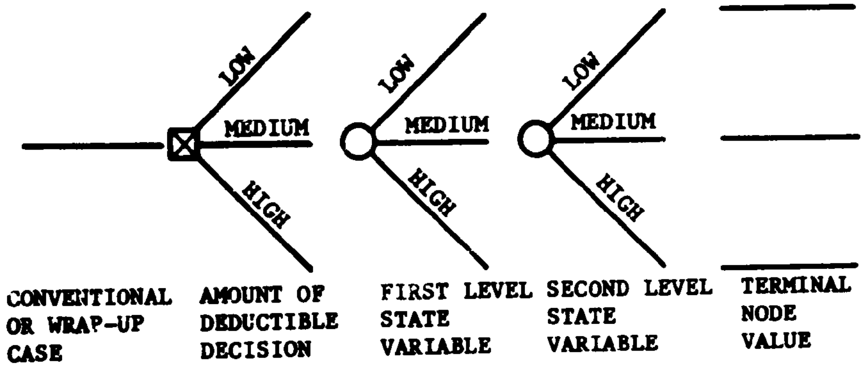


FIGURE 4-14 GENERAL FORM OF DECISION TREE

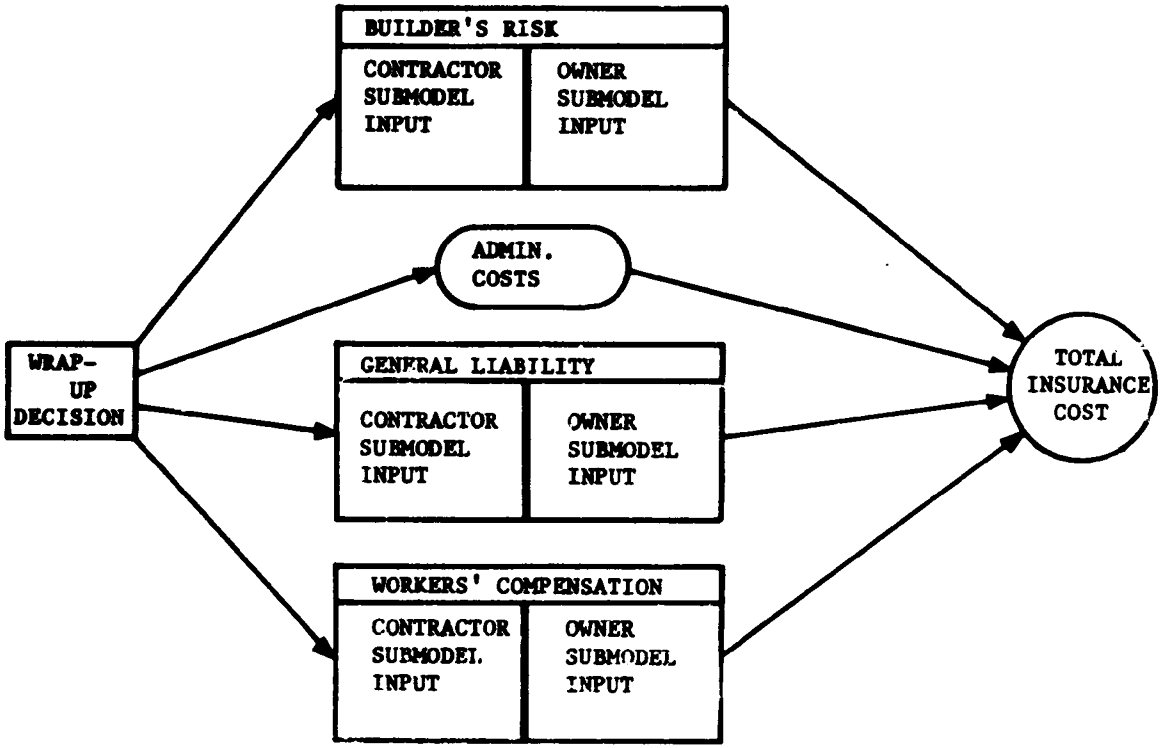


FIGURE 4-15 SCHEMATIC DIAGRAM OF INTEGRATED MODEL

consultant. This cost, of course, occurs only with the wrap-up program.

4.5.1 Model Output

For a given program, a simple addition of the separate submodels, with a given consistent deductible, will yield the total insurance cost. Utilizing the results as shown in Table 4-12, within each submodel the costs for each party, the contractor and the owner, are added together to produce a total cost for each submodel, for each type of insurance program. The process is summarized in Table 4-13. The desired objective is to minimize total cost. (Total cost includes all costs: insurance premiums, losses absorbed, loss control program costs, and dividends). For each submodel and for each type of program, there exists a most economical insurance coverage. The workers' compensation coverage, somewhat different in nature, has one value for each type of coverage. A further comparison will produce the most economical type of coverage for each of the types of insurance. The wrap-up insurance package is the most inexpensive for workers' compensation and comprehensive general liability, while the conventional program for the builders' risk coverage is the most economical. The cost of workmen's compensation is \$19,892,000: the comprehensive general liability coverage with a one million dollar ($\$1^M$) owner deductible and a one thousand dollar ($\$1^K$) contractor deductible costs \$8,392,000; the builders' risk coverage in the conventional program costs \$7,718,000. There is the additional cost of \$743,000 for administrative costs of the coordinated insurance program bringing the total cost of the most economical coverage to \$36,715,000.

4.5.2 Comparison to Real Coverages

A comparison was made between this type of coverage and the levels of coverage utilized by a major mass transit system—the Mass Transit Administration of Baltimore, Maryland on their current subway construction program.*

As a result of the deterministic sensitivity analysis, the amount of coverage required (variable name is "total coverage required") is found to be insensitive, i.e., its variation produces no corresponding significant

---

*Note that this example is concerned with a hypothetical Urban Transit Project, which is similar—but not identical—to the Baltimore project. The sample project is entirely underground.

TABLE 4-12 TOTAL COVERAGE COST TO OWNER OF FEASIBLE INSURANCE OPTIONS

(dollar amounts with, 000's omitted)

	WORKERS' COMPENSATION				
CONVENTIONAL -		$43,370	+ $ 2,087	= $45,457	*
WRAP-UP		$ 4,364	+ $15,528	= $19,892	*,&
	BUILDERS'RISK				
CONVENTIONAL -	$ 1 DED.	$10,150	+ $149	= $10,299	
	$ 10 DED.	$ 9,338	+ $149	= $ 9,487	
	$ 25 DED.	$ 7,569	+ $149	= $ 7,718	*,&
	$100 DED.	$10,860	+ $149	= $11,009	
WRAP-UP -	OWNER DED., CONTR. DED.				
	$ 1, $ 0	not known	+ $10,139	= #	
	$ 1, $ 1	$1,986	+ $10,119	= $12,105	
	$ 25, $ 0	not known	+ $ 7,939	= #	
	$ 25, $ 1	$1,986	+ $ 7,909	= $ 9,895	
	$ 25, $ 25	$2,828	+ $ 7,709	= $10,537	
	$100, $ 1	$1,986	+ $ 8,838	= $10,824	
	$100, $ 25	$2,828	+ $ 8,638	= $11,466	
	$100, $100	$7,540	+ $ 6,638	= $14,178	
	GENERAL LIABILITY				
CONVENTIONAL -	$ 5 DED.	$32,886	+ $690	= $33,576	
	$ 10 DED.	$23,446	+ $690	= $24,136	*
	$ 20 DED.	$16,820	+ $690	= $17,510	
WRAP-UP -	OWNER DED., CONTR. DED.				
	$ 50, $1	$1,232	+ $19,706	= $20,938	
	$ 100, $1	$1.232	+ $15,396	= $16,628	
	$1000, $1	$1,232	+ $ 7,160	= $ 8,392	*,&

* Denotes best decision within submodel for conventional and wrap-up.

& Denotes best decision within submodel among the wrap-up decisions.

\# Denotes that these combinations of deductibles are not feasible.

variation in the total cost. It is appropriate, however, to note the levels of these coverages and compare them to the coverages actually present in the study of the sample mass transit project.

The workers' compensation coverages are statutory with either type of coverage, wrap-up or conventional, and necessarily cannot vary. In the comprehensive general liability coverage, an interesting discrepancy occurs. The owner submodel has a $\$50^M$ coverage required, while the contractor perceives a nominal coverage of $\$25^M$. The builders' risk coverage has the same perturbation. The owner perceives a required coverage of $\$50^M$, while the contractor evaluated his limit at $\$30^M$. The "actual" coverage is at $\$30^M$. The opinions voiced by each of the parties provide some interesting insights. The contractor perceives the coverage required for him for both the builders' risk and comprehensive general liability as somewhat excessive. The contractor evaluates his exposures to be sizeably less, but is persuaded by the owner program to assimilate the variation on the coverages required resulting in a most likely or nominal value at the owner specified limit. The owner, on the other hand, views his exposures to be higher than the actual purchased coverage. This is amply reflected in his variation of the coverages on the upward side.

The ability of the methodology to capture this difference and to incorporate it within the structural model to produce an evaluation of total cost gives an indication of the power, flexibility, and applicability of the technical within a real environment. MTA employs a "total" wrap-up program where all major insurance coverages are included. The comprehensive general liability coverage includes a $100,000 owner deductible and a $1,000 contractor deductible. The builders' risk coverage has a $25,000 owner deductible and a $1,000 contractor deductible. Table 4-13 provides the result of the analysis for the true coverage limits. The total cost of these coverages as produced by the model are $45,118,000. The result of the most economical system as determined by our analysis is 19% less than if the coverages used by the Mass Transit Authority were applied to this hypothetical project. A comparison is also made between the respective insurance coverages. In the builders' risk coverage the most economical system is 10% less than the MTA coverages; and, for the general liability coverage, the most economical system if 47% less than the actual. The results of this comparison are

TABLE 4-13 TOTAL COST TO THE OWNER WITH TRUE COVERAGE LIMITS

(dollar amounts with ,000's omitted)

		BUILDERS' RISK		
CONVENTIONAL -	$ 1 DED.	$10,150 + $149	= $10,299	
	$ 10 DED.	$ 9,338 + $149	= $ 9,487	
	$ 25 DED.	$ 7,569 + $149	= $ 7,718	*,&
	$100 DED.	$10,860 + $149	= $11,009	
WRAP-UP -	OWNER DED., CONTR. DED.			
	$1, $0	not known + $8,857	= #	
	$1, $1	$ 1,986 + $8,837	= $10,823	
	$25, $0	not known + $6,626	= #	
	$25, $1	$1,985 + $6,596	= $ 8,582	*
	$25, $25	$2,828 + $6,426	= $ 9,254	
	$100, $ 1	$1,986 + $7,557	= $ 9,543	
	$100, $ 25	$1,828 + $7,357	= $10,185	
	$100, $100	$7,540 + $5,357	= $12,897	
		GENERAL LIABILITY		
CONVENTIONAL -	$ 5 DED.	$32,886 + $690	= $33,576	
	$ 10 DED.	$23,446 + $690	= $24,136	*
	$ 20 DED.	$16,820 + $690	= $17,510	
WRAP-UP -	OWNER DED., CONTR. DED.			
	$ 50, $1	$ 1,232 + $19,033	= $20,265	
	$ 100, $1	$ 1,232 + $14,669	= $15,901	
	$1000, $1	$ 1,232 + $ 6,487	= $ 7,719	*,&
		WORKERS' COMPENSATION		
CONVENTIONAL -		$43,370 + $ 2,087	= $45,457	*
WRAP-UP		$ 4,364 + $15,528	= $19,892	*,&

*** Best decision within submodel for type of insurance program**

& Best decision within submodel

 # Combinations of deductibles not feasible

presented in Table 4-14.

It should be emphasized again that these numbers represent risks for a hypothetical project, as perceived by the owner and one contractor on the MTA project. In the future, statistical data should be incorporated into the model to augment the subjective risk assessments. This will reduce the work required to perform each analysis, and will increase the generality and reliability of the technique.

4.6 DISCUSSION OF RESULTS

The output of the model is set forth above. Referring to Table 4-8, one can perceive the influence of the deductible amounts upon the total costs for the submodel. At first glance, the results seem anomalous. For the builders' risk submodel, the greater value the deductible assumes, the greater is the total cost, generally. It is observed that in the conventional program the costs decrease as the deductible increases from $1,000 to $25,000 but, then, increases dramatically at a $100,000 deductible. The wrap-up program shows a gradually increasing trend with an increased deductible. Since it is known that the premiums are decreasing with increased deductible, another source of cost must be responsible. This source is the amount of losses absorbed by the respective party. Considering the nature of builders' risk occurrences and their usual substantial cost, it is reasonable to expect dramatic increases in total cost with higher deductibles. Moreover, the contractor perceives that the bulk of these absorbed costs will be considerably higher than the experience the owner expects to face. Conversely, in the comprehensive general liability submodel, the opposite is true. As the deductible level increases, the total cost decreases. The explanation lies in the fact that while the premiums are again decreasing dramatically, the expected losses absorbed do not significantly increase. Both parties felt that in this case the bulk of all losses fell under the lower deductible $1,000 to $5,000, i.e., the insurance carrier was protecting them from extraordinary losses but not the commonly expected type of loss.

This led to the result of the wrap-up program containing the $1,000,000 owner deductible as the most economical by far. There are two readily perceived problems with purchasing an arrangement of this type. First, since the first or primary layer is now self-insuring, the claims handling expertise will either have to be purchased separately, at a higher percentage fee, or

TABLE 4-14 COMPARISON OF TOTAL COST OF INSURANCE TO THE OWNER (REAL VERSUS ANALYSIS RESULTS)

ACTUAL COVERAGES FOR TRANSIT SYSTEM ALL WRAP-UP	COVERAGES RESULTING FROM MOST ECONOMICAL ANALYSIS	% CHANGE
WORKERS'COMPENSATION (STATUTORY COVERAGE) $19,892,000.	WORKERS' COMPENSATION (STATUTORY COVERAGE) $19,892,000	0
BUILDERS' RISK ($30^{M} TOTAL COVERAGE) $25,000 OWNER DED. $ 1,000 CONTR. DED. $8,582,000	BUILDERS' RISK ($30^{M} TOTAL COVERAGE) $25,000 CONTR.DED. $ 7,718,000	-10%
GENERAL LIABILITY ($25^{M} TOTAL COVERAGE) $100,000 OWNER DED. $ 1,000 CONTR. DED. $15,901,000	GENERAL LIABILITY ($50^{M} TOTAL COVERAGE) $1,000,000 OWNER DED. $ 1,000 CONTR. DED. $ 8,392,000	-47%
ADMINISTRATIVE COSTS $ 743,000	ADMINISTRATIVE COSTS $ 743,000	0
TOTAL $45,118,000	TOTAL $36,715,000	-19%
RESULTS OF THE ANALYSIS		
WORKERS' COMPENSATION	**WRAP-UP**	**$19,892,000**
GENERAL LIABILITY	**WRAP-UP**	**8,392,000**
BUILDERS' RISK	**CONVENTIONAL**	**7,718,000**
ADMINISTRATIVE COSTS	**WRAP-UP**	**743,000**
	TOTAL	**$36,715,000**

the effort will have to be done with the owner's own forces. Second, there is some question as to whether such a deductible is politically or financially feasible. It was pointed out that there was a possibility of increased claims and lawsuits by third parties, if the local transit authority were responsible for nearly all losses. Actually, the federal government would be paying 80% of the cost through their subsidies.

Some discussion is needed for the wide difference in the workers' compensation coverage costs. The conventional program reflects the quotation of premiums based upon compressed air tunnel work, which has an extremely high premium rate. This was then applied over the entire project. In the wrap-up program, allowance was made for the considerable amount of work that fell outside this worker classification and was quoted at a substantially lower premium rate. Another source for the difference is the notion of premium feedbacks redounding to the owner. Contractors under conventional plans experience no dividends, but do realize a change in their experience modifier which affects their future insurance costs. Thus, they have no immediate savings to lessen the total cost and provide an incentive for safe operations. The owner, on the other hand, essentially is using the insurance carrier to hold his money to pay claims at their real cost, plus claim handling expense; then, the remainder is returned to the owner. This notion is accurate as long as the owner is able to achieve loss ratios that are as favorable as he presently expects. His feeling is that his safety program and the safety program he can force the contractor into implementing will produce a significantly better performance than the average (the average is a loss ratio of approximately 0.9 with the other 10% for claims' expenses).

As stated in the introduction, one of the benefits of the coordinated insurance program (wrap-up), is that the owner does not have to pay the heavy brokers' fee to place the insurance as does a contractor in placing it conventionally. The contractor is facing brokers' fees of 5% for workers' compensation and 15% for general liability and builders' risk. Roughly speaking, the contractors would pay about $4,000,000 in brokers' fees on the whole project, if it were placed conventionally. The owner is paying an administrative fee of only $743,000 (2.2%).

4.7 CONCLUSIONS REGARDING TEST OF MODEL

The applicability of the form of the risk analysis technique is simply demonstrated above. Given an owner decision of whether or not to utilize a coordinated insurance program, the analysis was able to capture the basic underlying uncertainties impacting such a decision. These uncertainties and their interactions were traced and studied to give an understanding of their impact on the objective function--the minimization of cost. Their significance was tested and pinpointed for further study. Their uncertainty was captured and utilized to produce a model which not only achieves the desired output of total cost but provides a means for study of the implications of decisions and of the risk components themselves.

This model has demonstrated its capability to capture the different perceptions of the different parties (at this time owner and contractor) and to assimilate them into the model to produce a meaningful result. The process provides a quantitative basis for negotiation by the parties, either directly or through the bidding process, to minimize the cost of risk to the project's owner.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Having developed a risk analysis model and carried out an example application, it is appropriate to reflect on the outcome of the study detailed in previous chapters. As with many preliminary studies, the most significant contribution of this research is the development of an approach or methodology. It is also significant, however, that the methodology was implemented to yield results of some immediate and measurable value. This chapter will attempt to provide a clear understanding of the manner in which those goals have been achieved. Further, recommendations concerning future implementation of the methodology will be made; and, avenues for additional research will be explored.

The major import of this study was to develop a quantitative approach for measuring the cost to an owner of risks and their allocation between different parties in transportation construction. The development of the framework of the conceptual model illustrated the logical structure of decisions, contract clauses, and implications of the allocation of risks, yielding a net worth of the project to each party. The interdependence and interaction of the various categories of risk were captured in graphic form as interaction diagrams. These graphic illustrations of the risk model were considered by several advisory board members to have significant value by providing an easily understandable illustration of the flow of risk between parties to a construction contract. They could be used as instructive tools to detail the effect of owner decisions (especially early ones in the life of a project) upon the allocation of the risks in the project; in this form, the structural models, although qualitative, provide the means for informed negotiation between parties to a contract to negotiate an optimal trade-off of risk for price.

Subsequently, the conceptual model was quantified successfully by applying an adapted decision analysis approach to a decision variable and its associated risks. It captured the important features of the problem and placed values on the disaggregate components of all costs pertinent to the analysis. It was able to dismiss those qualitative concerns of "great uncertainty" felt by both parties (owner and contractor) that proved to be of insignificant cost and effect as proved by the data collection and subsequent sensitivity analysis.

The salient additions to the basic decision analysis technique, as implemented in the course of this study, are:

- the incorporation directly into the modelling structure of risk as an incentive to performance by the party accepting the risk;
- explicitly accounting for the different perceptions about the significance of any risk category by each party, including the possibility of its presence in one model and not the other;
- the simultaneous development of two models incorporating two disparate decision-making centers addressing the same decision variables and essentially the same categories of risk (accounting of course for the different perceptions);
- utilizing the final product or output of one model (contractor's) as an input to another model (owner's) or using each model (contractor and owner) as direct input to a final, total model; and
- producing the final cost to the owner without duplication of costs, and maintaining the consistency of the two models while accounting for the different perceptions of each party.

To summarize, the methodology successfully quantified disaggregate costs, risk preference of the parties, and the uncertainties in the categories of risk in a probabilistic manner. It also indicated those state variables which provided the significant portion of the uncertainty in final costs, require further study.

Of immediate interest are the results of the application of the analysis technique to the owner decision of whether to use a "coordinated insurance program." The analysis showed that the most cost effective insurance plan was to have a coordinated "wrap-up" program incorporating workers' compensation and comprehensive general liability coverages, while placing the builders' risk coverage conventionally. The comprehensive general liability should provide a $\$50^{M}$ coverage with a $\$1^{M}$ owner deductible and a $1,000 contractor deductible. The builders' risk coverage should be a $\$30^{M}$ coverage with a $25,000 contractor deductible. The difference in owner's cost between this program and the use of a full "wrap-up" program as used on all recent U.S. subway projects was some $\$8^{M}$, or about one percent of total project costs!

Some methodological conclusions as a result of the studies are:

- the models (contractor and owner) should be developed concurrently to minimize the number of inconsistencies and general problem areas;

- the different phases of the methodology: model building, deterministic sensitivity analysis, and probabilistic phase requiring the interview process should be scheduled to provide some slack between phases to allow the results of each phase to settle, the inconsistencies to become apparent, and to provide the research team with time to study the implications as each phase passes; and
- in the consideration of the implications of risk, the person or persons acting as decision-makers should have a working knowledge of the issues addressed in the study, depth to perceive the subtleties, the scope to understand the entire project, and some information on the basic components of costs. (It may be necessary to interview two or more members of each decision-making entity in order to achieve this.)

The conceptual model and decision analysis methodology developed in this study are a management tool aimed at understanding the implications of risk, given a specific set of project characteristics. They are a method of solution, not a solution, and must be exercised to provide the answers sought.

5.2 RECOMMENDATIONS FOR FURTHER WORK

1) The greatest, single risk of mass transit construction is acknowledged by many experts to be the risk associated with uncertainty of the site geology. The analysis of this risk, providing insight into a quantifiable measure of the uncertainty and its effects on the total project cost, would be of tremendous interest throughout the industry. The determination of the optimum risk share and contract amount for this category of risk would be perceived as a major breakthrough. In addition, the "value of information" calculation would indicate an optimum amount that should be spent on site investigation program to improve the parties' understanding of the soil conditions, hence, minimizing the cost of the risk to them.

2) The incorporation of the third major party, the designer, into the model would be of enormous value in improving its validity and range of applications. This problem presents a different type of model. The designer has considerable leeway about some important decisions made early in a project that have great cost implications further into the project even after his work is complete. The issue of overconservatism of U.S. design practice and lack of innovation in design could be studied. The interaction

between owner and designer is somewhat different than with the contractor. Integration of all these parties into one conceptual model would provide significantly greater power for the subsequent analysis and allocation of risks.

3) The implementation of the Edgeworth Box Negotiation Model into the working methodology would enhance the ability of the analysis to optimize the trade-off of cost and risk allocation. The negotiation over contract clauses would be a direct, rather than a repetitive analysis. This approach would influence the industry structure in the direction of a more cooperative system of contract awards. This would facilitate not only the "best" contract but also improve the atmosphere surrounding transportation construction projects, further reducing costs.

4) Implicit in present analyses is the "average" contractor. The analysis considers the model of a single contractor and utilized him as representative of all contractors on the entire project. A study to account for the range of risk perceptions of different contractors expected to work on a project would be a valuable extension of this work. The model would account for variance among decision-makers as well as in cost.

5) Another topic of interest would be to develop the model into a matrix format. Utilizing the proximal decision analysis method described by Ronald Howard (1977, pp. 565-601), the correlation coefficients among risk variables could be calculated. This would enable the conceptual structure to be modelled as a complex multiplication of matrices; and, thereby, accounting for the interactions among disparate risk variables that contribute to the overall uncertainty. This would lead to the development of the model to the point where all major categories of risk in conjunction with the decision variables and contract clauses would be included in a total structural model. This model could be part of the basis of a permanent system. When integrated with a data base of historical costs, updating, and other features, this could produce a powerful management tool. Writing of contracts and specification of owner decisions for a given set of project characteristics could be modeled to yield an optimum risk share, total cost predictions, and expected contract values.

BIBLIOGRAPHY

Abrahamson, Max. "Contractual Risks in Tunneling: How They Should Be Shared." *Tunnels and Tunneling*, (November 1973), pp. 588-598.

Ashley, David Brian. "Construction Project Risk-Sharing." Ph.D. dissertation, Department of Civil Engineering, Stanford University, July 1977.

Baldwin, J.R. "Causes of Delay in the Construction Industry." *Journal of the Construction Division*. ASCE Vol. 97. No. CO2. Proc. Paper 8501. (November 1971), pp. 177-187.

Barrett, James E. *Insurance for Urban Transportation Construction*. U.S. Department of Transportation, Urban Mass Transportation Administration. Washington, D.C. Report No. UMTA-MA-0025-77-13. 1977.

Benjamin, Jack R., and Cornell, C. Allin. *Probability, Statistics, and Decision for Civil Engineers*. New York: McGraw Hill Book Company, 1970.

Birkmyer, A.J., and Richardson, D.L. *Systems Analysis of Rapid Transit Underground Construction*. Volumes I and II. U.S. Department of Transportation. Washington, D.C. Report Nos. DOT-TST-75-72.I and DOT-TST-75-72.II. 1974.

Cantor, Louis, Rubin, Robert, and Goldberg, Eugene H. "Legal Aspects of Open Cut Construction." *Journal of the Construction Division*. ASCE Vol. 101. No. CO4. (December 1975), pp. 923-931.

Carr, Robert I. "Paying the Price for Construction Risk." *Journal of the Construction Division*. ASCE Vol. 103. No. CO1. Proc. Paper 12827. (March 1977), pp. 153-161.

Dallaire, Gene. "Desperate Need to Slash Construction Costs of New Subways." *Civil Engineering*. (December 1976), pp. 37-43.

de Neufville, Richard, and Stafford, Joseph. *Systems Analysis for Engineers and Managers*. New York: McGraw Hill Book Company, 1971.

Dorfman, Robert. *Prices and Markets*. Englewood Cliffs: Prentice Hall, Inc. 1972.

Douglas, Walter S. "Present and Future Risk Distribution in Construction Contracts." *ASCE National Convention*. November 3-7, 1975. Denver, Colorado. Meeting Preprint 2555.

Fox, George A. "Subsurface Construction Contracts--A Contractor's View." *Journal of the Construction Division*. ASCE Vol. 100. No. CO2. Proc. Paper 10608. (June 1973), pp. 153-158.

Gilbane, Richard Thompson. "Insurance in the Construction Industry." Master of Science Thesis, Massachusetts Institute of Technology, February 1976.

Goldberg, Victor P. "Competitive Bidding and the Production of Precontract Information." *The Bell Journal of Economics*. Vol. 8. No. 1. (Spring 1977), pp. 250-261.

Howard, Ronald A. "Decision Analysis in Systems Engineering." *Readings in Decision Analysis*. Edited by Ronald A. Howard, et al. Menlo Park: Stanford Research Institute. (1977), pp. 45-81.

Howard, Ronald A. "The Foundations of Decision Analysis." *Readings in Decision Analysis*. Edited by Ronald A. Howard. Menlo Park: Stanford Research Institute. (1977), pp. 392-401.

Howard, Ronald A. "Risk Preference." *Readings in Decision Analysis*. Edited by Ronald A. Howard, et al. Menlo Park: Stanford Research Institute. (1977), pp. 429-465.

Howard, Ronald A. "Proximal Decision Analysis." *Readings in Decision Analysis*. Edited by Ronald A. Howard, et al. Menlo Park: Stanford Research Institute. (1977), pp. 565-601.

Immel, A. Richard. "BART's Many Woes Are Affecting Growth of Rail Mass Transit." *The Wall Street Journal*, Eastern Edition, June 29, 1977, p. 1.

Kahneman, Daniel, and Tversky, Amos. "Prospect Theory: An Analysis of Decision Under Risk." *Econometrica*, in press, 1978.

Mason, George E. "A Quantitative Risk Management Approach to the Selection of Construction Contract Provisions." Ph.D. dissertation, Department of Civil Engineering, Stanford University, April 1973.

Matheson, J.E., and Howard, R.A. "An Introduction to Decision Analysis." *Readings in Decision Analysis*. Edited by Ronald A. Howard, et al. Menlo Park: Stanford Research Institute. (1977), pp. 5-43.

National Research Council, U.S. National Committee on Tunneling Technology, Standing Subcommittee No. 4: Contracting Practices. *Better Contracting for Underground Construction*. U.S. Department of Transportation/UMTA Report No. MA-0600025-74-24. Washington, D.C. 1974.

O'Neill, John T. "Present and Future Risk Distribution in Construction--Viewpoint of the Owner." *ASCE National Convention*. November 3-7, 1975. Denver, Colorado, Meeting Preprint 2591.

Pedrelli, Nino, Levitt, Raymond E., and Einstein, Herbert H. "Assessing Overdesign in U.S. Subway Tunnel Support." Unpublished research report. Massachusetts Institute of Technology. 1978.

Pouliquen, Louis Y. *Risk Analysis in Project Appraisal*. World Bank Staff Occasional Papers Number Eleven. Baltimore: The Johns Hopkins University Press. 1970.

Raiffa, Howard. *Decision Theory--Introductory Lectures on Choices Under Uncertainty*. Reading: Addison-Wesley Publishing Company. 1968.

Smith, Stephen E., Wilson, Woodrow W., Burns, William C., and Rubin, Robert. "Contractual Relationships in Construction." *Journal of the Construction Division*. ASCE Vol. 101. No. CO4. (December 1975), pp. 907-921.

Stäel von Holstein, Carl-Axel S. "A Tutorial in Decision Analysis." *Readings in Decision Analysis*. Edited by Ronald A. Howard, et al. Menlo Park: Stanford Research Institute. (1977), pp. 117-145.

Stäel von Holstein, Carl-Axel S. "Probability Encoding in Decision Analysis." *Readings in Decision Analysis*. Edited by Ronald A. Howard, et al. Menlo Park: Stanford Research Institute. (1977), pp. 403-427.

Wagner, Harvey M. *Principles of Operations Research: With Applications to Managerial Decisions*. Englewood Cliffs: Prentice Hall, Inc., 1969.

Willenbrock, J.H. "Utility Function Determination for Bidding Models." *Journal of the Construction Division*. ASCE Vol. 99. No. CO1. Proc. Paper 9843. (July 1973), pp. 133-153.

APPENDIX A

PILOT, IN-HOUSE APPLICATION OF MODEL

Before initiating a detailed field investigation of a complex problem, the research team tested the methodology within the team itself. A relatively straightforward decision was chosen for analysis, and, to preserve the independent perceptions of the problem, which the methodology was designed to capture, one member of the research group assumed the role of the owner, another that of the contractor. The purpose of the trial analysis was twofold: to develop the proficiency of the research team in applying the methodology to decision problems; and, to evaluate the efficacy and robustness of the methodology in providing insight to these problems.

The question of owner-furnished materials was the owner's decision chosen for investigation because the issues involved were rather simple and direct thereby allowing the research group to concentrate on applying and evaluating the methodology. Further motivation for analyzing this decision was provided by the U.S. National Committee on Tunneling Technology of the National Academy of Sciences, in their report, Better Contracting for Underground Construction:

> At a time of spiraling material costs the owner should benefit from purchasing material for inclusion in the project, particularly when there is an extended time lag between the time of order and deliveries, and where the cost involved is substantial.

This methodology was specifically designed to identify and quantify benefits such as those alluded to by the Better Contracting group.

The analysis was conducted on the basis of a hypothetical project specifically designed to allow the investigation to focus on the owner-furnished materials decision. The "project" considered by the "contractor" consisted of excavating, placing the steel lining, grouting, and placing the concrete roadbed for a one-mile length of free-air, shield-driven, soft ground tunnel. The "system" considered by the "owner" was arbitrarily composed of thirty of these projects, identical in nature. The basic cost data used throughout the analysis was developed from informal conversations with various individuals actively involved in tunnel construction contracting. Table 1 summarizes the hypothetical project/system characteristics and costs.

A caveat is appropriate at this point: this analysis is not intended to prove or disprove the notion that the owners of tunnel projects should furnish certain construction materials to the contractors that build them. Rather, the analysis is based on a hypothetical project, and the different perceptions presented here may or may not represent the thinking of owners and contractors with regard to owner-furnished materials. Conversely, it is the objective of this analysis to demonstrate the capacity of the proposed methodology to capture the different perceptions of independent parties involved in the construction of transportation projects.

An interaction diagram representing the contractor's perception of the owner-furnished materials question was developed over the course of two sessions, each approximately two hours in length. (The analysts spent an additional four hours between sessions formulating a rough model based on the results of the first session.) From the diagram (Figure 1), it can be seen that the important uncertainties (state variables) from the contractor's standpoint were: the price of grout; the quantity of grout; the price of concrete; the base mill price, availability and transport costs of steel; the amount of project delay; and the direct unit cost of excavating the tunnel. In addition, the owner's decision was a state variable to the contractor because he had no control over its outcome. Finally, to avoid directly assessing the direct unit cost of labor and equipment for grouting, placing concrete, and steel liner erection, these costs were related to their input materials costs by assessing the percentages of direct unit costs that were accounted for by materials in each case. As these percentages were uncertain, they were also treated as state variables.

Three further comments are in order. First, the 0/1 relationship between the owner's decision and the price of grout, price of concrete, and price of steel indicates an "on/off" situation; if the owner does not furnish the materials, the relationship is "on" and the prices do figure into the contractor's model; if the owner does furnish the materials, then the relationship is off, and the contractor's bid excludes the cost of materials. Second, the markup factor of 20% avoids explicit treatment of the contractor's markup decision strategy, a whole other problem in itself. Finally, the output of the model is two quantities project bid and project profit. The first

TABLE 1 HYPOTHETICAL TUNNEL PROJECT CHARACTERISTICS

Length: 1 mile

Diameter: 18' 0"

Location: Baltimore

Type: Free-air, shield-driven in soft ground

Assumed Geology: Free-standing moist sand, no water problems

Construction: Fabricated steel liner segments with cast-in-place concrete bench. Voice space grouted under pressure

Assumed Contract Period: 2 years

Assumed Unit Prices (Derived from above):

ITEM		MATERIAL	LABOR & EQUIPMENT
Steel liner	($/LF)	1300	200
Concrete	($/CY)	35	100
Grout	($/BBL)	10	15
Excavation	($/LF)	-	800

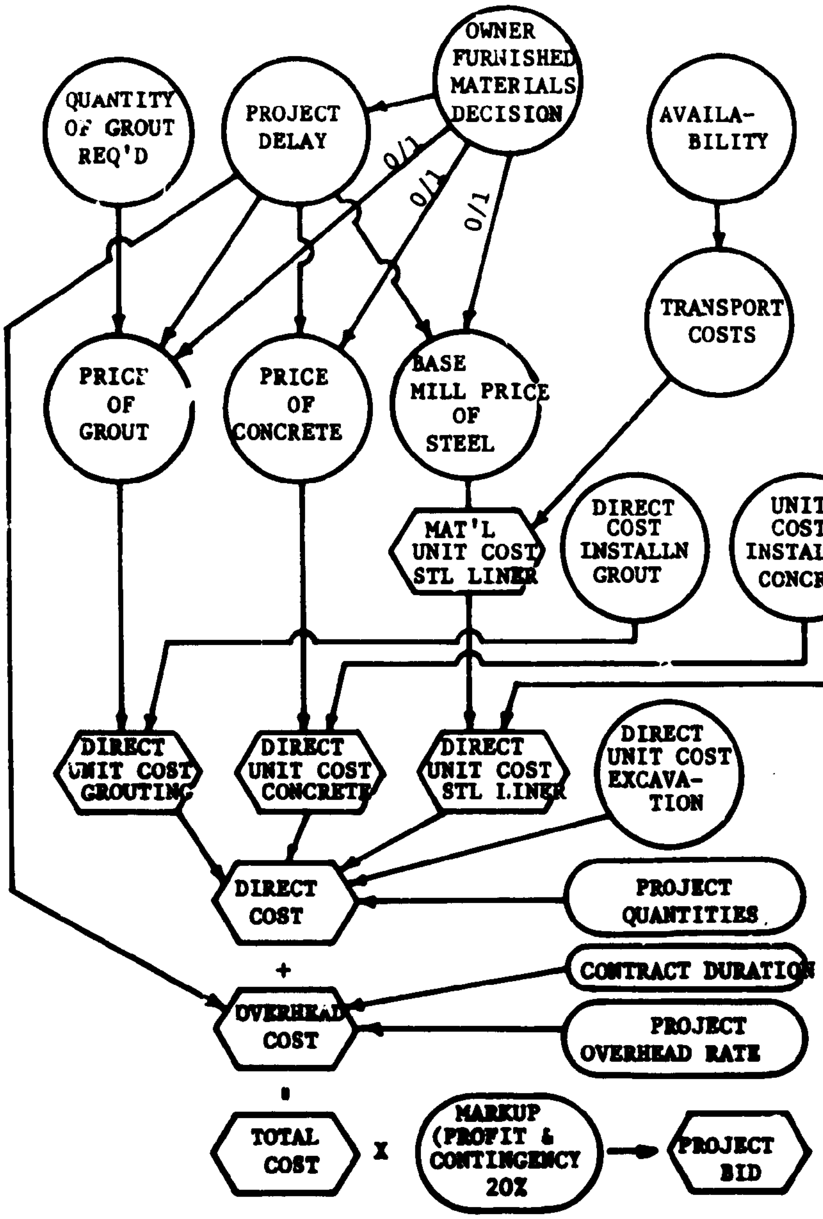


FIGURE 1 CONTRACTOR ORIGINAL MODEL

quantity is the evaluation variable of concern to the owner, while the second is important to the contractor.

After obtaining from the contractor the extreme and nominal values which each state variable could assume, a deterministic sensitivity analysis was performed to evaluate the sensitivity of the model outputs (project bid and project profit) to variations in state variables. The following variables were found to be important: the owner's decision, project delay, base price of steel, materials as a percentage of direct unit cost of steel liner erection, and the direct unit cost of excavation. The remaining original state variables were set at their nominal values and incorporated into the structural equations of the contractor's model. Figure 2 is a diagram of the reduced contractor's model.

The owner's interaction diagram was developed in about the same amount of time as the contractor's. As can be seen from Figure 3, the owner's model was somewhat less complex than the contractor's, involving in most cases only the addition of the independent costs resulting from either decision. The major uncertainties arising from a decision to furnish materials were administration costs; liability in the form of direct damages; the quantity discount available for lumped purchases; and the incremental project delay and associated costs (delay compensation to the contractor, opportunity costs) that might be caused by inefficient owner purchasing arrangements. If the owner decided not to furnish the materials, his uncertainty about the rate of inflation and the contractor's markup became important. The value of the other construction costs variable was determined from the nominal output of the contractor's model.

It is important to note that the owner considered furnishing only the fabricated steel liner sections, but not the concrete or the grout, because he felt that while he could exercise some control over the former, the quantities of the latter materials that would be required were so uncertain that furnishing said materials was one risk the owner was unwilling to assume. Thus, the owner and the contractor formulated their models under different assumptions, and, if the grout or concrete had been an important factor in the contractor's model, some reconciliation and restructuring of the models would have been required. The lesson to be learned is clear: care should be taken to ensure that the models are formulated under consistent assumptions and, if possible approximately concurrently, to prevent one model from dictating the structure of the other.

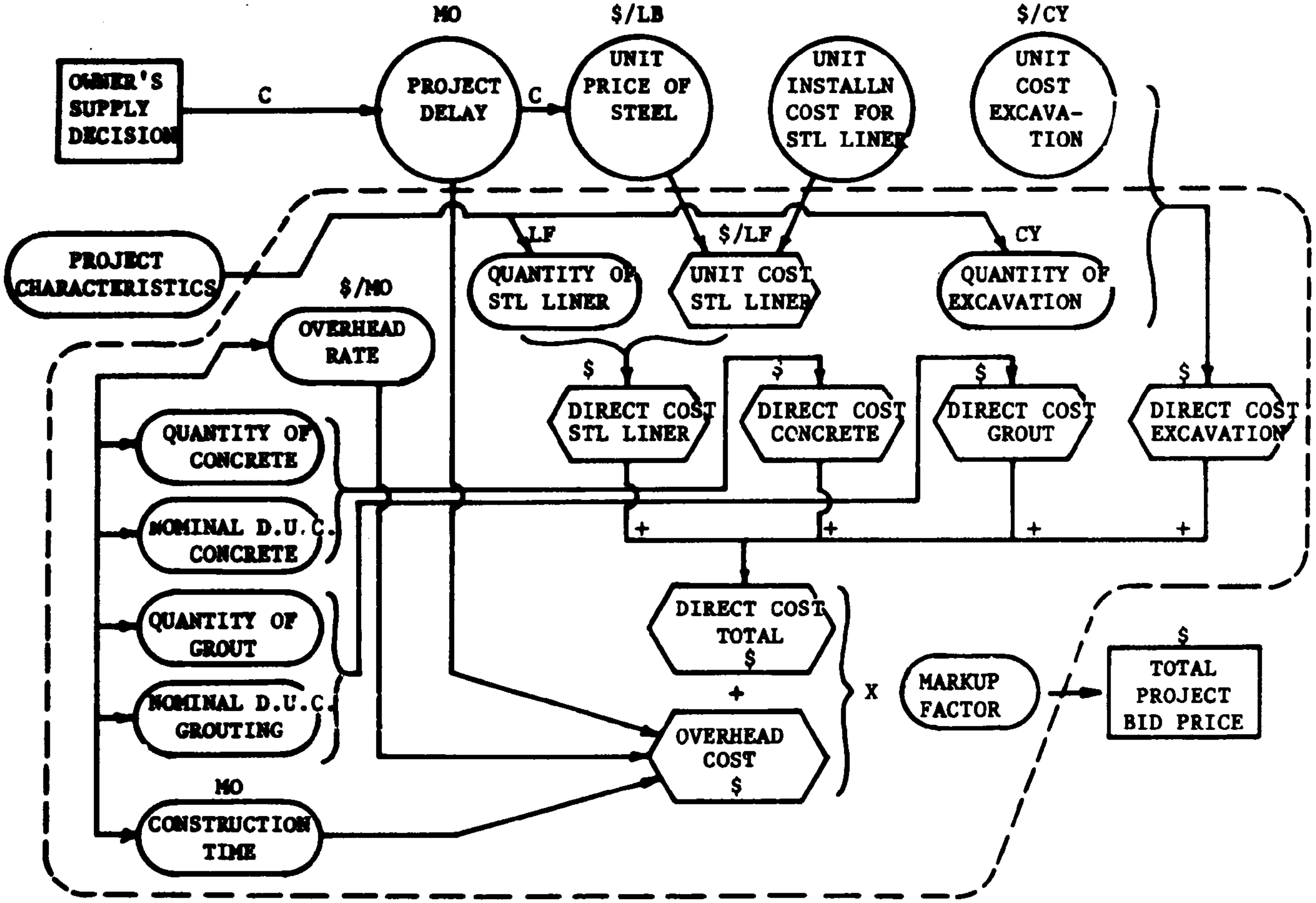
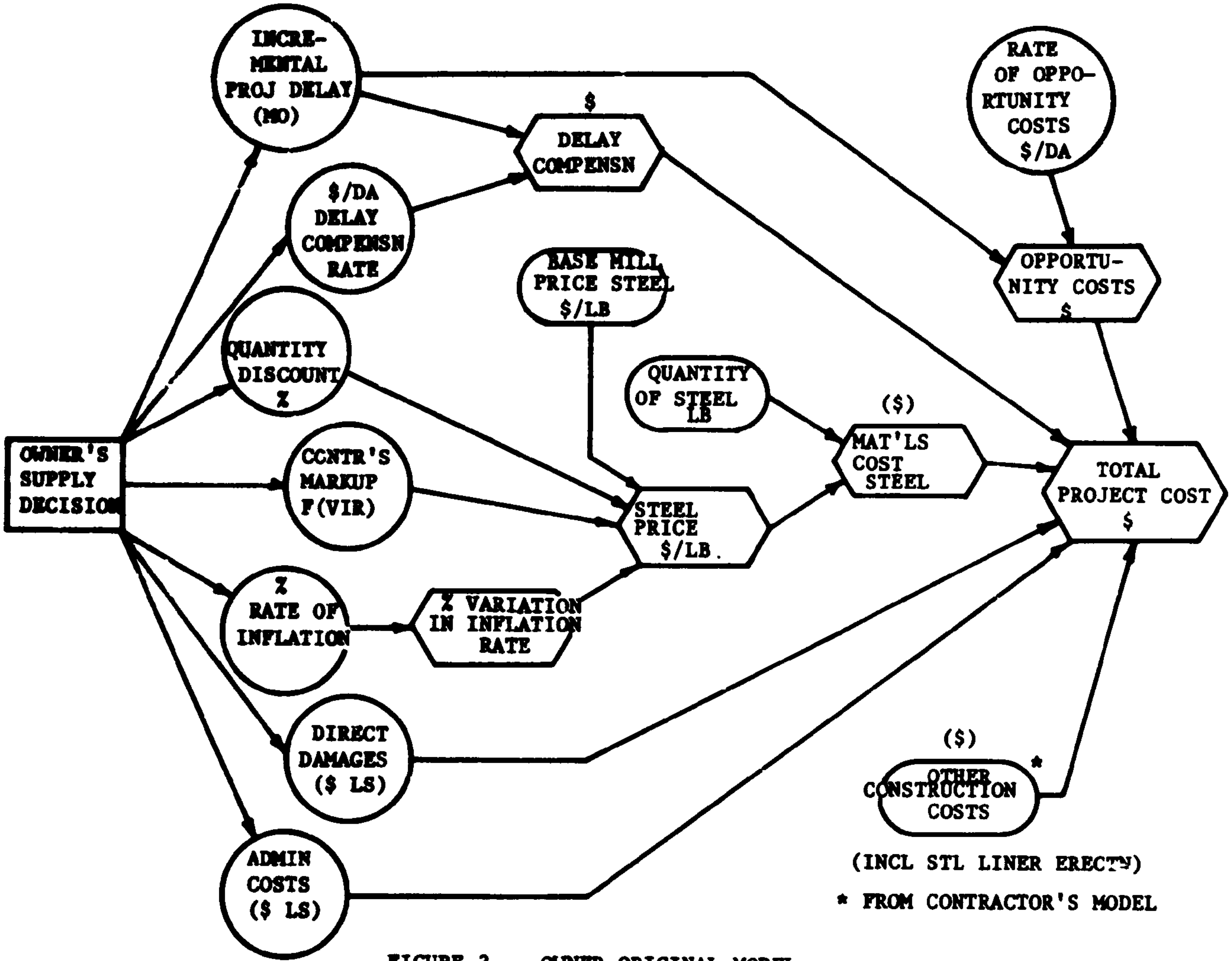


FIGURE 2 CONTRACTOR REDUCED MODEL



(INCL STL LINER ERECT'N)

* FROM CONTRACTOR'S MODEL

FIGURE 3 OWNER ORIGINAL MODEL

One further comment: ideally, the owner's evaluation variable should be some measure of the system's worth to the owner, but the evaluation of system worth is in itself a complex problem. To avoid becoming deeply entangled in evaluating system worth, the research team made the simplifying assumption that, in the short run, the system's worth to the owner is equal to what he's willing to pay for it (its expected cost). Stated more formally, the assumption was that, at the margin, marginal product = marginal cost. For the purpose of this analysis, this assumption seemed reasonable.

A deterministic sensitivity analysis was also run on the owner's model and the important state variables were found to be incremental project delay, delay compensation rate, rate of opportunity costs, and amount of direct damages. The other state variables were set at their nominal values and incorporated in the structural equations of the model. Figure 4 is a diagram of the reduced owner's model.

Once the important variables of each model had been determined, subjective probability assessments were obtained from the owner and contractor for each of the variables in his particular model. A simple reference process involving a probability wheel yielded the required cumulative distributions, and these were discretized for insertion in a decision tree format of each model. Since other variables were conditional on project delay given either owner decision, both distributions on project delay had to be discretized in a similar manner to be compatible with the subsequent conditional variables.

After all the required probabilities had been determined and terminal values calculated for each possible outcome of the decision trees, each tree was folded back to obtain the expected value of the decision in question. Figure 5 illustrates how these output values were combined to obtain a final comparison between the resulting cost of the owner's decision to furnish the steel liner and the cost of his decision not to.

Although the owner perceived additional costs resulting from his decision not to furnish materials, these costs arose completely from the owner's perception that the contractor would charge a markup on said materials, which he did. As this markup was already included in the total project cost, this would constitute double counting.

The material cost of the steel liner, which becomes part of the owner cost resulting from an owner decision to furnish materials, was derived from the contractor's model, since the owner was completely willing to rely on the

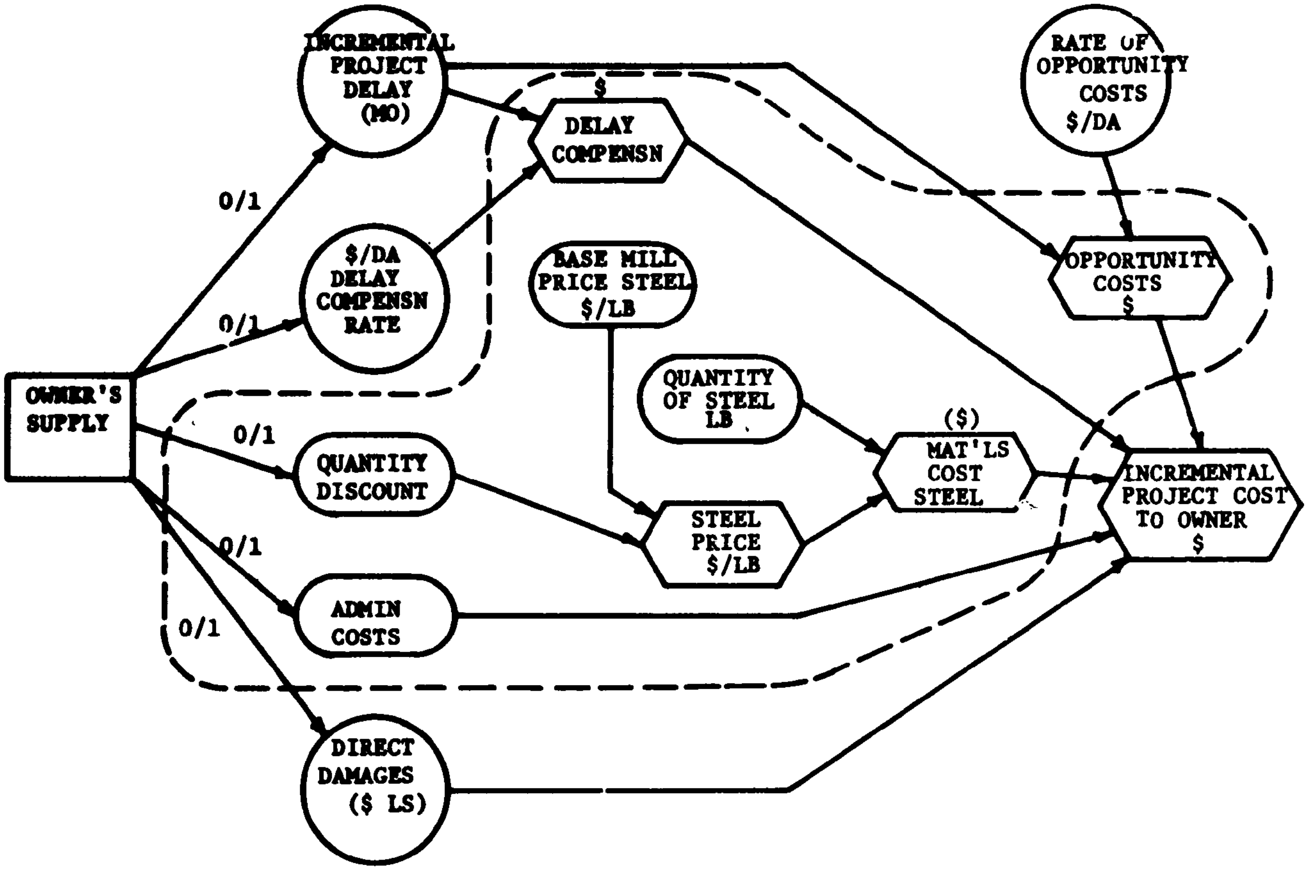
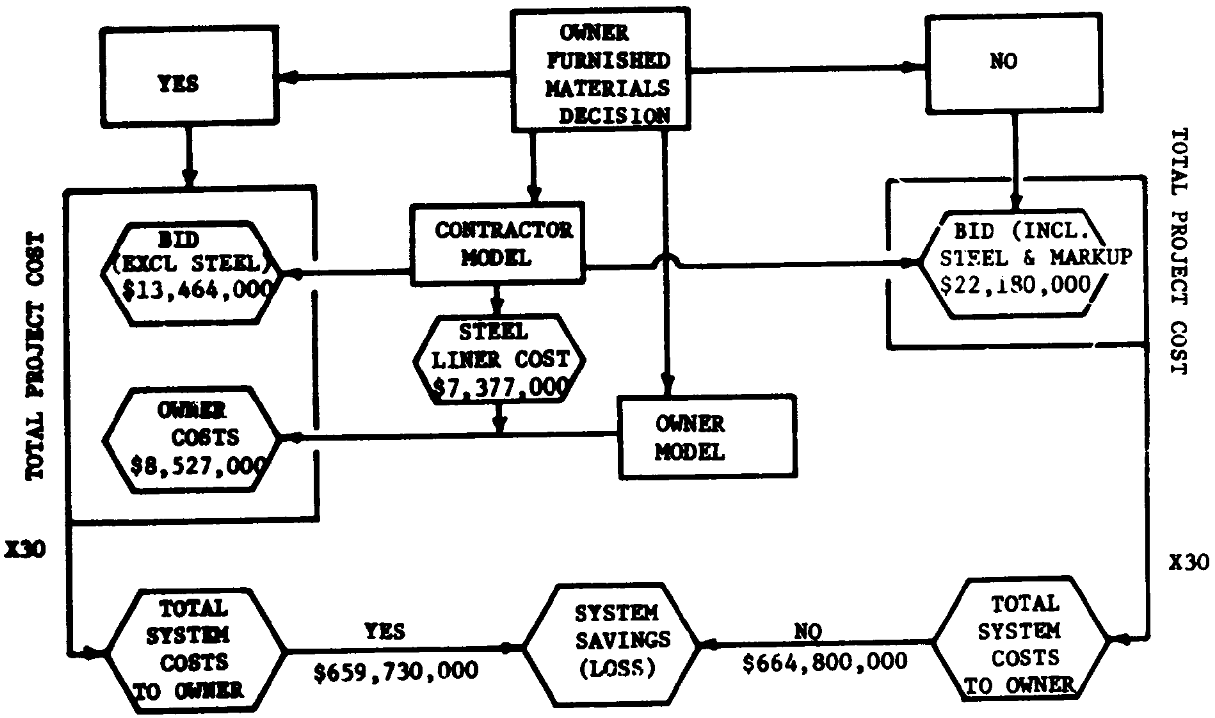


FIGURE 4 OWNER REDUCED MODEL



$5,070,000 FOR OWNER
FURNISHED STEEL LINER

FIGURE 5 EXPECTED VALUE DECISION

contractor's estimate of said cost.

Once the expected value decision analysis was completed, an expected utility analysis was undertaken to evaluate the impact of various levels of risk aversion on the part of the contractor. Unfortunately, as a result of the way in which the problem was formulated, the contractor did not face the possibility of loss, and thus varying the level of risk aversion had no impact; the expected utility result was no different than the expected value result.

APPENDIX B

DATA FOR WRAP-UP INSURANCE MODEL

The deterministic ranges and the probability distributions are the heart of the quantification of the coordinated insurance program model in Chapter 4. Sensitivities are calculated from the ranges to determine the significant variables for which the cumulative distributions are encoded. The probability distributions provide the quantification for the model output. A complete listing of the deterministic ranges for the contractor's model and the owner's model follows, respectively, for each insurance coverage submodel. The cumulative distributions of the significant variables succeeds the above listing in the same order.

DETERMINISTIC RANGES

CONTRACTOR'S WORKERS' COMPENSATION SUBMODEL

(dollar amounts with ,000's omitted)

VARIABLE NAME	VALUE LOW	 NOMINAL	 HIGH
Contractor's Mark-up	.25	.30	.60
Insurance Premiums	$2000	$3000	$5000
Brokers' Fee		-- 5% --	
Owner Enforcement|Wrap-up	Medium	High	High
O.E.| Conventional	Low	Medium	Medium
Contr. Safety Program Costs|O.E.-L		$275	
C.S.P.C.|O.E.-M	$110	$275	$550
C.S.P.C.|O.E.-H	$150	$310	$600

DETERMINISTIC RANGES

CONTRACTOR'S COMPREHENSIVE GENERAL LIABILITY SUBMODEL

(dollar amounts with ,000's omitted)

	VALUE		
VARIABLE NAME	LOW	NOMINAL	HIGH
Owner Required Coverage	$\$20^{M}$	$\$25^{M}$	$\$100^{M}$
Amount of Deductible|Wrap-Up	\$1	\$5	\$10
A.O.D.|Conventional	\$5	\$10	\$20
Evaluation of Exposure|O.R.C.-25^{M}		-- Low --	
E.O.E.|O.R.C.-100^{M}		Low	
E.O.E.|O.R.C.-20^{M}		Low	
Exposure to Deductible|1^{K} DED.		Low	
E.T.D.|5^{K} DED.		Medium	
E.T.D.|10^{K} DED.		Medium	
E.T.D.|20^{K} DED.		High	
Contr. Loss Control Program			
E.O.E.-L, E.T.D.-L		Low	
E.O.E.-L, E.T.D.-M	Medium	Medium	High
E.O.E.-L, E.T.D.-H		High	
# of Losses|C.L.C.P.-M	25	50	75
# of Losses|C.L.C.P.-L		75	
# of Losses|C.L.C.P.-H		50	
# of Claims|C.L.C.P.-M, 1^{K} DED.		25	
# of Claims|C.L.C.P.-M, 5^{K} DED.	10	20	50
# of Claims|C.L.C.P.-M, 10^{K} DED.	5	7	15
# of Claims|C.L.C.P.-M, 20^{K} DED.		2	

CONTRACTOR'S COMPREHENSIVE GENERAL LIABILITY SUBMODEL (continued)

	VALUE		
VARIABLE NAME	LOW	NOMINAL	HIGH
# of Claims|C.L.C.P.-H, 1^K DED.		20	
# of Claims|C.L.C.P.-H, 5^K DED.		15	
# of Claims|C.L.C.P.-H, 10^K DED.		5	
# of Claims|C.L.C.P.-H, 20^K DED.		1	
# of Claims|C.L.C.P.-L, 1^K DED.		35	
# of Claims|C.L.C.P.-L, 5^K DED.		25	
# of Claims|C.L.C.P.-L, 10^K DED.		10	
# of Claims|C.L.C.P.-L, 20^K DED.		3	
Average Amount of Loss|C.L.C.P.-M	$2	$4	$6
Average Amount of Loss|C.L.C.P.-H		$4	
Average Amount of Loss|C.L.C.P.-L		$4	
Cost of Loss Control Program|			
C.L.C.P.-M	$5	$100	$500
C.L.C.P.-L		$50	
C.L.C.P.-H		$200	
Percent Uninsurable|Wrap-Up	1/2%	1%	3%
Percent Uninsurable|Conventional	0	0	0
Brokers' Fee		-- 15% --	
Insurance Premiums at a Coverage of			
(20^M-25^M) | 5^K DED.	$480	$900	$1680
(20^M-25^M) | 10^K DED.	$330	$618	$1170
(20^M-25^M) | 20^K DED	$180	$336	$630
(100^M) | 5^K DED.	$534	$1000	$1870

CONTRACTOR'S COMPREHENSIVE GENERAL LIABILITY SUBMODEL (continued)

VARIABLE NAME	VALUE LOW	 NOMINAL	 HIGH
Insurance Premiums at a Coverage of			
(100^M) | 10^K DED.	$367	$688	$1303
(100^M) | 20^K DED.	$200	$374	$701

DETERMINISTIC RANGES

OWNER'S WORKERS' COMPENSATION SUBMODEL

(dollar amounts with ,000's omitted)

	VALUE		
VARIABLE NAME	LOW	NOMINAL	HIGH
Labor as % of Total Cost	25%	33%	40%
Owner Safety Program Cost	$2000	$3000	$4000
Ave. Modifiers of Contractors	0.90	1.00	1.10
Improved Effective Modifier|Ave.-1.00			
O.S.P.C.-3^{M}	0.85	0.90	0.95
O.S.P.C.-2^{M}		0.95	
O.S.P.C.-4^{M}		0.85	
Imp. Eff. Mod.|Ave.-0.90,O.S.P.C.-3^{M}		0.80	
Imp. Eff. Mod.|Ave.-1.10,O.S.P.C.-3^{M}		1.00	
*Rate Make-Up|Labor 25%		16.09/$100	
*Rate Make-Up|Labor 33%	9.29/$100	12.19/$100	15.09/$100
*Rate Make-Up|Labor 40%		10.06/$100	
Cost of Contr. Safety Program	$1000	$1500	$2000
Loss Ratio|C.C.S.P.-$\$1.5^{M}$,			
O.S.P.C.-$\$3^{M}$	0.40	0.50	0.70
O.S.P.C.-$\$4^{M}$		0.47	
O.S.P.C.-$\$2^{M}$		0.54	
Loss Ratio|C.C.S.P.-$\$1^{M}$, O.S.P.C.-$\$3^{M}$		0.50	
Loss Ratio|C.C.S.P.-$\$2^{M}$, O.S.P.C.-$\$3^{M}$		0.50	
Claim Handling Expense	9%	10%	14%

*(premium rate quoted in $/$100 of labor payroll dollars)

DETERMINISTIC RANGES

OWNER'S COMPREHENSIVE GENERAL LIABILITY SUBMODEL

(dollar amounts with ,000's omitted)

	VALUE		
VARIABLE NAME	LOW	NOMINAL	HIGH
Cost of Preconstr. Survey|Wrap-Up	$600	$750	$900
Total Coverage Required (T.C.T.)	$25,000	$50,000	$100,000
Amount of Deductibles	$50	$100	$1000
Primary Level Coverage|(P.L.C.)			
Total Coverage Required-50^{M}	$500	$1000	$2000
Total Coverage Required-25^{M}		$1000	
Total Coverage Required-100^{M}	Poor	Fair	Good
*Primary Premiums|P.L.C.-1^{M},100^{K} DED.			
M.C.-Fair	0.70/$100	0.75/$100	0.80/$100
M.C.-Good		0.55/$100	
M.C.-Poor		0.95/$100	
*Primary Premiums|P.L.C.-1^{M},50^{K} DED.			
M.C.-Fair		1.15/$100	
M.C.-Good		0.84/$100	
M.C.-Poor		1.46/$100	
*Umbrella Premium Rate (4^{M} excess 1^{M})			
M.C.-Fair	0.33/$100	0.38/$100	0.43/$100
M.C.-Good		0.30/$100	
M.C.-Poor		0.46/$100	

OWNER'S COMPREHENSIVE GENERAL LIABILITY SUBMODEL (continued)

	VALUE		
VARIABLE NAME	LOW	NOMINAL	HIGH
*Umbrella Premium Rate (20^M excess 5^M)|			
M.C.-Fair	0.20/$100	0.23/$100	0.26/$100
M.C.-Good		0.18/$100	
M.C.-Poor		0.28/$100	
*Umbrella Premium Rate(25^M excess 25^M)|			
M.C.-Fair	0.05/$100	0.06/$100	0.07/$100
M.C.-Good		0.05/$100	
M.C.-Poor		0.07/$100	
*Umbrella Premium Rate (50^M excess 50^M)|			
M.C.-Fair	0.02/$100	0.02/$100	0.03/$100
M.C.-Good		0.02/$100	
M.C.-Poor		0.03/$100	
Loss Control Program Costs	$660	$690	$720
Amount of Losses to Owner|100^K DED.	$500	$750	$1000
Amount of Losses to Owner|50^K DED.	$450	$675	$900
Amount of Losses to Owner|1^M DED.	$500	$750	$1000
Claim Handling Expense	3%	3.5%	4%
Dividends	0	$2500	$3000

Amount of Claims by Owner = Amount of Losses to Owner

* (premium rates are quoted in $/$100 of project value)

DETERMINISTIC RANGES

OWNER'S BUILDERS' RISK SUBMODEL

(dollar amounts with ,000's omitted)

VARIABLE NAME	VALUE LOW	 NOMINAL	 HIGH
Total Coverage Required (T.C.R.)	$30,000	$50,000	$75,000
Market Conditions	Poor	Fair	Good
Owner Deductible	$1	$25	$100
Contractor Ded. Wrap-Up	0	$1	$25
Contractor Ded. Conventional	0	$25	$100
Loss Control Program Costs (L.C.P.C.)	0	$300	$600
Primary Level Coverage (P.L.C.)	$1000	$5000	$10,000
Loss Ratio 25^K DED.,			
L.C.P.C.-Medium Level	0.50	0.55	0.60
L.C.P.C.-High Level		0.40	
L.C.P.C.-Low Level		0.75	
Amount of Losses to Owner 25^K DED.,			
L.C.P.C.-Medium Level	$150	$200	$300
L.C.P.C.-High Level		$175	
L.C.P.C.-Low Level		$500	
Amount of Losses to Owner 1^K DED.,			
L.C.P.C.-Medium Level		$20	
Amount of Losses to Owner 100^K DED.,			
L.C.P.C.-Medium Level		$2200	
Claim Handling Expense	1%	2.5%	3%

OWNER'S BUILDERS' RISK SUBMODEL (continued)

		VALUE	
VARIABLE NAME	**LOW**	**NOMINAL**	**HIGH**
*Primary Premium Rate(P.P.R.) $\mid 25^K$ DED.,			
P.L.C.-5^M, M.C.-Fair	0.18/\$100	0.29/\$100	0.40/\$100
P.L.C.-10^M, M.C.-Fair		0.48/\$100	
P.L.C.-1^M, M.C.-Fair		0.14/\$100	
P.L.C.-5^M, M.C.-Poor		0.36/\$100	
P.L.C.-5^M, M.C.-Good		0.26/\$100	
*P.P.R. $\mid 100^K$ DED.,			
P.L.C.-5^M, M.C.-Fair	0.13/\$100	0.20/\$100	0.28/\$100
P.L.C.-10^M, M.C.-Fair		0.34/\$100	
P.L.C.-1^M, M.C.-Fair		0.10/\$100	
P.L.C.-5^M, M.C.-Poor		0.25/\$100	
P.L.C.-5^M, M.C.-Good		0.18/\$100	
*P.P.R. $\mid 1^K$ DED.,			
P.L.C.-5^M, M.C.-Fair	0.31/\$100	0.49/\$100	0.68/\$100
P.L.C.-10^M, M.C.-Fair		0.82/\$100	
P.L.C.-1^M, M.C.-Fair		0.24/\$100	
P.L.C.-5^M, M.C.-Poor		0.61/\$100	
P.L.C.-5^M, M.C.-Good		0.44/\$100	
*Umbrella Premium Rate(U.P.R.) $\mid$ U.L.C. 45^M,			
M.C.-Fair	0.23/\$100	0.36/\$100	0.50/\$100
M.C.-Good		0.26/\$100	
M.C.-Poor		0.44/\$100	

*(premium rate quoted in \$/\$100 of contract value)

OWNER'S BUILDERS' RISK SUBMODEL (continued)

VARIABLE NAME	VALUE LOW	 NOMINAL	 HIGH
*Umbrella Premium Rate|U.L.C.-25^{M},			
M.C.-Fair	0.14/\$100	0.22/\$100	0.30/\$100
M.C.-Good		0.20/\$100	
M.C.-Poor		0.27/\$100	

*(premium rate quoted in \$/\$100 of contract value)

DETERMINISTIC RANGES

CONTRACTOR'S BUILDERS' RISK SUBMODEL

(dollar amounts with ,000's omitted)

	VALUE		
VARIABLE NAME	LOW	NOMINAL	HIGH
Owner Required Coverage	$\$20^{M}$	$\$30^{M}$	$\$40^{M}$
Amount of Deductible| Wrap-up	$1	$25	$100
A.O.D.1 Conventional	$1	$10	$25
Contr. Loss Control Program|			
1^{K} DED. and 10^{K} DED.		Low	
25^{K} DED.		Medium	
100^{K} DED.		High	
Cost of Loss Control Program|			
C.L.C.P.-L		$2	
C.L.C.P.-H		$200	
C.L.C.P.-M	$5	$20	$50
# of Losses |C.L.C.P.-M	10	50	200
# of Losses |C.L.C.P.-H		20	
# of Losses |C.L.C.P.-L		100	
# of Claims |C.L.C.P.-M, 1^{K} DED.	10	20	50
# of Claims |C.L.C.P.-M,10^{K} DED.	0	1	2
# of Claims |C.L.C.P.-M,25^{K} DED.	0	0.2	1
# of Claims |C.L.C.P.-M,100^{K} DED.	0	0	0
# of Claims |C.L.C.P.-H, 1^{K} DED.		10	
# of Claims |C.L.C.P.-H,10^{K} DED.		0.5	
# of Claims |C.L.C.P.-H,25^{K} DED.		0.1	

CONTRACTOR'S BUILDERS' RISK SUBMODEL (continued)

	VALUE		
VARIABLE NAME	LOW	NOMINAL	HIGH
# of Claims | C.L.C.P.-H,100^K DED.		0	
# of Claims | C.L.C.P.-L, 1^K DED.		50	
# of Claims | C.L.C.P.-L,10^K DED.		2	
# of Claims | C.L.C.P.-L,25^K DED.		0.5	
# of Claims | C.L.C.P.-L,100^K DED.		0	
Claim Processing Delay | Wrap-up	0.5 yr.	1 yr.	3 yrs.
C.P.D. | Conventional	0.5 yr.	0.75 yr.	1 yr.
Fixed Overhead Rate		-- $5/week --	
Opportunity Cost of Funds		-- 9% --	
Percent Claims Uninsurable | Wrap-up	1/4%	1/2%	1%
P.C.U. | Conventional	0	0	0
Project Delay | Wrap-up	1 week	3 weeks	5 weeks
P.D. | Conventional	1 week	3 233ks	5 weeks
Brokers' Fee		-- 15% --	
Total Amount of Losses |C.L.C.P.-H		20	
Total Amount of Losses |C.L.C.P.-M	26	52	78
Total Amount of Losses |C.L.C.P.-L		108	
Total Amount of Claims |CL.C.P.-L,			
1^K DED.		20	
10^K DED.		0	
25^K DED.		0	
100^K DED.		0	

CONTRACTOR'S BUILDERS' RISK SUBMODEL (continued)

VARIABLE NAME	VALUE LOW	NOMINAL	HIGH
Total Amount of Claims | C.L.C.P.-M			
1^K DED.	2	5	10
10^K DED.	0.2	0.5	1
25^K DED.	0.1	0.2	0.5
100^K DED.	0	0	0
Total Amount of Claims | C.L.C.P.-H,			
1^K DED.		2	
10^K DED.		0	
25^K DED.		0	
100^K DED.		0	
*Premium Rate (5^M Basic Level)			
25^K DED.	0.08/$100	0.21/$100	0.28/$100
*Premium Rate (15^M excess 5^M)			
25^K DED.	0.04/$100	0.10/$100	0.14/$100
*Premium Rate (20^M excess 20^M)			
25^K DED.	0.01/$100	0.03/$100	0.05/$100

FOR DEDUCTIBLE = 1^K INCREASE PREMIUMS BY 70%

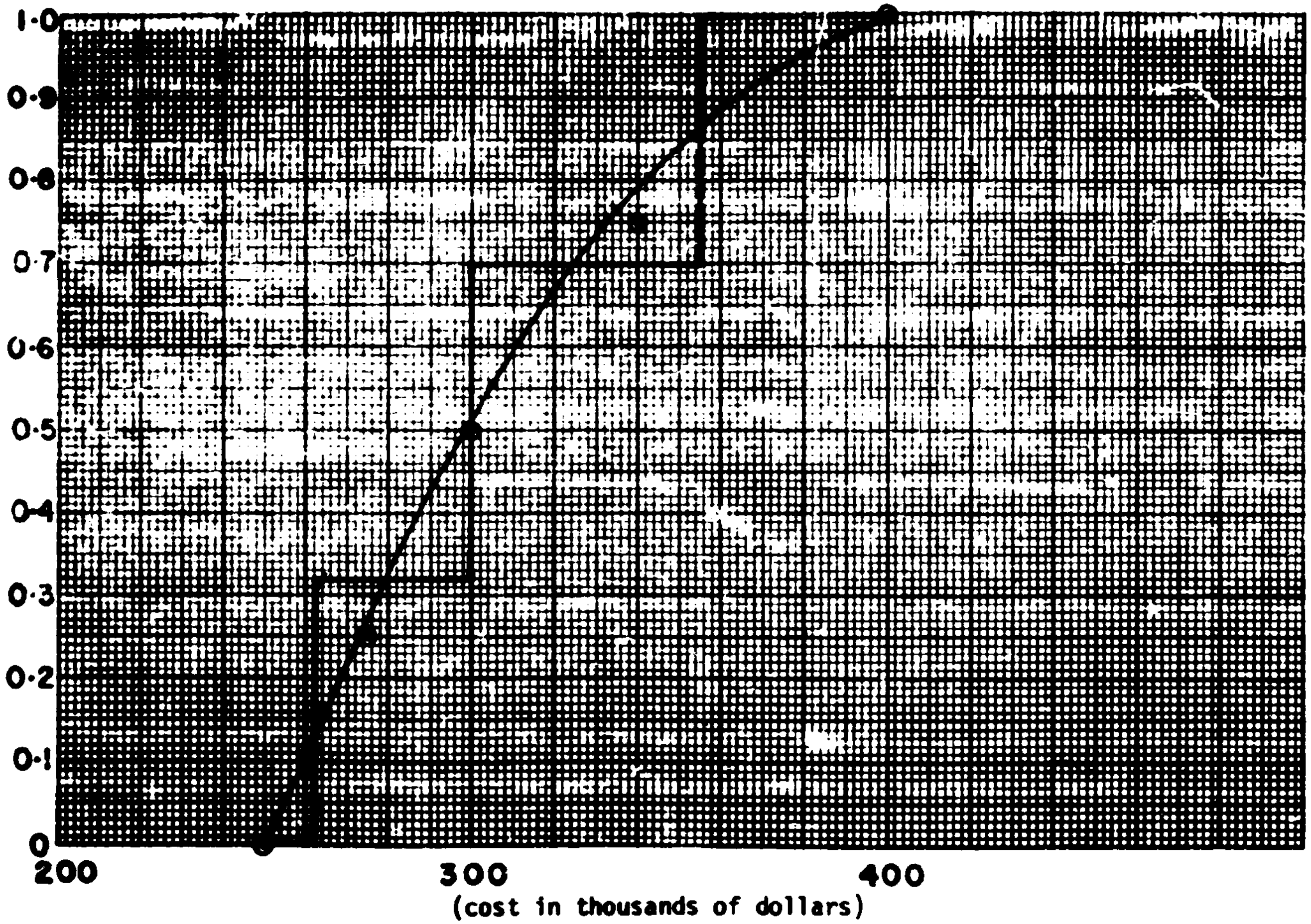
FOR DEDUCTIBLE = 10^K INCREASE PREMIUMS BY 30%

FOR DEDUCTIBLE = 100^K DECREASE PREMIUMS BY 30%

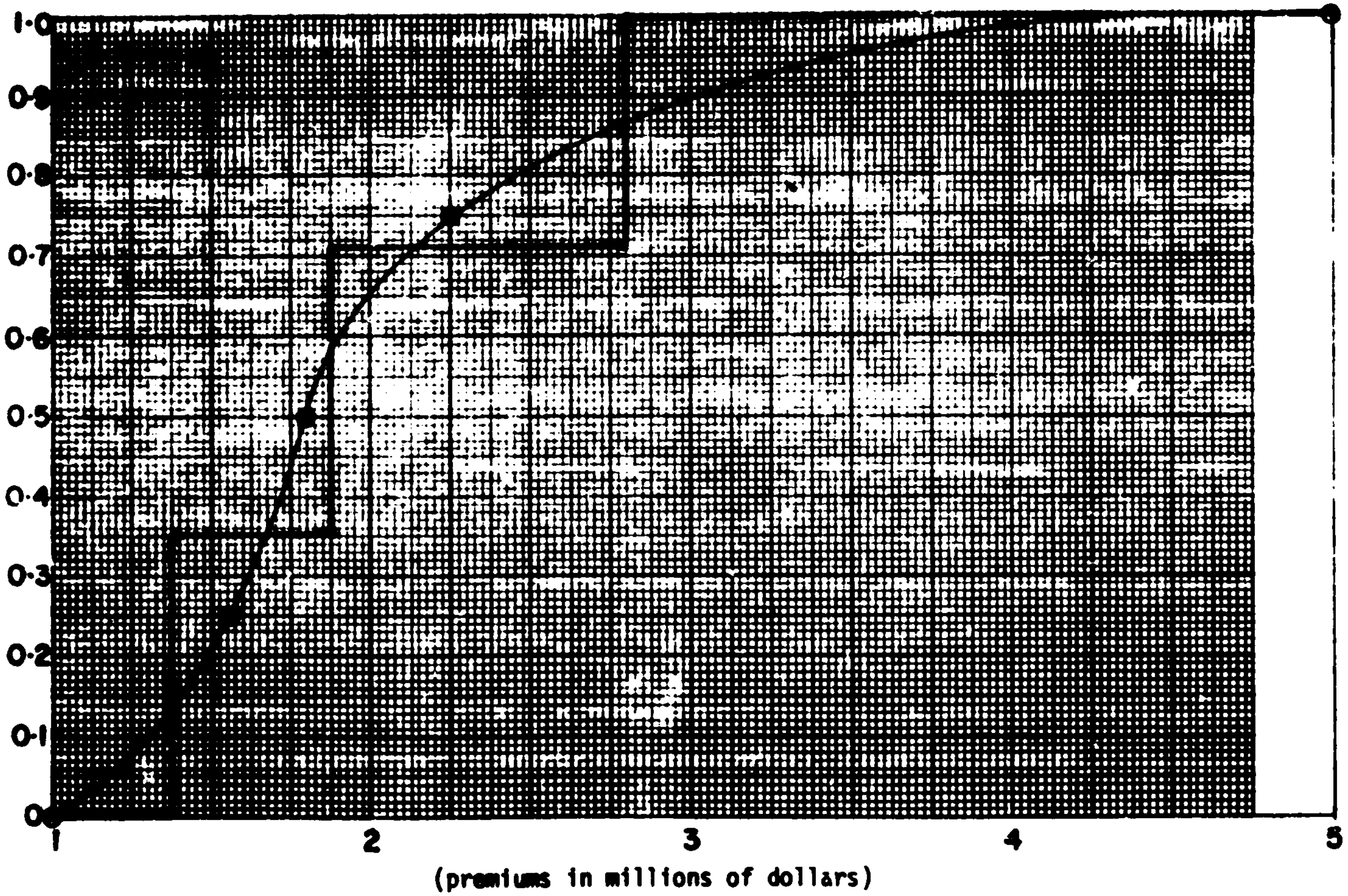
* (Premium rate quoted in $/$100 of project value)

DISCRETIZED
CUMULATIVE PROBABILITY
DISTRIBUTIONS OF
SENSITIVE VARIABLES FOR
CONTRACTOR MODEL

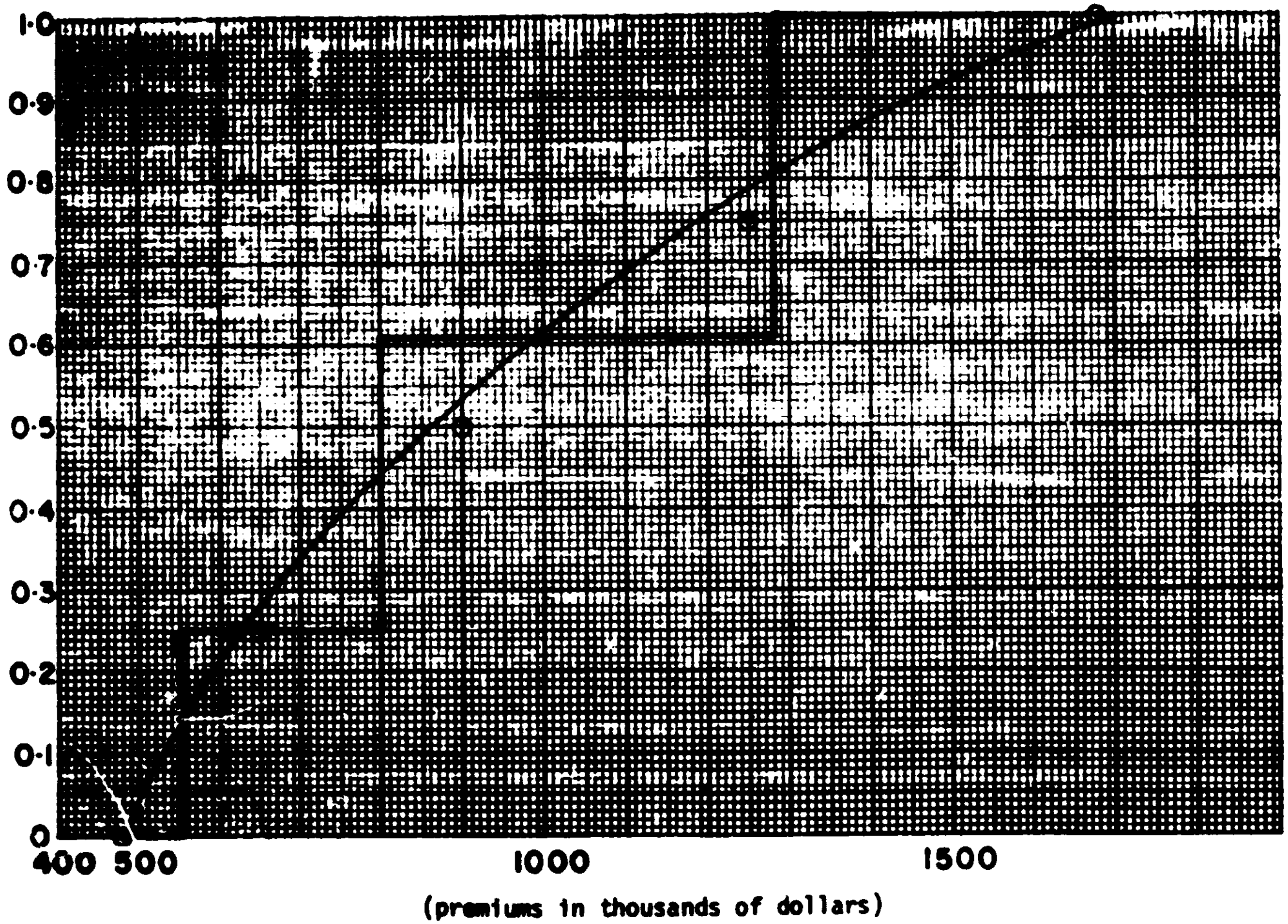
CONTRACTOR'S WORKERS' COMPENSATION SUBMODEL: CONTRACTOR SAFETY PROGRAM COSTS



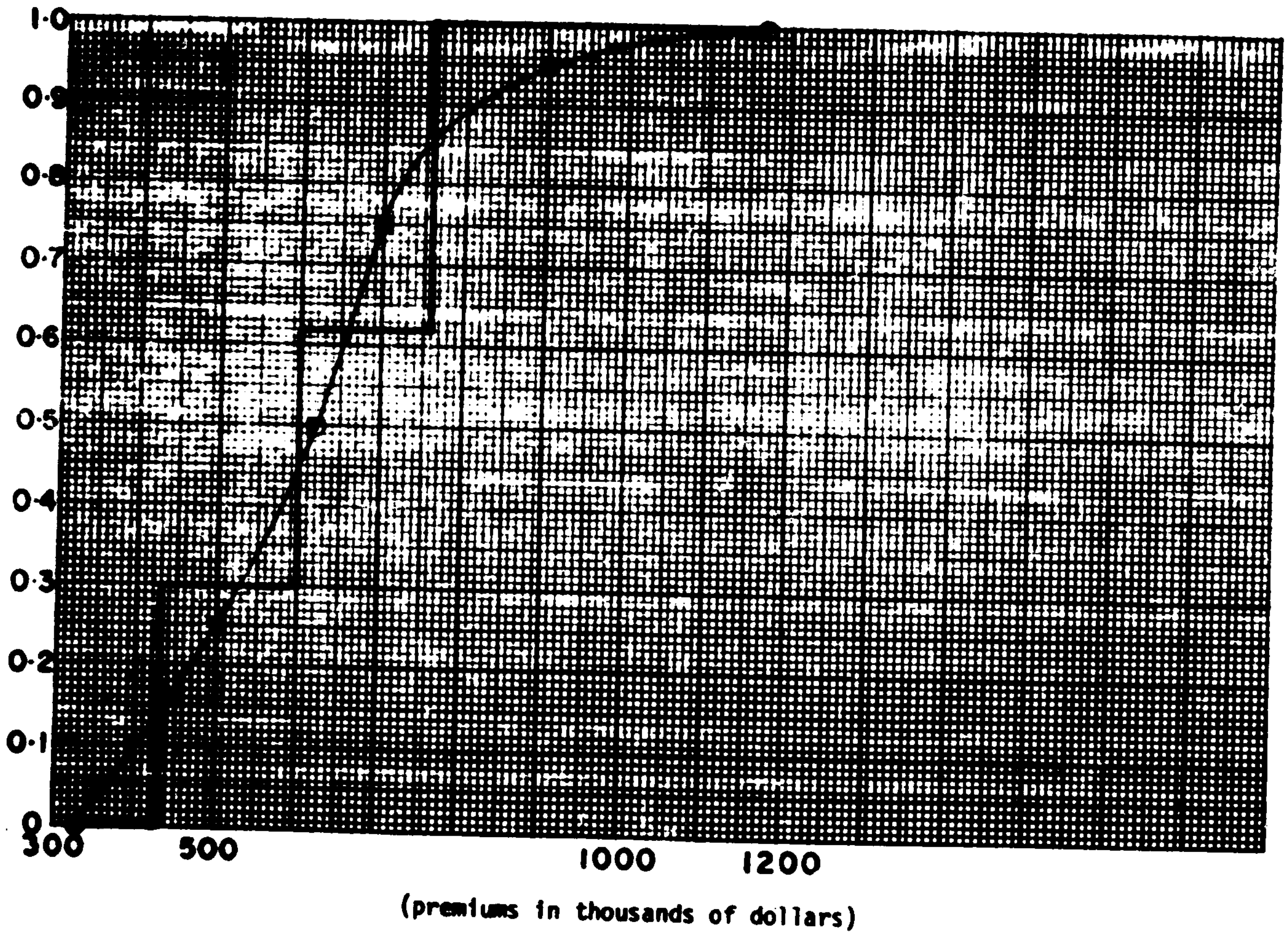
WORKERS' COMPENSATION PREMIUMS FOR CONTRACTOR SUBMODEL



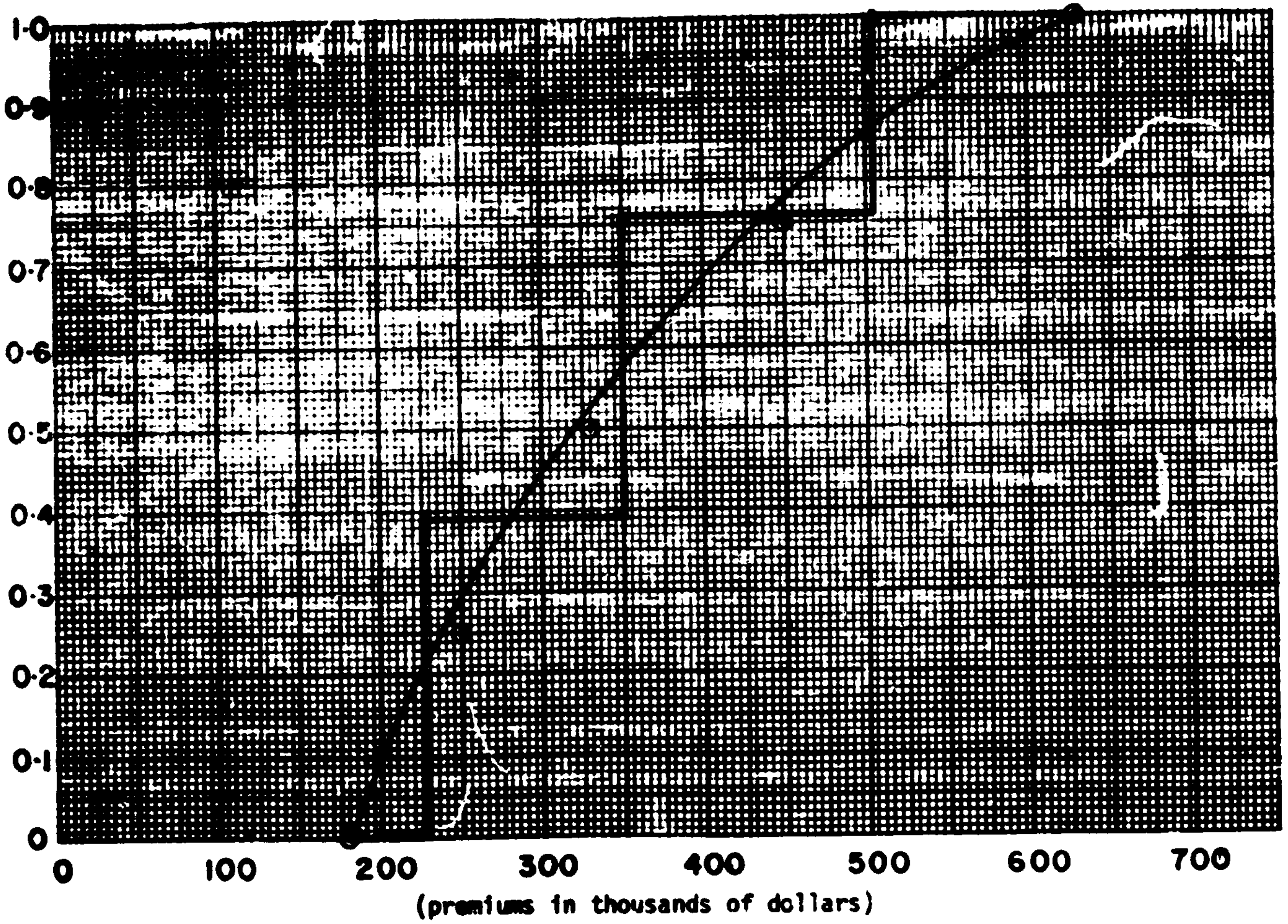
CONTRACTOR SUBMODEL: GENERAL LIABILITY PREMIUMS GIVEN 5^K DEDUCTIBLE



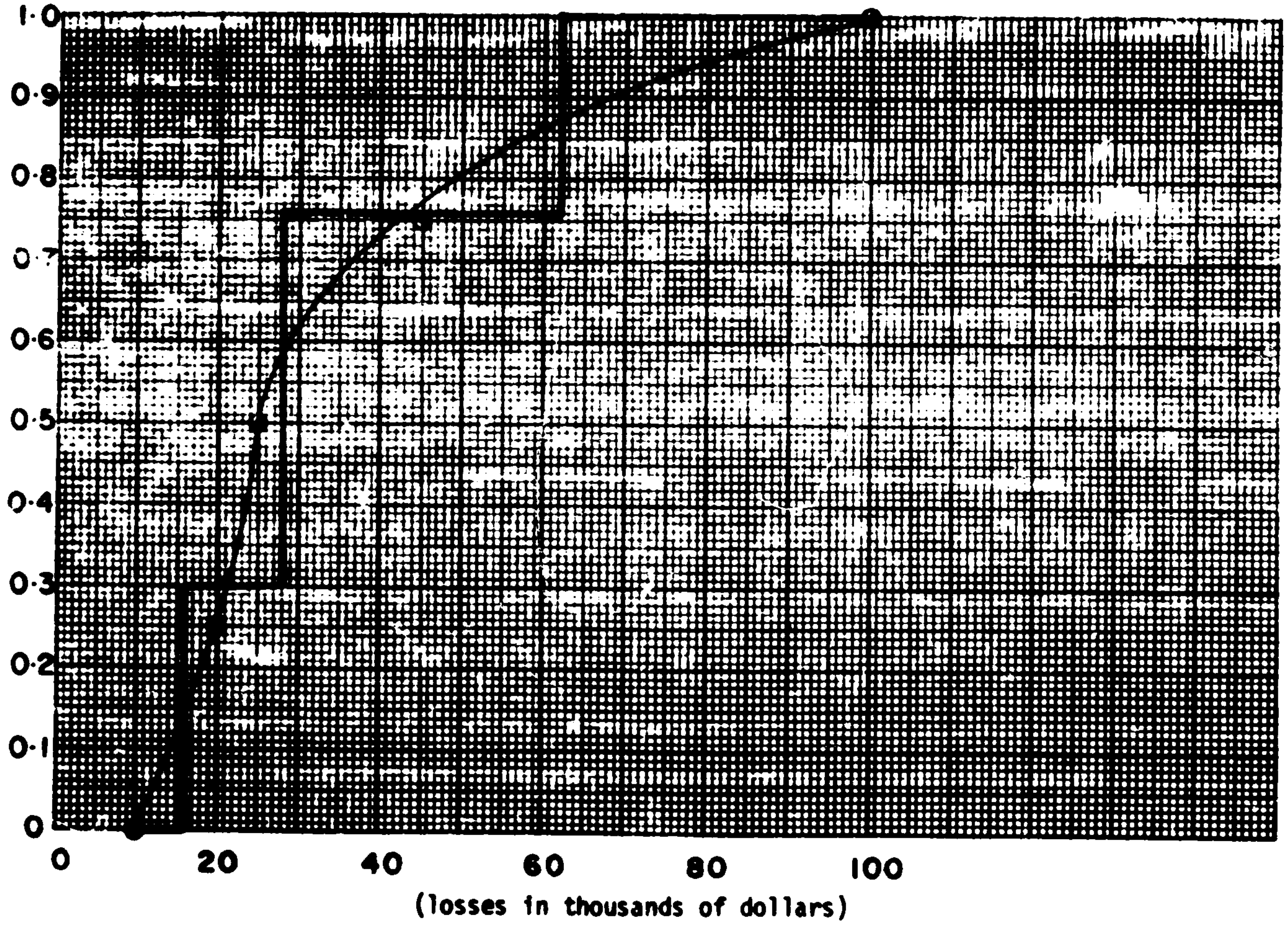
CONTRACTOR SUBMODEL: GENERAL LIABILITY PREMIUMS GIVEN 10^K DEDUCTIBLE



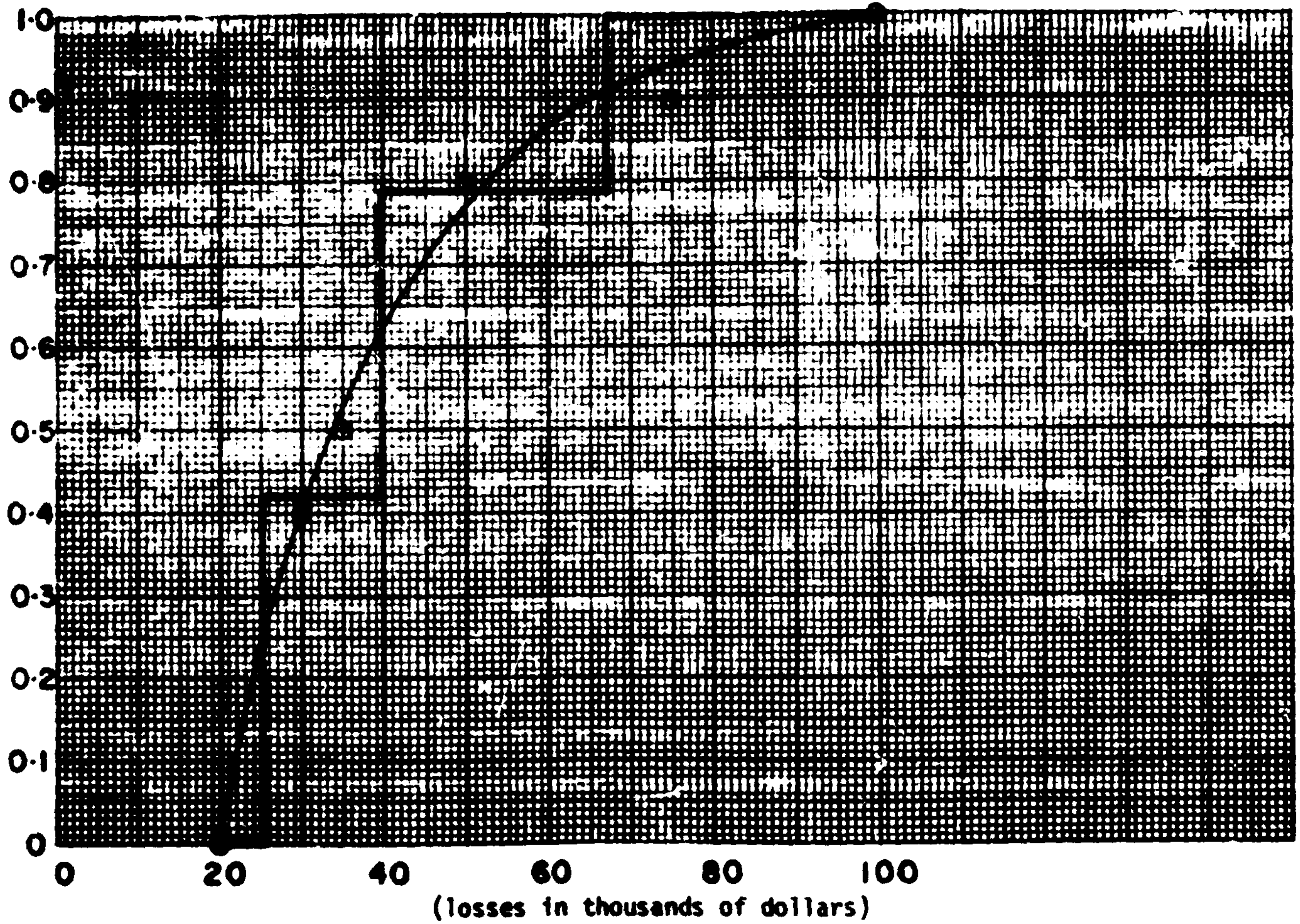
CONTRACTOR SUBMODEL: GENERAL LIABILITY PREMIUMS GIVEN 20^{K} DEDUCTIBLE



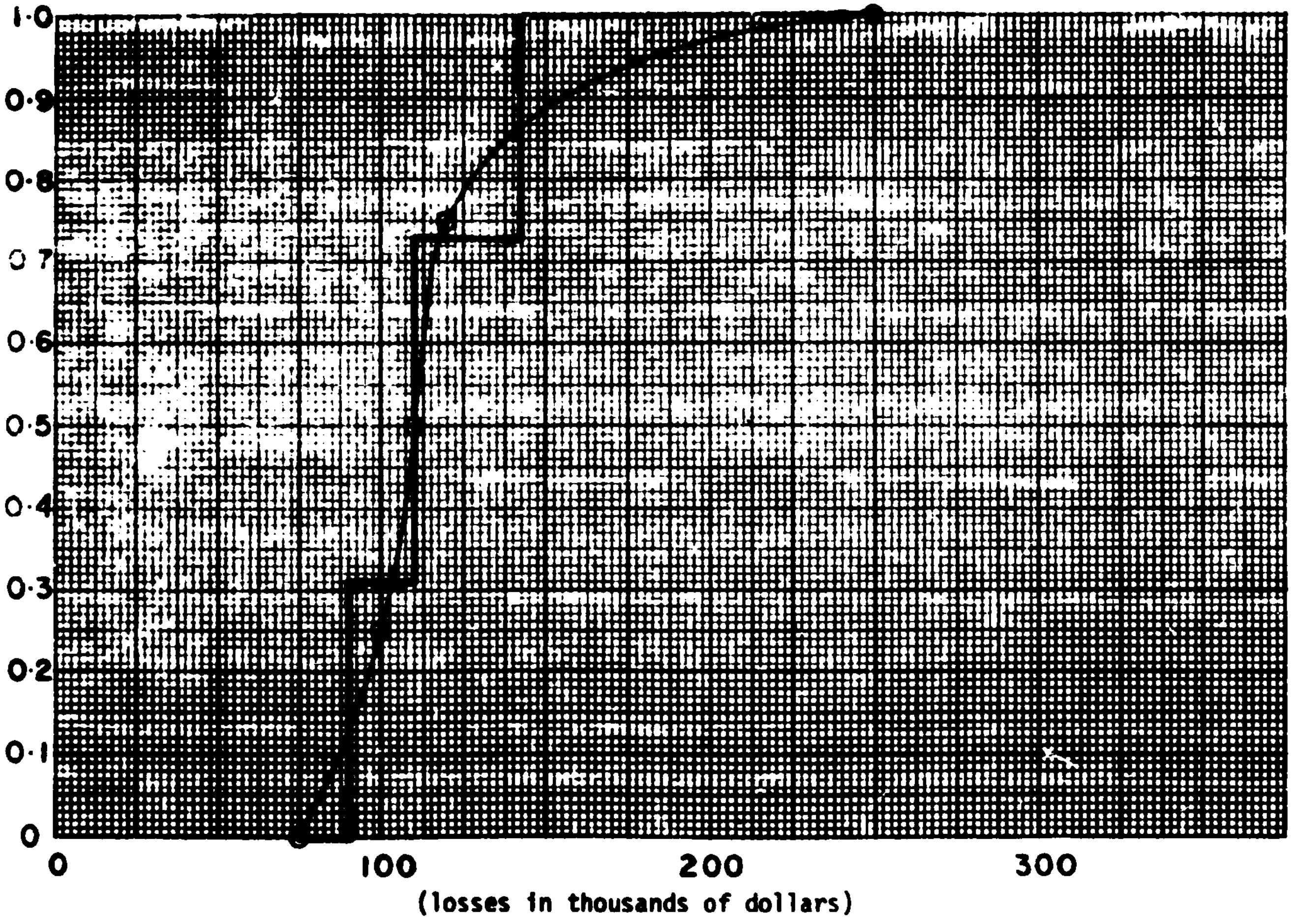
GENERAL LIABILITY LOSSES GIVEN 1^K DEDUCTIBLE, C.L.C.P. = LOW



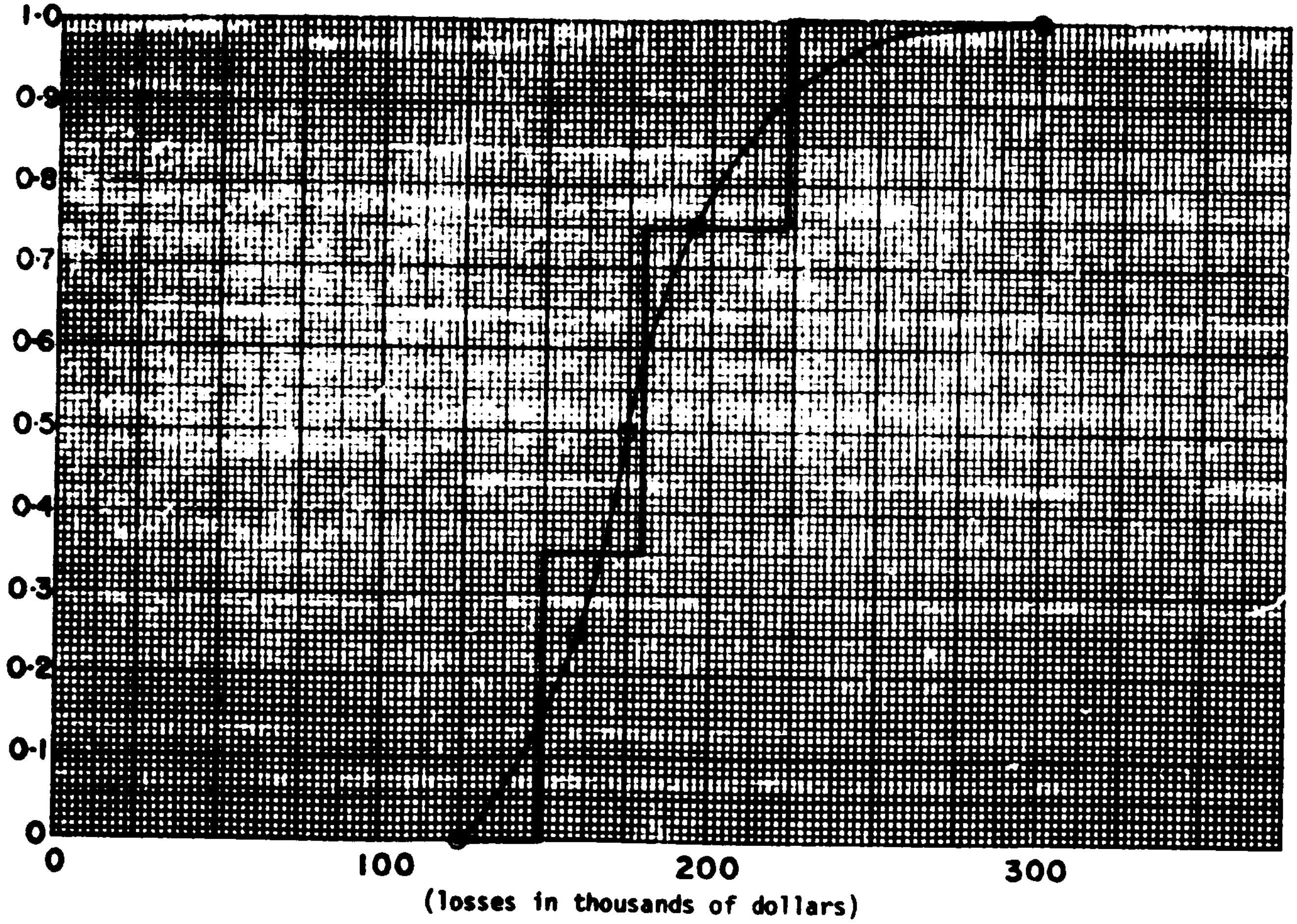
AMOUNT OF GENERAL LIABILITY LOSSES ABSORBED BY CONTRACTOR
GIVEN CONTRACTOR LOSS CONTROL PROGRAM MEDIUM, 5^K DEDUCTIBLE



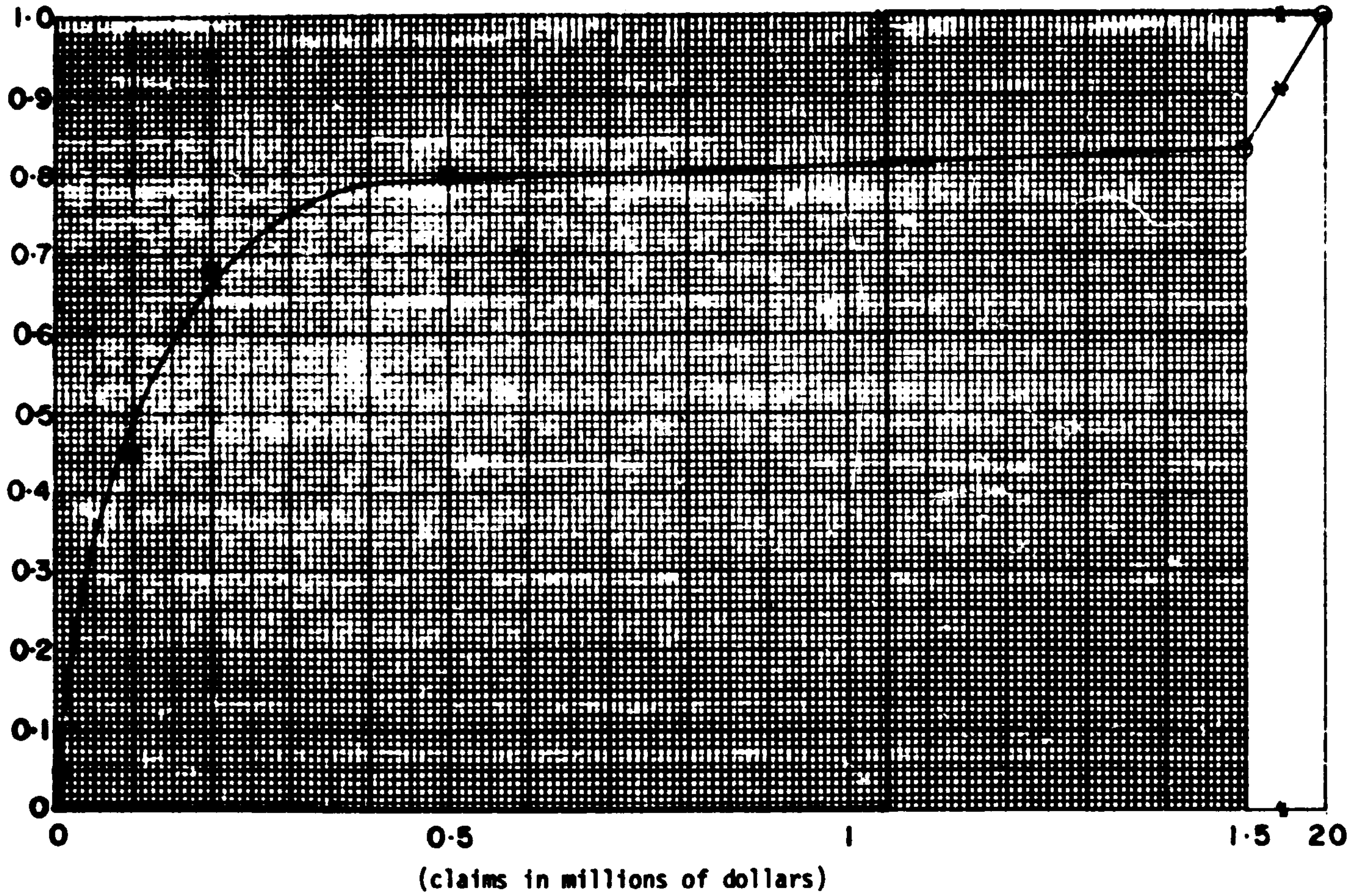
AMOUNT OF ABSORBED GENERAL LIABILITY LOSSES
GIVEN 10K DEDUCTIBLE AND MEDIUM LOSS CONTROL PROGRAM



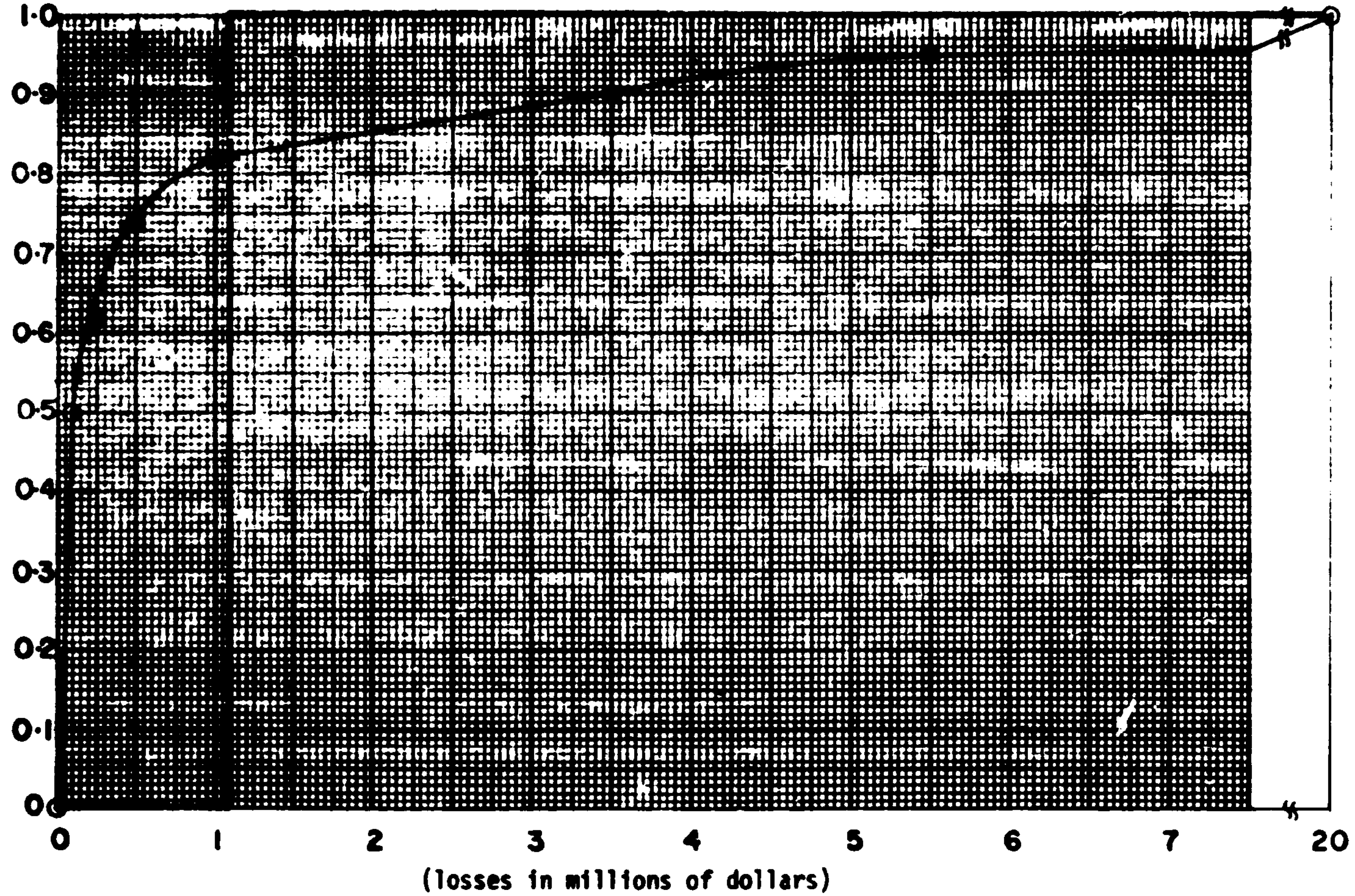
AMOUNT OF ABSORBED GENERAL LIABILITY LOSSES
GIVEN 20^K DEDUCTIBLE AND HIGH LOSS CONTROL PROGRAM



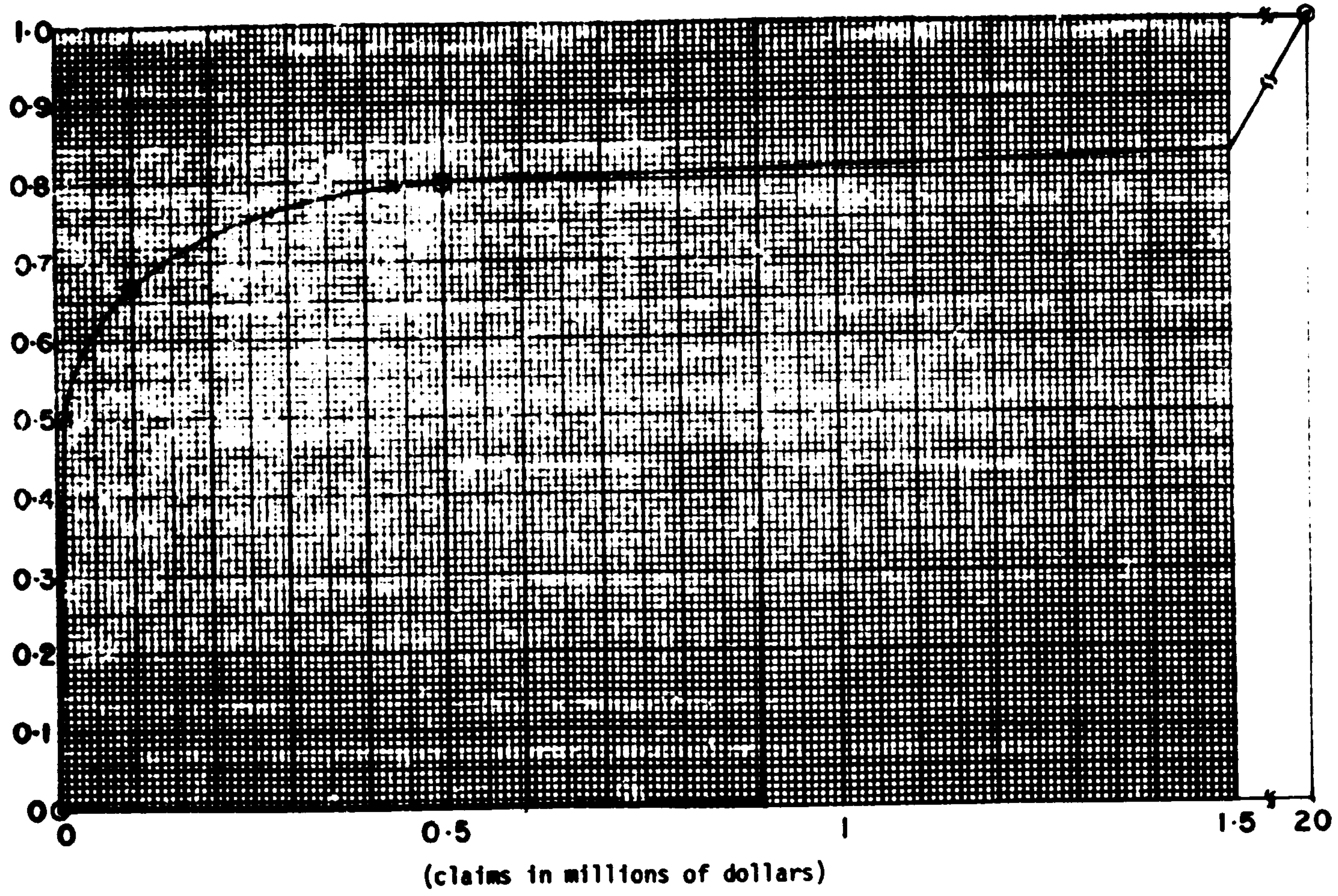
TOTAL AMOUNT OF CONTRACTOR BUILDERS' RISK CLAIMS
GIVEN 1^{K} DEDUCTIBLE AND LOW LOSS CONTROL PROGRAM



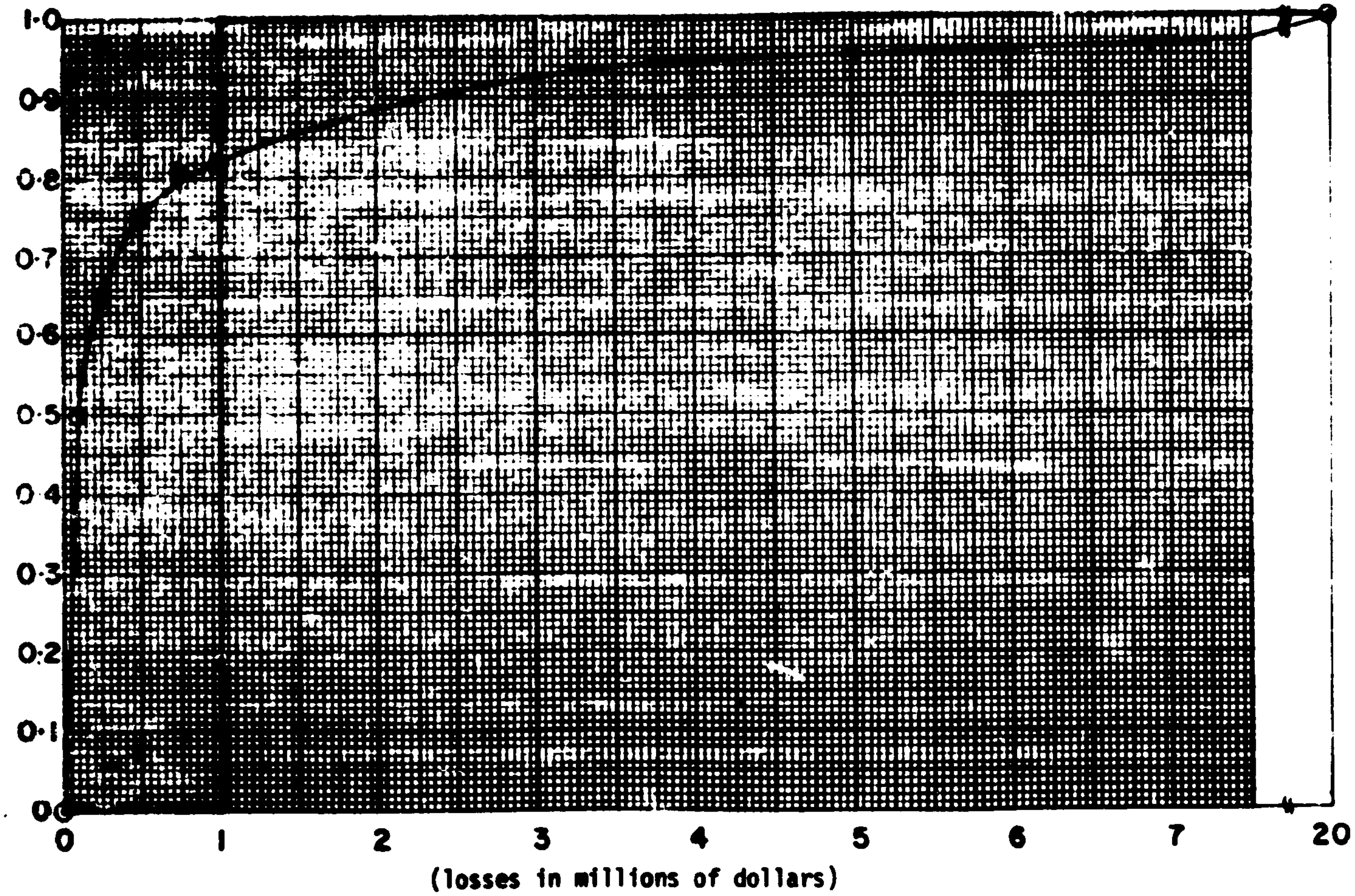
TOTAL AMOUNT OF BUILDERS' RISK LOSSES GIVEN LOW LOSS CONTROL PROGRAM



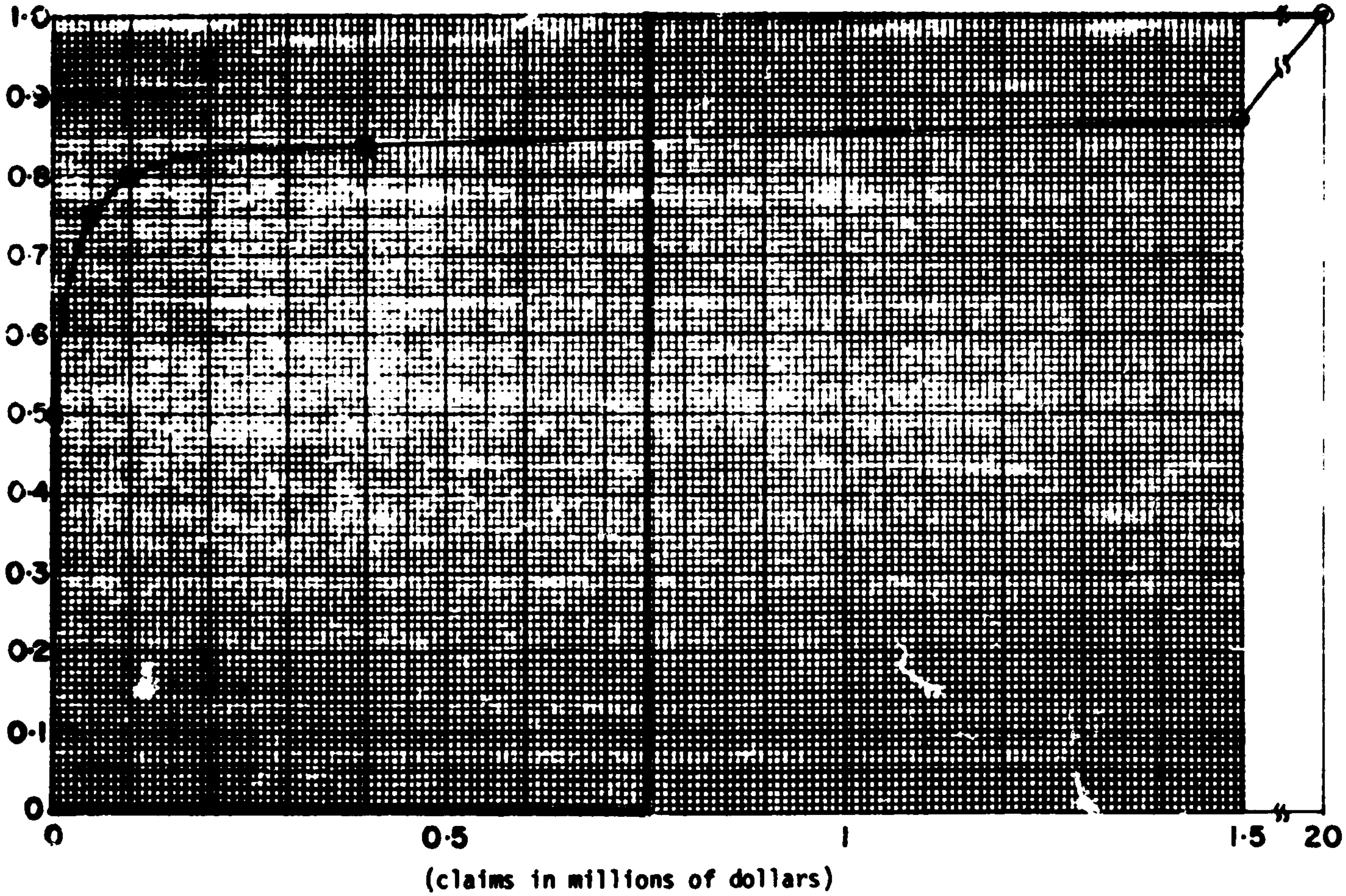
TOTAL AMOUNT OF CONTRACTOR BUILDERS' RISK CLAIMS
GIVEN 25^K DEDUCTIBLE AND MEDIUM LOSS CONTROL PROGRAM



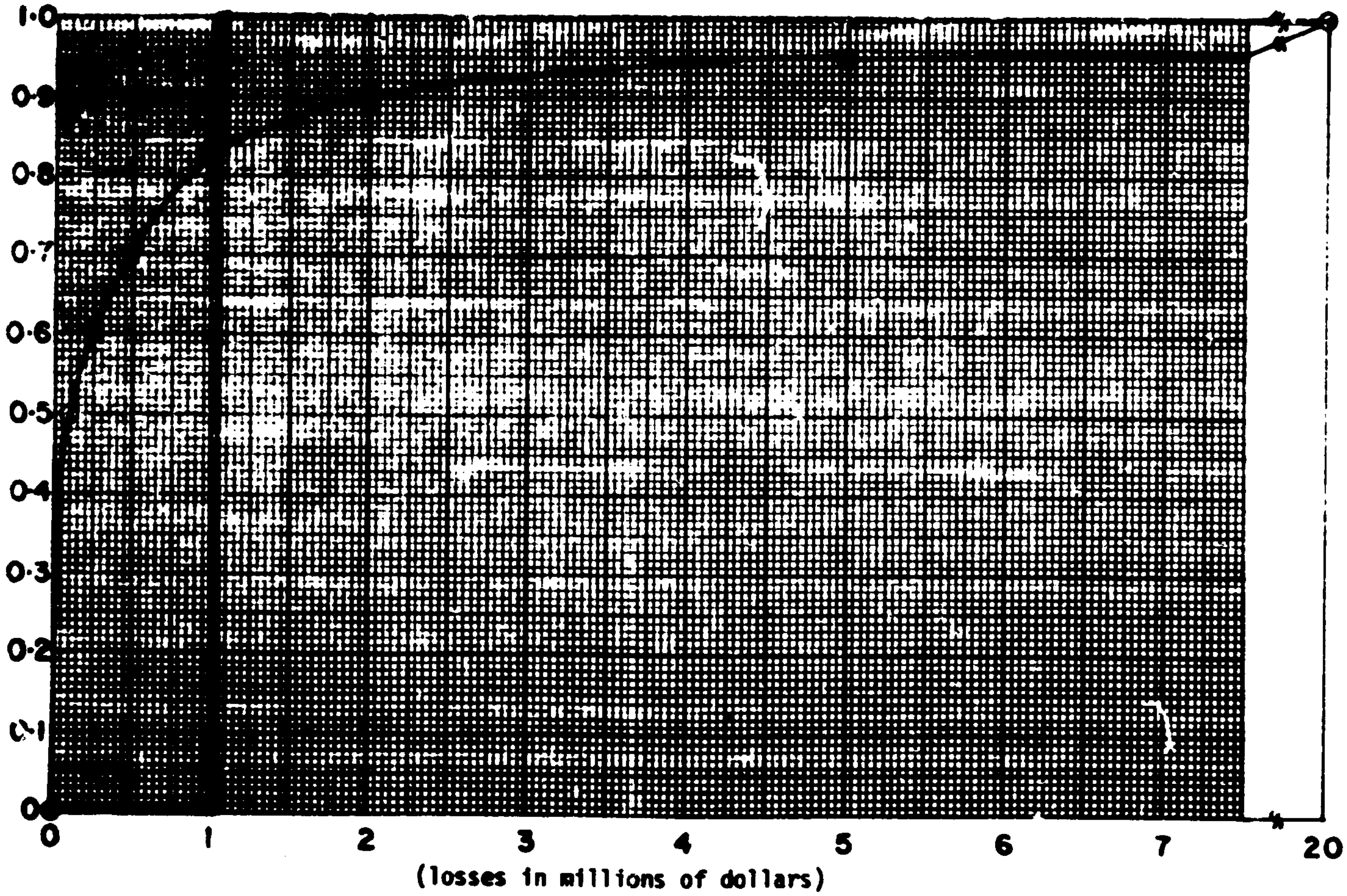
TOTAL AMOUNT OF BUILDERS' RISK LOSSES GIVEN MEDIUM LOSS CONTROL PROGRAM



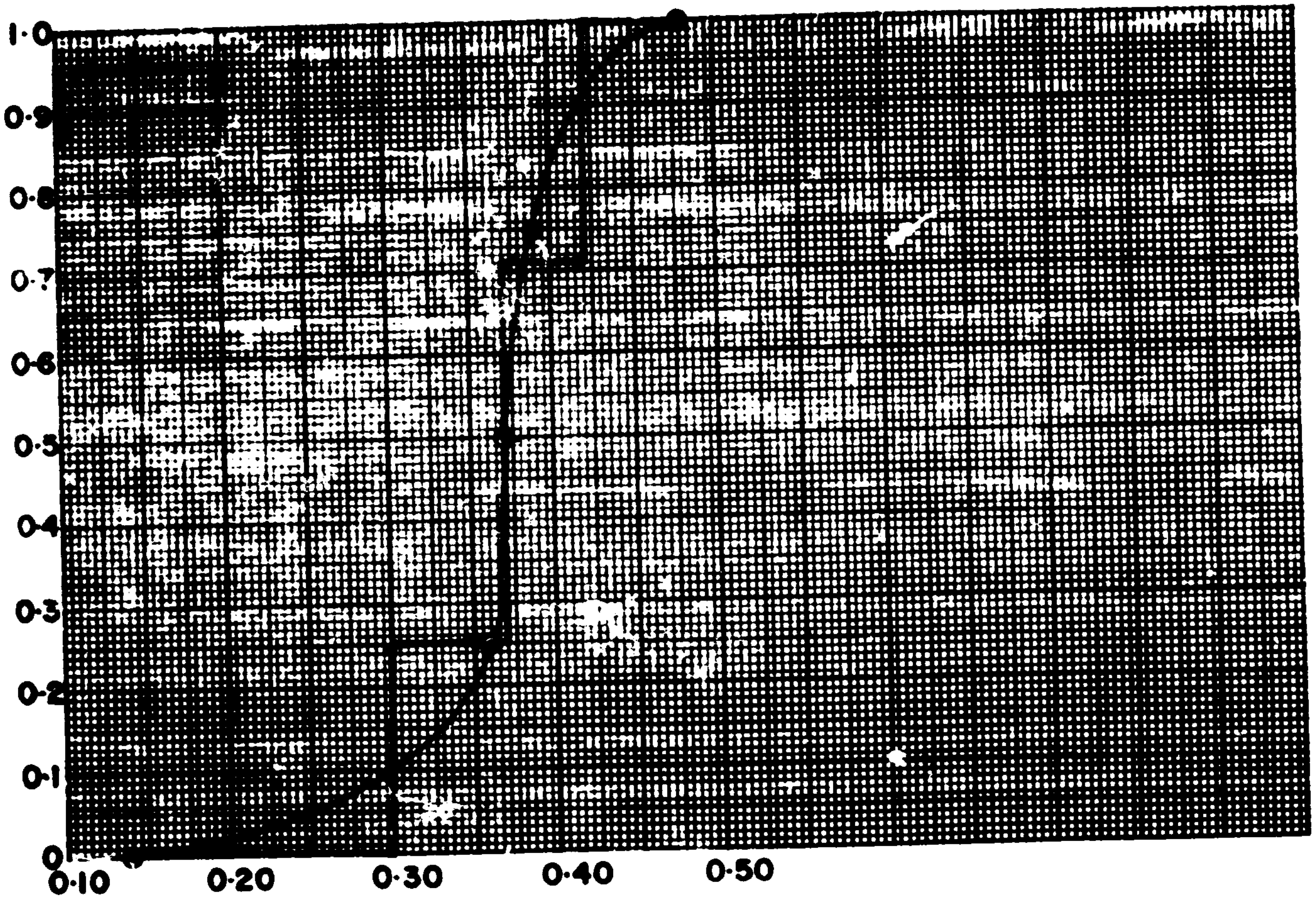
TOTAL AMOUNT OF CONTRACTOR BUILDERS' RISK CLAIMS
GIVEN 100^K DEDUCTIBLE AND HIGH LOSS CONTROL PROGRAM



TOTAL AMOUNT OF BUILDERS' RISK LOSSES GIVEN HIGH LOSS CONTROL PROGRAM

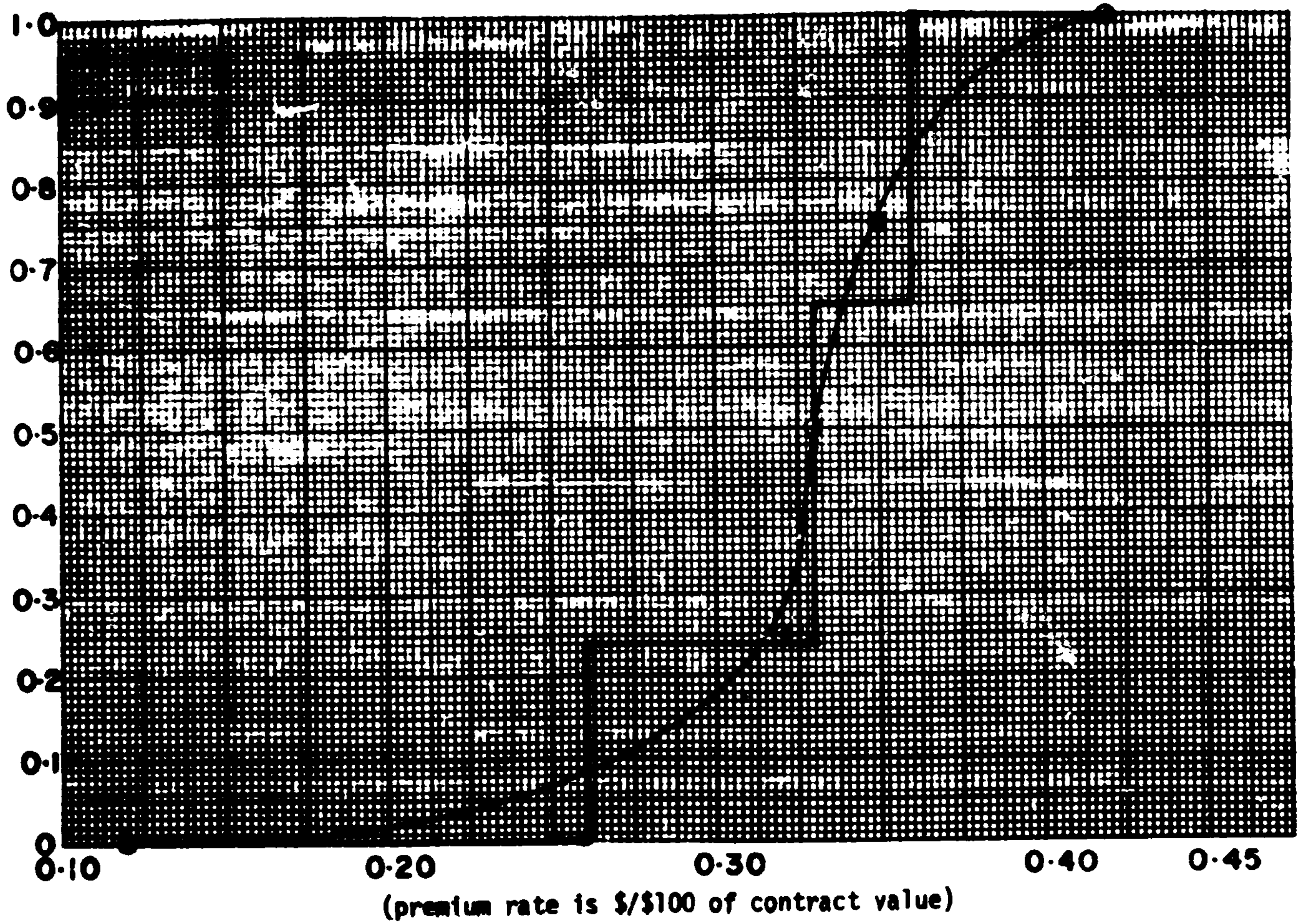


CONTRACTOR BUILDERS' RISK PREMIUMS, CONVENTIONAL CASE
GIVEN 1^K DEDUCTIBLE AT 5^M BASIC LEVEL

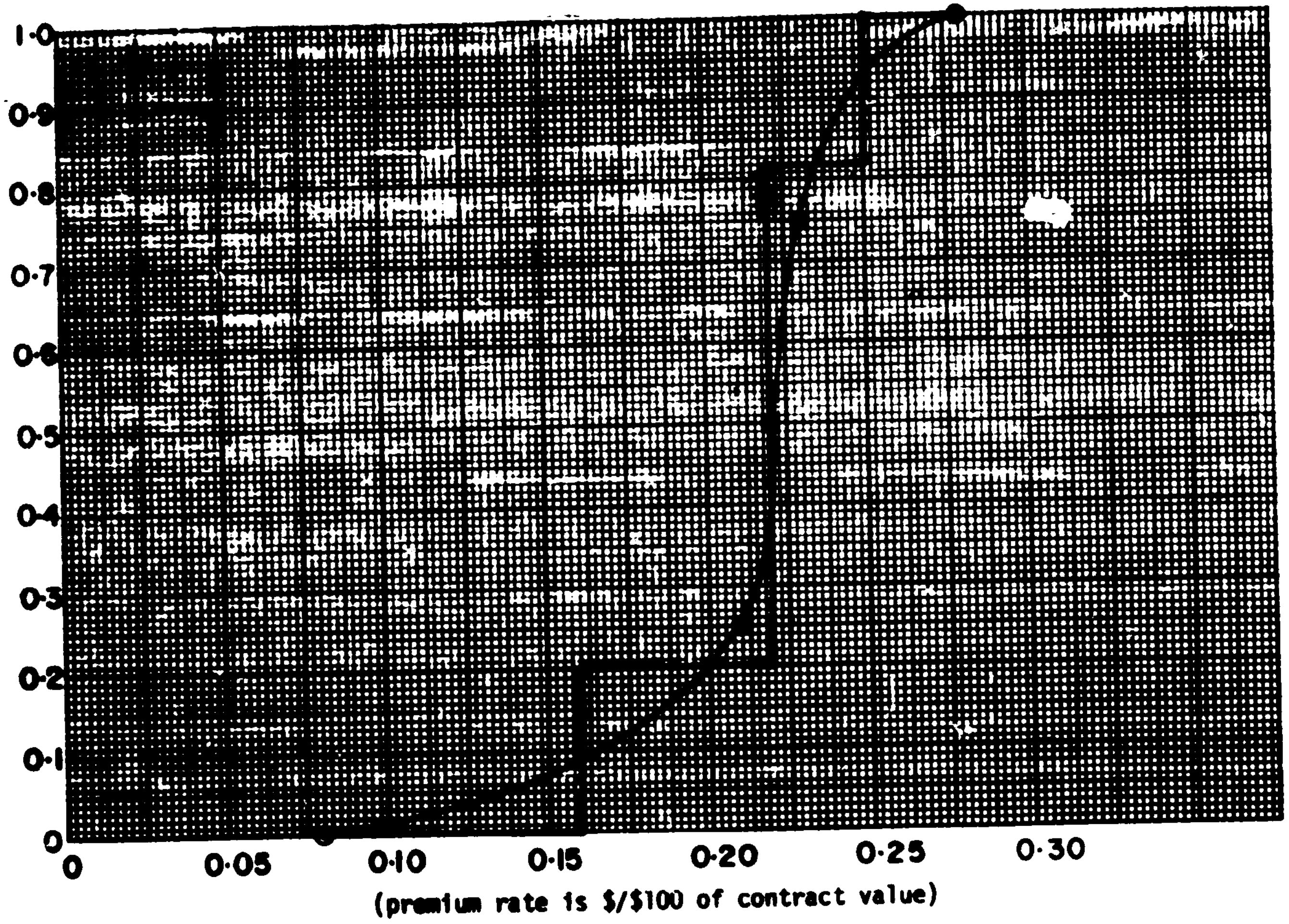


(premium rate is \$/\$100 of contract value)

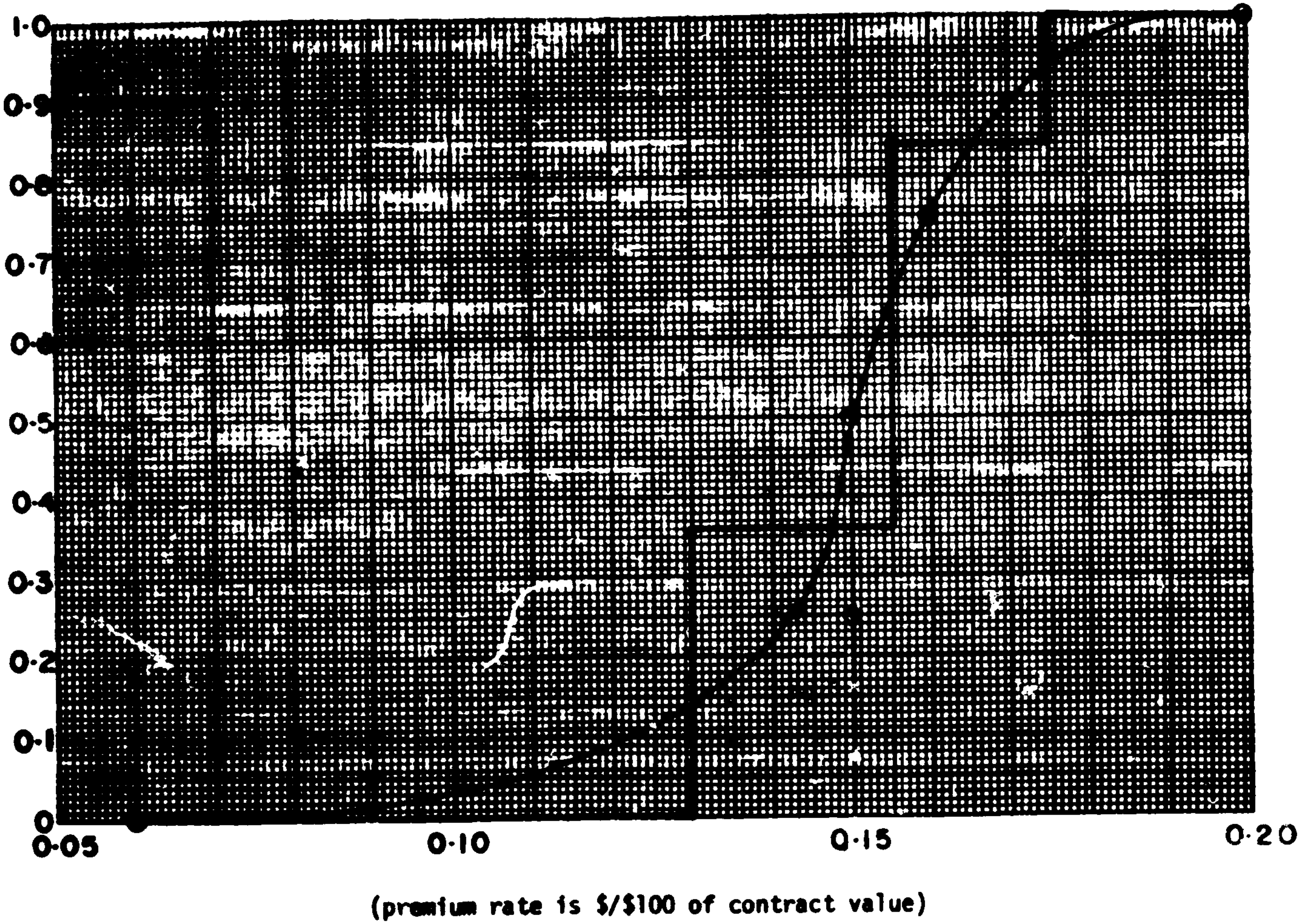
CONTRACTOR BUILDERS' RISK PREMIUMS, CONVENTIONAL CASE
GIVEN 10^K DEDUCTIBLE AT 5^M BASIC LEVEL



CONTRACTOR BUILDERS' RISK PREMIUMS, CONVENTIONAL CASE
GIVEN 25^K DEDUCTIBLE AT 5^M BASIC LEVEL

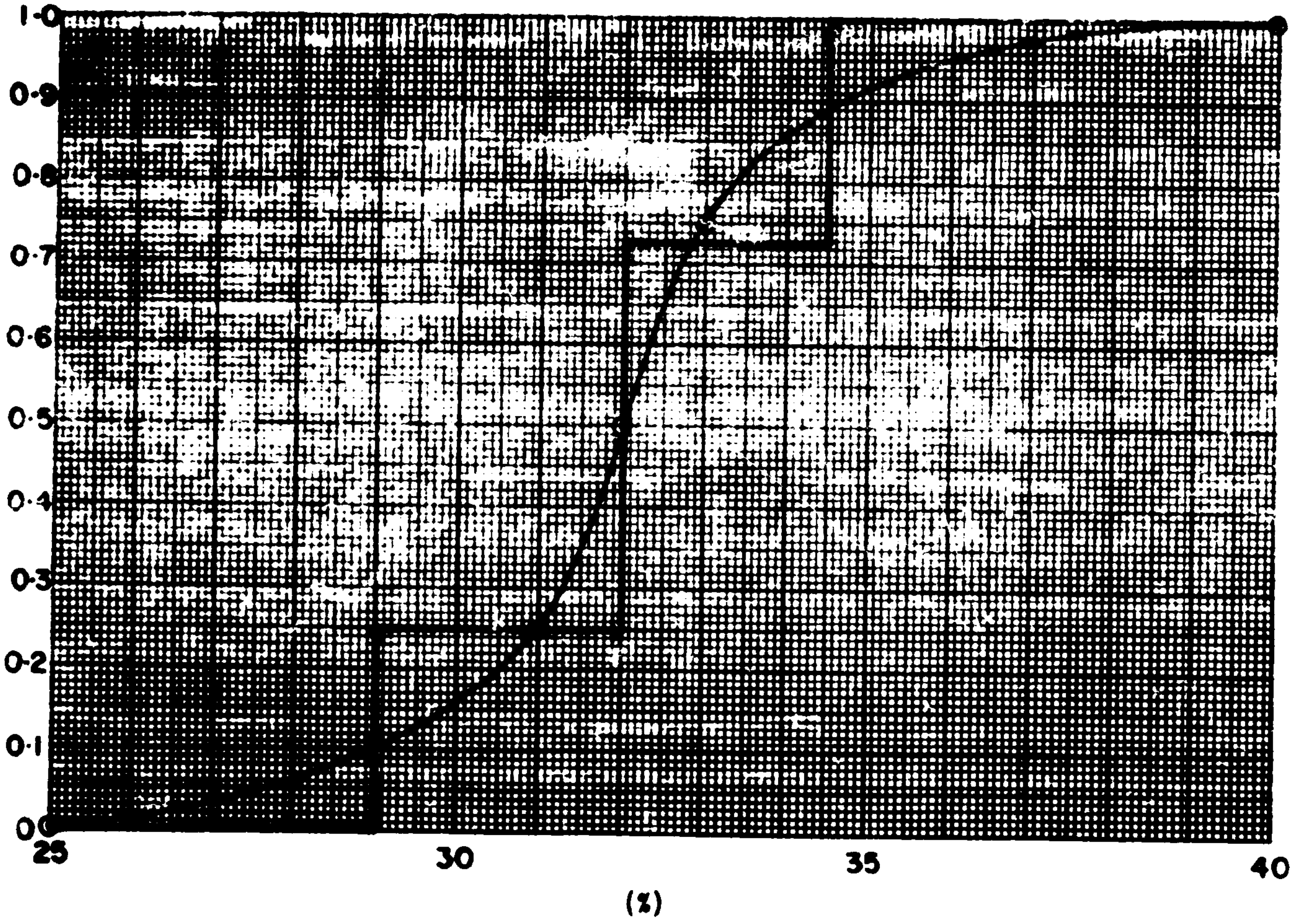


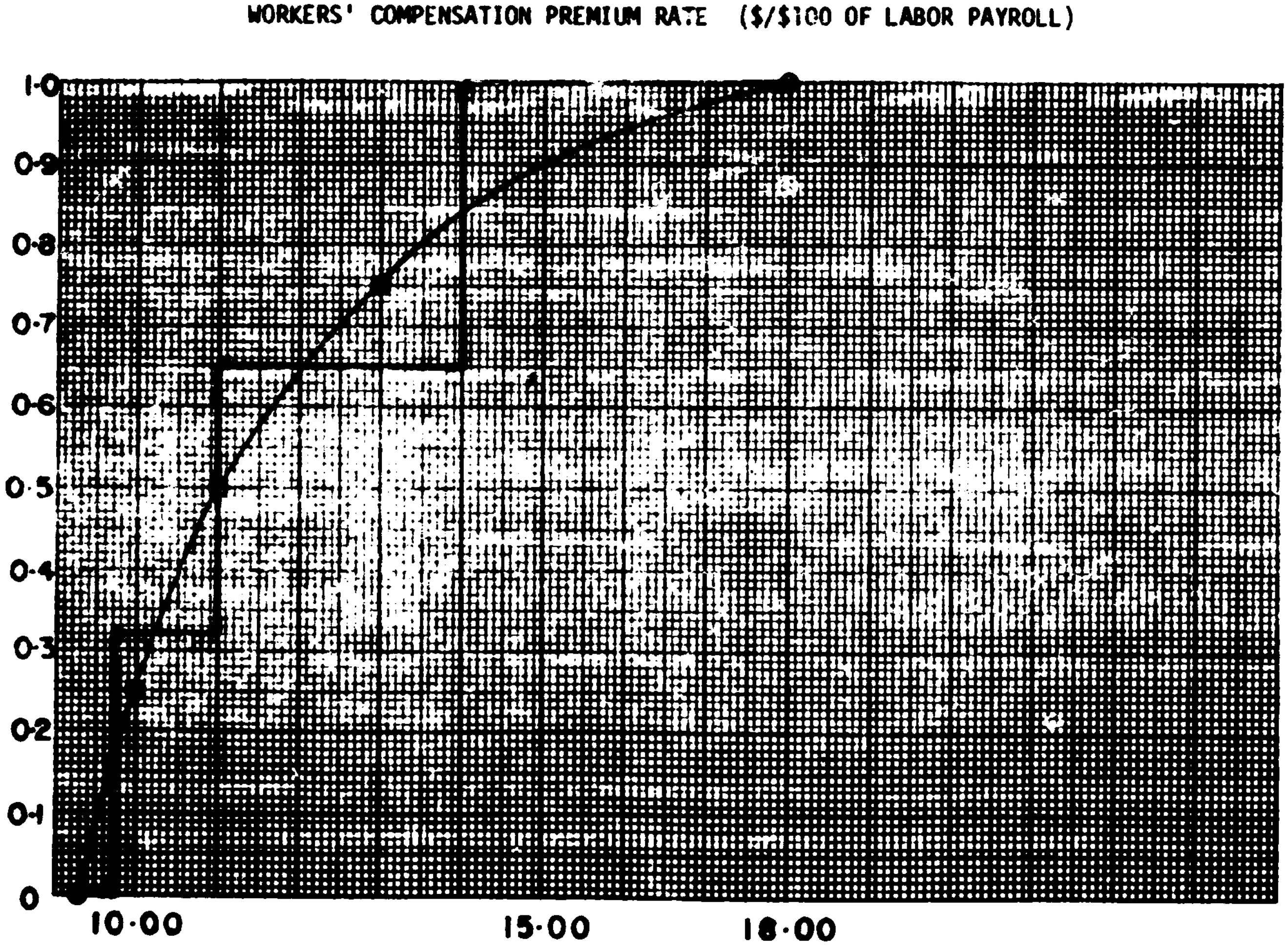
CONTRACTOR BUILDERS' RISK PREMIUMS, CONVENTIONAL CASE
GIVEN 100^K DEDUCTIBLE AT 5^M BASIC LEVEL



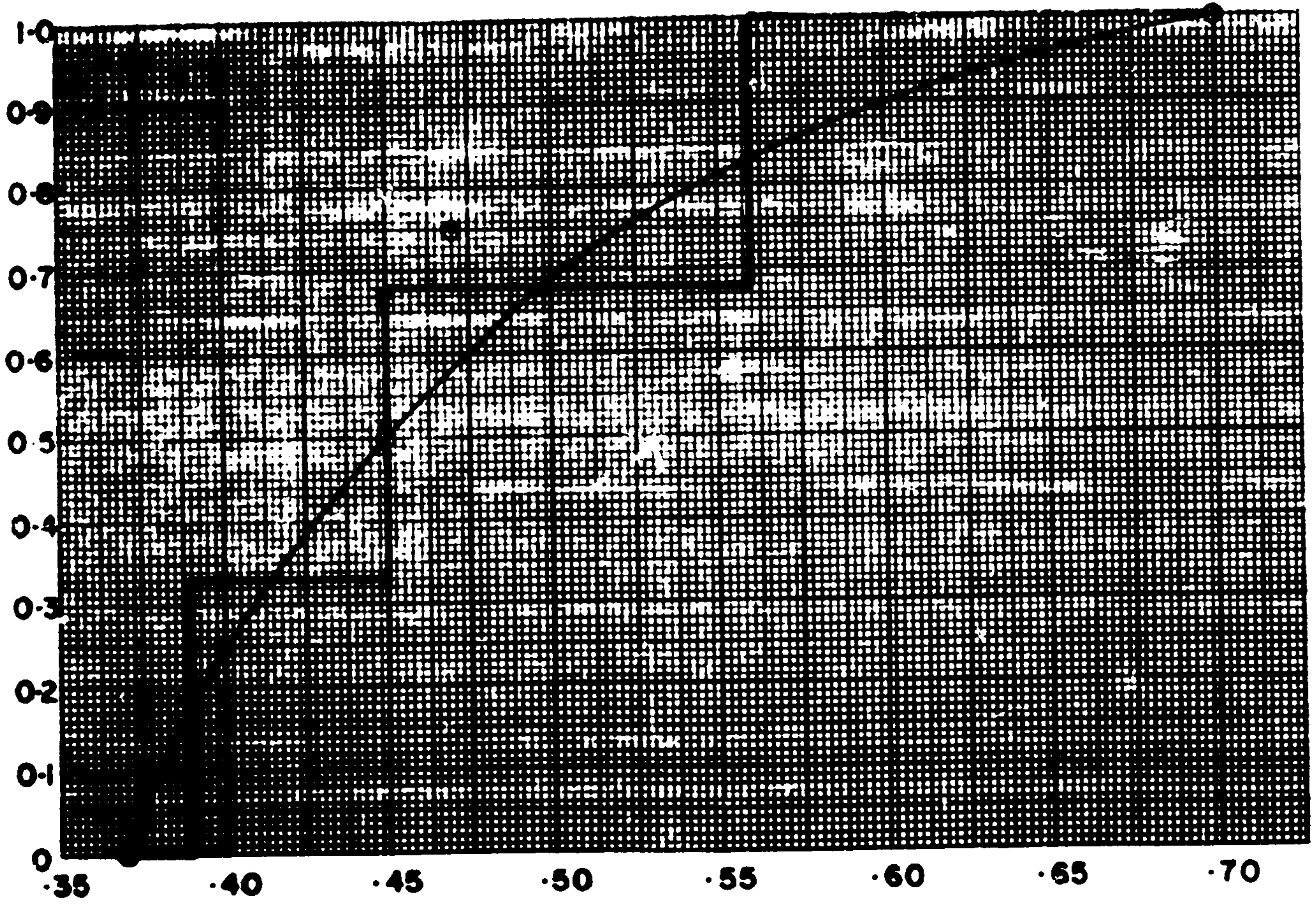
DISCRETIZED
CUMULATIVE PROBABILITY
DISTRIBUTIONS OF
SENSITIVE VARIABLES FOR
OWNER MODEL

LABOR PAYROLL DOLLARS AS A PERCENT OF PROJECT VALUE

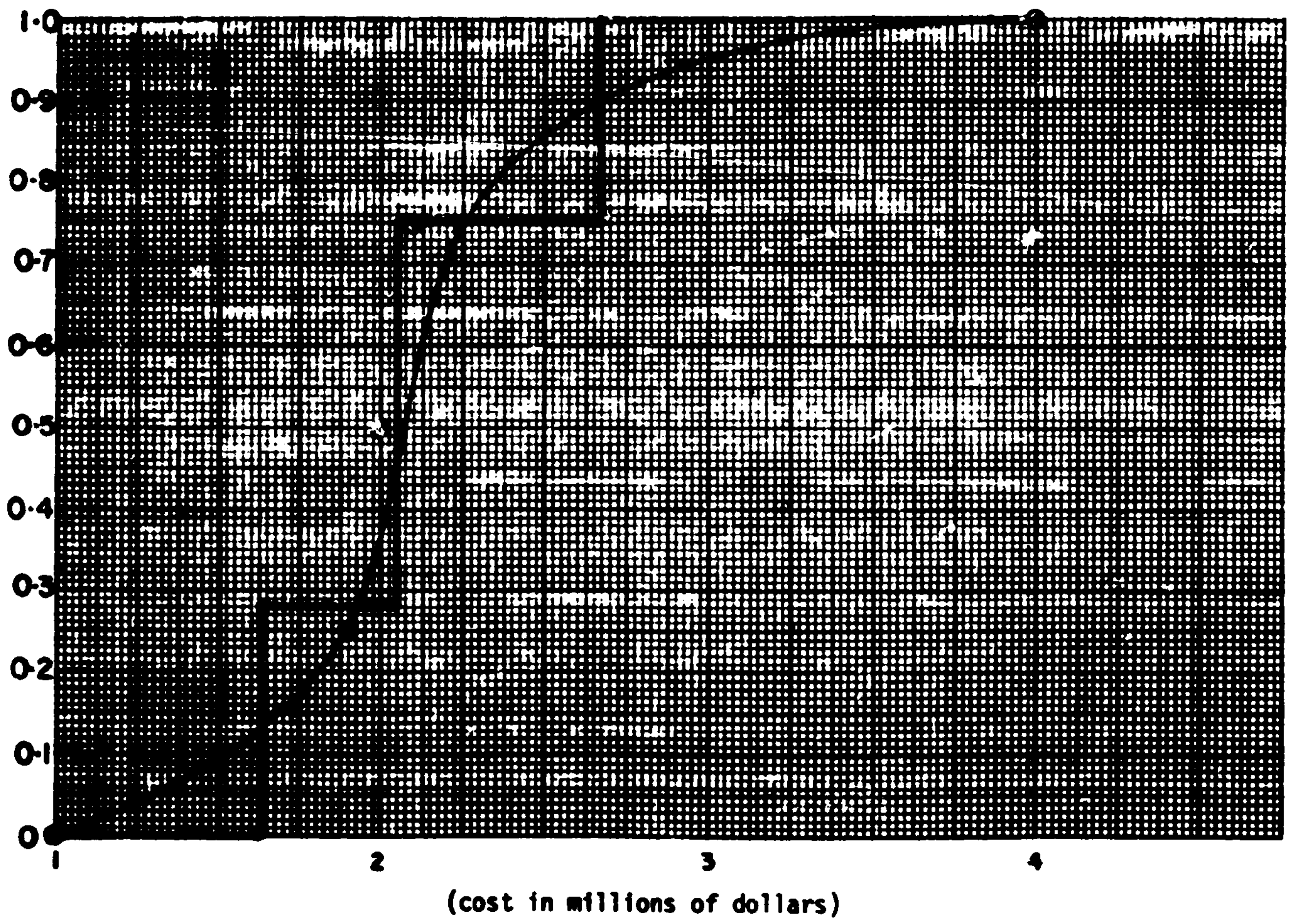



WORKERS' COMPENSATION PREMIUM RATE ($/$100 OF LABOR PAYROLL)
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0
10·00
15·00
18·00

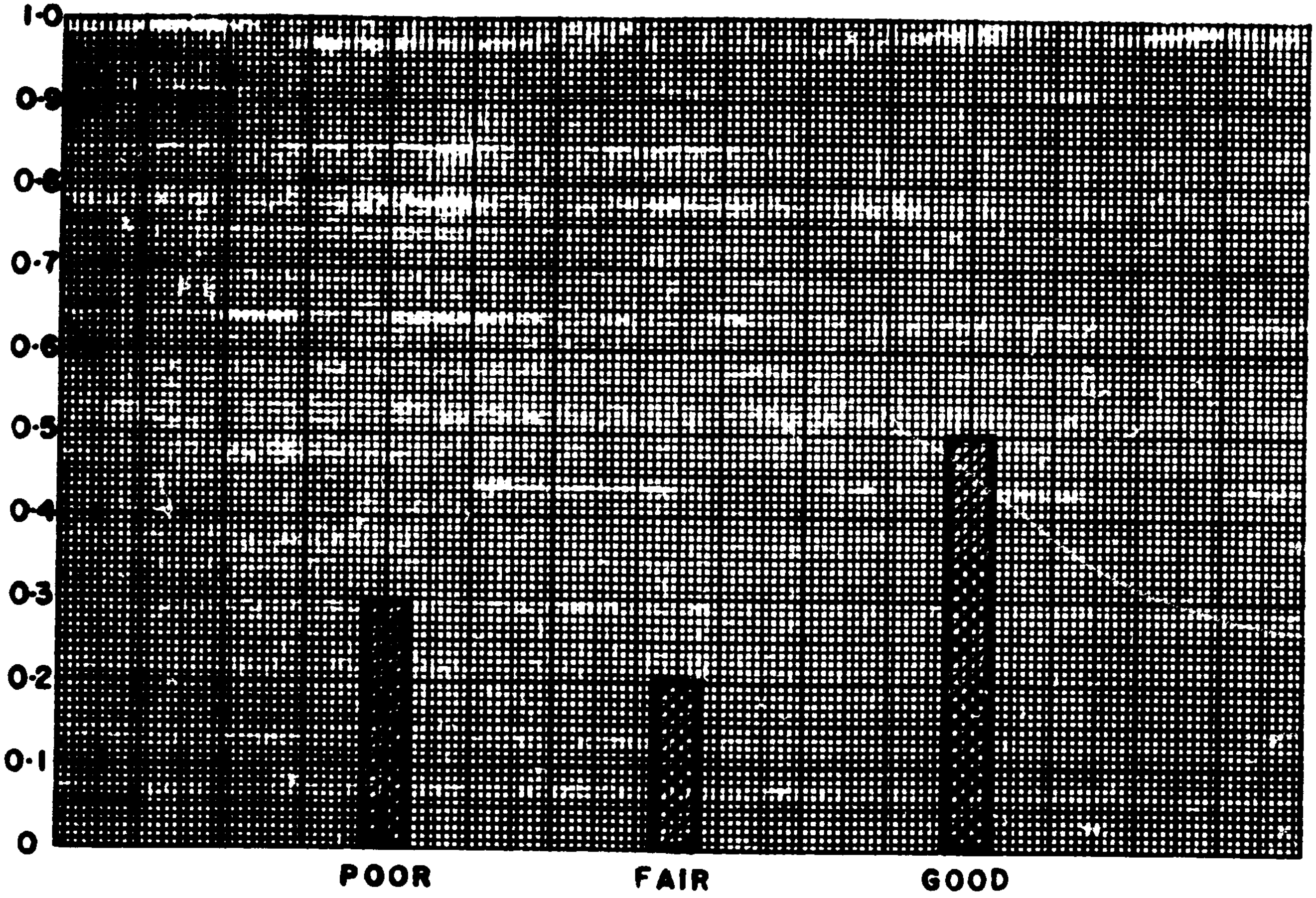
LOSS RATIO ON WORKERS' COMPENSATION COVERAGE GIVEN AN OWNER SAFETY PROGRAM OF $3,000,000 AND A CONTRACTOR SAFETY PROGRAM OF $1,500,000



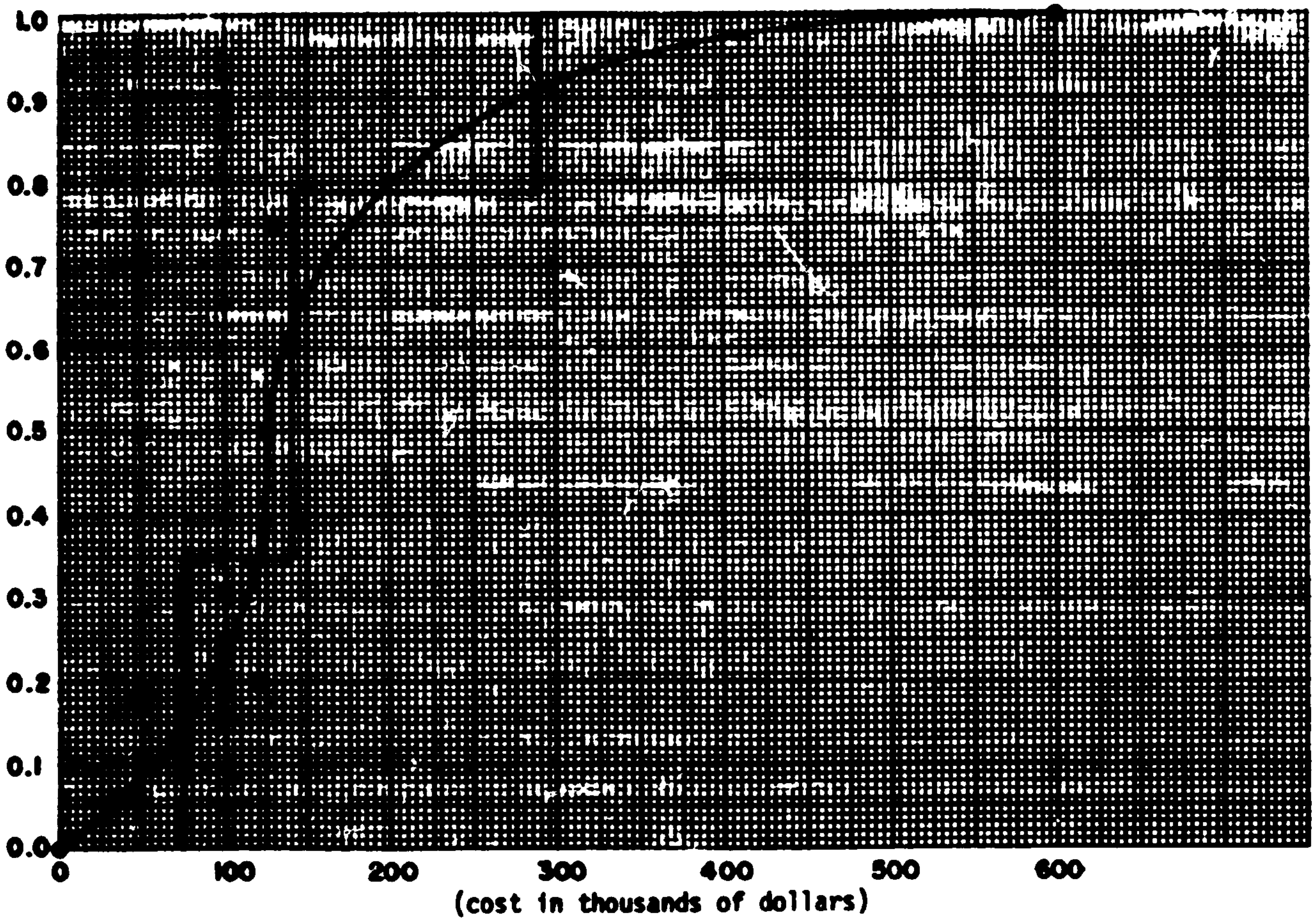
OWNER SAFETY PROGRAM UNDER A CONVENTIONAL INSURANCE PROGRAM



MARKET CONDITIONS FOR GENERAL LIABILITY AND BUILDERS' RISK INSURANCE COVERAGES



OWNER'S LOSS CONTROL PROGRAM UNDER A CONVENTIONAL BUILDERS' RISK INSURANCE PROGRAM



APPENDIX C

REPORT OF NEW TECHNOLOGY

Since the work on this contract was an analytical effort in the behavioral sciences no patentable item is reported. However this effort has produced innovations such as a new conceptual and schematic representation of risk in a construction project (page 29, et passim), a new survey technique for quantifying a decision-maker's subjective probabilities (page 31, et passim), and a first application of the technique in the construction industry (page 32, et passim).

250 Copies