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ECONOMIC FACTORS IN TUNNEL CONSTRUCTION

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FINAL REPORT

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16. Abstract

This report decribes a new cost estimating system for tunneling. The system is designed so that it may be used to aid planners, engineers, and designers in evaluating the cost impact of decisions they may make during the sequential stages of planning and design of urban transportation tunnels.

In developing a cost estimating technique and method, an extensive review was made of currently available estimating systems. Techniques were adapted from the systems studied where applicable, and new methodologies were developed as needed for optimization.

A detailed estimating technique is used in which units of effort are converted to obtain a base cost for a "standard" tunnel constructed in 1976 in Washington, DC. Correction factors may then be applied to obtain the costs in other time frames and geographic locations. The use of units of effort provides a technical base which does not change rapidly with time, but may be updated as changes in technology and productivity occur.

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PREFACE

This study has been undertaken to develop a tunneling cost estimating method suitable for use by owners, planners, and designers of urban mass transportation systems. The method developed will enable them to make economic tradeoff studies of the costs of construction of alternative routes and layouts. These costs can be factored into planning and design to provide a rational basis for selection of routes which will reduce future urban mass transportation construction costs.

This study was prepared by the Underground Technology Development Corporation in association with Singstad, Kehart, November and Hurka (SKNH) for the Office of Rail and Construction Technology, Office of Technology Development and Deployment, of the Urban Mass Transportation Administration, U.S. Department of Transportation, under contract with the Transportation Systems Center, in Cambridge, Massachusetts.

The report is the work of many persons: Eugene L. Foster was the principal investigator; Irwin Toporoff guided the technical effort by SKNH; Winton D. Wightman designed and developed the model; Richard McDonald prepared the computer program and data base; William N. Lucke assisted in the analytical effort; Fred Merrick provided valuable data on BART system costs; and James Dobsa contributed his drafting skills.

Many persons at the U.S. Department of Transportation extended themselves to help us. We wish to thank Gilbert Butler of the Office of Rail and Construction Technology of UMTA for his assistance. Special thanks must go to the technical monitors for this contract at the Transportation Systems Center, Andrew Sluz and Santo Gozzo. Their help in supervising, criticizing, and checking this work is deeply appreciated.

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

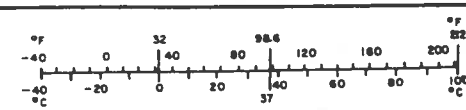

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

APPENDIXES

FIGURES

TABLES

1. INTRODUCTION

1.1 OBJECTIVE AND SCOPE

The objective of this study is to develop versatile and accurate techniques for the estimation of tunneling costs, and to draft guidelines for systems analyses of tunnel designs based on those techniques. Analytical tools developed during the program are intended to be usable by urban transportation planners and designers to help them to understand more clearly the cost consequences of the decisions made at each sequential stage of design. The techniques are based upon extensive experience in cost estimating, and take account of both construction and non-construction factors. Cost projections are accurate to the level of detail required in each subsequent stage of design.

The scope of the program has included the following features:

a. A review of cost estimating techniques and systems analysis methods for comparing alternate tunnel sites and designs; and selection/development of an optimum combination.

b. The development of a construction cost data base which contains quantitative descriptions of all important factors known to influence tunnel construction costs. A framework is provided for acquisition of future cost data.

c. Verification of the techniques and cost factors developed during the program.

In selecting an optimum cost estimating technique and a systems model with which it could be used, the following requirements were set:

a. The estimate must take account of the technical factors associated with construction. This means that it must develop costs on the basis of the units of effort required (labor, equipment, and materials) to construct a given reach of tunnel under given conditions. Individual construction tasks must be separable and identifiable so that the effects of changing one or more of them may be found.

b. The systems analysis model must provide a means of estimating the effects of non-construction factors on total costs. These may amount to 50 percent or more of base costs (for construction only) and failure to include them as a series of separate, quantified effects will seriously affect the accuracy of predicted total costs.

c. The systems analysis techniques must be usable by people having minimal knowledge of construction procedures. It must provide them with quick, inexpensive answers of the necessary accuracy for use at different stages in the design sequence.

d. All cost factors must be based on experience data, with the exception of those related to new technological advances, which must be capable of insertion into the model as they occur. Provision must be made for periodic review and update.

e. All classes of users should be accommodated; owners, designers, planners, contractors, and researchers. This does not necessarily infer that all of the needs of such a diverse group will be completely satisfied, as the roles and missions of each may be different. Therefore, some compromises in developing the program are necessary so that the needs of each class may be reasonably well satisfied. The following appear to represent the major uses of the estimating techniques as required by the various users:

<u>Planner-Owner</u>

- Evaluate route or site alternatives.
- Estimate financing and budgetary requirements.
- Estimate construction schedule and time.
- Estimate costs for real estate, engineering design, construction supervision, financing, administration, etc.

<u>Designers-Engineers</u>

- Evaluate alternate construction methods.
- Estimate construction costs.
- Establish detailed construction schedule.
- Assess geologic, labor, materials and equipment uncertainties.
- Evaluate geometric alternatives.
- Evaluate effect of improved technology.
- Evaluate design alternatives.

<u>Contractors</u>

- Make gross check of contractor cost estimates.
- Evaluate risk in construction alternatives.
- Check construction schedule and cash flow requirements.

f. The technique must be capable of handling all geologic conditions from soft unstable ground to hard rock, and all geographic settings.

g. Since the advance rate has greater effect on costs than any other construction factor, there must be a capability of varying this parameter, including selection of an appropriate rate by the user of the program.

h. The volume of data in the data bank must be kept within reasonable limits so as not to place undue burden on storage and retrieval. Also, the updating and revision of the data bank must be able to be accomplished by simple and rapid measures.

i. To keep the current program as simple as possible, only mined-line sections will be costed at this time. Cut and cover, stations, immersed tube, etc. may be considered at a later time.

1.2 STUDY APPROACH

The study was initiated by a review of several existing cost estimating systems which represent a spectrum of estimating techniques. Emphasis was placed on comparing the application purpose, geologic setting, construction method, and system inputs and outputs. The purpose of this review was to determine the capabilities and limitations of various estimating techniques, and to enable selection of desirable features for incorporation in the model to be developed. The review and analysis of these techniques are contained in Sections 2 and 3.

Following the above review and analysis is a discussion in Section 4 of the selection of optimum techniques and methods for inclusion in the model.

Section 5 describes the non-construction items which must be factored into the model to arrive at total project costs. Consideration of the non-construction costs represents somewhat of a departure from previously developed techniques which have only partially covered these types of costs.

The data base, program verification, and draft guidelines describing the model and its operation are covered in Sections 6, 7, and 8.

Finally, recommendations for future action are presented in Section 9, and Sections 10 and 11 contain a list of references and a report of inventions.

2. REVIEW OF COST-ESTIMATING TECHNIQUES

2.1 INTRODUCTION

A review and an analysis have been made of techniques currently available to estimate tunneling costs. It was found that of the eight techniques studied, only three are based on methodologies which are used to any extent at the present time. The others have either been available but not accepted by the industry, or simply have not been available long enough to be adopted for general use.

In general, the cost-estimating techniques developed to date have placed heavy emphasis on technical detail and have given little in-depth consideration to the non-technical factors which often have major cost impacts. Furthermore, they have been developed with simplicity as a major objective, with the result that their level of accuracy leaves much to be desired. Thus, none of the techniques reviewed provides a practical, logical and universal basis for estimating the cost of future tunnels. On the other hand, several of them provide valuable insight into one or more facets of the construction estimating problem. These insights should be recognized, and used whenever possible in planning a new methodology which hopefully will be useful to and accepted by the industry.

Tables 2-1 a, b, c, d, e, and f have been prepared to provide a quick reference summary of the characteristics of

TABLE 2-1a. CHARACTERISTICS OF COST ESTIMATING TECHNIQUES

	POTENTIAL USERS					PURPOSE																
COSTING SYSTEM	OWNERS	DESIGNERS	PLANNERS	CONTRACTORS	RESEARCHERS	EVALUATE ROUTE OF SITE ALTERNATIVES	EVALUATE ALTERNATE CONSTRUCTION METHODS	COST ESTIMATES AND PROJECTIONS	CONSTRUCTION TIME ESTIMATES	CONSTRUCTION SCHEDULES	ESTIMATED ADVANCE RATE	ESTIMATED CYCLE TIME	ESTIMATED CREW AND STAFF REQUIREMENTS	PRODUCTIVITY ESTIMATES	ASSESS GEOLOGIC UNCERTAINTIES	EVALUATE SIZE AND SHAPE ALTERNATIVES	EVALUATE DEPTH ALTERNATIVES	EVALUATE SHAFT SPACING AND LOCATION	EVALUATE RESEARCH PROGRAMS AND OBJECTIVE	EVALUATE COST/BENEFITS OF NEW TECHNOLOGY	UPDATE AND REVISE PRIOR TIME AND COST ESTIMATES	EVALUATE COST/BENEFITS OF CHANGED CONST. METHODS
COHART	X	X	X	X	X	X	X	X	X							X	X	X	X	X		
COSTUN	X	X	X	X	X	X	X	X	X							X	X	X	X	X		
MIT	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X			X	X	X	X
GRC			X		X		X	X	X	X									X	X		X
BECHTEL	X	X	X		X	X	X	X											X	X		X
FOSTER MILLER	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X		X
UNIT PRICE APPROACH	X	X	X		X	X	X	X								X					X	
SKNH	X	X	X		X	X	X	X							X	X	X					

TABLE 2-1b. CHARACTERISTICS OF COST ESTIMATING TECHNIQUES

COSTING SYSTEM	GEOLOGIC APPLICATIONS		CONSTRUCTION METHODS				
	ROCK	SOFT GROUND	TBM	SHIELD	CUT AND COVER	IMMERSED TUBE	DRILL AND BLAST
COHART	X		X				X
COSTUN	X	X	X	X	X	X	X
MIT	X		X				X
GRC	X		X				X
BECHTEL		X	X	X	X		
FOSTER MILLER	X	X	X	X	X		X
UNIT PRICE APPROACH	X	X	X	X	X	X	
SKNH	X	X	X	X	X	X	X

TABLE 2-1c. CHARACTERISTICS OF COST ESTIMATING TECHNIQUES

COSTING SYSTEM	SYSTEM INPUTS																														
	GEOMETRY										CONSTRUCTION FACTORS									ADJUSTMENTS AND INDIRECT COST											
	SIZE	SHAPE	DEPTH	TUNNEL SLOPE	SHAFT INCLINATION	SHAFT LOCATIONS	SEGMENT LENGTHS	TOTAL LENGTHS	SIDE SLOPES (cut and cover)	DISTANCE TO DISPOSAL AREA	EXCAVATION METHOD	MATERIALS HANDLING METHOD	GROUND STABILIZATION METHOD	ADVANCE RATE	CONSTRUCTION WORK WEEK	PRIMARY SUPPORT	FINAL LINER	ENVIRONMENTAL CONTROLS	OBSTRUCTIONS-(UTILITIES)	PROFIT MARGIN	CONSTRACTORS OVERHEAD MARGIN	REGIONAL ADJUSTMENT FACTOR	MATERIAL COST ESCALATION	LABOR COST ESCALATION	EQUIPMENT COST ESCALATION	FINANCING COST-OWNER	FINANCING COST-CONSTRACTOR	DESIGN, ADMIN. AND SUPERVISION	COST OF REAL PROPERTY	COST OF BONDS INSURANCE, PERMITS	PROBABILITY ESTIMATES
COHART	X	X	X	X	X	X	X				X	X		X▲	X▲	X▲	X▲			X▲	X▲	X◆	X◆	X◆	X◆						
COSTUN	X	X	X	X	X	X	X		X	X	X▲	X▲		X▲	X▲	X▲	X▲			X▲	X▲	X◆	X◆	X◆	X◆						
MIT	X	X				X	X	X			X	X	X	X	X	X	X	X		X	X										X
GRC	X	X	X				X	X			X	X	X			X		X		X	X										
BECHTEL							X	X			X		X													X		X		X	
FOSTER MILLER	X	X				X	X	X		X	X	X	X	X	X	X	X			X	X		X	X	X						
UNIT PRICE APPROACH	X	X	X					X			X					X	X	X				X	X	X							
SKNH	X	X	X				X	X			X					X	X	X				X	X	X							X

▲ OPTIONAL INPUT - INPUT BY COMPUTER IF NOT INPUTED BY USER

◆ OPTIONAL INPUT - WILL NOT BE INPUTED BY COMPUTER IF NOT INPUTED BY USER

TABLE 2-1d. CHARACTERISTICS OF COST ESTIMATING TECHNIQUES

	SYSTEM INPUTS																			
	GEOLOGY																			
COSTING SYSTEM	R.Q.D.	COMPRESSIVE STRENGTH	SHEAR STRENGTH	ROCK CLASSIFICATION	SOIL CLASSIFICATION	COHESION - C	INTERNAL FRICTION-Ø	ROCK TEMPERATURE	AIR TEMPERATURE	WATER INFLOW	GROUND WATER ELEV.	SOUND ROCK ELEV.	IMPERVIOUS LAYER ELEVATION	EFFECTIVE GRAIN SIZE	UNIT WEIGHT	PERMEABILITY	STABILITY NUMBER	ROCK ABRASIVENESS	PRESENCE OF GAS	SEGMENT INTERDEPENDENCY
COHART	X			X				X	X	X					X					
COSTUN	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X▲	X▲	X			
MIT	X	X		X						X									X	X
GRC	X	X		X				X		X					X			X		
BECHTEL																				
FOSTER MILLER	X				X					X								X		
UNIT PRICE APPROACH				X	X						X	X	X							
SKNH				X	X						X	X	X							

▲ OPTIONAL INPUT - INPUTED BY COMPUTER IF NOT INPUTED BY USER

TABLE 2-1e. CHARACTERISTICS OF COST ESTIMATING TECHNIQUES

COSTING SYSTEM	COST DATA DERIVATION							
	EMPIRICAL	BID RECORDS	COMPUTER STORED COST DATA	COMPUTER STORED COST EQUATIONS	USER FURNISHED	TYPICAL CREW ORGANIZATION	TYPICAL MATERIALS REQUIRMENTS	TYPICAL EQUIPMENT REQUIRMENTS
COHART	X			X		X	X	X
COSTUN	X			X		X	X	X
MIT			X		X			
GRC			X		X			
BECHTEL		X	X					
FOSTER MILLER					X	X	X	X
UNIT PRICE APPROACH	X	X						
SKNH	X	X						

TABLE 2-1f. CHARACTERISTICS OF COST ESTIMATING TECHNIQUES

COSTING SYSTEM	SYSTEM OUTPUTS: LABOR COST	MATERIAL COST	EQUIPMENT COST	ACTIVITY COST	SUB ACTIVITY COST	TOTAL CONSTR. COST	MOBILIZATION-DEMOB-ILIZATION COST	SEPARATE TUNNEL AND SHAFT COST	OWNER COST FOR DESIGN AND SUPERVISION	FINANCING COST	VENTILATION COST AND REQUIREMENTS	PUMPING COST AND REQUIREMENTS	POWER COST AND REQUIREMENTS	UNDERPINNING COST	UTILITY RELOCATION COST	LEGAL COST	CLAIMS COST	TRAFFIC CONTROL, CLEANUP COST, ETC.	TOTAL PROJECT COST	OVERRUN-UNDERRUN RISK	CONSTRUCTION TIME	CONSTRUCTION SCHEDULE	FINANCING SCHEDULE	CASH FLOW SCHEDULE	ADVANCE RATE	CYCLE COST	CYCLE TIME
COHART	X	X	X	X	X	X		X			X	X									X						
COSTUN	X	X	X	X	X	X		X			X	X									X						
MIT	X	X	X	X		X	X														X	X			X	X	X
GRC	X	X	X	X	X	X					X	X	X								X	X					
BECHTEL				X	X	X													X								
FOSTER MILLER	X	X	X	X	X	X		X										X			X	X			X	X	X
UNIT PRICE APPROACH						X		X			X			X	X			X	X								
SKNH								X											X								

each of the techniques considered in the review. The headings are generally self-explanatory. Taken together, they describe individual capabilities, and also provide an indication of desirable features which are not fully incorporated in current techniques. Further descriptions of the capabilities and limitations of each technique are given under separate headings in the following paragraphs.

2.2 COHART AND COSTUN (1) (2)*

The COHART program was developed by Harza Engineering Company specifically for hard rock applications. The experience gained in the development of COHART led to subsequent preparation of COSTUN, which extends the estimating capabilities of the method to soft ground, cut and cover, shield, and immersed-tube methods of construction. COSTUN, therefore, replaces COHART since the former is able to handle all geological situations and construction methods, although the program is more lengthy and complex. In some rock situations, it may be more convenient to use COHART since its inputs and program deck are much simpler than those of COSTUN.

Both COHART and COSTUN were intended to provide the following:

a. Cost estimates for planning and feasibility studies.

b. Basis for tunnel route selection.

c. Identification of minimum cost construction methods.

---

* Superscripts refer to numbered documents in the list of references.

d. Trade-offs of alternative tunnel geometries.

e. A check on reasonableness of engineers' and contractors' estimates.

f. A basis for evaluating the cost/effectiveness and usefulness of research programs and new technology.

The Harza programs are, therefore, more applicable to the needs of owners, designers, planners, and researchers than to those of contractors. Contractors are not excluded, but use by them would probably be limited primarily to verification and check on reasonableness of detailed bid estimates in order to detect gross errors or omissions. These programs represent powerful tools for evaluating the economics of alternative routes, tunnel geometries, construction methods, and other features of tunnel projects, the cost of which planners and designers strive to minimize. Researchers also can evaluate the cost/benefits of new technology and research programs, and project future costs based on various technological improvements.

Computer data storage requirements are minimized by use of cost equations rather than detailed stored data. The cost equations are derived from empirical data, typical crew configurations, and other data accumulated by Harza engineers. These equations relate to a specific geographic area (Chicago) and time frame (1969), and are extrapolatable to other areas and time frames by factors which may be entered by the user. Factors may also be entered relative to contractor overhead and profit margins, and to increased labor, material, and equipment costs due to escalation of the cost of living. In operation, the equations are solved using selected design, geological and construction parameters; providing as output the costs of labor, equipment, and materials for major activities (materials handling), sub-activities (muck loading), and job totals.

One of the most important inputs is advance rate, since total labor costs, which constitute a major portion of total tunnel costs, are highly sensitive to this parameter. For purposes of this study, it has been assumed that direct labor costs are a linear function of advance rate. Indirect labor costs are also affected but not to the same degree. An advance rate may be entered as input if desired. If not, the program will compute an advance rate based on a consideration of geology, diameter, and method of construction. The capability to insert advance rate is a valuable feature which permits the user to evaluate the sensitivity of cost to advance rate for a particular situation.

Neither of the programs consider such project costs as contractor mobilization, underpinning, bonds, financing, insurance, legal, engineering, supervision or other administrative or technical costs required to prosecute the work. Such costs can be quite large. An additional disadvantage is that the output is expressed in terms of discrete values based on discrete inputs. This means that the programs do not take into consideration the possibility that inputs may have some probability of variance, with outputs having ranges of cost values associated with these input variations. Thus, the Harza models will not examine the probability and cost implications of unexpected changes in geology. It is possible to evaluate such changes by computer runs using varied inputs, but such runs will not enable evaluation based on probability of occurrence.

As mentioned above, costs are based on Chicago and for 1969. These may be adjusted to any other city or time frame by entering as input a factor to express the ratio of costs in the city in question relative to Chicago. This feature is obviously a necessity in any cost estimating system so that the system is not permanently tied to a specific geography and period of time. Harza experience has shown that regional costs may vary throughout the US by factors of 0.8 to 2.0 of the costs designed into their cost equations. These variations are due to work productivity, union rules, limitations on construction practices, safety requirements, and other local rules and customs. Changes in labor, material, and equipment costs are expected to escalate with time according to rises in the cost of living or for other reasons, and a factor may be entered to revise the 1969 value to take this into account.

Adjustments may also be made for contractor overhead and profit margins. The program will automatically enter 25% as the overhead margin if no entry has been made by the user.

Similarly, a profit margin may be entered by the user based on competitive factors or other criteria, and if not entered, the program will itself enter 4 percent. These features are useful in any program with which it is desired to simulate varied situations.

The program does not compute mobilization or de-mobilization costs, although it does compute set-up costs in the case of TBM operation. Thus, neither of the programs are suitable for small projects in which the mobilization and de-mobilization costs may be a significant portion of total project cost. This is a shortcoming and should be taken into consideration in the development of any advanced program model.

A special feature of the program is that costs are computed from stored cost equations. These equations have been developed from empirical data, field experience, and typical labor organizational structures for the various construction methods and situations. The concept of computing cost by stored equations appears to represent an expeditious approach for those situations in which rates of change occur in predictable patterns.

Geologic classification presents several problems to the cost program designer. RQD is a convenient method of classifying rock for support purposes. One should recognize, however, that RQD is not necessarily a precise criterion for tunnel support requirements. For example, the RQD of a rock strata may be quite different for horizontal rather than inclined or vertical core borings. Thus, in the real world RQD must be used with caution and interpreted in terms of the lithography. Nevertheless, it is a valuable means of classifying rock quality.

Rock compressive strength is also a required input for computing advance rate in TBM operation. One of the deficiencies in the program is that it does not compute the cost of replacement cutters for TBM operation. This cost, together with the economic value of lost production time and other equipment maintenance costs, may represent a substantial sum of money which should not be overlooked.

In the case of soft ground, the problem of quantitative classification becomes even more difficult. No really satisfactory numerical system exists. The COSTUN program uses stability numbers suggested by Ralph Peck, to define the degree of face stability. The stability number is a function of the characteristics of the soil surrounding the tunnel and of the depth and size of the opening. It varies from 1 to 11. Lower numbers indicate more stable, and higher numbers less stable conditions. From this index number, the program computes the lining and stabilization requirements for tunnels and the wall design and stabilization required for open cuts.

In the case of ground requiring stabilization, the details of the method must be specified. Three methods are considered; compressed air, de-watering and injection grouting. The requirements and costs of each of these are related to the stability numbers described above.

Work week definition is a necessary part of the COSTUN program since it affects construction time and costs. If not inputed, the program will assume a 6 day - 24 hour/day-week.

In summary, the COHART and COSTUN programs have the following major features:

Advantages

a. Cover all geologies and construction methods.

b. Provide basis for evaluating cost implications of various geologies, geometries and construction methods.

c. Permit use of variable advance rates to demonstrate the sensitivity of cost to this factor.

d. Allow adjustment for geographic cost variations and for time escalation of material, labor, and equipment costs.

e. Permit use of user selected overhead and profit margins.

f. Minimize computer data storage requirements through use of cost equations.

g. Use simple quantitative systems for classifying rock and soft ground geology.

h. Provide for work-week inputs.

Disadvantages

a. Does not compute the following:

(1) Exploration, engineering, design, supervision, and owner's overhead costs.

(2) Contingencies.

(3) Financing costs.

(4) Mobilization and de-mobilization costs.

(5) Insurance, legal, and real estate costs.

(6) Underpinning and utility relocation costs.

(7) Costs associated with business disruption, traffic re-routing street clean-up, power consumption, TBM cutter replacement, repairs, and downtime.

b. Does not consider the probabilities of uncertainties in geology and construction operations.

c. Not suitable for small projects.

d. Combines cost data with productivity data in equations, therefore, updating of data in computer memory is a tedious process.

2.3 MASSACHUSETTS INSTITUTE OF TECHNOLOGY (MIT)[3]

The MIT tunnel cost model is a computer based simulation of the tunnel construction process. It is designed to evaluate the effects of uncertainties in geology and in the performance of men and equipment on construction schedules and costs. The factors which affect time and cost are treated as random variables. The MIT model has been developed for rock tunneling only, and is not applicable to other types of geological conditions.

There are three sub-models: geology, excavation operations, and tunnel construction. The geological sub-model accepts inputs describing possible combinations of geological conditions, together with estimates of their probabilities of occurrence. These are arranged on a "parameter tree." Four parameters are used, major defects, RQD, water inflow, and strength of the formation. Each may be characterized as high, medium, or low. The output of the geological sub-model is a set of possible geological conditions together with their corresponding probabilities of occurrence. These in turn are input to the excavation operations sub-model, which computes the rate of advance and corresponding probability for each. These are obtained by simulating excavation operations under the full range of geological conditions.

The rates of advance are finally input to the tunnel construction sub-model. This converts rate of advance into time schedules and costs for each geological condition. The tunnel construction sub-model takes account of variations in excavation rate, unscheduled maintenance,mishaps, random variations in productivity, and other unscheduled events.

Construction operations are grouped under four major headings or components; excavation, support, groundwater control, and probe drilling. A matrix is employed to relate components, construction methods and techniques, probabilities, and costs. Computations are performed on a cycle basis, such as the "pull" of a drill and blast operation or the stroke of a TBM. Cycle time is computed for each combination of methods and conditions. Cycle length in feet is divided by cycle time to obtain a rate of advance. Summations of cycle times and costs provide totals for the tunnel.

The MIT model uses PERT techniques to schedule project activities and to compute the duration of construction. A carefully prepared schedule of this type facilitates resource planning, and is useful during the construction phase as well. When unforeseen events occur during construction, plans can be modified by simulation and an optimum approach worked out for finishing the remainder of the work.

The model places relatively little emphasis on unit cost data, relying instead on major classifications. Costs are tied to project activities. Contingency costs are incorporated through estimates of uncertainty rather than as lump sum additions to the bottom line.

Cycle costs are computed for each method and each set of conditions simultaneously with cycle times and rates of advance. Labor rates are computed outside the framework of the model and are based on crew size, skill requirements, and wage rates for each construction method. Significant material costs are computed from basic data under each activity function. Other costs are expressed on a dollars per foot basis. Equipment costs, including fuel, maintenance, and operation are handled on a working hour basis.

One of the decisions a contractor must make is whether to use an inexpensive construction method which is relatively inflexible or an expensive method capable of dealing with a variety of geological conditions. The making of this type of decision will be facilitated by use of the model, through which a range of probabilities and consequences can be explored prior to selection of equipment.

The MIT model should be useful to owners, planners, designers, and researchers. It is an aid for comparing alternate choices, since it can easily provide a large number of answers to the question "what if?" For researchers, it provides a basis for certain types of benefit/cost analyses. Contractors will find the model useful as a means of evaluating the relative risks of alternative courses of action.

In summary, the MIT model has the following major features:

Advantages

a. It provides a range of time and cost values associated with ranges of conditions which might be encountered. This is useful for comparing alternate routes as well as for risk assessment.

b. It provides a means of dealing with unexpected contingencies encountered during construction. By simulating events for the remainder of the project, the contractor can quickly select an optimum method with which to proceed.

c. The use of PERT provides outputs which are useful both in the planning stages and subsequently during construction.

d. The probabilistic approach provides a framework which is close to real world conditions. Nothing is absolute; events only have some finite probability of happening. This approach to cost evaluation is valuable and needs to have wider application by those who consider costs and their effects.

Disadvantages

a. Proper use of the model requires sound understanding, both of construction methods and of simulation techniques. These capabilities are often not available within one organization.

b. The model is capable of generating a large number of outputs for each set of assumed site conditions and construction methods. There is a real danger that insight into the significance of the results may be hidden in the large volume of outputs.

c. Gross errors in cost projections may be difficult to detect because of the treatment within the program of the different levels of detail.

d. No provision is made within the program for escalation.

e. The assignment of probabilities is somewhat arbitrary and may be subject to considerable error. The effect of errors of this type on final accuracy is variable, so that the user may be misled without having a real "feel" for the source of a specific inaccuracy.

f. Does not include non-construction costs.

2.4 GENERAL RESEARCH OPERATION (GRC)

The GRC model is a performance and cost simulator for tunneling in rock. This type of model might be used by planners and researchers as an aid in analyzing relative cost and performance characteristics of existing and proposed tunneling methods.

The basic approach in developing the model has been to allow the user to easily solve tunneling problems rather than to waste time in extra computer programming or operation. Attempts are made to keep inputs simple and flexible to facilitate rapid changes in input and to provide the option of selecting any new and novel or hypothetical method for tunnel construction. Unfortunately, the number of subroutines is still quite extensive and input data is relatively detailed. In any event, the original objective calling for simplicity in manipulating the model is essential if wide acceptance and use by planners is to be achieved.

The model embraces four major functional elements; rock fragmentation, materials handling, ground support, and environmental control. While each has perhaps equal importance in tunnel construction, GRC has elected to emphasize the first two, probably because of their greater potential for development of novel methods.

In detailing the model, rock fragmentation and materials handling are each broken down into major activities, for example "boring machine fragmentation." The major activities are further detailed into a number of subroutines, for example "cutter change and wear." Altogether, 38 subroutines plus 4 major programs comprise the program. The method of ground support is input to the program by the user; so is environmental control which includes ventilation, mechanical cooling, and water removal.

The subroutines are structured into four major working programs. The "geology program" is considered to be the most important and has been carefully and extensively designed. It is used as a tool for building a file of data which represents the geological conditions found within a given three-dimensional model of a region of rock. The "tunneling program" creates a tunnel file from data inputs and from the geology file. A third program allows creation of the tunnel file from card input, bypassing the geology program. Lastly, the control program provides coordination over the working programs and subroutines, and supervises the generation of final cost and performance outputs.

The program computes an advance rate based on tunnel diameter and compressive strength of the rock. This is probably the most important parameter in any cost calculation as the direct labor costs, which constitute the predominant cost in tunnel construction, are directly related to advance rate. Indirect labor and other costs are also affected, but not to the same degree as are the costs of direct labor. Thus, any error in calculating the advance rate can have a very large influence on total project costs. Such errors may be the rule rather than the exception, because the model does not take account of unanticipated breakdowns of equipment or changes in geology.

The cost data file is established by the user inputing unit cost data appropriate to the particular problem to be simulated. The cost reports generated by the program reflect both overall cost and element cost by selected categories. Direct labor, for example, will be applicable to a specified activity, such as the cost per hour of the crew to operate the boring machine. An output of this nature is useful to facilitate a cost/benefit analysis of new tunneling machines or techniques.

In summary, the GRC program is limited to simulations to assess relative performance and costs of different tunneling methods and techniques. It is therefore oriented toward providing the capability of evaluating and comparing optional construction processes, rather than the spectrum of design alternatives which a planner might wish to examine. For example, the planner might wish to evaluate the effect of tunnel depth on cost or the relationship of diameter to cost. While these might be accomplished on the GRC model, the basic structure of the model does not lend itself to making these calculations in a simple manner.

The GRC program has the following significant features:

Advantages

a. Provides method for evaluating the relative performance and cost of novel construction methods and techniques.

b. Manual cost data input facilitates simulation for varied time and geographic settings.

c. Designed for simplicity in manipulating the model.

d. Provides analysis of interaction between construction features, identifying major incompatibilities and cost implications.

e. Designed to serve researchers to focus research and development to yield greatest improvements.

f. Flexible as to method and technique of construction.

Disadvantages

a. Does not cover all geologies and construction methods.

b. Does not provide basis for evaluating cost implications of various geologies, geometries and construction methods.

c. Does not provide for use of manually-introduced advance rates.

d. Specific cost data must be entered for each project to be simulated.

e. Large data storage requirements.

f. No consideration given in the program to uncertainties in time, equipment, labor, material, or geology.

2.5 BECHTEL

The Bechtel analysis develops generalized models for four specific types of underground construction: cut and cover station, cut and cover line tunnel, free-air driven line tunnel, and compressed air-driven line tunnel. The models were developed along the lines indicated in Table 2-1. Starting with input parameters describing tunnel geometry, the model has basic cost elements for utilities, deck and traffic control, underpinning, excavation, muck disposal, concrete, backfill, restoration, and comparable elements for shield tunneling. These are in turn modified to take account of physical controls such as utility density, traffic conditions, existing structures, ground conditions, fill demand, architectural requirements, and weather. When they have been modified, the basic cost elements are added together to obtain a basic project cost. This cost is then modified to account for institutional controls, including schedule and timing, insurance, safety, building permits, labor productivity, and financing costs. This results in a total project cost as shown in Table 2-1.

The Bechtel concept of building total costs from basic construction operations is a good one. However, the way in which these are related to costs is subject to some question.

In many cases, the cost of a construction operation at a given site was taken to be the average of the bid price quoted for that operation by the three lowest bidders. Those familiar with the construction industry will recognize that unit prices are frequently adjusted to obtain financial front loading, to lay the groundwork for profit optimization, or for other purposes. Thus, the average quoted by the three lowest bidders may bear little resemblance to actual costs, and may be on occasion completely misleading. For this reason, the Bechtel model, in its present form, does not appear to offer acceptable capabilities for accurate cost prediction.

The concept of developing "standard" cost elements and correcting them for "non-standard" conditions is a promising one which deserves further consideration. However, the present model does not appear to be based on viable cost data, and is therefore not considered to be usable without the benefit of more rational cost information.

The Bechtel technique of cost estimation has the following noteworthy features:

Advantages

a. It has the capability of taking account of all factors believed to influence project costs.

b. Specific operations are broken out in a way which permits their costs to be developed and modified in a methodology which takes account of the interaction of each control with the operation under consideration.

Disadvantages

a. Cost data developed to date has been based on questionable methods of cost analysis. Unit prices based on the average values quoted by the three lowest bidders are subject to considerable variation and do not, in general, represent actual costs.

b. The system has not been developed to a point where it can be applied to enough cases from various regions to verify its usefulness.

2.6 FOSTER-MILLER ASSOCIATES (FMA)

The FMA estimating system was developed for use in preparing contractors' bids for tunnel construction. The philosophical approach and many of the procedures used are well adapted to this need, but tend to be less applicable to the needs of owners, planners and designers.

Contractors have learned from experience that a construction cost estimate must take account of details. Frequently, an item which appeared to be insignificant at first glance has a major impact on cost when construction is underway. For this reason, the FMA system employs a very detailed model. The model is also highly interactive with the user. One must select the "best" construction method, including crew and equipment, and plan the construction sequence. The model provides an orderly framework within which one can record these choices and cost them out. It is, in effect, a check list which assures that important items will not be overlooked. In addition, it contains standard forms on which data can be entered and costs developed leading from consideration of small details through to summations which lead to total cost. A flow chart for the FMA system is shown in Figure 4-1.

The principal ingredients considered (Table 2-1) are direct costs, plant and equipment, indirect costs, escallation, financing and contingency costs, and profit. Direct costs include labor, the operation of equipment, supplies, permanent materials, and sub-contracts. Costs associated with plant and equipment include the cost of ownership plus mobilization and demobilization. Indirect costs include the salaries of supervisory, engineering, and office personnel; expenses for the business-type costs of operations such as legal and audit, consultants, office supplies, heat, transportation, etc; and services which cannot be allocated to particular bid items such as compressed air, janitorial services, yard work, etc.

Escallation factors are usually different for labor, equipment, and materials, and are applied separately to these items in the FMA model. Financing costs are relatively straightforward, since they depend on the amount of capital required to be tied up on the job and the going rate for the use of that capital. Contingency is considered within the context of the FMA system to be a subjective judgment made by the contractor. In setting the contingency, judgment is based on a number of intangible factors, including an assessment of the degree of uncertainty in the information upon which the bid was based.

Profit, the remaining item on the flow diagram, is set by the contractor, and is based on the extent of his desire or need to be low bidder and his estimate of what it will take to do so.

The FMA estimating system has the following noteworthy features:

Advantages

a. It provides an orderly framework within which to develop and combine detailed costs for a construction project.

b. It is applicable to a wide range of construction methods.

c. The FMA system has proven to be reliable and accurate when used by experienced construction personnel.

d. The approach is widely accepted in the industry by those who must make accurate estimates of tunnel costs.

Disadvantages

a. In its present manual form, the FMA system is tedious and cannot be applied quickly to a wide variety of "what if?"situations.

b. The level of detail covered by the FMA system is too great for general use by planners and engineers, particularly during program stages in which relatively little information is known.

c. The system requires its user to have fairly extensive construction experience for proper use in obtaining accurate results.

2.7 UNIT PRICE

The unit price estimating technique is based upon records from past construction costs. In developing this data, the user has available the unit costs per pound of steel, per cubic yard of concrete, per cubic yard of excavation, etc. from a number of projects done in different geographical locations and geological settings. When a new tunnel is to be estimated, calculations are made of the quantities of each of the above items required for that tunnel. By searching the records, one may find a tunnel which is judged to be similar in location and other conditions. Unit prices for that tunnel are then applied to the quantities estimated for the new tunnel. The results are summed to obtain the estimated cost of the new tunnel.

A further simplification is sometimes introduced, with tunnel costs being estimated on a straight "per foot of tunnel" basis, without considering any of the quantity details.

The accuracy of an estimate produced by the unit price methodology depends upon several factors. The first is the degree to which the conditions for the new tunnel actually resemble those of the tunnel(s) from which unit price data is being used. The costs are treated at such a broad level of detail that similarity or lack of it is not always apparent. Thus, the planner or designer may overlook a significant dissimilarity and thereby apply unit prices which are grossly in error.

The second possible source of error is the fact that the data used is historical. In times of stable inflationary trends, the historical data can safely be used. In the uncertain financial climate which has existed during the past several years, the data lag problem has created serious discrepancies between owners' (engineers') estimates and those of the contractors who bid the job.

A third source of error is that a unit price approach does not take account of bidding climate, contracting procedures, environmental effects, and a number of other controls which have substantial cost impacts. All of these are lumped together to give a regional cost, but change in any one of them may impact bid prices substantially. Since they are not separated, it is difficult or impossible to correct the estimated price for their effects.

Some agencies who use the unit price technique have attempted to make adjustments for changes in location and time by applying factors taken from the Engineering News Record (ENR) index of Heavy Construction or other adjustment indexes. This helps to improve accuracy, but the record of comparisons between engineers' estimates and lowest contractor bids shows that in many cases there is still a substantial difference.

Unit price data from an historical project is sometimes obtained by averaging the unit prices quoted by the three lowest bidders on that project. This approach introduces errors due to the frequent contractor practice of unbalancing bids to obtain "up front" money to finance the project.

Despite the above disadvantages, the unit price cost estimating technique is simple, easily used, flexible, and widely accepted. It will undoubtedly continue to be used by owners and engineers to make "quick and dirty" assessments of the probable cost of future tunnels.

Summarizing, the unit price technique has the following features worth noting:

<u>Advantages</u>

a. It is accepted by the industry, and widely used by engineers and others who must make a quick estimate of probable tunnel costs.

b. It is simple to use.

c. It is flexible, with the number of conditions to which it can be applied being limited only by the ability of the user to find data for similar conditions.

d. It can be adjusted, using the ENR indexes, to take account of some sources of error.

e. It is relatively inexpensive to use.

Disadvantage

a. It lumps many influence factors together in a way which obscures their individual effects. This makes adjustment to account for changing conditions difficult or impossible to take into account.

b. The accuracy of the estimate is strongly dependent upon the skill of the estimator in recognizing data which applies to "similar" conditions.

c. Data for use in the system is sometimes obtained from averaging the bidder's quantities, a process which is subject to errors due to unbalancing of bid.

d. Total costs depend upon a product of quantities and unit prices, so accuracy is directly dependent upon the accuracy of quantity estimates. Since the method often is applied when a quick answer is desired, errors in quantity estimates are a strong possibility.

2.8 SINGSTAD, KEHART, NOVEMBER, AND HURKA (SKNH) SYSTEM

SKNH has developed a method for establishing budget costs for projects as well as for evaluating the cost of alternative schemes. This method consists of establishing a unit cost per-linear-foot of a typical rapid transit tunnel (of 18' diameter). Using this circular tunnel configuration in sound rock as the basis for cost, factors are then established for other conditions. For instance, if a single track tunnel in sound rock has a factor of 1.0, then the same tunnel in poor rock might be 1.5, costing 50% more. Mixed-faced conditions and/or water conditions can be taken into account in a similar way.

Having established the factor for any size and configuration of tunnel, one computes the number of cost units for a particular alternative. For instance, a sound rock tunnel of 1,000 feet would be equal to 1,000 units (1.0 x 1,000 ft.). Another alternative consisting of 300 ft. of poor rock, 500 ft. of sound rock and 100 ft. of mixed-face will have 1,150 units of cost (1.5 x 300 + 1.0 x 500 + 2.0 x 100). In this way, knowing the reach (extent) of each type of tunnel condition it is possible to estimate the total number of units for each alternative. The alternative with the lowest number of units would then be the least costly.

It it also possible to use this method to determine the range of cost for various types of conditions within a single alternative. One can assume the best and worst geological conditions and thereby establish the potential range of cost for any alternative. To arrive at a total cost for any scheme, one need only establish the cost of the basic unit of tunnel (which in this case is an 18 ft. diameter concrete-lined rapid transit tunnel in sound rock). This cost per foot of tunnel can be modified to take into account different geographical locations as well as inflation factors and labor agreements, etc. Additional factors that can be incorporated into the estimating method include shaft locations and spacings as well as traffic, spoil removal and other environmental restrictions.

The SKNH method has proved quite successful in establishing a budget figure for a particular project when very little input was available. Similarly, it permits evaluation of various alternatives involving different corridors, alignments, and profiles without requiring a heavy investment in engineering effort. Obviously, as one refines the final alternatives, the cost of the one or two remaining alternatives can then be more accurately determined by unit price or contractor's type estimates.

In summary, SKNH has evolved a specialized procedure for quick in-house evaluation of costs of tunnel projects. The procedure, however, can only be used to provide an order of magnitude cost for various alternatives. To provide a more accurate final cost, unit price or contractor's type estimates must be used.

The SKNH cost estimating technique has the following features:

Advantages

a. It has been used successfully to estimate approximate costs when relatively little detailed input data was available.

b. It is quick and easy to use with only modest manpower requirements.

c. It is useful in initial evaluation of the probable cost of alternative routes or of the range of probable costs of a particular alternative.

Disadvantage

It does not take account of details, and is thus limited in accuracy.

2.9 CONCLUSION

Eight cost estimating techniques have been reviewed in Section 2. These are believed to represent all of the techniques currently available for use. Tabulations of the advantages and disadvantages of each show that no one technique is capable of meeting the requirements outlined in the goals of the present study. However, many of them do have useful features, and the final model developed should make use of these characteristics to the maximum extent possible. Thus, the new model will make full use of the best features of past techniques, while providing an expanded capability which is not currently available.

3. REVIEW OF SYSTEMS ANALYSIS METHODS

3.1 INTRODUCTION

One of the most important factors which emerges from studies of current cost-estimating systems is the almost total reliance of estimators on technical details. Technical information, however sparse, has a certain credibility which makes it appealing. Abstract and sometimes intangible social or emotional factors seem to be avoided wherever possible. Thus, although insurance costs may be affected not only by the premiums quoted for owner vs contractor-furnished coverage, no account is usually taken of the effect on cost of the different attitudes engendered by the two methods for writing insurance. Likewise, the bidding climate, which has a significant effect on bid prices, is usually not included in any tangible way in engineers' estimates. Harza has analyzed one of the factors involved, the number of bidders, and has shown that this can cause significant differences. However, many owners or contractors do not include even this rather simple effect in any direct way.

Thus, it appears, on the basis of our review, that owners and engineers simply have not bothered to analyze the effects of non-technical factors, even though these may influence bid prices by very large percentages. Contractors do factor them in, but strictly on a "witch doctor" basis. This is done by the managers and/or owners of the company submitting the bid. In a final discussion session just prior to bid submission, they will consider the owner's reputation for dealing fairly with contractors, the confidence level in the technical data upon which the estimate was based, the number and condition of competing bidders, and similar intangibles. When these factors have all been considered in general terms, a concensus is reached on the bid price necessary to get the job. Depending on how badly the contractor wants the job, a price is selected which will either (1) get the job, even at high risk, because it is wanted badly; or (2) will be competitive but comfortable; or (3) will be high and provide exceptional profitability because it is not needed badly anyhow. This process of price selection depends a great deal upon "feel" for the local situation, and is much more of an art than a science. Most contractors, if asked to list the intangible factors they normally consider and tell how they are weighted, will say they have never bothered to look at such things in that much detail. This contrasts sharply with their view on technical factors, which are nearly always considered in great detail. Thus, none of the systems now in use take full account of all the important factors which influence the bid price of a tunnel.

3.2 AVAILABLE TECHNIQUES

The techniques presently available for estimating tunnel costs have been analyzed and are discussed in the "Review of Cost-Estimating Techniques", Section 2. There are three general types:

Type I employs detailed analysis. That is, the cost estimate is developed through detailed computation. First, the construction method to be employed is determined. Then this method, together with data on the geometry and geology of the tunnel, is used to extract labor, materials, and equipment quantities and costs from a predetermined data base. Adjustments are then made for a variety of factors such as regional, escalation, competitive, etc. Computation is then made for contingency, overhead, and profit. Finally, the non-construction costs, such as insurance, are added to provide the total cost of the project.

The known techniques in use today which employ detailed analysis, such as the Foster-Miller estimating system, estimate the construction costs rather accurately, however, none compute all of the associated non-construction costs. These latter costs can have a considerable influence on total costs.

Type 2 techniques use comparative analysis. In this technique, the tunnel is costed by using historical data on previously constructed tunnels to establish unit costs for the various major elements (i.e. excavation, lining, etc.) These costs are then used to prepare curves or equations from which the cost of proposed tunnels can be determined once the geometry and geology are known. Certain corrections have to be made for such things as escalation, regional differences, etc. Again, all of the non-construction type of factors are not calculated. The Harza and the Bechtel programs are examples of use of this technique. Although the method is perhaps suitable for rapid planning calculations, it is unsuitable for contractor use other than as a check on the reasonableness of bid prices.

Type 3 techniques employ probability analysis to enable consideration of the possible occurrence of variations in geology, labor costs, materials prices, and other elements, the cost of which cannot be accurately predicted prior to initiation of construction operations and which are subject to variation during the construction period. The MIT program is a typical example.

3.3 COST ESTIMATION REQUIREMENTS AND AVAILABILITY OF DATA DURING SEQUENTIAL DESIGN STAGES

The sequential design stages in the development of a rapid transit system and the level of detail necessary for each have been discussed by Bechel[5] and need not be repeated here. Five stages of planning and design are shown in Table 3-1, together with an indication of the probable accuracy with which tunneling costs are being estimated using current costing techniques. Also indicated are target accuracies to be used as a guide in the development of new costing methods. Although the latter accuracy values have been

TABLE 3-1. ACCURACY OF TUNNEL COST ESTIMATES

STAGE	SCOPE	ACCURACY OF COST ESTIMATE	
		PRESENT ESTIMATING METHODS	REQUIRED OF NEW METHOD
Conceptual Planning	Selection of alternative routes which would meet traffic requirements.	±50%	±50%
Preliminary Layout of Routes	Origin and destination studies; layout drawings; impact studies; discussions with local jurisdictions.	±50%	±50%
Feasibility & Economic Studies	Technical and operational definitions of system; detailed analysis of economic and environmental impacts.	±40%	±30%
Preliminary Design	Preparation of standards and design criteria; refining of route locations; design studies and development of preliminary drawings.	±30%	±20%
Final Design & Specifications	Review of preliminary design; finalization of designs and specifications; preparation of bid documents.	±20%	±10%

selected on a purely arbitrary basis, they nevertheless reflect the desirability for greater accuracy in cost estimating especially in the final stages of engineering a project. This is not a necessity in the early stages as traffic factors, demography, politics and other considerations play a significantly greater role and influence in system planning and layout than construction costs.

Of all the factors which influence tunnel construction costs, subsurface conditions are undoubtedly the most significant. The use of geological information by the many groups involved in the sequential design stages of a rapid transit system may be described as follows:

a. Planners. During the planning stage, factors of primary interest are political, demographic and social. The earliest plans are conceptual. They show possible route and station locations and are based upon existing and projected future travel patterns within the area to be served by the system. These patterns are established through origin and destination studies which include consideration of the growth plans of the affected communities as well as analyses of the interface relationships between the rapid transit system and other transportation modes. Since approval must usually be obtained from various local jurisdictions, the planner's primary skills must include both an awareness of the social and environmental factors involved, and the political judgment to discuss them in a proper way when dealing with other people.

Significantly, understanding the implications of subsurface conditions on system construction costs has not been one of the more important assets of urban planners. Traditionally, the planner's knowledge of geologic and construction factors has been limited to the generalization: "surface construction in soil is less expensive than subsurface construction." One might question such a broad generalization especially when environmental, social, and other impacts of both a tangible as well as intangible nature are not given due consideration. In any event planners should be prepared to evaluate all costs and benefits before arriving at any conclusion as to cost advantages of particular alternatives.

If a tool were available which could be used by people who are not knowledgeable about the details of subsurface condition-related construction costs, the early consciousness, however it may be introduced, is conducive to economical design. Too often, plans are made and finalized, after which changing them to reduce costs becomes difficult for the person or organization which made them.

b. Designers. Underground structures differ from surface structures because of the special construction and loading conditions associated with their subsurface location.

The designer must develop a design which will satisfactorily meet those conditions. Success depends upon several factors, two of which predominate: designer competence, and quality of the site information available.

Competence is a crucial ingredient in a number of ways. One of the very important areas is in the relationship of design to construction costs. The engineer who is not capable of mentally "constructing" a structure using the best construction techniques available as it is being designed, will almost certainly produce an expensive design. There is more to this than the question of whether or not the structure can be built. The more important question is whether it can be built economically.

Another way in which competence is important involves judgment about the available data. Geological information is never complete. In the early stages of the design sequence, available data may consist only of U.S. Geological Survey maps or reports, reports from state agencies or professional organizations, or information which was gathered for another purpose. The designer should be flexible enough to build on this data while at the same time retaining the flexibility needed to deal with new conditions as they are identified.

As the design progresses, preliminary geological reports are prepared for the proposed route. Preliminary soil/rock load criteria are given, and the general geology of the route begins to unfold. This frequently calls for adjustments to the initial design, hopefully without requiring a complete redesign.

Finally, detailed geological reports are prepared for specific sections in which this type of information is considered essential to good design. These reports should normally be available prior to or during final design. Using information from them, together with case histories covering other subsurface construction in the area, the designer finalizes the design.

At each stage in this process, the designer must understand the implications of new information for the design and for construction costs. Where necessary, the design must be changed to achieve more economical construction. Small percentage savings in construction costs often justify the costs of major changes in design. For example, if geologic data and interpretation indicate a potential mixed-face condition which could result in substantially increased construction costs, the designer would be expected to explore the possibility of revising system grades to avoid such a situation.

One of the important implications of the sequential availability of information described above is that designs will seldom be based upon the designer's current perception of conditions upon which the structure will be built and operated. Usually, designers lose their designs on "worst case" conditions. This leads to a tendency to overdesign resulting in more expensive structures. A suitable cost estimating system, properly applied at sequential stages of design, would be of value in calling attention to design decisions which might lead to costly construction. Such a system would not only help the inexperienced designer to do a better job, but also be an aid to the highly competent designer as well, since it would aid in "fine tuning" to achieve the most economical design possible.

Estimating systems commonly used now do not provide this capability. Those employing unit pricing or comparative pricing techniques require their user to have a high degree of skill and experience. Recognizing subtle differences between construction under one set of conditions vs. another may be difficult or impossible. This is particularly true where the estimating system obscures the inter-relationships between the important technical and non-technical parameters by lumping many of them together. A system which can remove some of the skill requirements from cost estimating and/or cost comparison between alternates should contribute measurably to design improvements and achieve a reduction in cost for much of the underground construction now under design.

c. Architectural Design. Architectural layouts of the overall size and shape of the structures begin prior to the feasibility and economic studies. There is evidence that a number of these layouts have been developed without taking adequate account of the relationships between structural shape and construction costs. One solution to this problem

It is our philosophy that a tunnel cost estimating system, if it is to be useful and have the desired degree of accuracy, should take into consideration the factors described above. If it employs the types of processes and reasoning by which actual tunneling costs are determined, then historical data and information about current practice can be incorporated into it and used in a rational way. The accuracy obtained will be consistent with the accuracy and level of detail available at each stage of planning and design. In this way, it can provide the information needed by the owners, planners, and designers of underground rapid rail transit systems.

4.3 DESCRIPTION OF SYSTEM

The cost estimation and analysis system developed in the program is shown schematically in Figure 4-1. Costing for the system is accomplished by separately costing each of the significant cost components arranged across the figure. The data bank contains estimates for amounts of labor, equipment, and material required to execute the work for each cost component under various prescribed conditions. The data bank also contains unit pricing information which when combined with the above yields base costs for each of the components. After adjustment of base costs for non-construction type cost factors (See Section 5), component costs are totaled to establish total project costs.

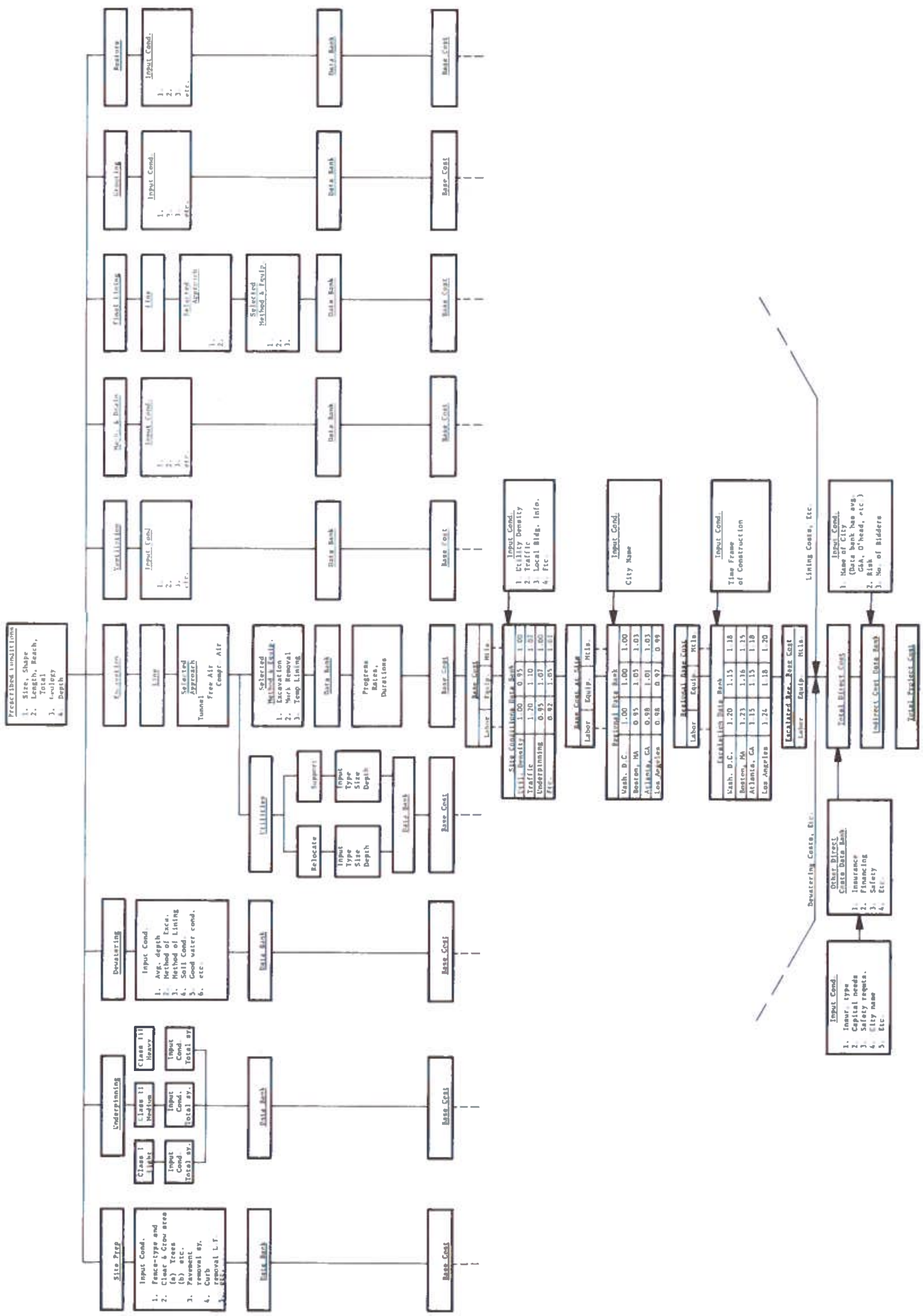

FIGURE 4-1. SYSTEM DIAGRAM

For purposes of illustration, a typical computational sequence for "excavation" will be described. The user of the system begins by selecting a set of prescribed conditions for the tunnel to be constructed. These include size, (principal cross-sectional dimensions), and shape (round, horseshoe, etc.), length, (both total length and the reach, or distance between shafts), geology, (based on a few generalized classifications), and depth (beneath the local ground surface). For a section of line tunnel a construction approach is selected. If, for example, there appears to be no serious water problems, tunneling in free air might be chosen as the preferred method. In cases where there may be a probability that compressed air will be required, cost comparisons can be made by doing estimates on both the free and compressed air approaches.

For the moment, suppose that free air appears to be a reasonable construction approach. The next step is to select methods and equipment to be used in free air. In the illustration, one might select an excavation method such as shield with wheel excavator, digger shield or shield with hand excavation; for muck removal, train and rail cars or rubber tired vehicles; for primary lining, ribs and lagging, segmented precast concrete, corrugated or structural steel liner.

Each of the choices mentioned above has associated with it certain amounts of labor, equipment, and materials, together with certain rates of advance. Thus, experience may have shown that a shield with wheel excavator operating above the water table in sandy clay requires a heading crew of nine and is able to advance at a rate of three feet per hour in a 19 feet diameter circular tunnel in Washington, D.C.* These statistics will be stored in a data bank which also contains up-to-date wage and equipment rates.

The data bank will also have information about the support crews required, both in the tunnel and on the surface, for a secondary lining, say ribs and lagging, and a muck haulage system, say rail, which will match the characteristics of the shield. Current equipment and materials costs for primary lining and muck haulage will also be included.

Data bank information will be prepared as illustrated on pages 75, 76, 77, and 78 for each possible combination of tunneling equipment and construction conditions. This will be set up so that current labor/equipment/material costs can be inserted, after which the computer will combine them with crew size and other pertinent information related to the selected construction techniques. Note that crew size and amounts and types of equipment and materials depend upon the current technological state of practice. These quantities change only with changes in practice, and can be updated as new methods become available. Thus, data bank storage will contain some information which changes very slowly with time, together with wage rates and equipment/materials costs, which change more rapidly.

*The proposed system will use Washington, D.C. as a base city. Changes for crew sizes and labor, equipment, and material costs can then be made on a regional basis. This is discussed in later paragraphs.

The final output of the activities just described is the base cost of a tunnel built by the chosen construction method in the prescribed geological environment with average site conditions. Base cost must be corrected for factors related to the site, the region, and the time frame of actual construction. This is done as illustrated in the "excavation-line tunnel" column of Figure 4-1.

The first correction is made for site conditions. A data bank is equipped with multipliers for labor, equipment, and materials to account for differences between actual and average site conditions. These cover such physical conditions as utilities, which may be of low, medium, or high density; local buildings, which may be insensitive, nominally sensitive, or very sensitive to ground settlement; local traffic problems which may be small, normal, or large; etc. Note that the multiplier applied at this stage is a correction to excavation costs to take account of the effect of site conditions on those costs. For example, the actual cost of moving utilities, if this is required, is computed in a separate column. Under "excavation-line tunnel" the utility factor corrects for the slowdown in tunneling rates and/or other changes resulting from the fact that there are utilities present when excavation is underway.

The next correction to be applied is the regional factor. The data bank is input with the name of the city where the tunnel is to be built. This causes multipliers to be applied to labor, equipment, and materials costs to correct for the difference between the specified city and Washington, D.C. The types of differences considered are union practices such as featherbedding, the extra costs of special equipment to meet environmental requirements such as noise control, the effects of regional weather on construction costs, tax effects, etc. When these factors have been taken into account, a <u>regional base cost</u> has been defined.

Finally, the labor, equipment, and materials elements of the regional base cost are escalated to take account of the time frame in which construction will actually take place.

Other factors shown across the top of Figure 4-1 which contribute to total direct cost such as dewatering, final lining, grouting, etc. are brought into the estimate at this stage. Each of these has been treated similarly to the way described for "excavation-line tunnel" above, so that its final cost reflects site, regional and time frame corrections. Another group of contributors, known as "other direct costs," includes the cost of insurance, financing, safety programs, obtaining building permits, etc.

Total direct costs, the sum of the escalated regional base costs of all the items enumerated, are then combined with indirect costs to obtain <u>total project cost</u>. Indirect costs are obtained from a data bank which contains information for each city relating to average overhead and general and administrative expenses (G&A) charged by companies operating in that city. In addition, the data bank has factors to be applied to projected costs to take account of the degree of risk involved, as well as the probable degree of competition measured in terms of the number of bidders expected. These factors must, of course, be used with care when they are being applied to relatively distant time frames (5 to 10 years).

4.4 ADVANTAGES OF SYSTEM

The proposed estimating system has the following advantages:

a. The framework for cost development is similar to that employed in contractor's cost estimates. Since tunneling costs are ultimately based on this approach, the system has a high potential for accurate cost prediction within the limits of the data available at the time an estimate is made.

b. Estimates will be based on historical performance data for the construction methods employed coupled with current costs for labor, equipment, and materials. Corrections for site and regional factors and for the time-frame of construction, which are applied to base costs, are based on a combination of historical and projected data, giving them strong credibility.

Indirect costs, too, will be based on established values, adjusted for projected future changes. This will provide a reliable framework for their determination.

c. One of the uses to be made of the system is to make rapid cost comparisons between alternate alignments and designs within the same region. Differential costs can be obtained with good accuracy in most cases because they require taking differences between well established construction costs without the need to take small differences between large numbers which were based on some of the less tangible institutional factors.

d. The system appears to be well adapted to computerization, in terms of initial inputs, memory storage requirements, and the probable cost of individual runs.

e. The system should be useable by planners and others who do not have strong construction backgrounds. It provides this type of individual with several alternate choices, each of which has been organized to be correct from a construction standpoint. One may try each of them for the conditions selected and obtain the cost differentials between them.

DATA BANK		LABOR	CLASS CODE: 111323		
Air	1	Free air	Method of excav.	3	Shield/wheel excavator
Size	1	15' to 19' dia.	Temporary support	2	Ring Beam & Lagging
Shape	1	Round	Method of Mucking	3	Rail to Shaft Hoist

OPERATION: Tunnel Excavation
CREW: Heading Crew

	No./Shift			Rate per Hour	Shift Differential		Total/Shift			Total/Day		
	1st	2nd	3rd		2nd	3rd	1st	2nd	3rd	1 Shift	2 Shifts	3 Shifts
Shifters	1	1	1	8.55	6.05	6.55	68.40	74.45	74.95	68.40	142.85	217.80
Miners	5	5	4	8.05	4.25	5.85	322.00	343.25	281.00	322.00	665.25	946.25
Operators	2	2	1	10.10	5.50	7.10	161.60	167.10	87.10	161.60	328.70	416.60
Mechanics	1	1	-	10.25	5.50	7.10	82.00	87.50	-	82.00	169.50	169.50
Totals	9	9	6				634.00	672.30	443.05	634.00	1306.30	1750.15

DATA BANK		EQUIPMENT COSTS	CLASS CODE: 111323		
Air	1	Free air	Method of Excav.	3	Shield/wheel excavator
Size	1	15' to 19' dia.	Temporary Support	2	Ring beams & Lagging
Shape	1	Round	Method of Mucking	3	Rail to shaft hoist

OPERATION: Tunnel Excavation

EQUIP. SPREAD Underground

	OPERATING COSTS									OWNERSHIP		TOTAL COST/DAY		
	No./shift			Hours Per Shift	Cost Per Hour	Cost Per Shift	Total Oper Cost/Day			Total Units	Cost Per Day	1st	2nd	3rd
	1	2	3				1st	2nd	3rd					
Shield/wheel/erector	1	1	1	6						1				
Conveyor/car loader unit	1	1	1	6						1				
Locomotives 20T	2	2	1	8						3				
Muck Cars 12 CY	20	20	10	8						24				
Flat Cars	3	3	1	8						4				
Ventilation Fans 25HP	2	2	2	8						3				
Fan line car	1	1	-	4						1				
Man Trip car	2	2	2	2						2				
Pumps 6"	1	1	1	8						2				
Pumps 3"	2	2	2	8						4				
Pumps 1"	2	2	2	8						4				
Car Dumper	1	1	1	6						1				
Air Tuggers	3	3	3	4						4				
California Switch	1	1	1	8						1				

Tunnel Excavation — MATERIALS

Air	1	Free	Temp. Support	2	Ring beams/Lagging
Size	1	15' to 19'	Method mucking	3	Rail to shaft hoist
Shape	1	Round			
Method	3	Shield/Wheel			

Legend: OD=Tunnel Driven Dia.
L=Length Tunnel Reach
D=Depth at Shaft

	Unit Material Cost	$ COST	PER
PERMANENT MATERIALS			
1. Ring Beams 4' C-c W8x24			
Quantity (OD - 0.33)' ( ) ($\frac{24}{4}$) =			
(OD - 0.33) 6 #/LF Tunnel	$0.25/LB	(0.25)(OD-0.33)6	$/LF Tun
2. Lagging 6"x6" or 6"x8"			
Quantity=(OD - 0.25) ( ) (6") BF/LF Tunnel	$0.20/BF	(0.2)(OD-.25) 6	$/LF Tun
EXPENDABLE MATERIALS			
1. Rail 90#/YD (30#/LF Tunnel			
Quantity 2x30 60#/LF Tunnel	$0.16/LB	(0.16)(60)	/LF Tun
2. Nuts, Bolts & Spikes 2#LF	$1.00/LB	2.00	/LF Tun
3. Switches 2 @ Shaft plus/per 2000 LF			
Quantity - 2+L/2000 ea.	$1500 ea.	1500(2+L/2000)	LS Per Reach
4. Railroad ties 5"x6"x6' @ 2.5' C-C			
Quantity=L/2.5 ea.	$3.00 ea.	(3) (L/2.5)	LS Per Reach
5. Fanline 30" C/W Hangers & Anchors			
Quantity = (D+L) LF	$15/LF	15 (D+L)	LF Per Reach

MATERIALS

	Unit Material Cost	$ COST	PER
6. Discharge Line 8" ØC/W Fittings			
Quantity = (D+L) LF	$8/LF	8 (D+L)	LS Per Reach
7. Airline 4" Ø C/W Fittings			
Quantity (D+L) LF	$5/LF	5 (D+L)	LS Per Reach
8 Small Tools @ 8% Labor			
Wh=Wages Heading Crew			
Wu=Wages U.G. Support Crew			
WS=Wages Surface Support Crew			
Quantity=Wh+Wu+Ws	$0.08	(0.08)(Wh+Wu+Ws)	LS Per Reach
9. Safety Equip. @5% Labor			
Quantity=Wh+Wu+Ws	$0.05	(.05)(Wh+Wu+Ws)	LS Per Reach
10. Misc. Air Hose, Cable, Etc.			
Quantity=LF Tunnel	$20/LF	20 (L)	Per LF Tun.
11. Temp. Electric Supply - Lights, Transformers			
Quantity = (D+L) LF	$20/LF	20 (D+L)	LS Per Reach

5. NON-CONSTRUCTION COSTS

5.1 COST GROUPINGS

In addition to the costs associated with providing the labor, materials, and equipment to perform the construction work, costs are incurred for non-construction items which are essential to the successful execution of a construction project. These latter costs are associated with the planning, management, and control over technical, operational and financial aspects of the project.

It is of interest to note that there is a distinction between those non-construction costs which are planned and over which the owner has some control, and those costs over which the owner has little or no control. For example, site investigations and project management are in the former category, whereas legal costs and area building permits are representative of the latter. The above is of particular significance with respect to planning activities having the objective of optimizing costs and therefore one of the early tasks in the preliminary stages of a project should be to identify those non-construction costs which are relatively fixed and those over which the owner has some control.

Certain of the non-construction cost items may be termed "Influence Factors," that is, those cost items which serve to modify the estimated cost of construction. The other group of cost items are those which are incurred to either support the needs of the construction process, or are of an institutional nature and are simply added to the construction cost to obtain total project costs. These cost items are referred to as the "Support and Institutional Costs." The two groups are further delineated below:

<u>Influence Factors</u>

Schedule Slippage	Change Orders
Bidding Climate	Escalation
Regional Factors	Weather and Climate
Productivity Factors	

<u>Support and Institutional Costs</u>

Insurance	Construction Management
Building Permits	Engineering Design
Traffic Control	Legal Costs
Financing Costs	Project Management
Real Estate Acquisition	Environmental-Community Interface Costs
Geologic Investigation	

To serve as a basis for establishing values for the non-construction cost items, comparative cost data has been assembled from three actual on-going projects. Two of these projects are for mass transit, and the third is for a utility type project. Major dissimilarities in the management and organization of the three projects serve to make comparative analyses rather difficult, and in some cases various items of data were impossible to gather since the project organizations have not as a common practice maintained records on all items for which data are desired. Nevertheless, the effort involved in assembling data which were available was worthwhile, and did result in at least establishing provisional values which can be used in the model until more refined ones can be determined through later studies.

The following are detailed explanations of the nature and extent of effect of the non-construction costs.

5.2 INFLUENCE FACTORS

5.2.1 Schedule Slippage

Schedule slippage may be caused by a number of factors. When neighborhood or environmental groups take their grievances into the courts after a contract has been awarded, temporary or permanent restraining orders may stop construction until the grievances have been settled. Labor strikes also cause delays. Changes in plans by any of the agencies involved or failure to make executive decisions at the political level are another. Two of the most common causes for schedule slippage are the failure of the contractor to effectively manage and execute the work in a timely manner and failure to use the most effective construction methods for conditions encountered. There are also causes which are not the fault of the contractor or the owner, such as, natural disaster and unanticipated problems or working conditions.

The end result of schedule slippage is almost always increased cost because of work being postponed to later time periods. Increased costs may be caused by the effects of inflation, by changes in construction methods and schedules, or by an increased length of time required for engineering, inspection, and support services. In some cases, equipment may no longer be available or usable, and so added equipment costs will be incurred. All these factors influence the ultimate cost of the project. Costs invariably increase with increased slippage.

As an example of costs which might be incurred due to schedule slippage, the original plan for one of the three projects analyzed called for a six year program. The actual time to complete the program turned out to be 12 years. This was caused by lengthy delays due to court suits; negotiations with cities on routing, design, and station plans; and a variety of other factors. The delays of course pushed expenditures into later years when prices were higher. The cost of delays due to inflation alone totaled $116 million which constituted 7.2% of total project costs.

Costs due to schedule slippage are related to slippage time in complex ways. Details may differ markedly in individual cases, and there does not appear to be any basis at this time for estimating costs in an accurate, analytical manner. It will be helpful, however, to develop a highly simplified model for the slippage/cost relationships. The curves on Figure 5-1, together with the explanation which follows, will

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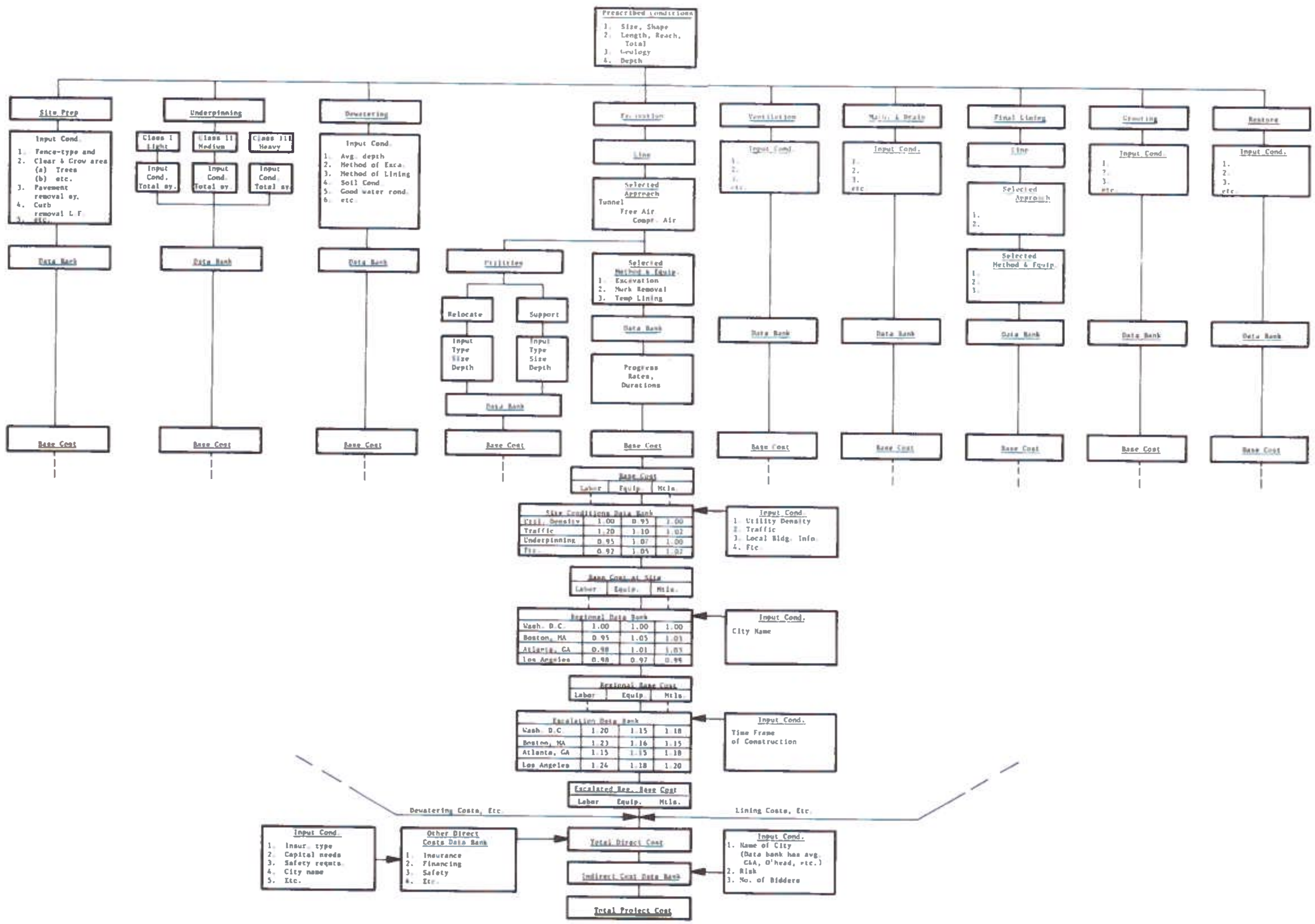

FIGURE 4-1. SYSTEM DIAGRAM

For purposes of illustration, a typical computational sequence for "excavation" will be described. The user of the system begins by selecting a set of prescribed conditions for the tunnel to be constructed. These include size, (principal cross-sectional dimensions), and shape (round, horseshoe, etc.), length, (both total length and the reach, or distance between shafts), geology, (based on a few generalized classifications), and depth (beneath the local ground surface). For a section of line tunnel a construction approach is selected. If, for example, there appears to be no serious water problems, tunneling in free air might be chosen as the preferred method. In cases where there may be a probability that compressed air will be required, cost comparisons can be made by doing estimates on both the free and compressed air approaches.

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Shape	1	Round	Method of Mucking	3	Rail to Shaft Hoist

OPERATION: Tunnel Excavation
CREW: Heading Crew

	No./Shift			Rate per Hour	Shift Differential		Total/Shift			Total/Day		
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Operators	2	2	1	10.10	5.50	7.10	161.60	167.10	87.10	161.60	328.70	416.60
Mechanics	1	1	-	10.25	5.50	7.10	82.00	87.50	-	82.00	169.50	169.50
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OPERATION: Tunnel Excavation

EQUIP. SPREAD Underground

	OPERATING COSTS									OWNERSHIP		TOTAL COST/DAY		
	No./shift			Hours Per Shift	Cost Per Hour	Cost Per Shift	Total Oper Cost/Day			Total Units	Cost Per Day	1st	2nd	3rd
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Man Trip car	2	2	2	2						2				
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Car Dumper	1	1	1	6						1				
Air Tuggers	3	3	3	4						4				
California Switch	1	1	1	8						1				

Tunnel Excavation		MATERIALS			
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Legend: OD=Tunnel Driven Dia.
L=Length Tunnel Reach
D=Depth at Shaft

	Unit Material Cost	$ COST	PER
PERMANENT MATERIALS			
1. Ring Beams 4' C-c W8x24			
Quantity (OD - 0.33)' ( ) ($\frac{24}{4}$) =			
(OD - 0.33) 6 #/LF Tunnel	$0.25/LB	(0.25)(OD- 0.33)6	$/LF Tun
2. Lagging 6"x6" or 6"x8"			
Quantity=(OD - 0.25) ( ) (6") BF/LF Tunnel	$0.20/BF	(0.2)(OD- .25) 6	$/LF Tun
EXPENDABLE MATERIALS			
1. Rail 90#/YD (30#/LF Tunnel			
Quantity 2x30 60#/LF Tunnel	$0.16/LB	(0.16)(60)	/LF Tun
2. Nuts, Bolts & Spikes 2#LF	$1.00/LB	2.00	/LF Tun
3. Switches 2 @ Shaft plus/per 2000 LF			
Quantity - 2+L/2000 ea.	$1500 ea.	1500(2+L/2000)	LS Per Reach
4. Railroad ties 5"x6"x6' @ 2.5' C-C			
Quantity=L/2.5 ea.	$3.00 ea.	(3) (L/2.5)	LS Per Reach
5. Fanline 30" C/W Hangers & Anchors			
Quantity = (D+L) LF	$15/LF	15 (D+L)	LF Per Reach

MATERIALS

	Unit Material Cost	$ COST	PER
6. Discharge Line 8" ØC/W Fittings			
Quantity = (D+L) LF	$8/LF	8 (D+L)	LS Per Reach
7. Airline 4" Ø C/W Fittings			
Quantity (D+L) LF	$5/LF	5 (D+L)	LS Per Reach
8. Small Tools @ 8% Labor			
Wh=Wages Heading Crew			
Wu=Wages U.G. Support Crew			
WS=Wages Surface Support Crew			
Quantity=Wh+Wu+Ws	$0.08	(0.08)(Wh+Wu+Ws)	LS Per Reach
9. Safety Equip. @5% Labor			
Quantity=Wh+Wu+Ws	$0.05	(.05)(Wh+Wu+Ws)	LS Per Reach
10. Misc. Air Hose, Cable, Etc.			
Quantity=LF Tunnel	$20/LF	20 (L)	Per LF Tun.
11. Temp. Electric Supply - Lights, Transformers			
Quantity = (D+L) LF	$20/LF	20 (D+L)	LS Per Reach

5. NON-CONSTRUCTION COSTS

5.1 COST GROUPINGS

In addition to the costs associated with providing the labor, materials, and equipment to perform the construction work, costs are incurred for non-construction items which are essential to the successful execution of a construction project. These latter costs are associated with the planning, management, and control over technical, operational and financial aspects of the project.

It is of interest to note that there is a distinction between those non-construction costs which are planned and over which the owner has some control, and those costs over which the owner has little or no control. For example, site investigations and project management are in the former category, whereas legal costs and area building permits are representative of the latter. The above is of particular significance with respect to planning activities having the objective of optimizing costs and therefore one of the early tasks in the preliminary stages of a project should be to identify those non-construction costs which are relatively fixed and those over which the owner has some control.

Certain of the non-construction cost items may be termed "Influence Factors," that is, those cost items which serve to modify the estimated cost of construction. The other group of cost items are those which are incurred to either support the needs of the construction process, or are of an institutional nature and are simply added to the construction cost to obtain total project costs. These cost items are referred to as the "Support and Institutional Costs." The two groups are further delineated below:

<u>Influence Factors</u>

Schedule Slippage	Change Orders
Bidding Climate	Escalation
Regional Factors	Weather and Climate
Productivity Factors	

<u>Support and Institutional Costs</u>

Insurance	Construction Management
Building Permits	Engineering Design
Traffic Control	Legal Costs
Financing Costs	Project Management
Real Estate Acquisition	Environmental-Community Interface Costs
Geologic Investigation	

To serve as a basis for establishing values for the non-construction cost items, comparative cost data has been assembled from three actual on-going projects. Two of these projects are for mass transit, and the third is for a utility type project. Major dissimilarities in the management and organization of the three projects serve to make comparative analyses rather difficult, and in some cases various items of data were impossible to gather since the project organizations have not as a common practice maintained records on all items for which data are desired. Nevertheless, the effort involved in assembling data which were available was worthwhile, and did result in at least establishing provisional values which can be used in the model until more refined ones can be determined through later studies.

The following are detailed explanations of the nature and extent of effect of the non-construction costs.

5.2 INFLUENCE FACTORS

5.2.1 Schedule Slippage

Schedule slippage may be caused by a number of factors. When neighborhood or environmental groups take their grievances into the courts after a contract has been awarded, temporary or permanent restraining orders may stop construction until the grievances have been settled. Labor strikes also cause delays. Changes in plans by any of the agencies involved or failure to make executive decisions at the political level are another. Two of the most common causes for schedule slippage are the failure of the contractor to effectively manage and execute the work in a timely manner and failure to use the most effective construction methods for conditions encountered. There are also causes which are not the fault of the contractor or the owner, such as, natural disaster and unanticipated problems or working conditions.

The end result of schedule slippage is almost always increased cost because of work being postponed to later time periods. Increased costs may be caused by the effects of inflation, by changes in construction methods and schedules, or by an increased length of time required for engineering, inspection, and support services. In some cases, equipment may no longer be available or usable, and so added equipment costs will be incurred. All these factors influence the ultimate cost of the project. Costs invariably increase with increased slippage.

As an example of costs which might be incurred due to schedule slippage, the original plan for one of the three projects analyzed called for a six year program. The actual time to complete the program turned out to be 12 years. This was caused by lengthy delays due to court suits; negotiations with cities on routing, design, and station plans; and a variety of other factors. The delays of course pushed expenditures into later years when prices were higher. The cost of delays due to inflation alone totaled $116 million which constituted 7.2% of total project costs.

Costs due to schedule slippage are related to slippage time in complex ways. Details may differ markedly in individual cases, and there does not appear to be any basis at this time for estimating costs in an accurate, analytical manner. It will be helpful, however, to develop a highly simplified model for the slippage/cost relationships. The curves on Figure 5-1, together with the explanation which follows, will

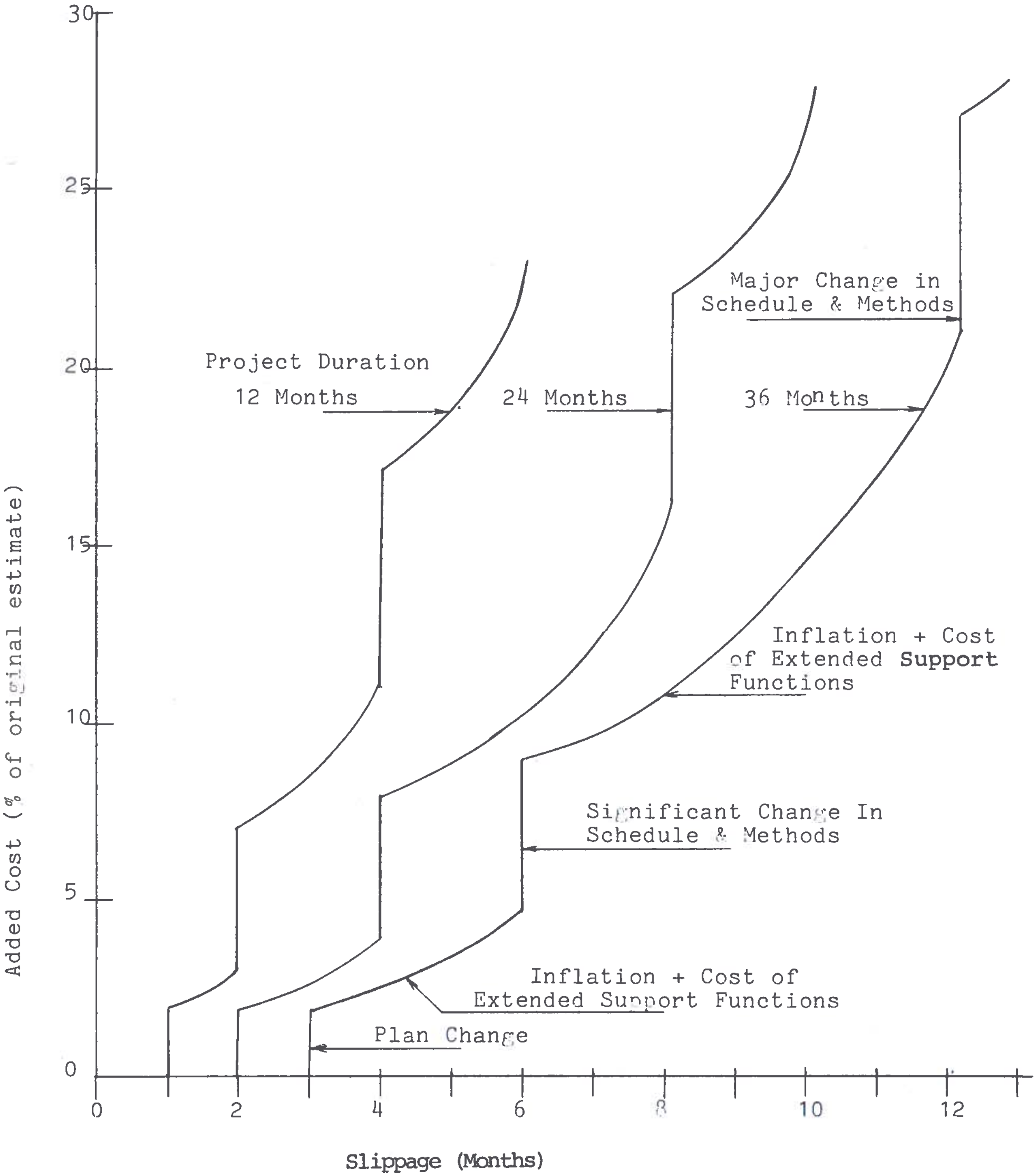

FIGURE 5-1. HYPOTHETICAL VARIATION IN SLIPPAGE COST WITH SLIPPAGE

provide some insight into the mechanisms involved.

Curves are shown on Figure 5-1 for projects having durations of 12, 24, and 36 months. Three project durations were illustrated because the increments of time shown on the horizontal axis have different effects on projects of different durations. The cost percentages which must be added to the original estimate are also assumed to vary with project durations so that the curves cannot be combined on a single, non-dimensionalized basis.

We shall now discuss the labeled regions of a typical curve. For small slippage, perhaps less than 10% of project duration, added costs will be small. At some point close to 10%, construction plans must be reworked, and this results in some added cost, (2% as shown by the lower left vertical lines). Slippage in excess of 10% requires that support functions, (management, traffic control, water pumping, etc.) be extended significantly beyond their originally scheduled duration. Some costs will be affected by inflation as well. These combined effects cause an upward trend in added costs whose slope increases with greater slippage. At some point, perhaps between 15 and 20% slippage, construction schedules and methods have to be changed significantly. This causes the second vertical jog, (4 percent shown on the curves). After this reorganization, slippage again causes an upward trend in added costs which reflects the influence of inflation and extended support functions. This continues up to perhaps 30% of initially planned project duration, at which time major changes must be made in schedule and methods, resulting in another vertical jog.

The exact nature of the slippage/added cost relationship is not known, and further study of historical examples would be necessary to establish fully credible numerical values. However, Figure 5-1 does demonstrate the way in which added costs are likely to build up as a result of the factors which influence them. Note especially that the rate of cost increase becomes greater with increasing time of slippage. This is consistent with what experience has shown might reasonably be expected to occur.

System-wide experience for the three projects analyzed has shown that added costs of at least 4.5% of original estimates, and up to 7.2% are clearly attributable to schedule slippage. A more detailed study of the cost consequences of schedule slippage would define more precisely the percentage cost increases which might legitimately be made, and the way in which such increases might be applied within the framework of the cost model. However, for purposes of the present study it must be assumed that if values associated with system-wide averages are applied, they will be accurate for a large sample of tunnels even though the values may be appreciably in error on specific projects.

The effects of delays on the costs of the Washington Metro System are worth citing. By 1975 the cost of delays had totaled \$627 million, almost 16% of project total costs at that time. The causes of the delays were:(6)

		(In Millions)
a.	Congressional delays in funding.	\$55.3
b.	Disputes with local & federal agencies.	90.6
c.	Legal actions by citizen groups.	77.0
d.	Labor problems, permit defficulties, and acts of God.	19.5
e.	Design changes.	26.5
f.	Unanticipated geologic problems.	21.7
g.	Real estate acquisition delays.	17.0
h.	Inflation.	319.7
		\$627.3

At the present time a value of 6%, representing an average cost increase due to schedule slippage, will be used in the model.

5.2.2 Bidding Climate

This has been discussed in Section 4.

5.2.3 Regional Factors

Harza concluded, from having compared a number of low bids with COSTUN estimates, that regional factors exist. These were lumped into a single multiplier for each region which was to be applied to overall costs. The Harza ratios are probably reasonable for average values when many tunnels are being considered. They do not, however, distinguish between projects whose cost ratios for labor/equipment/materials vary, nor do they show the relative effects of other influence factors. In the present program, we have taken a first cut at separating out the components of the Harza cost ratios.

The Harza cost ratios are assumed to be related to relative labor costs and productivity (Columns (1) and (2) of Table 5-1); materials costs; equipment costs; environmental and competitive factors; and special risk and restriction factors associated with regional geology, weather, and contract management. As shown in the table, the sum of the corrections for all of these factors is assumed to equal the increased cost given for a particular region by the Harza cost ratio.

Washington, D.C. has been chosen as the base for the present computations, hence all entries for this region are shown as 100%, requiring 0 corrections in all categories. This region has been taken to be representative of the U.S. East Coast cities, (with the exception of New York).

By comparison, comparable tunneling projects in New York City (NYC) have been found to cost 1.67 times as much. In developing a breakdown for this cost ratio, we collected data for the relative wage, materials, and equipment cost ratios for NYC. The correction to be applied to total project costs was developed by assuming that the labor/equipment/materials ratio of a typical tunnel is

TABLE 5-1. BREAKDOWN OF COMPONENTS OF HARZA COST RATIOS

	(1) Labor Wage Ratio (Corr)	(2) Productivity (Corr)	(3) Materials (Corr)	(4) Equipment (Corr)	(5) Competitive Factors (Corr)	(6) Risk a Special Restriction (Corr)	(7) Harza Cost Ratio
Wash DC	100% (0)	100% (0)	100% (0)	100% (0)	6-7 100% (0)	0% (0)	100%
NYC	117.67 (+.07)	62.5%[1] (+.24)	100.21 (0)	111.00 (+.02)	1-2(129%) (+.29)	+5% (+.05)	167%
West Coast	117.46 (+.07)	92% (+.04)	99.34% (.003)	98% (-004)	8+(94%) (-.06)	-4% (-.04)	100%
East Coast	100% (0)	100% (0)	100% (0)	100% (0)	6-7(100%) (0)	0 (0)	100%
Central USA	108.48% (+.03)	121% (-.07)	104.5% (+.02)	105% (+.01)	8+(94%) (-.06)	-.3% (-.03)	90%

[1]Local labor practices.

40/20/40. Thus, with average labor wage rates 17.67 percent higher, project total costs are 40 percent of 17.67 or 7% higher. The correction to overall project costs, (+ .07) is shown immediately under the wage cost ratio 117.67 percent for NYC. Materials and equipment costs are weighted similarly at 0 and +0.02, respectively for NYC. The number of bidders (Column 5) on recent NYC contracts has been comparatively low, and we have inserted a correction (+0.29) which is the markup on the basic technical estimate normally associated with 1-2 bidders. The risk and special restriction correction is assumed to be (+.05), 5 percent higher than in Washington, D.C. This is our estimate based on conversations with contractors, the majority of whom feel that doing business in the NYC area is more difficult, with more potential problems from high congestion and other conditions.

Productivity, Column (2) is the last column to be filled, and it is derived from the Harza cost ratio combined with the other data. The effect of productivity may be expressed as

$$C_p = R_L \left(\frac{1}{P} - 1\right) \qquad (1)$$

where C_p is the correction to be applied to the technical estimate for productivity.

R_L is the ratio of labor costs to total project costs in technical estimate; and P is the productivity ratio of the

TABLE 5-2. REGIONAL FACTORS

REGION	(1) LABOR	(2) EQUIPMENT	(3) MATERIALS	(4) OTHER
Washington, DC and East Coast	0	0	0	0
New York City	(+)0.97	(+)0.17	(+)0.05	(+)0.44
Central USA	(-)0.13	(+)0.02	(+)0.014	(-)0.04
West Coast	(+)0.238	(-)0.059	(-)0.047	(+)0.065

labor force based on work units per man hour.

Equation (1) shows that with a productivity of 50 percent, overall project costs will increase by the amount of labor costs in the technical estimate.

The 62.5 percent productivity factor shown in Column (2) for NYC is made up of two components. Union work rules require the use of about 30 percent more people in the work crew than for Washington, and this reduces the output per man hour (productivity) to 77 percent of its normal value for equal rates of advance. The productivity per person appears to be lower, being of the order of 81 percent. The latter is influenced by worker attitudes, efficiency of organization of the work force, and similar factors.

Other values in Table 5-1 have been developed in a similar way. The central US appears to have very high productivity. This is independently substantiated by reports of high rates of tunnel construction for a number of tunnels in this area.

In developing regional factors for the major sections of the country, we have employed the productivity data derived in Table 5-1, corrected for risks and special restrictions (Column 6). The results are shown in Table 5-2. Again using New York City as an illustration. Table 5-2, Column (1), shows that the cost of labor developed in the technical estimate must be increased by 0.97, or 97%. This factor is obtained by dividing the wage ratio by productivity, 117.67/.625 to obtain a new labor cost of 1.88 times original, and then multiplying by 1.05 to take account of risk and special restrictions (Column (6), Table 5-1) to obtain 1.97. This represents an increase of 97 percent, which is shown as +0.97 in Column (1), Table 5-2. Regional factors for other localities and for equipment and materials are derived in a similar way.

"Other" costs, Column (4), Table 5-2, are those parts of the TSC estimate which are entered as "plug" or sub-contract prices. These are total prices which may be broken down into labor, equipment, and materials using a 40/20/40 ration.

The regional factors shown in Table 5-2 are to be applied to each component of cost in the basic technical estimate. The results are summed to obtain the total cost of constructing the given tunnel in the region of interest.

5.2.4 Productivity Factors

Productivity relates to the efficiency or effectiveness of labor. Several factors influence productivity. One of these is the training and experience of crews. The time required to perform a task decreases with repeated performance. Thus, the time to perform "N" tasks = $N^{0.926}$ the time to perform the first. Changes in design or construction procedures are to be avoided as they require retraining and education of crews with consequent increase in the time to perform tasks.

The efficiency of labor may also depend upon whether the work week of an individual is extended beyond the usual 8 hour - 5 days, or perhaps even whether the customary working area is reduced so that workers are crowded. The effect of the latter may be estimated by the following equation: (7)

$$E\% = 10(10 - \frac{n}{N})$$

where: E = Efficiency

n = Customary space

N = Available space

and $\frac{n}{N} < 1.25$

The effect of crowded working conditions is best illustrated in the case of small diameter tunnels, wherein the construction cost-per-foot may be equal to or greater than that for larger tunnels.

The productivity factors require further verification and direct application to tunneling situations; therefore, they will not be applied separately in the current model.

5.2.5 Change Orders

Change orders are required for a number of reasons. In some cases, they result from changes in system design brought about by political, environmental, or technological factors. In others, the existence of design errors may be revealed while construction is in progress. Changed geological conditions sometimes involve extra costs to the contractor, and a change order may be issued to reimburse for these costs.

One of the projects analyzed experienced what might properly be called a "learning period" in the issuance of change orders. The first one or two contracts of each type, mixed tunnel, cut and cover, rock, soft ground, etc., had many change orders. At that stage, the dollar value of change orders added approximately 15 percent to the owner's estimate of project costs. Later, as the system management group and the engineers and contractors gained more experience in design and construction, the volume of change orders decreased to a value of 5-6 percent of the owner's estimate of project costs. It appears that a value of 5 percent is probably the minimum which can be anticipated.

One of the other projects analyzed had not issued many change orders. There were several reasons for this. First, the geology is fairly well known and rather uniform in character. Thus there are very few instances in which changed geologic conditions necessitate design changes. Secondly, contracts do not contain a changed conditions clause. Consequently, it is not necessary for the owner to reimburse contractors for additional costs resulting from unforeseen or unpredictable situations. Change orders which have been issued have related mainly to appurtenances, such as pumping stations, rather than tunnels.

The third project analyzed had an unusually good experience with change orders. Through the use of special contract provisions which seem to have minimized the adversary relationship between owner and contractor, the system was able to maintain an overall average for all types of changed conditions of approximately 3.4 percent of the engineer's estimate.

Based on our present understanding of the conditions for the three systems studied, we draw the following conclusions:

a. The value of change orders will depend upon the experience of the owner and contractors in working together on the project. At the start most organizations will experience a learning period which may begin with costs as high as 10-15 percent of engineer's estimates. These will later drop to the 5 percent range, providing experienced designers are employed and good management practices are used.

b. Change order costs will be affected by local geological conditions and the degree to which those conditions are understood. For bad, or poorly defined conditions, the number and value of change orders will be higher.

In view of the above, it is suggested that an allowance of 10 percent of the engineer's estimate be made for change orders on the first two contracts of each type (i.e. mined tunnel, cut and cover, etc.) to be undertaken in any new underground transit system. Thereafter, an allowance of 5 percent should be made for all subsequent contracts.

A more detailed examination of the complex interrelationships which govern the dollar value of change orders should be made later.

5.2.6 Escalation

Between 1960 and 1971 the consumer price index rose 36.7 percent, and the index of general construction rose 111.6 percent. During that same period, the ENR Index moved from 75 to 125. These values are perhaps not to be considered normal or necessarily repeatable in the future, as the Vietnam War exerted considerable influence during that particular time.

The long term trend (5+ years) of recent costs as shown in Figures 5-2, 5-3, and 5-4; and Table 5-3 yields the following average index increases which will be used in the model:

Wages	=	6.5 percent/year
Materials	=	6.0
Equipment	=	7.2

It is noted that the equipment index increased dramatically between 1974 and 1976. This was undoubtedly due to large exports to the Soviet Union and shipments for the Alaskan Pipeline during that period. It is not anticipated that heavy buying pressures such as this will be repeated in the foreseeable future.

5.2.7 Weather and Climate

Weather affects the cost of a construction project in several ways. The first and obvious effect is on surface travel. In areas having heavy snowfalls, the ability of crew members to commute to the site is affected. A typical

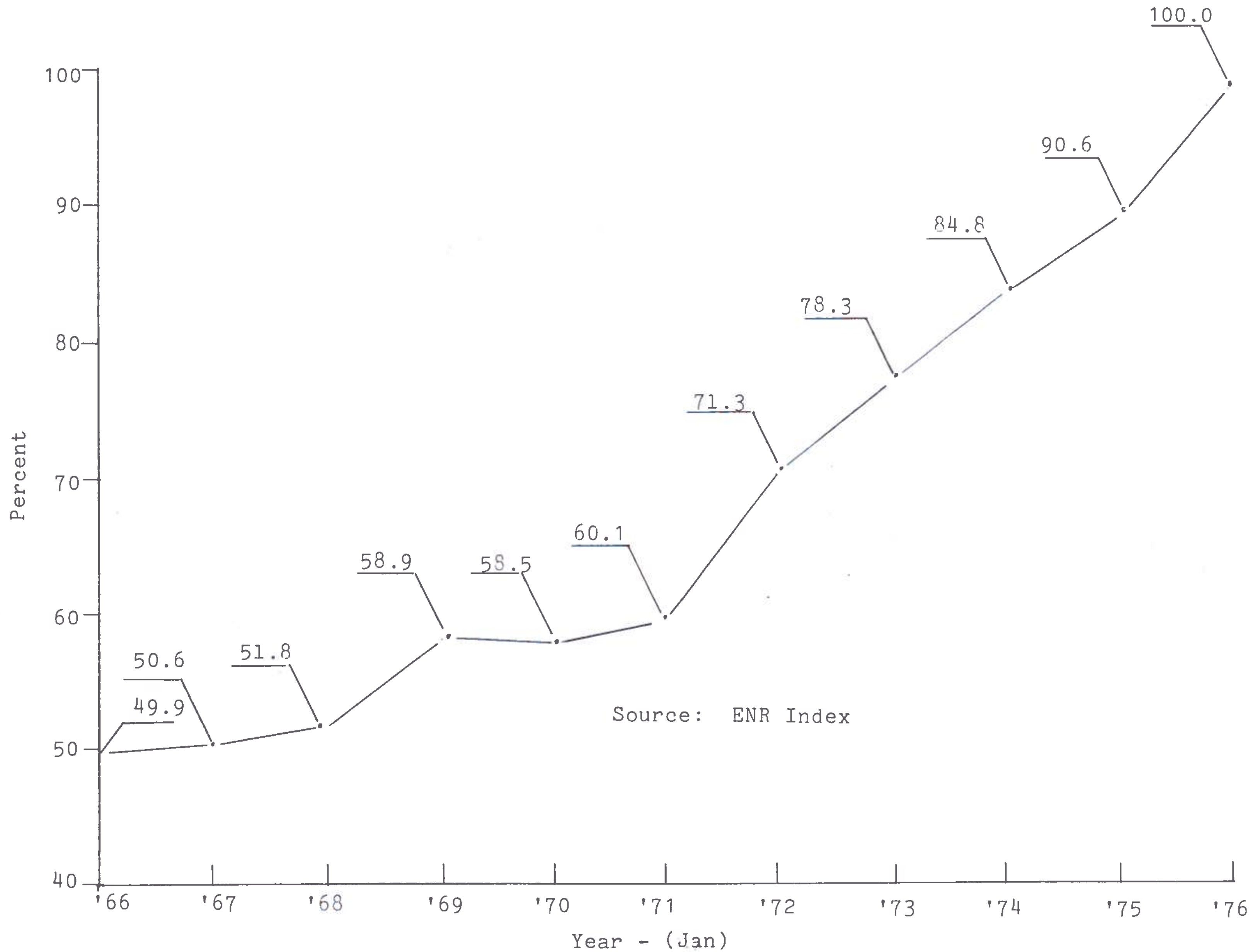

FIGURE 5-2. MATERIAL INDEX
(1976 BASE PRICE)

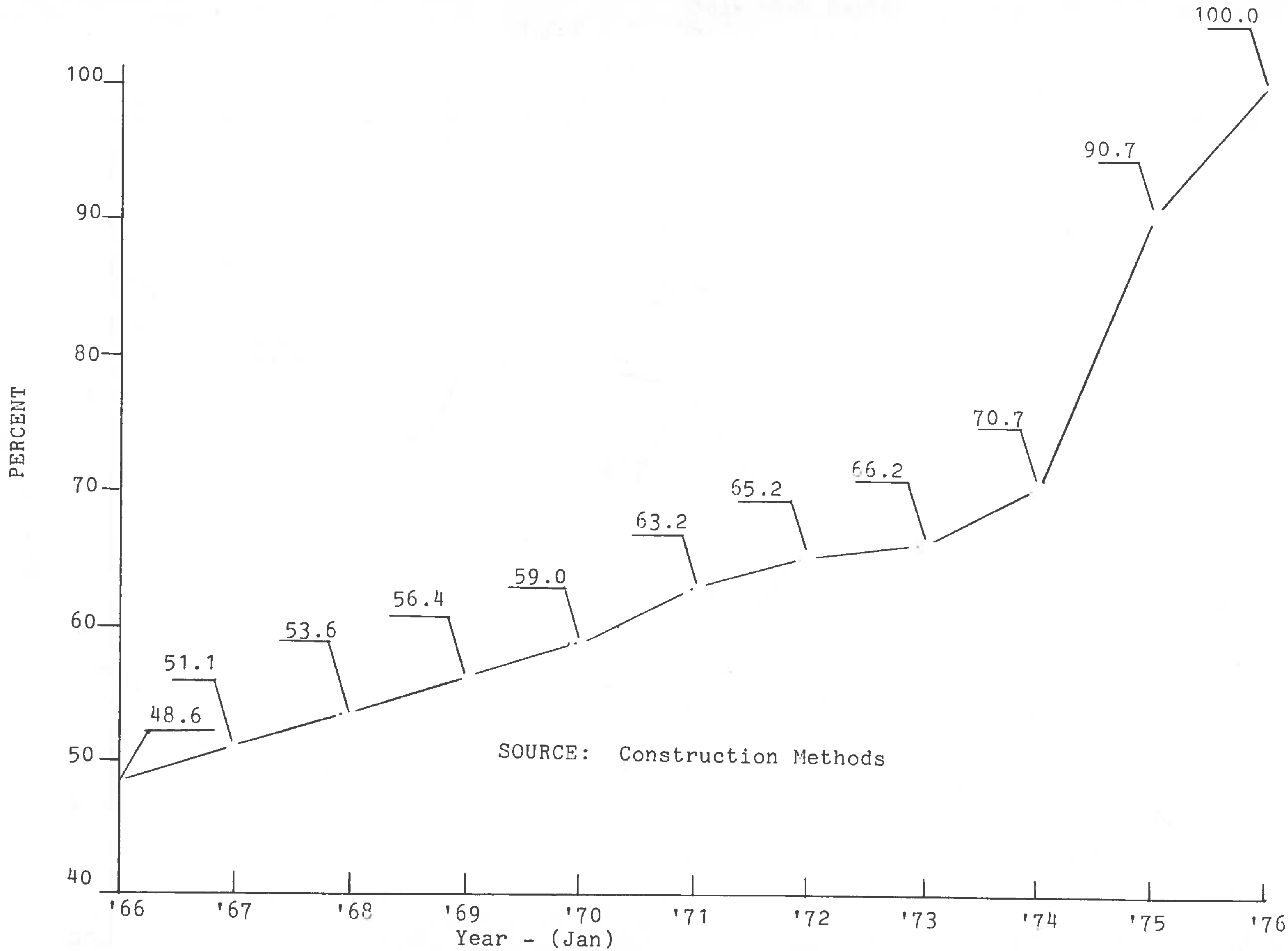

FIGURE 5-3. EQUIPMENT INDEX
(1976 BASE PRICE)

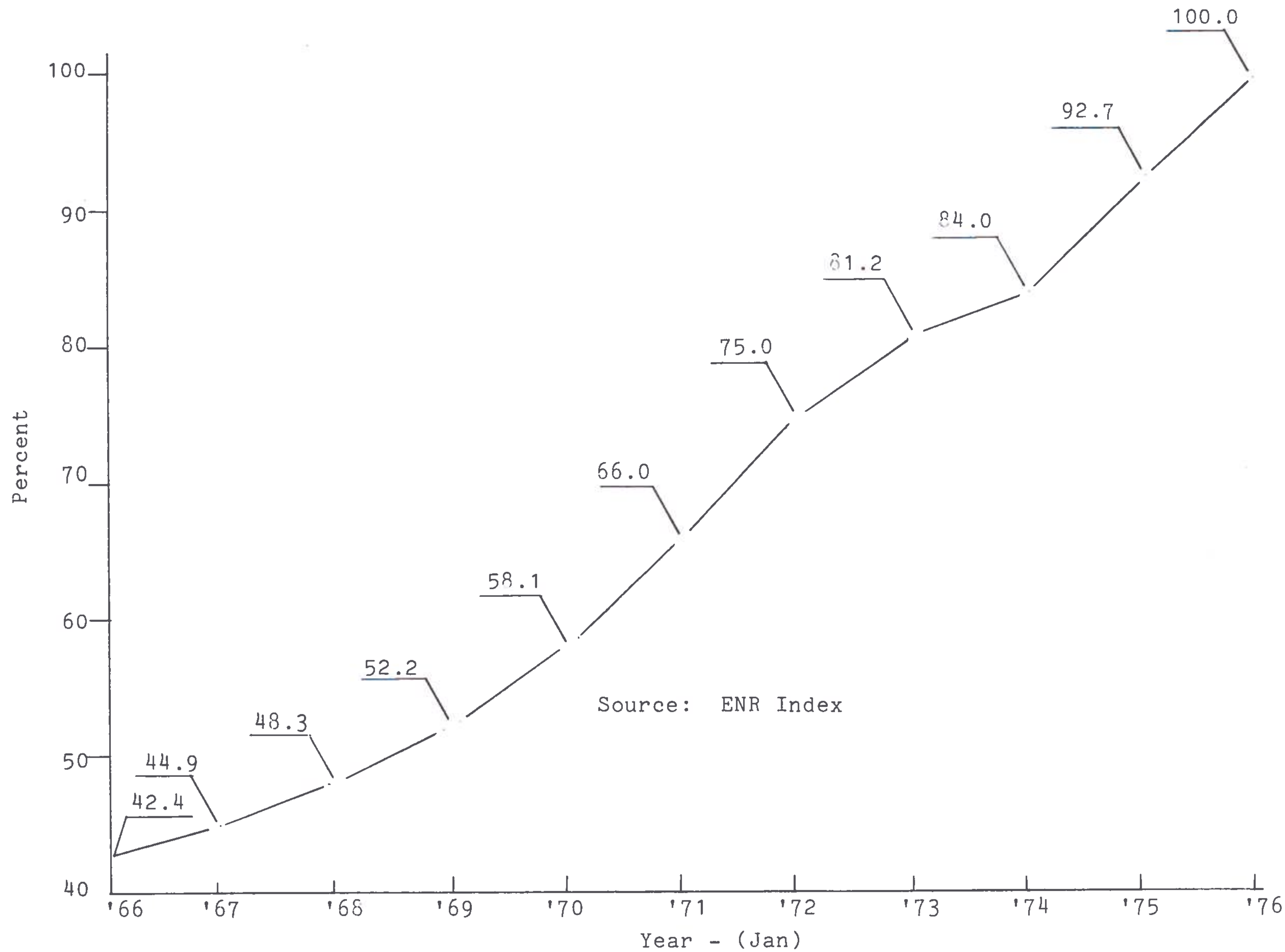

FIGURE 5-4. WAGE INDEX (1976 BASE WAGE)

TABLE 5-3. SKILLED LABOR INDEX FOR BALTIMORE MD

	INDEX	%	ANNUAL % CHANGE
1976	192	100	
			3.12
1975	186	96.88	
			4.69
1974	177	92.19	
			3.65
1973	170	88.54	
			7.81
1972	155	80.73	
			9.90
1971	136	70.83	
			7.81
1970	121	63.02	
			5.21
1969	111	57.81	
			4.16
1968	103	53.65	
			3.13
1967	97	50.52	
			2.08
1966	93	48.44	

heavy snow storm immobilizes traffic for one day and affects commuting in urban areas for one day thereafter. One would expect a loss of one day's construction output from commuting problems per storm.

A secondary effect is the interaction between materials flow to and from the site with local travel conditions. Lining and support materials, fuel, and other tunneling supplies are normally brought in by truck and this has the potential of being affected by travel conditions. These materials, however, are normally stored at the site, and the principal effect of a storm may be to slow down the rate at which they are transferred into the tunnel, thereby slowing construction.

Since weather constitutes an "Act of God", provision is usually made in contracts to excuse contractors for weather conditions which are above and beyond what can reasonably be considered normal. For example, one of the three projects analyzed made an allowance for unusual rainfalls; 1 1/2 day contract extension for rainfalls accumulating 0.25" - 0.5", and 3 days if exceeding 0.5".

Climate also has an effect on construction costs, mainly on the efficiency and effectiveness of labor. For example, tunnels at high altitudes have severe problems and high labor costs due to living conditions and reduced labor productivity. No attempt has been made in the program to quantify these effects, although the regional labor factors probably include some of the climatic influences on labor. Numerical factors for weather and climate are not currently assembled and therefore these factors are not included in the model.

5.3 SUPPORT AND INSTITUTIONAL COSTS

5.3.1 Insurance

A great deal has been written about the pros and cons of wrap-up insurance. The Sub-Committee on Contracting Practices of the U.S. National Committee for Tunneling Technology has recommended wrap-up, although it is admitted that problems may be posed for contractors who enjoy a good working relationship with their own insurance companies. It is not possible to say at this time whether wrap-up insurance is more or less expensive, all factors considered, than individual insurance. Significantly, one of the sample projects analyzed experimented with individual insurance before going to wrap-up. A second employed wrap-up from the beginning. The third has always required contractors to be individually insured, so no records are available to reveal the actual cost of insurance for the project.

Insurance costs reported escalated from 2.45 percent, of the volume of work covered during the 1968 midpoint timeframe to 4 percent of volume covered for the 1973 midpoint time. The increase in premium costs is believed to reflect an increase both in the number and size of claims per unit of contract work covered. Future insurance costs could be projected, based on the above percentages, by making an assumption about the rate of premium growth. If premiums are assumed to grow at a compound rate, an increase of 10 percent per year would lead to premium costs of 8 percent of the contract price by 1980. If a linear relationship is assumed, an increase of 0.31 points per year would lead to a premium cost of 6 percent of contract price by 1980. The latter value will be used for the TSC cost model.

Future costs will, of course, depend upon the amount of coverage found to be necessary, as well as upon the accident rate, the claim rate, and the size of the claims. The numbers assumed above and plotted on Figure 5-5 need to be examined in greater depth at a later time.

5.3.2 Building Permits

The acquisition of necessary building permits is usually left to the contractor and therefore the costs of such permits are included in bids. Since the dollar value of permits is very small compared with total project costs (1 percent), and the cost and method for calculating permit costs varies with each municipality, it has been decided to eliminate this type of cost from the present model.

5.3.3 Traffic Control

This is a relatively small cost compared with total project costs for the mined tunnels of the present study and consequently will not be included in the model at this time.

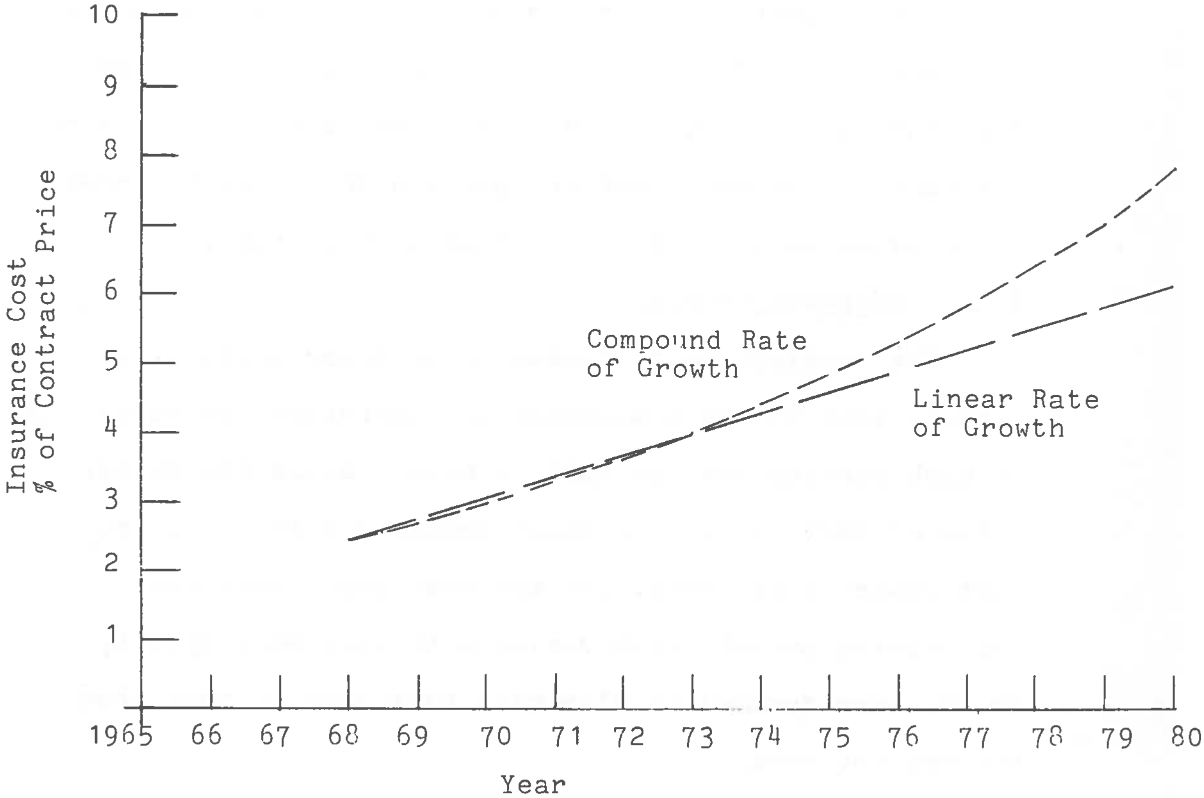

FIGURE 5-5 INSURANCE COST PROJECTION

5.3.4 Financing Costs

The cost of working capital required to mobilize and handle operating cash flow requirements is normally charged to the job. Financing costs are reduced in many projects today by providing a lump sum mobilization payment. This also tends to discourage unbalanced bidding.

The owner's payment policies affect project cash flow and in turn influence financing costs. If the payment schedule reduces the contractor's cash requirements, it will also lower financing charges, and consequently bid price. However, since this money may in turn be obtained at some financing cost to the owner, especially if money is raised by bond issue, financing costs are eventually reflected in the cost of the project. Since the owner's borrowing costs are likely to be several points lower than those of the contractor, there may still be a net saving by using an accelerated payment schedule.

A method of computing approximate finance costs is as follows:

Finance Cost in \$ = (average monthly project costs) X N X annual interest rate X duration of project in months.

where: N = Time lag to receive progress payment from owner in years.

Example: (N = 90 days = 0.25 years)

Finance Cost = 1,000,000 x 0.25 x 9% x 18 mo. = \$40,500.00

5.3.5 Real Estate Acquisition

The cost of real estate acquisitions for any project may vary between wide extremes based on the following factors:

a. Permanent accesses to surface (stations, inlets, stairwells, etc.)

b. Need to use private property.

c. Geographic location of acquisitions.

d. Local real estate values.

e. Local public policy.

f. Availability of "quick take" laws.

g. Urgency to proceed quickly.

Costs also depend upon whether property is to be purchased, leased, or rights such as easements and rights-of-way acquired. Purchase usually requires the largest outlay of capital whereas leases involve smaller but recurring costs.

One of the projects analyzed required little if any acquisition of real estate by purchase as all accesses to the underground were generally on public property. Another project, however, experienced costs of from 0 to 42 percent of individual project costs.

The cost of easements varies considerably from project to project, the following representing the major parameters:

a. Whether cut and cover or tunneling methods are used.

b. Depth of system below surface.

c. Degree of disruption of surface activities.

d. Local government policy.

e. Public need for the project.

f. Existence of "quick-take" laws.

g. Cost to owner for legal and engineering services and advice.

As an example of costs of easements, one of the U.S. transit authorities has found through experience that reasonable compensation to an owner may be computed as follows:

> Cost of easement per square foot of horizontal area of the subway under the owner's property = 50 percent of the annual rental per square foot of buildings on the surface.

One of the projects on the other hand has been operating under a long standing policy of $1 per linear foot of tunnel, and in cases where the owner resists condemnation, a suitable figure, still small, is usually negotiated.

In view of the wide variations in cost of real estate acquisition and the dependency of cost on the local values and conditions, these costs will not be included in the model.

5.3.6 Geologic Investigation

The cost of geological investigation can vary widely, depending upon methods employed and the use of data to be obtained. Some of the factors which have the greatest influence on costs are the spacing and depth of bore holes, type of geology, laboratory work required, and the complexity of the interpretive analysis.

In one of the study projects, investigations are estimated at $1.84/ft of tunnel in soil with bore holes every 500 ft. Core borings with boxed cores cost $18.00 per foot of bore depth. Aerial surveys are considerably cheaper at $1/ft of tunnel, but also yield much less information than other techniques.

The following statistics are representative of present experience as to the cost of geotechnical investigations.

	Percent of Total Project Cost
New York Transit	= 1.0
Philadelphia	= 0.05
Washington	= 0.37
Finland	= 3.6
Great Britain	= 0.5 - 1.0
Continental Europe	= 3.0 - 8.0
U.S. Average	=<1.0

Although considerably less is spent in the U.S. than the rest of the world on geotechnical investigations, there are indications that this pattern is changing as U.S. agencies give increased recognition to the importance of more complete and accurate geotechnical information in bid solicitations. At the present time, as a compromise, a value of 1 percent will be used in the model.

5.3.7 Construction Management

Construction management involves responsibility for the conduct of the fiscal and physical aspects of construction. This includes the inspection of work, negotiation of changes, maintenance of schedules, safety, certification of pay quantities, quality control, and other field activities which have the objective of protecting the owner and of providing him with a quality product at a reasonable price. In most cases construction management is performed by an organization under contract to the owner. In some cases, however, the design/engineering organization may also perform the construction management function.

The cost of construction management varies with the size and complexity of a project, and in general may be expressed as a percentage of project value. The relationship between project management cost and project cost is shown in Figure 5-6.

It is recommended that 3.9 percent of the owner's estimate be used as the input value for the TSC Cost Model. This is the average for the three projects studied. The exact nature of the relationship depicted in Figure 5-6 should be explored more fully in a future program at which time more exact criteria can be developed for inputs to the model.

5.3.8 Engineering Design

The cost of engineering design varies with the size and complexity of the tunneling project. For large, relatively straightforward projects the experience of all of the systems surveyed indicates that design costs should be of the order of

0.5 percent of the technical estimate. For more complex large projects, this cost may range upward to the 3-5 percent range. Smaller projects experience higher percentages, typically 5-10 percent.

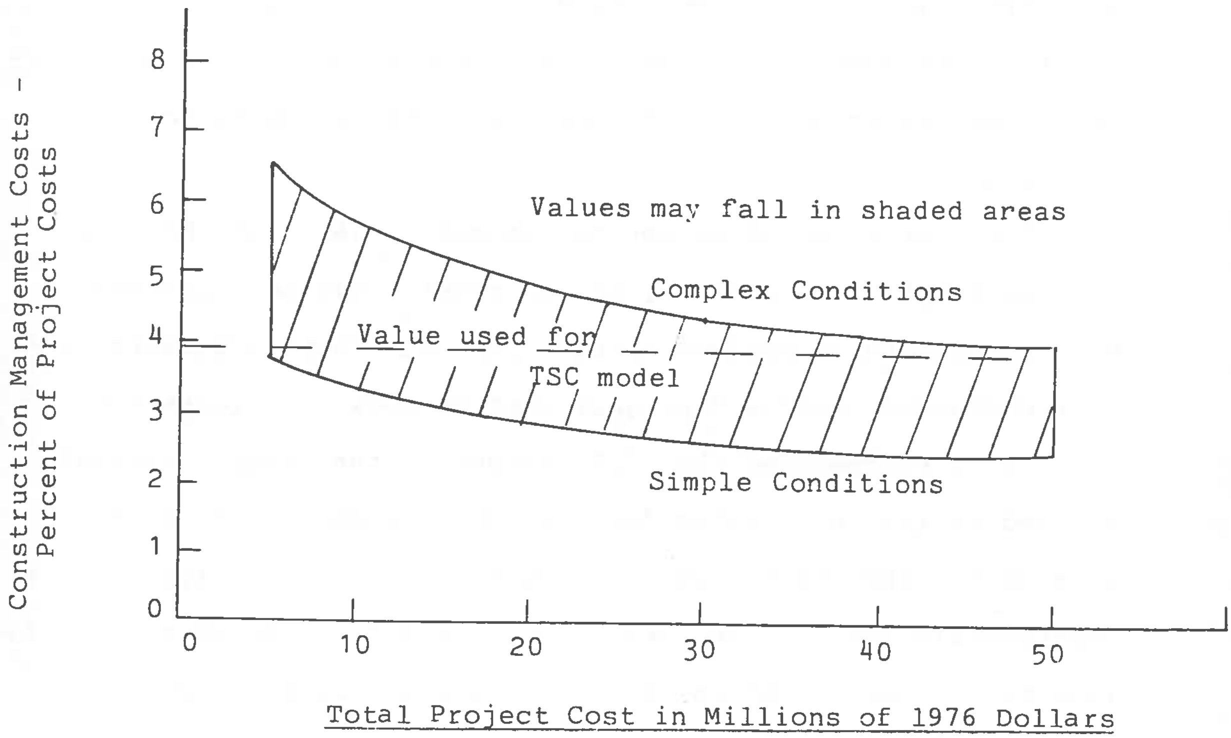

FIGURE 5-6. CONSTRUCTION MANAGEMENT COST AS A FUNCTION OF PROJECT COST

5.3.9 Legal Costs

Most agencies maintain attorneys on their staffs to handle the day-to-day legal questions. Claims sometimes require large legal staffs, especially if the claim is to be litigated in court. Therefore, in these cases outside counsel is usually retained. The cost of counsel together with court costs can vary widely depending on the size of the claim, and perhaps even more importantly, the complexity of the case.

In any event, these costs tend to be small compared to total project costs, and statistical data as to the amount of these costs is not currently available. Therefore, legal costs will not be included in the present model.

5.3.10 Project Management

Project management, as used here, is defined as the planning, engineering, and administration of a project. It may be performed by the owner's staff, by an organization under contract, or a combination of the two. The functions involved in carrying out project management include financial, legal, engineering, design, architectural, geotechnical, scheduling, budgeting, and construction planning. Construction management is not included and is defined here as a separate activity.

The cost of project management varies with the size of the project and with the complexity of the structure and the site. For the three projects analyzed, the relationship which is judged to represent the range of values is shown on Figure 5-7. The cost of project management for a particular project

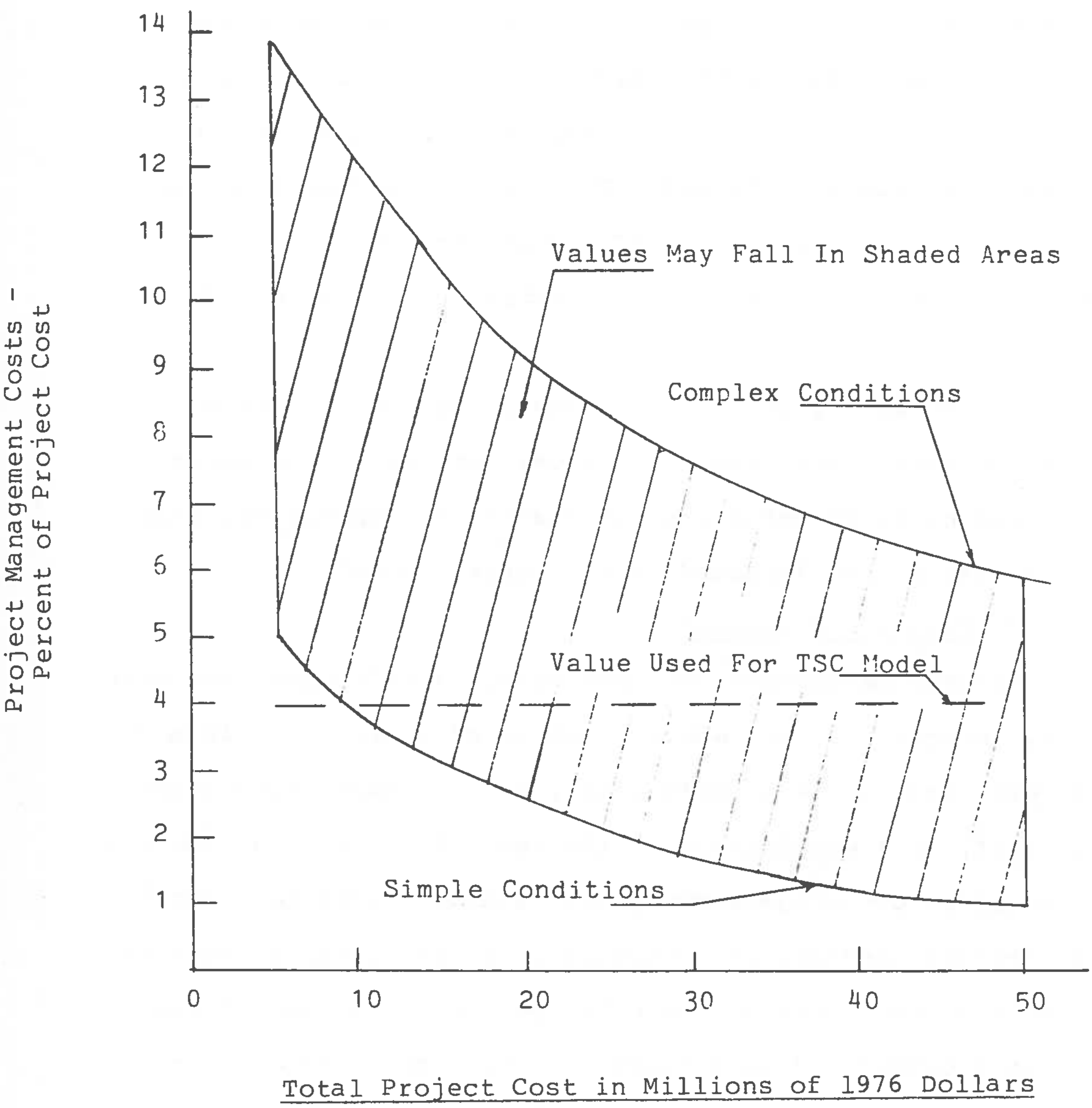

FIGURE 5-7. PROJECT MANAGEMENT COST AS A FUNCTION OF TOTAL PROJECT COST

should fall within the shaded area, which varies between 1 percent for simple cases to 14 percent for more complex ones. There is a general tendency for the percentages to be lower for larger projects, typical of the well known economy of scale which is experienced in many management situations. Superimposed on this are the effects of complexity as shown by the lower bound ("simple conditions"), and by the upper bound ("complex conditions").

The value chosen for the TSC cost model is a constant 4 percent which represents an average value consistent with the values common to a large number of metro projects. It would be desirable in any future program to study this item in more detail, and to develop criteria for evaluating the cost of project management according to parameters which could be used during the planning and design stages of a project.

5.3.11 Environmental-Community Interface Costs

This category of costs may vary between wide extremes. Dominant factors governing costs are the local regulations and rules relative to noise, pollution, vibration, vehicle usage, site aesthetics, and other matters, all of which impose restrictions upon the contractor and thus add to costs.

While most of these costs are associated with construction operations, there are others which may have an effect upon project financial resources. For example, local citizens may demand covered and expensive stations rather than the more austere ones originally planned.

Since these types of cost factors must be evaluated separately for each municipality, no attempt has been made to include them in the model.

6. CONSTRUCTION COST DATA BASE

The basic concept of the model, as explained in other sections, is that construction costs consist of two elemental units: (1) the Amount of Effort required to do work, which remains virtually constant with time for a given set of conditions; and (2) the Value of Effort which varies with time, location and other factors. The construction data base is made up of two data banks as diagrammed in Figure 6-1. The "Effort" quantities for tunnel construction, according to any combination of given conditions, is selected from Data Bank 1. Against these quantities the current "Values of Effort" from Data Bank 2 are applied in order to obtain the total cost of construction.

DATA BANK 1 - EFFORT

Data Bank 1 is a catalog of the "Effort" requirements for construction of soft ground tunnels by each of the common methods currently employed, and for all combinations of physical parameters which normally affect the quantities involved.

As will be noted from Figure 6-1, Data Bank 1 has been subdivided into two sections which we have labeled Specific Effort and Application. The Specific Effort identifies the unit amounts of effort (per shaft, per day, per foot of tunnel, etc.) required in terms of labor crew make-up, equipment spreads, and material quantities, for performing each of the typical tasks of tunnel construction for all common methods of soft ground tunnel construction currently employed.

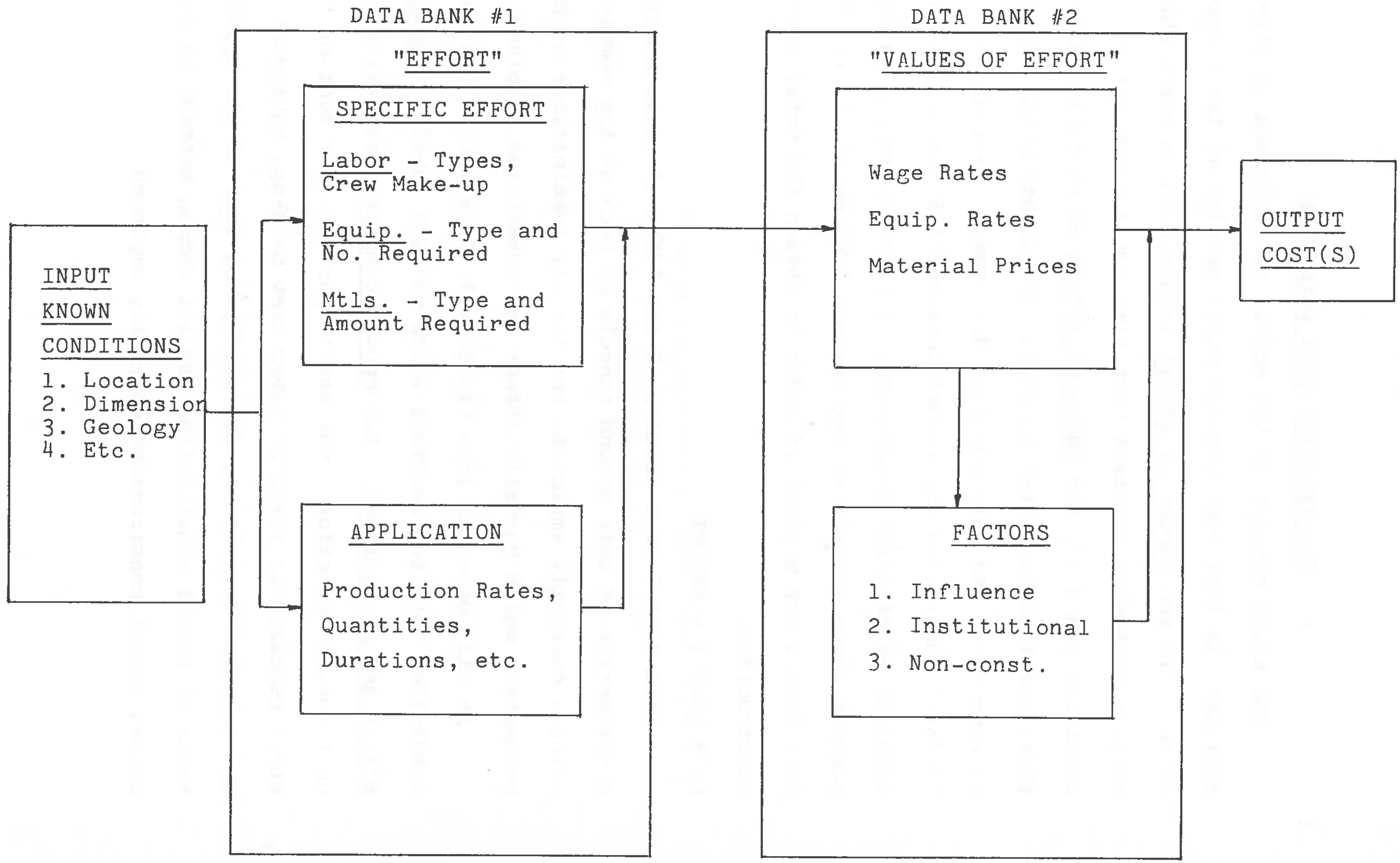

FIGURE 6-1. DATA BANKS

The Application section defines the total amount of specific effort necessary for any given case, as determined by the physical conditions of tunnel size and length, geology, etc., and the construction methods employed. This consists of production rates, durations, and/or quantities for the various tasks according to the determining parameters.

The Data Bank 1 information, as accumulated for this study, is largely confined in detail to only those construction items directly involved in the tunneling process; i.e., tunnel excavation and lining. For completeness and illustration, other related construction items such as dewatering, underpinning, ground treatment (grouting) which we have called "Secondary" items, have been included in Figure 4-1 on a less detailed basis. It is anticipated that these secondary items will be analyzed in more detail in future studies.

The information summarized in Data Bank 1 has been accumulated from detailed analyses of crews, equipment, methods and production of more than twenty soft ground tunnels built in the US in the last ten years, including BARTD, WMATA, NYC Transit System, and from applicable portions of numerous other tunnel projects.

DATA BANK 2 - VALUES OF EFFORT

Data Bank 2 consists of a listing of wage rates, equipment ownership and operating costs, material prices and other typical or standard prices which must be extended against the quantities developed in Data Bank 1 to arrive at a cost for construction of a specific project. Since these values vary with time and location, it is evident that they must be referenced to a given base. The "Values" or "Prices" reflect those in the Metropolitan Washington DC area as of January 1, 1976. Costs for other regions or time frames may be computed either by accumulating and inserting actual prices for the specific time and location, or by applying factors provided in the model for regional and escalation effects.

A second feature of Data Bank 2 is labeled "Factors." Factors are provided as a means of conversion for the regional and escalation effects mentioned above as well as for evaluating the more obtuse costs of institutional conditions, such as bidding climate and environmental policies, and certain non-construction costs such as insurance, design and construction management costs which are more easily handled on a statistical basis. Development of these factors is explained in other sections.

In conclusion, it should be emphasized that although the construction data base assembled in this limited study has been concentrated in the areas of soft ground transit tunnel construction, augmented only by such detailed additional data as was considered necessary to illustrate and verify the model concept, the concept can be applied to all areas of tunnel construction, including hard rock, cut and cover and compressed air. Since the data bank of Effort was formulated to remain constant with time for given conditions, this expanded application would simply involve expanding the data base to include those areas. Similarly, new technology which might provide additional methods of tunnel construction would not change the data base but would simply augment it. Updating would be restricted primarily to the periodic insertion of new labor, equipment, and materials prices as conditions dictate.

7. CONCEPT VERIFICATION

The method of verifying the model concept was to select several historical projects for which the physical parameters and costs were known, and compare costs computed by using the model to actual construction costs. Three representative projects were chosen on the basis of variety of conditions and availability of known data. (Detailed computer cost computations are included in Section 8.) Analyses were made of total contract versus tunnel costs only in order to determine detailed accuracy of that portion of the model.

7.1 WMATA SECTION D-8a

Principal features of this project were 5393 LF of concrete-lined tunnel through moderate ground requiring some soil stabilization, an 800 ft. x 75 ft. cut-and-cover subway station and four vent and fan structures. The section chosen for analysis was the 2996 LF tunnel section east of the station structure. Excavation was performed by a shield with hoe-type digger arm. Temporary support consisted of expanded ring beams with lagging.

Comparison of Total Costs

Total contract value	$27,436,012
Actual construction costs . . . . for this portion of the work	5,837,000
FMA model estimate	6,345,400
Difference	$ 508,440
Variation from actual.	8.7%

Comparison of Tunnel Costs

Actual tunnel construction costs	$ 4,445,000
FMA model estimate	4,331,783
Difference	$ 113,217
Variation from actual.	2.5%

7.2 WMATA SECTION F-2a - WASHINGTON, DC

A total length of 8820 LF of tunnel was driven in difficult ground conditions and passing beneath several large bridge abutments and piers. Excavation was performed by a shield with a backhoe digger arm. Steel segments functioned as both temporary and final lining.

Comparison of Total Costs

Total contract price	$35,657,777
Less extraneous items not. . . . . included in model (utilities, etc.)	2,284,450
Actual net construction costs	33,373,327
FMA model estimate	31,017,223
Difference	2,356,104
Variation from actual.	7.1%

Comparison of Tunnel Excavation Costs

Actual tunnel excavation costs, including structural steel liner, liner backfill grouting, and (prorated) mobilization and general engineering items	$25,720,657

FMA Model Costs, excavation, liner, and backfill grouting.	$19,340,778	
Prorated indirect costs: $6,681,887 \times \frac{19.3m}{24.3m} =$	5,307,013	
Net estimated cost.		24,647,791
Difference.		1,072,866
Variation from actual		4.2%

Comparison of Tunnel Concrete Costs

Actual, including prorated general expense items		1,281,744
FMA Model Costs:		
Tunnel concrete costs:	989,318	
Prorated indirects $6,681,887 \times \frac{1.0m}{24.3m} =$	274,975	
Net estimated cost		1,264,293
Difference.		17,451
Variation from actual		1.4%

7.3 WMATA SECTION D-6

This project consisted of 8115 LF of concrete lined soft ground tunnel along with the construction of an 800 ft. x 75 ft. cut-and-cover subway station and six vent and fan structures. The section studied was the 3803 LF of tunnel west of the subway station. Geology was favorable and a wheel type excavator was used with expanded ring beam and lagging support.

Comparison of Total Costs

Total contract value.	$31,617,000
Actual construction costs for this. . . portion of the work	6,443,000
FMA model estimate	6,731,122
Difference.	288,122
Variation from actual	4.5%

Comparison of Tunnel Costs

Actual tunnel construction costs . . .	4,603,000
FMA model estimate.	5,044,022
Difference.	441,022
Variation from actual	9.6%

7.4 COMPARISON SUMMARY

The tabulation in Table 7-1 is not intended to imply any predicted accuracy of results for universal application of the system model. That remains the subject of more extensive sampling and evaluation. What is indicated is that within the scope of application of this study, the FMA Model appears to be a valid method for evaluating the costs of soft ground tunnel construction and is capable of yielding results within 10 percent of actual cost.

TABLE 7-1. SUMMARY COST COMPARISONS

	WMATA F-2a		WMATA D-6		WMATA D-8a	
	Total Project	Tunnel Only	Total Project	Tunnel Only	Total Project	Tunnel Only
Actual Cost	$ 33,373,327	$ 27,002,401	$ 6,443,000	$ 4,603,000	$ 5,837,000	$ 4,445,000
Model Estimate	31,017,223	25,912,084	6,731,122	5,044,022	6,345,440	4,331,783
	2,356,104	1,090,317	288,122	441,022	508,440	113,217
Percent Actual	7.1%	4.0%	4.5%	9.6%	8.7%	2.5%

8. GUIDELINES FOR OPERATION OF TSC MODEL

8.1 GENERAL GUIDELINES

The TSC model is a step-by-step method for computing the costs of soft ground tunnel construction through the process of evaluating the amount of "Effort" required to construct the tunnel and applying current values to the quantities of effort.

As explained in Section 6, a construction data base is provided which (1) catalogs the effort requirements for construction of any soft ground tunnel according to current state-of-the-art methods, and (2) provides current values for each element of effort. The basic process then, for evaluating specific costs for any given example is to first select and summarize the "Effort" requirements for the given conditions from the "Catalog," then apply the current prices or "Values" to those quantities.

The general operating procedure for the TSC model is represented in the flow diagram Figure 8-1. The process is initiated for any given example by first listing all relevant known information as input data. (An Input Data Sheet is provided for this purpose - See Section 8.3). The input data references specific information in the data base unique to the solution of that given example for both construction and non-construction costs.

Following the flow chart through the construction cost items, it is noted that these costs are divided into two sub-headings, Tunnel Cost Items and Secondary Cost Items.

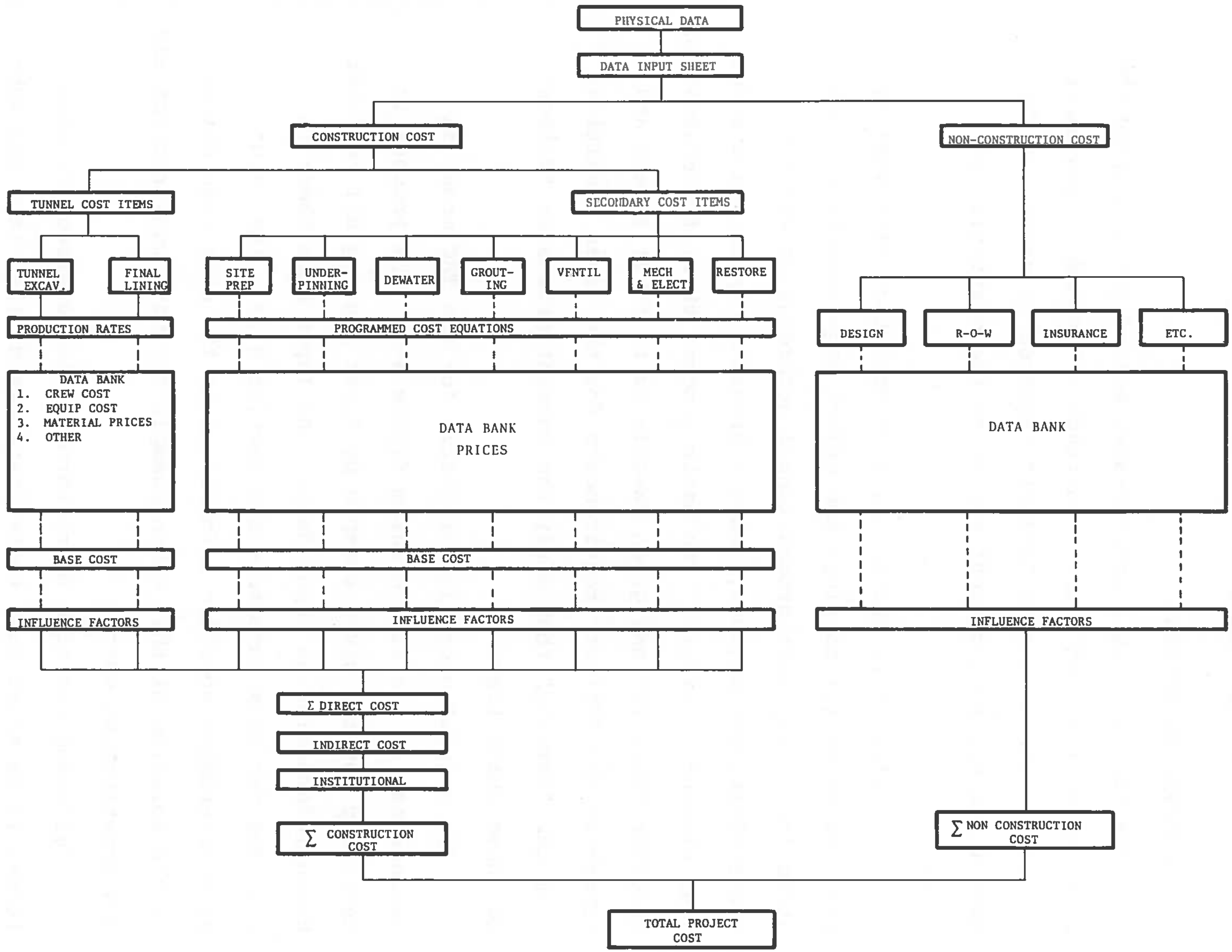

FIGURE 8-1. OPERATIONAL FLOW CHART

Tunnel Cost Items and Secondary Cost Items are computed independently to arrive at a total direct construction cost. Since the primary focus of this study is on the Tunnel Cost Items, we will follow through this branch of the flow chart in detail.

The tunnel costs involve two independent operations, the excavation and temporary support of the tunnel and the installation of final lining. In both cases, there may be several construction methods or techniques for accomplishing the operations, each of which is associated with a unique cost solution, therefore, a choice must be made in the input data as to the assumed construction method. Alternate methods may be chosen for subsequent evaluation as an economic comparison. Invalid assumptions for construction methods not consistent with the given physical conditions will automatically be rejected by the model.

The construction methods chosen and the physical parameters of the example will dictate specific data bank production rates and durations for accomplishing the work. They will also reference the unique combination of labor crews, equipment and materials normally required to perform each task, permitting the user to compute the total amount of effort (labor, equipment and materials) required for each task. By applying the data bank prices to these quantities, the total tunnel costs are computed based on Washington, D.C. costs as of January 1, 1976. To project these costs to other regions or time frames it is necessary to apply the appropriate influence factors for regional effects and escalation to the base costs. These are given in the data bank.

As previously mentioned, the <u>Secondary Direct Cost</u> headings are a partial list of peripheral tunnel tasks that are normally associated with tunnel construction and are included both to acknowledge the fact that there are other costs to be considered and to illustrate the fact that the model is capable of expansion to incorporate all associated costs. Practical considerations for this study, however, have limited the data bank detail for these secondary cost items. For these items, cost equations have been provided which approximate the general condition.

Once all of the adjusted construction costs have been computed, they are summarized to a Total Direct Cost. To this is added the Indirect Costs (overhead, profit margin, etc.) and the institutional costs as provided in the data bank, the sum of which is the Total Construction Cost.

Non-construction costs have been expressed as percentage factors of the construction costs for the purpose of this study. Therefore, once the Total Construction Costs are known, non-construction costs can be computed from the appropriate factors given in the data bank. The Total Project Cost is the summation of Total Construction and Total Non-Construction Costs.

Section 8.3, "Input Data Sheet," and Section 8.4, "Computational Method," provide detailed step-by-step instructions for operation of the system model. Section 8.4 also provides three computer-run examples to illustrate the application of the TSC Model.

8.2 LIMITATIONS AND SPECIAL CONSIDERATIONS

One consideration for a practical tunnel estimating model is that it be adaptable to computer techniques. The TSC Model was conceived with this in mind and is, in fact, more simply structured and utilized on a computer basis. In order to present the data base, for example, in a manner that would facilitate manual solution in illustrating the model, some of the tedious cost extensions for wage and equipment rates have been included in the "Effort" data bank. It should be realized that in the pure model form for computer application, all costs would be stored separately from the "Effort" data in accordance with the model concept, and cost extensions would be performed within the program.

Since there are exceptions to every rule, the model has been so constructed that the data base can be overridden by a manual input at any point to provide for any odd or extreme condition that may arise which does not conform to the established standard.

This study recognizes the existence but has not attempted to quantify certain vague or complex cost relationships, such as the impact cost of construction on the interfacing society, or the costs of rights-of-way and easements.

8.3 INPUT DATA SHEET

The Input Data Sheet has been so constructed that each question is referenced to pertinent data in the system data bank.

It is imperative to the operation of the model that each question be answered. (If information is not known, an assumption may be made until such time as input conditions are fully known.)

The Input Data Sheet (Figure 8.2) should be self-explanatory for the most part, except for the questions addressed below.

<u>Line 4</u> - Although the occurrence of tunnel shapes other than circular in soft ground is recognized, this study has been limited to circular tunnels and condition 1 is mandatory.

<u>Line 7</u> - Similarly, this study is limited to free air tunnels and condition 1 is imposed.

<u>Line 9</u> - The tunnel alignment must be analyzed according to the properties of the material through which it passes and sections (reaches) of like or similar properties must be identified.

A. The geological conditions for soft ground tunneling in this model have been classified according to three tunneling properties into five types as defined below.

Class I	Stiff Cohesive Clay
Class II	Cohesive Sand and Gravel
Class III	Non-Cohesive Sand and Gravel
Class IV	Running Sand, Silt, Gravel
Class V	Mixed Face (Hard Ground Intrusions)

B. Groundwater Conditions - This is a judgmental factor relating not only to the soil permeability but to factors such as impervious overlying strata which may inhibit the inflows, depth (or height) of water table, recharge potential from lakes, etc. Therefore, groundwater classification may be selected on judgmental basis of potential for inflows.

Class I	Light
Class II	Medium
Class III	Heavy

<u>Line 11.A.2</u> - The term "Full Round" refers to placing the cast-in-place concrete around the full circumference of the tunnel in one pass, rather than placing the invert first and the arch at a later time.

<u>Line 11.A.3</u> - "Invert Only" refers to the cases where segment steel or precast concrete tunnel lining functions as both "temporary" (Construction) and final lining.

<u>Line 11.C.5</u> - The conveyor method of transport is a valid alternate and is recognized as such herein, however, its use is not as yet common enough to warrant development of costs in this study. It is acknowledged as a potential subject for future inclusion.

Line 11.D - The shifts per day for concreting operations have been arbitrarily established at 3 shifts/day for this study.

Line 11.E - The shifts per day for placing concrete have been arbitrarily established at 2 shifts per day for this study.

Line 12.B - The classifications for site clearing are defined as follows:

Class I	Grass, topsoil, few trees
Class II	30-50% tree removal, some minor structures
Class III	Heavy foliage, trees, structures

Line 13.A - Classifications for restoration grading are as follows:

Class I	Topsoiling/seeding only
Class II	Seeding, some sodding and shrubs
Class III	Extensive landscaping and replanting of shrubs and trees

Line 14.A - Alternative 1 is arbitrarily predetermined for this study.

Line 15 - Underpinning applies only to those structures within the 1:1 influence line of the structure. Classifications are determined as follows:

Class I	(Light)	One and two story wooden frame buildings
Class II	(Medium)	Masonry residences and light industrial or commercial buildings

Class III	(Heavy)	Large masonry structures; multi-story buildings; bridges; etc.

Line 16 - Number of Bidders. This is normally a judgmental factor, depending on such conditions as the type, size and location of the project but can reasonably be predicted in an area where similar work is common. For soft ground tunnels in Washington, D.C., a typical number might be 5; in New York City, perhaps 2.

PROJECTED COST OF TUNNEL CONSTRUCTION

INPUT DATA SHEET

PROJECT: ______________________________

RUN NO. ____________________ DATE: ____________

1. Location: (1) East Coast
   (2) New York City
   (3) Midwest
   (4) West Coast ______

2. Projected Start: Select number 0 through 10, corresponding to calendar year in which project is projected to start, subsequent to base date of January 1, 1976. Example: Number (2) would correspond to a start within the calendar year January 1, to December 31, 1978. (Negative numbers indicate past projects.) ______

3. Length: Enter total length of tunnel in linear feet (l.f.). If twin tubes, enter sum of both tubes. ______l.f.

4. Shape: (1) Circular
   (2) Horseshoe ___1___

5. A. Diameter: Enter driven diameter (o.d.) in feet ______ft.
   B. Diameter: (1) 15' to 19' (2) 19' to 24' ______ft.

6. Number of Shafts: ______

7. Air: (1) Free or (2) Compressed ___1___

8. Number of Tubes: (1) Single or (2) Twin ______

9.

Reach No.	Geology Type	Length	Avg. Depth	Class of Groundwater

Figure 8-2a

INPUT DATA SHEET

10. Excavation and Temporary Support:

    A. Method of Excavation:

        1. Shield/Hand excavation ______

        2. Shield/Digger arm

        3. Shield/Wheel excavator ______

    B. Temporary Support:

        1. Ring beams/Liner

        2. Ring beams/Lagging

        3. Structural steel liner

        4. Precast segments ______

    C. Method of Mucking:

        1. Rubber tire to shaft hoist

        2. Rubber tire to portal

        3. Rail to shaft hoist

        4. Rail to portal

    D. Number shifts/day excavating: ______

11. Permanent lining; Cast-in-place, reinforced concrete:

    A. Method of Placing:

        1. Invert and Arch

        2. "Full Round"

        3. Invert only ______

    B. Pour Restraints:

        1. Bulkhead (50 to 100 ft.)

        2. Continuous placement ______

Figure 8-2b

INPUT DATA SHEET

C. Method of Transport

1. Rubber tire from portal
2. Rubber tire from dropline
3. Rail from portal
4. Rail from dropline
5. Pump ______

D. Number shifts/Day Concreting Operations: 3

E. Number shifts/Day Placing Concrete: 2

12. Site Preparation:

A. Pavement removal: Approx. amount of work area paved as a percent of total work area. (To nearest 10%.) ______

B. Clearing:

1. Class I
2. Class II
3. Class III ______

13. Restoration:

A. Grading and Vegetation of Restored Area:

1. Class I
2. Class II
3. Class III ______

B. Paving: Approximate amount of work area to be paved, expressed as a percent of total work area. (To nearest 10%.) ______

Figure 8-2C

INPUT DATA SHEET

14. Ventilation:

    A. Method:

        1. Conventional

        2. Other ___1___

15. Underpinning: Enter area (s.f.) of buildings or portion of buildings within the 45^{o} influence line which falls within each of the following classifications.

    A. Class I Light ______s.f.

    B. Class II Medium ______s.f.

    C. Class III Heavy ______s.f.

16. Anticipated Number of Bidders: ______

Figure 8-2d

8.4 COMPUTATIONAL METHOD

It was originally intended that the model would be developed for manual computation only. However, during the course of the work it became evident that it would be most advantageous to store the data base and to perform the calculations by computer. For this initial effort, a Wang Model 2200 was programmed for the calculations and storage of the data base on disc files. The large volume of this data precludes publishing it as a printed report. However, a hard copy, together with instructions for performing a manual computation, is available in the Office of the Transportation Systems Center, Cambridge, Mass.

To illustrate the output of the model, the costs of three projects of the Washington D.C. Metro (WMATA) have been calculated and the computer printouts are shown as follows:

Figure 8-6a-aa	******	WMATA Section D-8A
Figure 8-7a-p	******	WMATA Section D-6
Figure 8-8a-p	******	WMATA Section F-2A

Abbreviations used in the printouts are contained in figures 8-3, 8-4, and 8-5.

Included in the printout for WMATA Section D-8A only are CREW and EQUIPMENT SPREAD DETAIL SHEETS for excavation and concreting.

ABBREVIATIONS - LABOR

1	SHIFTER	SH	25	LABORER (TOP SIDE)	LR
2	MINER	MI	26	PUMPMAN (CONC. PUMP)	PC
3	OPERATOR	OR	27	FOREMAN	FO
4	MECHANIC	ME	28	OILER	OL
5	MOTORMAN	MO	29	NIPPER	NI
6	DUMPMAN	DM	30	CARPENTER FOREMAN	CF
7	BRAKEMAN	BM	31	IW FOREMAN	IF
8	PUMPMAN	PM	32	SIGNALMAN	SM
9	BULLGANG OPERATOR	BO			
10	BULLGANG LABOR	BL			
11	ELECTRICIANS	EL			
12	BULLGANG FOREMEN	BF			
13	HOIST OPERATOR	HO			
14	HOIST OILER	HR			
15	COMPRESSOR OPERATOR	CO			
16	ELEVATOR MAN	EM			
17	DUMPMAN	DP			
18	MASTER MECHANIC	MM			
19	ELECTRICIAN FOREMAN	EF			
20	TEAMSTER	TM			
21	CRANE OPERATOR	CR			
22	CRANE OILER	CI			
23	IRONWORKER	IW			
24	CARPENTER	CP			

Figure 8-3

ABBREVIATIONS - EQUIPMENT

1	HOIST & HEADFRAME	HH
2	MUCK BIN & FEEDER	MF
3	966 LOADER	L6
4	CHERRY PICKER 20 TON	CH
5	CRANE 60 TON	CR
6	FLATRACK TRUCK	FT
7	COMPRESSOR 1200 CFM	CO
8	SHIELD/WHEEL/ERECTOR	SW
9	CONVEYOR/CAR LOADER UNIT	CC
10	LOCOMOTIVE	LO
11	MUCK CAR	MC
12	FLAT CAR	FC
13	VENTILATION FAN 25HP	VF
14	MANTRIP CAR	MT
15	PUMP 6 IN.	P6
16	PUMP 3 IN.	P3
17	PUMP 1 IN.	P1
18	CAR DUMPER	CD
19	AIR TUGGER	AT
20	CALIFORNIA SWITCH	CS
21	SCREED	SD
22	CONVEYOR 400 FT.	CV
23	AGITATOR CAR	AC
24	VIBRATOR 3 IN.	VB
25	FORMS 50 FT.	FR
26	FORM TRAVELER (HYDR)	FV
27	HIGH CAR	HC
28	CONCRETE PUMP	CP
29	VIBRATOR FORM	VM
30	FAN LINE CAR	FN
31	SHIELD/DIGGER ARM	DS
32	TRANSITMIX TRUCK	CT
33	TRACTOR/HOE	TH
34	LOAD/HAUL/DUMP UNIT	LH
35	HYD. SHIELD/ERECTOR	SE
36	MOTOR GRADER-12E	MG
37	TRACTOR/TRAILER	TT
38	988 LOADER	L8

Figure 8-4

ABBREVIATIONS - MATERIALS

1	RING BEAMS & LINER PL.	RB	26	CLEAR & GRUB LIGHT	C1
2	RING BEAMS & LAGGING	RG	27	CLEAR & GRUB-AVG.	C2
3	SEG. STR. STEEL LINER	SL	28	CLEAR & GRUB-HEAVY	C3
4	PRECAST SEG. CONC. LINER	CL	29	TOPSOILING/SEEDING	G1
5	FANLINE 30 IN.	FL	30	SEEDING/SODDING/SHRUBS	G2
6	AIRLINE 4 IN.	AL	31	LANDSCAPING/SHRUBS/TREES	G3
7	DISCHARGE LINE 8 IN.	DL	32	VENTILATION	VN
8	SMALL TOOLS	ST	33	DRAINAGE - INSTALL SHAFT	MD
9	SAFETY EQUIP. & SUPPLIES	SE	34	GROUD - CY	CG
10	TEMP. ELECTRIC	TE	35	DRAINAGE SHAFT/FT	GR
11	TEMP. ELECTRIC	TL	36	DRAINAGE TUN/FT	PG
12	RAIL 90 LB	RL	37	VENTILATION - MECH	R1
13	NUTS/BOLTS/SPIKES	NB	38	SEDIMENT CONTROL	DW
14	SWITCHES	SW	39	SITE PREP. CLEARING	SC
15	MISC. TUNNEL SUPPLIES	MS	40	PAVEMENT REMOVAL	PR
16	R/R TIES	RT	41	DEMOLATION	DM
17	CONCRETE	CO	42	FENCING	FE
18	REINFORCING STEEL	RS	43	PAVING	PV
19	FORM LUMBER	FR	44	INVERT CURING	IC
20	BULKHEAD LUMBER	BL	45	UNDERPINNING - CLASS 1	U1
21	FORM OIL	FO	46	UNDERPINNING - CLASS 2	U2
22	CURING COMPOUND	CC	47	UNDERPINNING - CLASS 3	U3
23	SLICKLINE 6 IN.	SK	48	INT. DEWATER SETUP	ID
24	DROP HOLES	DH	49	VENT STR. SETUP	VS
25	MUCK HAULING	MH			

Figure 8-5

PROJECTED COST OF TUNNEL CONSTRUCTION

INPUT DATA SHEET

PROJECT: WMATA - SECTION D-8A; EAST SECTION

RUN NO. 2 DATE: 2/14/77

1. Location: (1) East Coast
   (2) New York City
   (3) Midwest
   (4) West Coast — 1

2. Projected Start: Select number 0 through 10, corresponding to calendar year in which project is projected to start, subsequent to base date of January 1, 1976. Example: Number (2) would correspond to a start within the calendar year January 1, to December 31, 1978. (Negative numbers indicate past projects.) — -3

3. Length: Enter total length of tunnel in linear feet (l.f.). If twin tubes, enter sum of both tubes. — 2,996 l.f.

4. Shape: (1) Circular
   (2) Horseshoe — 1

5. A. Diameter: Enter driven diameter (o.d.) in feet — 20.7 ft.
   B. Diameter: (1) 15' to 19' (2) 19' to 24' — ____ ft.

6. Number of Shafts: — 2

7. Air: (1) Free or (2) Compressed — 1

8. Number of Tubes: (1) Single or (2) Twin — 2

9.

Reach No.	Geology Type	Length	Avg. Depth	Class of Groundwater
1	1	1,996	46	2
2	4	200	46	2
3	1	800	46	2

Figure 8-6a

INPUT DATA SHEET

10. Excavation and Temporary Support:

    A. Method of Excavation:

        1. Shield/Hand excavation — 2

        2. Shield/Digger arm

        3. Shield/Wheel excavator

    B. Temporary Support: — 2

        1. Ring beams/Liner

        2. Ring beams/Lagging

        3. Structural steel liner

        4. Precast segments

    C. Method of Mucking: — 3

        1. Rubber tire to shaft hoist

        2. Rubber tire to portal

        3. Rail to shaft hoist

        4. Rail to portal

    D. Number shifts/day excavating: — 3

11. Permanent lining; Cast-in-place, reinforced concrete:

    A. Method of Placing:

        1. Invert and Arch

        2. "Full Round"

        3. Invert only — 1

    B. Pour Restraints:

        1. Bulkhead (50'-100')

        2. Continuous placement — 1

    C. Method of Transport:

        1. Rubber tire from portal

Figure 8-6b

INPUT DATA SHEET

2. Rubber tire from dropline
3. Rail from portal
4. Rail from dropline
5. Conveyor
6. Pump — 6

D. Number shifts/Day Concreting Operations: — 3

E. Number shifts/Day Placing Concrete: — 2

12. Site Preparation:

A. Pavement removal: Approx. amount of work area paved as a percent of total work area. (To nearest 10%.) — 30

B. Clearing:

1. Class I
2. Class II
3. Class III — 1

13. Restoration:

A. Grading and Vegetation of Restored Area:

1. Class I
2. Class II
3. Class III — 1

B. Paving: Approximate amount of work area to be paved, expressed as a percent of total work area (To nearest 10%.) — 30

14. Ventilation:

A. Method:

1. Conventional
2. Other — 1

Figure 8-6c

INPUT DATA SHEET

15. Underpinning: Enter area (s.f.) of buildings or portion of buildings within the 45° influence line which falls within each of the following classifications:

A.	Class I - Light	1,000 s.f.
B.	Class II - Medium	0 s.f.
C.	Class III - Heavy	0 s.f.

16. Anticipated Number of Bidders: 5

Figure 8-6c-1

OUTPUT DATA FORM

PROJECTED COST OF TUNNEL CONSTRUCTION

PROJECT NAME: WMATA - SECTION D-8A; EAST SECTION

DATE: 6/30/77

RUN NUMBER: 1 CODE: 121223

TOTAL PROJECTED COST: $6,345,440

INPUT CONDITIONS

LOCATION: WASHINGTON DC

PROJECTED START: -3

TUNNEL LENGTH: 2996 FT.

SHAPE: CIRCULAR

DIAMETER: 20.7 FT

AIR: FREE

NUMBER OF TUBES: 2

REACH NO.	GEOLOGY TYPE	LENGTH	DEPTH	GROUNDWATER
1	1	1996	46	2
2	4	200	46	2
3	1	800	46	2

METHOD OF EXCAVATION: SHIELD/DIGGER ARM

TEMPORARY SUPPORT: RING BEAMS/LAGGING

METHOD OF MUCKING: RAIL TO SHAFT HOIST

NUMBER OF SHIFTS / DAY EXCAVATING: 3

METHOD OF PLACING CONCRETE: INVERT & ARCH

POUR RESTRAINTS: BULKHEADS (50' C-C)

METHOD OF CONCRETE TRANSPORT: PUMP

NUMBER OF SHIFTS DAY CONCRETE OPERATIONS: 3

NUMBER OF SHIFTS DAY PLACING CONCRETE: 2

PAVEMENT REMOVAL-PERCENT OF WORK AREA: 30

CLEARING CLASS: 1

RESTORATION CLASS: 1

PERCENT OF WORK AREA TO BE PAVED: 30

VENTILATION: CONVENTIONAL

UNDERPINNING

CLASS 1 LIGHT: 1000 SF
CLASS 2 MEDIUM: 0 SF
CLASS 3 HEAVY: 0 SF

Figure 8-6d

CONSTRUCTION COST SUMMARY

CODE: 121223

ITEM	QUANTITY	BASE COST	UNIT COST	ADJ. TOTAL COST
SITE PREPARATION	LS	76970	59297.92	59297
UNDERPINNING	LS	20000	15408.00	15408
DEWATERING	LS	43734	33692.71	33692
EXCAVATION	2996 LF	2541251	631.69	1892557
FINAL LINING	2996 LF	1630916	398.25	1193179
GROUTING	2996 LF	239680	61.63	184649
VENTILATION	LS	873600	673021.44	673021
MECHANICAL & DRAINAGE	LS	624520	481130.20	481130
RESTORATION	LS	132000	101692.80	101692
TOTAL DIRECT COST (BASE)		6182672		4634629
INDIRECT COST		1007400		776101
TOTAL COST (GROSS)		7190073		5410731
INSTITUTIONAL FACTOR		934709		703395
NET CONSTRUCTION COST		8124783		6345440

Figure 8-6e

ITEM COSTS

CODE: 121223

1. SITE PREPARATION

	QUANTITY	UNIT COST	TOTAL COST
CLEARING	8.0 AC	1500.00	12000
PAVEM'T. REMOVAL	2.4 AC	19200.00	46080
FENCING	2361.2 LF	8.00	18890
TOTAL BASE COST			76970
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.229		-17672
TOTAL DIRECT COST			59297

Figure 8-6f

2. UNDERPINNING

CODE: 121223

	QUANTITY	UNIT COST	TOTAL COST
CLASS 1	1000.0 SF	20.00	20000
CLASS 2	0.0 SF	50.00	0
CLASS 3	0.0 SF	100.00	0
TOTAL BASE COST			20000
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.229		-4592
TOTAL ADJUSTED COST			15408

Figure 8-6g

3. DEWATERING

CODE: 121223

	QUANTITY	UNIT COST	TOTAL COST
EXTERNAL	200.0 FT	200.00	40000
TUNNEL	111.7 D	33.42	3734
TOTAL BASE COST			43734
REGIONAL ADJ.	0.000		0
ESCALATION	-0.229		-10041
TOTAL DIRECT COST			33692

Figure 8-6h

4. EXCAVATION

CODE: 121223

A. PRODUCTION

REACH NO.	LENGTH	ADVANCE RATE PER/DAY	SHIFTS PER DAY	DURATION SHIFTS	DURATION DAYS
1	1996 LF	52	3	115.1	38.3
2	200 LF	25	3	24.0	8.0
3	800 LF	52	3	46.1	15.3
TOTAL	2996 LF		3	185.3	61.7

Figure 8-6i

4. (B)

EXCAVATION COST SUMMARY

CODE 121223

	UNIT COST	QUANTITY		LABOR	EQUIP.	MATERIALS	OTHER	TOTAL
SETUP	260000		LS				260000	260000
HEADING CREW	2655	062	D	166687				166687
U. G. SUPPORT CREW	4281	062	D	268715				268715
SUR. SUPPORT CREW	3581	062	D	224809				224809
U. G. EQUIPMENT	3928	062	D		246582			246582
SURFACE EQUIPMENT	2272	062	D		142611			142611
RING BEAMS & LAGGING	186.7	2996	LF			559560		559560
RAIL	0.16	5992	LB			28761		28761
RAIL HARDWARE	2.00	5992	LB			11984		11984
SWITCHES	1500.00	4	EA			6000		6000
TRACK TIES	3.00	1199	EA			3598		3598
FANLINE	15.00	3134	LF			47010		47010
DISCHARGE LINE	8.00	3134	LF			25072		25072
AIR LINE	5.00	3134	LF			15670		15670
TEMP. ELECTRIC	40.00	3134	LF			125360		125360
MISC. SUPPLIES	10.00	2996	LF			29960		29960
MUCK HAULING	64.31	2996	LF				192689	192689
SMALL TOOLS	8% OF LABOR					52816		52816
SAFETY EQUIP.	5% OF LABOR					33010		33010
SUBTOTAL-BASE COST				660211	389194	938803	452689	2440899
PAYROLL T. & I.	0.092			60739	0	0	0	60739
MISC. OVERTIME	0.060			39612	0	0	0	39612
SUBTOTAL				760563	389194	938803	452689	2541251
REGIONAL FACTOR	0.000			0	0	0	0	0
REGIONAL FACTOR	0.000			0	0	0	0	0
REGIONAL FACTOR	0.000			0	0	0	0	0
REGIONAL FACTOR	0.000			0	0	0	0	0
ESCALATION FACTOR	-0.188			-142986	0	0	0	-142986
ESCALATION FACTOR	-0.217			0	-84455	0	0	-84455
ESCALATION FACTOR	-0.338			0	0	-317315	0	-317315
ESCALATION FACTOR	-0.229			0	0	0	-103937	-103937
TOTAL DIRECT COST	0.000			617577	304739	621488	348752	1892557

Figure 8-6j

DATA BANK LABOR CLASS CODE: 121223

TUNNEL EXCAVATION

HEADING CREW

	NO/SHIFT			RATE/	SH/DIF'L		TOTAL / SHIFT			TOTAL / DAY		
	1ST-	2ND-	3RD	HOUR	2ND	3RD	1ST	2ND	3RD	1SH	2SH	3SH
SH	1	1	1	10.23	0.00	0.00	81.88	81.88	81.88	81	163	245
MI	6	6	6	9.73	0.00	0.00	467.28	467.28	467.28	467	934	1401
OR	3	3	3	11.57	0.00	0.00	277.68	277.68	277.68	277	555	833
ME	1	1	0	10.94	0.00	0.00	87.52	87.52	0.00	87	175	175
	11	11	10				914	914	826	914	1828	2655

Figure 8-6k

DATA BANK LABOR CLASS CODE: 121223

TUNNEL EXCAVATION

U. G. SUPPORT CREW

	NO/SHIFT			RATE/	SH/DIF'L		TOTAL / SHIFT			TOTAL / DAY		
	1ST-	2ND-	3RD	HOUR	2ND	3RD	1ST	2ND	3RD	1SH	2SH	3SH
SH	1	1	1	10.23	0.00	0.00	81.88	81.88	81.88	81	163	245
MI	4	4	4	9.73	0.00	0.00	311.52	311.52	311.52	311	623	934
BL	4	2	2	8.78	0.00	0.00	281.12	140.56	140.56	281	421	562
BO	1	1	1	11.32	0.00	0.00	90.56	90.56	90.56	90	181	271
PM	1	1	1	11.32	0.00	0.00	90.56	90.56	90.56	90	181	271
MO	2	2	1	11.32	0.00	0.00	181.12	181.12	90.56	181	362	452
ME	2	2	1	10.94	0.00	0.00	175.04	175.04	87.52	175	350	437
EL	2	1	1	12.70	0.00	0.00	203.20	101.60	101.60	203	304	406
BM	2	2	1	8.78	0.00	0.00	140.56	140.56	70.28	140	281	351
DM	1	1	0	8.51	0.00	0.00	68.08	68.08	0.00	68	136	136
SM	1	1	1	8.78	0.00	0.00	70.28	70.28	70.28	70	140	210
	21	18	14				1693	1451	1135	1693	3145	4281

Figure 8-61

DATA BANK LABOR CLASS CODE: 121223

TUNNEL EXCAVATION

SUR. SUPPORT CREW

	NO/SHIFT			RATE/	SH/DIF'L		TOTAL / SHIFT			TOTAL / DAY		
	1ST	2ND	3RD	HOUR	2ND	3RD	1ST	2ND	3RD	1SH	2SH	3SH
BF	1	1	1	10.23	0.00	0.00	81.88	81.88	81.88	81	163	245
BL	2	2	2	8.78	0.00	0.00	140.56	140.56	140.56	140	281	421
HO	1	1	1	11.57	0.00	0.00	92.56	92.56	92.56	92	185	277
HR	1	1	1	10.94	0.00	0.00	87.52	87.52	87.52	87	175	262
BO	1	1	1	11.32	0.00	0.00	90.56	90.56	90.56	90	181	271
DM	1	1	0	8.51	0.00	0.00	68.08	68.08	0.00	68	136	136
TM	2	1	1	7.32	0.00	0.00	117.12	58.56	58.56	117	175	234
MM	1	0	0	12.07	0.00	0.00	96.56	0.00	0.00	96	96	96
ME	2	2	1	10.94	0.00	0.00	175.04	175.04	87.52	175	350	437
EF	1	1	1	13.20	0.00	0.00	105.60	105.60	105.60	105	211	316
EL	1	0	0	12.70	0.00	0.00	101.60	0.00	0.00	101	101	101
CO	1	1	1	11.32	0.00	0.00	90.56	90.56	90.56	90	181	271
EM	1	1	1	8.51	0.00	0.00	68.08	68.08	68.08	68	136	204
SM	1	1	1	8.78	0.00	0.00	70.28	70.28	70.28	70	140	210
CR	1	0	0	11.57	0.00	0.00	92.56	0.00	0.00	92	92	92
	18	14	12				1478	1129	973	1478	2607	3581

Figure 8-6m

DATA BANK EQUIPMENT COSTS CLASS CODE: 121223

TUNNEL EXCAVATION

U. G. EQUIPMENT

	OPERATING COSTS									OWNERSHIP		TOTAL COST PER DAY		
	NO. UNITS PER SHIFT 1ST	2ND	3RD	AVG HRS OPER SH (EACH)	COST HR OPERATE	COST/ SHIFT	TOTAL PER DAY OPERATING COST 1ST	2ND	3RD	TOTAL NO REQ'D.	COST /DAY	1 SHIFT	2 SHIFTS	3 SHIFTS
DS	1	1	1	6	45.00	270.0	270.0	270.0	270.0	1	700.0	970.0	1240.0	1510.0
FN	1	1	0	4	2.50	10.0	10.0	10.0	0.0	1	16.0	26.0	36.0	36.0
P6	1	1	1	8	0.50	4.0	4.0	4.0	4.0	2	5.0	14.0	18.0	22.0
P3	2	2	2	8	0.30	2.4	4.8	4.8	4.8	4	4.0	20.8	25.6	30.4
P1	2	2	2	8	0.15	1.2	2.4	2.4	2.4	4	3.0	14.4	16.8	19.2
AT	3	3	3	4	0.50	2.0	6.0	6.0	6.0	4	5.0	26.0	32.0	38.0
CC	1	1	1	6	25.00	150.0	150.0	150.0	150.0	1	400.0	550.0	700.0	850.0
LO	2	2	1	8	12.00	96.0	192.0	192.0	96.0	3	120.0	552.0	744.0	840.0
MC	20	20	10	8	0.20	1.6	32.0	32.0	16.0	24	8.0	224.0	256.0	272.0
FC	4	4	2	8	0.20	1.6	6.4	6.4	3.2	6	5.0	36.4	42.8	46.0
MT	2	2	2	2	0.20	0.4	0.8	0.8	0.8	2	8.0	16.8	17.6	18.4
CD	1	1	1	6	1.50	9.0	9.0	9.0	9.0	1	12.0	21.0	30.0	39.0
CS	1	1	1	8	5.00	40.0	40.0	40.0	40.0	1	25.0	65.0	105.0	145.0
VF	2	2	2	8	0.80	6.4	12.8	12.8	12.8	3	8.0	36.8	49.6	62.4
											TOTALS	2573	3313	3928

Figure 8-6n

DATA BANK   EQUIPMENT COSTS   CLASS CODE: 121223

TUNNEL EXCAVATION

SURFACE EQUIPMENT

	OPERATING COSTS									OWNERSHIP		TOTAL COST PER DAY		
	NO. UNITS PER SHIFT 1ST	2ND	3RD	AVG HRS OPER SH (EACH)	COST HR OPERATE	COST/ SHIFT	TOTAL PER DAY OPERATING COST 1ST	2ND	3RD	TOTAL NO REQ'D.	COST /DAY	1 SHIFT	2 SHIFTS	3 SHIFTS
HH	1	1	1	8	16.00	128.0	128.0	128.0	128.0	1	200.0	328.0	456.0	584.0
MF	1	1	0	8	10.00	80.0	80.0	80.0	0.0	1	30.0	110.0	190.0	190.0
CH	1	1	1	6	14.00	84.0	84.0	84.0	84.0	1	130.0	214.0	298.0	382.0
FT	2	1	1	6	2.50	15.0	30.0	15.0	15.0	2	10.0	50.0	65.0	80.0
CO	2	2	2	8	9.00	72.0	144.0	144.0	144.0	2	80.0	304.0	448.0	592.0
CR	1	0	0	6	24.00	144.0	144.0	0.0	0.0	1	300.0	444.0	444.0	444.0
											TOTALS	1450	1901	2272

Figure 8-60

5. CONCRETE

CODE: 121223

A. PRODUCTION

	LENGTH	ADVANCE RATE PER/DAY	SHIFTS PER DAY	DURATION SHIFTS	DURATION DAYS
INVERT	2996 FT	150	2	39.9	19.9
ARCH	2996 FT	100	2	59.9	29.9
TOTALS				99.8	49.9

Figure 8-6p

5. B

CONCRETE COST SUMMARY

CODE 121223

	COST	UNIT QUANTITY	LABOR	EQUIP.	MATERIALS	OTHER	TOTAL
SETUP	100000	LS				100000	100000
U. G. INVERT CREW	6740	20 D	134810				134810
SURFACE INVERT CREW	2767	20 D	55345				55345
U. G. ARCH CREW	6579	30 D	197391				197391
SURFACE ARCH CREW	2942	30 D	88288				88288
U. G. INVERT EQUIP.	1487	20 D		29748			29748
SURFACE INVERT EQUIP	1535	20 D		30700			30700
U. G. ARCH EQUIP.	2244	30 D		67326			67326
SURFACE ARCH EQUIP.	1374	30 D		41220			41220
CONC. FOR LINING	114	2996 LF			342310		342310
REINFORCING STEEL	91	2996 LF			273848		273848
OVERRUN CONCRETE	11	2996 LF			34231		34231
CURING COMPOUND	1. 08	2996 LF			3247		3247
MISC. SUPPLIES	10	2996 LF			29960		29960
SLICKLINE	12	3295 LF			39547		39547
FORM OIL	1. 08	2996 LF			3247		3247
BULKHEAD LUMBER	8. 51	2996 LF			25509		25509
SMALL TOOLS	8% OF LABOR				38066		38066
SAFETY EQUIPMENT	5% OF LABOR				23791		23791
SUB-TOTAL BASE COST			475836	168994	813759	100000	1558589
PAYROLL, T. & I.	0. 092		43776				43776
MISC. OVERTIME	0. 060		28550				28550
SUBTOTAL			548163	168994	813759	100000	1630916
REGIONAL FACTOR	0. 000		0	0	0	0	0
REGIONAL FACTOR	0. 000		0	0	0	0	0
REGIONAL FACTOR	0. 000		0	0	0	0	0
REGIONAL FACTOR	0. 000		0	0	0	0	0
ESCALATION FACTOR	-0. 188		-103054	0	0	0	-103054
ESCALATION FACTOR	-0. 217		0	-36671	0	0	-36671
ESCALATION FACTOR	-0. 338		0	0	-275050	0	-275050
ESCALATION FACTOR	-0. 229		0	0	0	-22960	-22960
TOTAL DIRECT COST	0. 000		445108	132322	538708	99999	1193179

Figure 8-6q

DATA BANK LABOR CLASS CODE: 116C

TUNNEL LINING-CIP CONC.

U. G. INVERT CREW

	NO/SHIFT 1ST	2ND	3RD	RATE/ HOUR	SH/DIF'L 2ND	3RD	TOTAL / SHIFT 1ST	2ND	3RD	TOTAL / DAY 1SH	2SH	3SH
SH	2	2	1	10.23	0.00	0.00	163.76	163.76	81.88	163	327	409
MI	18	18	8	9.73	0.00	0.00	1401.84	1401.84	623.04	1401	2803	3426
PC	1	1	0	11.32	0.00	0.00	90.56	90.56	0.00	90	181	181
ME	2	1	1	10.94	0.00	0.00	175.04	87.52	87.52	175	262	350
BF	1	1	1	10.23	0.00	0.00	81.88	81.88	81.88	81	163	245
BL	2	2	2	8.78	0.00	0.00	140.56	140.56	140.56	140	281	421
EL	2	1	1	12.70	0.00	0.00	203.20	101.60	101.60	203	304	406
OL	1	1	0	10.94	0.00	0.00	87.52	87.52	0.00	87	175	175
PM	1	1	1	11.32	0.00	0.00	90.56	90.56	90.56	90	181	271
OR	0	0	2	11.57	0.00	0.00	0.00	0.00	185.12	0	0	185
MO	1	1	1	11.32	0.00	0.00	90.56	90.56	90.56	90	181	271
OR	1	1	0	11.57	0.00	0.00	92.56	92.56	0.00	92	185	185
BM	1	1	1	8.78	0.00	0.00	70.28	70.28	70.28	70	140	210
	33	31	19				2688	2499	1553	2688	5187	6740

Figure 8-6r

DATA BANK LABOR CLASS CODE: 116C

TUNNEL LINING-CIP CONC.

SURFACE INVERT CREW

	NO/SHIFT			RATE/	SH/DIF'L		TOTAL / SHIFT			TOTAL / DAY		
	1ST-2ND-3RD			HOUR	2ND	3RD	1ST	2ND	3RD	1SH	2SH	3SH
FO	1	1	1	9.01	0.00	0.00	72.08	72.08	72.08	72	144	216
LR	3	3	2	8.51	0.00	0.00	204.24	204.24	136.16	204	408	544
BO	1	1	1	11.32	0.00	0.00	90.56	90.56	90.56	90	181	271
TM	1	0	0	7.32	0.00	0.00	58.56	0.00	0.00	58	58	58
EF	1	0	0	13.20	0.00	0.00	105.60	0.00	0.00	105	105	105
DP	1	1	0	8.51	0.00	0.00	68.08	68.08	0.00	68	136	136
CP	2	0	0	10.99	0.00	0.00	175.84	0.00	0.00	175	175	175
MM	1	0	0	12.07	0.00	0.00	96.56	0.00	0.00	96	96	96
ME	2	1	1	10.94	0.00	0.00	175.04	87.52	87.52	175	262	350
CO	1	1	1	11.32	0.00	0.00	90.56	90.56	90.56	90	181	271
HO	1	1	1	11.57	0.00	0.00	92.56	92.56	92.56	92	185	277
HR	1	1	1	10.94	0.00	0.00	87.52	87.52	87.52	87	175	262
	16	10	8				1317	793	656	1317	2110	2767

Figure 8-6s

ATA BANK LABOR CLASS CODE: 116C

UNNEL LINING-CIP CONC.

. G. ARCH CREW

	NO/SHIFT 1ST	2ND	3RD	RATE/ HOUR	SH/DIF'L 2ND	3RD	TOTAL / SHIFT 1ST	2ND	3RD	TOTAL / DAY 1SH	2SH	3SH
H	2	2	1	10.23	0.00	0.00	163.76	163.76	81.88	163	327	409
I	16	16	10	9.73	0.00	0.00	1246.08	1246.08	778.80	1246	2492	3270
C	1	1	0	11.32	0.00	0.00	90.56	90.56	0.00	90	181	181
L	1	1	0	10.94	0.00	0.00	87.52	87.52	0.00	87	175	175
L	2	1	1	12.70	0.00	0.00	203.20	101.60	101.60	203	304	406
E	2	2	1	10.94	0.00	0.00	175.04	175.04	87.52	175	350	437
F	1	1	1	10.23	0.00	0.00	81.88	81.88	81.88	81	163	245
L	2	2	2	8.78	0.00	0.00	140.56	140.56	140.56	140	281	421
M	1	1	1	11.32	0.00	0.00	90.56	90.56	90.56	90	181	271
R	1	1	1	11.57	0.00	0.00	92.56	92.56	92.56	92	185	277
O	1	1	1	11.32	0.00	0.00	90.56	90.56	90.56	90	181	271
M	1	1	1	8.78	0.00	0.00	70.28	70.28	70.28	70	140	210
	31	30	20				2532	2430	1616	2532	4963	6579

Figure 8-6t

DATA BANK LABOR CLASS CODE: 116C

TUNNEL LINING-CIP CONC.

SURFACE ARCH CREW

	NO/SHIFT 1ST	2ND	3RD	RATE/ HOUR	SH/DIF'L 2ND	3RD	TOTAL / SHIFT 1ST	2ND	3RD	TOTAL / DAY 1SH	2SH	3SH
FO	1	1	1	9.01	0.00	0.00	72.08	72.08	72.08	72	144	216
LR	3	3	2	8.51	0.00	0.00	204.24	204.24	136.16	204	408	544
BO	1	1	1	11.32	0.00	0.00	90.56	90.56	90.56	90	181	271
TM	2	1	1	7.32	0.00	0.00	117.12	58.56	58.56	117	175	234
EF	1	0	0	13.20	0.00	0.00	105.60	0.00	0.00	105	105	105
DM	1	1	0	8.51	0.00	0.00	68.08	68.08	0.00	68	136	136
CP	2	0	0	10.99	0.00	0.00	175.84	0.00	0.00	175	175	175
MM	1	0	0	12.07	0.00	0.00	96.56	0.00	0.00	96	96	96
ME	2	1	1	10.94	0.00	0.00	175.04	87.52	87.52	175	262	350
CO	1	1	1	11.32	0.00	0.00	90.56	90.56	90.56	90	181	271
HO	1	1	1	11.57	0.00	0.00	92.56	92.56	92.56	92	185	277
HR	1	1	1	10.94	0.00	0.00	87.52	87.52	87.52	87	175	262
	17	11	9				1375	851	715	1375	2227	2942

Figure 8-6u

DATA BANK EQUIPMENT COSTS CLASS CODE: 116E

TUNNEL LINNING-CIP CONC.

UNDERGROUND INVERT

	OPERATING COSTS									OWNERSHIP		TOTAL COST PER DAY		
	NO. UNITS PER SHIFT 1ST	2ND	3RD	AVG HRS OPER SH (EACH)	COST HR OPERATE	COST/ SHIFT	TOTAL PER DAY OPERATING COST 1ST	2ND	3RD	TOTAL NO REQ'D.	COST /DAY	1 SHIFT	2 SHIFTS	3 SHIFTS
SD	1	1	0	7	0.80	5.6	5.6	5.6	0.0	1	34.0	39.6	45.2	45.2
LO	1	1	1	8	12.00	96.0	96.0	96.0	96.0	2	120.0	336.0	432.0	528.0
MT	2	2	1	2	0.20	0.4	0.8	0.8	0.4	2	8.0	16.8	17.6	18.0
CP	1	1	0	7	16.00	112.0	112.0	112.0	0.0	1	225.0	337.0	449.0	449.0
FN	0	0	0	0	2.50	0.0	0.0	0.0	0.0	1	16.0	16.0	16.0	16.0
TH	0	0	1	8	13.00	104.0	0.0	0.0	104.0	1	110.0	110.0	110.0	214.0
FC	2	2	2	4	0.20	0.8	1.6	1.6	1.6	2	5.0	11.6	13.2	14.8
VB	6	6	0	7	0.10	0.7	4.2	4.2	0.0	12	1.0	16.2	20.4	20.4
P6	1	1	1	8	0.50	4.0	4.0	4.0	4.0	2	5.0	14.0	18.0	22.0
P3	2	2	2	8	0.30	2.4	4.8	4.8	4.8	4	4.0	20.8	25.6	30.4
P1	4	4	4	8	0.15	1.2	4.8	4.8	4.8	8	3.0	28.8	33.6	38.4
VF	2	2	2	8	0.80	6.4	12.8	12.8	12.8	3	8.0	36.8	49.6	62.4
MC	2	2	2	4	0.20	0.8	1.6	1.6	1.6	3	8.0	25.6	27.2	28.8
											TOTALS	1009	1257	1487

Figure 8-6v

DATA BANK EQUIPMENT COSTS CLASS CODE: 116E

TUNNEL LINING-CIP CONC.

SURFACE INVERT

	NO. UNITS PER SHIFT 1ST	2ND	3RD	AVG HRS OPER SH (EACH)	COST HR OPERATE	COST/ SHIFT	TOTAL PER DAY OPERATING COST 1ST	2ND	3RD	OWNERSHIP TOTAL NO REQ'D.	COST /DAY	TOTAL COST PER DAY 1 SHIFT	2 SHIFTS	3 SHIFTS
L6	1	0	0	4	14.00	56.0	56.0	0.0	0.0	1	130.0	186.0	186.0	186.0
CH	1	1	1	6	14.00	84.0	84.0	84.0	84.0	1	130.0	214.0	298.0	382.0
FT	1	1	1	6	2.50	15.0	15.0	15.0	15.0	1	10.0	25.0	40.0	55.0
CO	2	2	1	8	9.00	72.0	144.0	144.0	72.0	2	80.0	304.0	448.0	520.0
HH	1	1	1	4	16.00	64.0	64.0	64.0	64.0	1	200.0	264.0	328.0	392.0
											TOTALS	993	1300	1535

Figure 8-6w

DATA BANK EQUIPMENT COSTS CLASS CODE: 116E

TUNNEL LINNING-CIP CONC.

UNDERGROUND ARCH

	OPERATING COSTS									OWNERSHIP		TOTAL COST PER DAY		
	NO. UNITS PER SHIFT 1ST	2ND	3RD	AVG HRS OPER SH (EACH)	COST HR OPERATE	COST/ SHIFT	TOTAL PER DAY OPERATING COST 1ST	2ND	3RD	TOTAL NO REQ'D.	COST /DAY	1 SHIFT	2 SHIFTS	3 SHIFTS
FR	4	4	4	8	1.00	8.0	32.0	32.0	32.0	4	150.0	632.0	664.0	696.0
FV	1	1	1	8	6.50	52.0	52.0	52.0	52.0	1	100.0	152.0	204.0	256.0
HC	3	3	3	8	0.50	4.0	12.0	12.0	12.0	3	20.0	72.0	84.0	96.0
CP	1	1	0	7	16.00	112.0	112.0	112.0	0.0	1	225.0	337.0	449.0	449.0
MT	2	2	1	2	0.20	0.4	0.8	0.8	0.4	2	8.0	16.8	17.6	18.0
LO	1	1	1	8	12.00	96.0	96.0	96.0	96.0	2	120.0	336.0	432.0	528.0
VF	2	2	2	8	0.80	6.4	12.8	12.8	12.8	3	8.0	36.8	49.6	62.4
FN	1	0	0	4	2.50	10.0	10.0	0.0	0.0	1	16.0	26.0	26.0	26.0
VB	6	6	0	7	0.10	0.7	4.2	4.2	0.0	12	1.0	16.2	20.4	20.4
VM	8	8	0	7	0.10	0.7	5.6	5.6	0.0	14	1.0	19.6	25.2	25.2
P6	1	1	1	8	0.50	4.0	4.0	4.0	4.0	2	5.0	14.0	18.0	22.0
P3	2	2	2	8	0.30	2.4	4.8	4.8	4.8	4	4.0	20.8	25.6	30.4
FC	2	2	2	4	0.20	0.8	1.6	1.6	1.6	2	5.0	11.6	13.2	14.8
											TOTALS	1690	2028	2244

Figure 8-6x

DATA BANK EQUIPMENT COSTS CLASS CODE: 116E

TUNNEL LINING-CIP CONC.

SURFACE ARCH

	OPERATING COSTS									OWNERSHIP		TOTAL COST PER DAY		
	NO. UNITS PER SHIFT 1ST	2ND	3RD	AVG HRS OPER SH (EACH)	COST HR OPERATE	COST/ SHIFT	TOTAL PER DAY OPERATING COST 1ST	2ND	3RD	TOTAL NO REQ'D.	COST /DAY	1 SHIFT	2 SHIFTS	3 SHIFTS
CH	1	1	1	6	14.00	84.0	84.0	84.0	84.0	1	130.0	214.0	298.0	382.0
FT	2	1	1	6	2.50	15.0	30.0	15.0	15.0	2	10.0	50.0	65.0	80.0
CO	2	2	1	8	9.00	72.0	144.0	144.0	72.0	2	80.0	304.0	448.0	520.0
HH	1	1	1	4	16.00	64.0	64.0	64.0	64.0	1	200.0	264.0	328.0	392.0
											TOTALS	832	1139	1374

Figure 8-6y

6. GROUTING

CODE: 121223

	QUANTITY	UNIT COST	TOTAL COST
BACKFILL OF LINER	0.0 LF	0.00	0
CONTACT GROUTING	2996.0 LF	80.00	239680
STABILIZATION GROUTING	0.0 LF	0.00	0
TOTAL BASE COST			239680
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.229		-55030
TOTAL DIRECT COST			184649

Figure 8-6z

7. VENTILATION

CODE: 121223

	QUANTITY	UNIT COST	TOTAL COST
STRUCTURES	2996.0 LF	291.58	873600
TOTAL BASE COST			873600
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.229		-200578
TOTAL DIRECT COST			673021

Figure 8-6aa

8. MECHANICAL AND DRAINAGE

CODE: 121223

	QUANTITY	UNIT COST	TOTAL COST
PERMANENT DRAINAGE	2996.0 LF	74.93	224520
VENTTILATION - MECH	2996.0 LF	133.51	400000
TOTAL BASE COST			624520
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.229		-143389
TOTAL DIRECT COST			481130

Figure 8-6bb

9. RESTORATION

CODE: 121223

	QUANTITY	UNIT COST	TOTAL COST
LANDSCAPING	8.0 AC	1500.00	12000
PAVING	11616.0 SY	10.33	120000
TOTAL BASE COST			132000
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.229		-30307
TOTAL DIRECT COST			101692

Figure 8-6cc

PROJECTED COST OF TUNNEL CONSTRUCTION

INPUT DATA SHEET

PROJECT: WMATA - SECTION D-6; WEST SECTION

RUN NO. 2 DATE: 7/14/77

1. Location: (1) East Coast
(2) New York City
(3) Midwest
(4) West Coast 1

2. Projected Start. Select number 0 through 10, corresponding to calendar year in which project is projected to start, subsequent to base date of January 1, 1976. Example: Number (2) would correspond to a start within the calendar year January 1, to December 31, 1978. (Negative numbers indicate past projects.) -2

3. Length. Enter total length of tunnel in linear feet (l.f.). If twin tubes, enter sum of both tubes. 3,803 l.f.

4. Shape: (1) Circular
(2) Horseshoe 1

5. A. Diameter: Enter driven diameter (o.d.) in feet 21 ft.
B. Diameter: (1) 15' to 19' (2) 19' to 24' ____ ft.

6. Number of Shafts: 2

7. Air: (1) Free or (2) Compressed 1

8. Number of Tubes: (1) Single or (2) Twin 2

9.

Reach No.	Geology Type	Length	Avg. Depth	Class of Groundwater
1	1	3,803	47	2

Figure 8-7a

INPUT DATA SHEET

10. Excavation and Temporary Support:

A. Method of Excavation:

1. Shield/Hand excavation — 3
2. Shield/Digger arm
3. Shield/Wheel excavator — 2

B. Temporary Support:

1. Ring beams/Liner
2. Ring beams/Lagging
3. Structural steel liner
4. Precast segments — 3

C. Method of Mucking:

1. Rubber tire to shaft hoist
2. Rubber tire to portal
3. Rail to shaft hoist
4. Rail to portal

D. Number shifts/day excavating: — 1

11. Permanent lining; Cast-in-place, reinforced concrete:

A. Method of Placing:

1. Invert and Arch
2. "Full Round"
3. Invert Only — 1

B. Pour Restraints

1. Bulkhead (50'-100')
2. Continuous placement — 1

Figure 8-7b

INPUT DATA SHEET

C. Method of Transport

1. Rubber tire from portal
2. Rubber tire from dropline
3. Rail from portal
4. Rail from dropline
5. Conveyor
6. Pump ___6___

D. Number shifts/Day Concreting Operations: ___3___

E. Number shifts/Day Placing Concrete: ___2___

12. Site Preparation:

A. Pavement removal: Approx. amount of work area paved as a percent of total work area. (To nearest 10%.) ___30___

B. Clearing:

1. Class I
2. Class II
3. Class III ___1___

13. Restoration:

A. Grading and Vegetation of Restored Area:

1. Class I
2. Class II
3. Class III ___2___

B. Paving: Approximate amount of work area to be paved, expressed as a percent of total work

Figure 8-7c

area. (To nearest 10%.) 30

14. Ventilation:

    A. Method:

        1. Conventional

        2. Other 1

15. Underpinning: Enter area (s.f.) of buildings or portion of buildings within the 45^{o} influence line which falls within each of the following classifications.

    A. Class I - Light 1,000 s.f.

    B. Class II - Medium 0 s.f.

    C. Class III - Heavy 0 s.f.

16. Anticipated Number of Bidders: 5

Figure 8-7d

OUTPUT DATA FORM

PROJECTED COST OF TUNNEL CONSTRUCTION

PROJECT NAME: WMATA - SECTION D-6 - WEST SECTION

DATE: 2/14/77

RUN NUMBER: 2 CODE: 121323

TOTAL PROJECTED COST: $6,731,122

INPUT CONDITIONS

LOCATION: WASHINGTON DC

PROJECTED START: -2

TUNNEL LENGTH: 3803 FT.

SHAPE: CIRCULAR

DIAMETER: 21 FT

AIR: FREE

NUMBER OF TUBES: 2

REACH NO.	GEOLOGY TYPE	LENGTH	DEPTH	GROUNDWATER
1	1	3803	47	2

METHOD OF EXCAVATION: SHIELD/WHEEL EXCAVATOR

TEMPORARY SUPPORT: RING BEAMS/LAGGING

METHOD OF MUCKING: RAIL TO SHAFT HOIST

NUMBER OF SHIFTS / DAY EXCAVATING: 1

METHOD OF PLACING CONCRETE: INVERT & ARCH

POUR RESTRAINTS: BULKHEADS (50' C-C)

METHOD OF CONCRETE TRANSPORT: PUMP

NUMBER OF SHIFTS DAY CONCRETE OPERATIONS: 3

NUMBER OF SHIFTS DAY PLACING CONCRETE: 2

PAVEMENT REMOVAL-PERCENT OF WORK AREA: 30

CLEARING CLASS: 1

RESTORATION CLASS: 2

PERCENT OF WORK AREA TO BE PAVED: 30

VENTILATION: CONVENTIONAL

UNDERPINNING
- CLASS 1 LIGHT: 1000 SF
- CLASS 2 MEDIUM: 0 SF
- CLASS 3 HEAVY: 0 SF

Figure 8-7e

CONSTRUCTION COST SUMMARY

CODE: 121323

ITEM	QUANTITY	BASE COST	UNIT COST	ADJ. TOTAL COST
SITE PREPARATION	LS	76970	62853.94	62853
UNDERPINNING	LS	20000	16332.00	16332
DEWATERING	LS	5693	4648.94	4648
EXCAVATION	3803 LF	3127106	649.17	2468803
FINAL LINING	3803 LF	2093174	425.08	1616588
GROUTING	3803 LF	304240	65.32	248442
VENTILATION	LS	875200	714688.32	714688
MECHANICAL & DRAINAGE	LS	640760	523244.61	523244
RESTORATION	LS	144000	117590.40	117590
TOTAL DIRECT COST (BASE)		7287144		5773192
INDIRECT COST		1173071		957930
TOTAL COST (GROSS)		8460216		6731122
INSTITUTIONAL FACTOR		0		0
NET CONSTRUCTION COST		8460216		6731122

Figure 8-7f

ITEM COSTS

CODE: 121323

1. SITE PREPARATION

	QUANTITY	UNIT COST	TOTAL COST
CLEARING	8.0 AC	1500.00	12000
PAVEM'T. REMOVAL	2.4 AC	19200.00	46080
FENCING	2361.2 LF	8.00	18890
TOTAL BASE COST			76970
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.183		-14116
TOTAL DIRECT COST			62853

Figure 8-7g

2. UNDERPINNING

CODE: 121323

	QUANTITY	UNIT COST	TOTAL COST
CLASS 1	1000.0 SF	20.00	20000
CLASS 2	0.0 SF	50.00	0
CLASS 3	0.0 SF	100.00	0
TOTAL BASE COST			20000
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.183		-3668
TOTAL ADJUSTED COST			16332

Figure 8-7h

3. DEWATERING

CODE: 121323

	QUANTITY	UNIT COST	TOTAL COST
EXTERNAL	3803.0 FT	0.00	0
TUNNEL	209.6 D	27.15	5693
TOTAL BASE COST			5693
REGIONAL ADJ.	0.000		0
ESCALATION	-0.183		-1044
TOTAL DIRECT COST			4648

Figure 8-7i

4. EXCAVATION

CODE: 121323

A. PRODUCTION

REACH NO.	LENGTH	ADVANCE RATE PER/DAY	SHIFTS PER DAY	DURATION SHIFTS	DURATION DAYS
1	3803 LF	26	1	146.2	146.2
TOTAL	3803 LF		1	146.2	146.2

Figure 8-7j

4. (B) EXCAVATION COST SUMMARY
CODE 121323

	COST	QUANTITY	UNIT	LABOR	EQUIP.	MATERIALS	OTHER	TOTAL
SETUP	270000		LS				270000	270000
HEADING CREW	816	147	D	120283				120283
U. G. SUPPORT CREW	1693	147	D	249462				249462
SUR. SUPPORT CREW	1478	147	D	217745				217746
U. G. EQUIPMENT	3883	147	D		571875			571875
SURFACE EQUIPMENT	1450	147	D		213540			213540
RING BEAMS & LAGGING	184. 9	3803	LF			703174		703174
RAIL	0. 16	7606	LB			36508		36508
RAIL HARDWARE	2. 00	7606	LB			15212		15212
SWITCHES	1500. 00	5	EA			7500		7500
TRACK TIES	3. 00	1522	EA			4566		4566
FANLINE	15. 00	3850	LF			57750		57750
DISCHARGE LINE	8. 00	3850	LF			30800		30800
AIR LINE	5. 00	3850	LF			19250		19250
TEMP. ELECTRIC	40. 00	3850	LF			154000		154000
MISC. SUPPLIES	10. 00	3803	LF			38030		38030
MUCK HAULING	66. 19	3803	LF				251733	251733
SMALL TOOLS	8% OF LABOR					46999		46999
SAFETY EQUIP.	5% OF LABOR					29374		29374
SUBTOTAL-BASE COST				587492	785416	1143166	521733	3037808
PAYROLL T. & I.	0. 092			54049	0	0	0	54049
MISC. OVERTIME	0. 060			35249	0	0	0	35249
SUBTOTAL				676791	785416	1143166	521733	3127106
REGIONAL FACTOR	0. 000			0	0	0	0	0
REGIONAL FACTOR	0. 000			0	0	0	0	0
REGIONAL FACTOR	0. 000			0	0	0	0	0
REGIONAL FACTOR	0. 000			0	0	0	0	0
ESCALATION FACTOR	-0. 160			-108286	0	0	0	-108286
ESCALATION FACTOR	-0. 152			0	-119383	0	0	-119383
ESCALATION FACTOR	-0. 293			0	0	-334947	0	-334947
ESCALATION FACTOR	-0. 183			0	0	0	-95685	-95685
TOTAL DIRECT COST	0. 000			568504	666032	808218	426047	2468803

Figure 8-7k

5. CONCRETE

CODE: 121323

A. PRODUCTION

	LENGTH	ADVANCE RATE PER/DAY	SHIFTS PER DAY	DURATION SHIFTS	DURATION DAYS
INVERT	3803 FT	150	2	50.7	25.3
ARCH	3803 FT	100	2	76.0	38.0
TOTALS				126.7	63.3

Figure 8-71

5. B

CODE 121323

CONCRETE COST SUMMARY

	COST	UNIT QUANTITY	LABOR	EQUIP.	MATERIALS	OTHER	TOTAL
SETUP	100000	LS				100000	100000
U. G. INVERT CREW	6740	26 D	175253				175253
SURFACE INVERT CREW	2767	26 D	71949				71949
U. G. ARCH CREW	6579	39 D	256609				256609
SURFACE ARCH CREW	2942	39 D	114775				114775
U. G. INVERT EQUIP.	1487	26 D		38672			38672
SURFACE INVERT EQUIP	1535	26 D		39910			39910
U. G. ARCH EQUIP.	2244	39 D		87523			87523
SURFACE ARCH EQUIP.	1374	39 D		53586			53586
CONC. FOR LINING	117	3803 LF			447200		447200
REINFORCING STEEL	94	3803 LF			357760		357760
OVERRUN CONCRETE	11	3803 LF			44720		44720
CURING COMPOUND	1. 09	3803 LF			4181		4181
MISC. SUPPLIES	10	3803 LF			38030		38030
SLICKLINE	12	4183 LF			50199		50199
FORM OIL	1. 09	3803 LF			4181		4181
BULKHEAD LUMBER	8. 98	3803 LF			34179		34179
SMALL TOOLS	8% OF LABOR				49486		49486
SAFETY EQUIPMENT	5% OF LABOR				30929		30929
SUB-TOTAL BASE COST			618587	219692	1060869	100000	1999149
PAYROLL, T. & I.	0. 092		56910				56910
MISC. OVERTIME	0. 060		37115				37115
SUBTOTAL			712612	219692	1060869	100000	2093174
REGIONAL FACTOR	0. 000		0	0	0	0	0
REGIONAL FACTOR	0. 000		0	0	0	0	0
REGIONAL FACTOR	0. 000		0	0	0	0	0
REGIONAL FACTOR	0. 000		0	0	0	0	0
ESCALATION FACTOR	-0. 160		-114018	0	0	0	-114018
ESCALATION FACTOR	-0. 152		0	-33393	0	0	-33393
ESCALATION FACTOR	-0. 293		0	0	-310834	0	-310834
ESCALATION FACTOR	-0. 183		0	0	0	-18340	-18340
TOTAL DIRECT COST	0. 000		598594	186298	750034	99999	1616588

Figure 8-7m

6. GROUTING

CODE: 121323

	QUANTITY	UNIT COST	TOTAL COST
BACKFILL OF LINER	0.0 LF	0.00	0
CONTACT GROUTING	3803.0 LF	80.00	304240
STABILIZATION GROUTING	0.0 LF	0.00	0
TOTAL BASE COST			304240
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.183		-55797
TOTAL DIRECT COST			248442

Figure 8-7n

7. VENTILATION

CODE: 121323

	QUANTITY	UNIT COST	TOTAL COST
STRUCTURES	3803.0 LF	230.13	875200
TOTAL BASE COST			875200
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.183		-160511
TOTAL DIRECT COST			714688

Figure 8-7o

8. MECHANICAL AND DRAINAGE

CODE: 121323

	QUANTITY	UNIT COST	TOTAL COST
PERMANENT DRAINAGE	3803.0 LF	63.30	240760
VENTTILATION - MECH	3803.0 LF	105.18	400000
TOTAL BASE COST			640760
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.183		-117515
TOTAL DIRECT COST			523244

Figure 8-7p

9. RESTORATION

CODE: 121323

	QUANTITY	UNIT COST	TOTAL COST
LANDSCAPING	8.0 AC	3000.00	24000
PAVING	11616.0 SY	10.33	120000
TOTAL BASE COST			144000
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.183		-26409
TOTAL DIRECT COST			117590

Figure 8-7q

PROJECTED COST OF TUNNEL CONSTRUCTION

INPUT DATA SHEET

PROJECT: WMATA F2A

RUN NO. 1 DATE: 2/14/77

1. Location: (1) East Coast
(2) New York City
(3) Midwest
(4) West Coast — 1

2. Projected Start: Select number 0 through 10, corresponding to calendar year in which project is projected to start, subsequent to base date of January 1, 1976. Example: Number (2) would correspond to a start within the calendar year January 1, to December 31, 1978. (Negative numbers indicate past projects.) — -2

3. Length: Enter total length of tunnel in linear feet (l.f.). If twin tubes, enter sum of both tubes. — 8,820 l.f.

4. Shape: (1) Circular
(2) Horseshoe — 1

5. A. Diameter: Enter driven diameter (o.d.) in feet — 18 ft.
B. Diameter: (1) 15' to 19' (2) 19' to 24' — ____

6. Number of Shafts: — 3

7. Air: (1) Free or (2) Compressed — 1

8. Number of Tubes: (1) Single or (2) Twin — 2

9.

Reach No.	Geology Type	Length	Avg. Depth	Class of Groundwater
1	3	800	80	2
2	4	2000	80	3
3	3	6020	80	2

Figure 8-8a

INPUT DATA SHEET

10. Excavation and Temporary Support:

A. Method of Excavation:

1. Shield/Hand excavation — 2
2. Shield/Digger arm
3. Shield/Wheel excavator — 3

B. Temporary Support:

1. Ring beams/Liner
2. Ring beams/Lagging
3. Structural steel liner
4. Precast segments — 3

C. Method of Mucking:

1. Rubber tire to shaft hoist
2. Rubber tire to portal
3. Rail to shaft hoist
4. Rail to portal

D. Number shifts/day excavating: — 2

11. Permanent lining; Cast-in-place, reinforced concrete:

A. Method of Placing:

1. Invert and Arch
2. "Full Round"
3. Invert only — 3

B. Pour Restraints:

1. Bulkhead (50'-100')
2. Continuous placement — 2

Figure 8-8b

INPUT DATA SHEET

C. Method of Transport:

1. Rubber tire from portal
2. Rubber tire from dropline
3. Rail from portal
4. Rail from dropline
5. Conveyor
6. Pump — 4

D. Number shifts/Day Concreting Operations: — 3

E. Number shifts/Day Placing Concrete: — 2

12. Site Preparation:

A. Pavement removal: Approx. amount of work area paved as a percent of total work area. (To nearest 10%.) — 10

B. Clearing:

1. Class I
2. Class II
3. Class III — 1

13. Restoration:

A. Grading and Vegetation of Restored Area:

1. Class I
2. Class II
3. Class III — 1

B. Paving: Approximate amount of work area to be paved, expressed as a percent of total work

Figure 8-8c

INPUT DATA SHEET

area. (To nearest 10%.) 10

14. Ventilation:

    A. Method:

        1. Conventional

        2. Other 1

15. Underpinning: Enter area (s.f.) of buildings or portion of buildings within the 45^{o} influence line which falls within each of the following classifications.

    A. Class I - Light ______ s.f.

    B. Class II - Medium ______ s.f.

    C. Class III - Heavy 8,000 s.f.

16. Anticipated Number of Bidders: 5

Figure 8-8d

OUTPUT DATA FORM

PROJECTED COST OF TUNNEL CONSTRUCTION

PROJECT NAME: WMATA - SECTION F2A

DATE: 2/14/77

RUN NUMBER: 1 CODE: 111233

TOTAL PROJECTED COST: $31,331,087

INPUT CONDITIONS

LOCATION: WASHINGTON DC

PROJECTED START: -1

TUNNEL LENGTH: 8820 FT.

SHAPE: CIRCULAR

DIAMETER: 18 FT

AIR: FREE

NUMBER OF TUBES: 2

REACH NO.	GEOLOGY TYPE	LENGTH	DEPTH	GROUNDWATER
1	3	800	80	2
2	4	2000	80	3
3	3	6020	80	2

METHOD OF EXCAVATION: SHIELD/DIGGER ARM

TEMPORARY SUPPORT: STRUCTURAL STEEL SUPPORT

METHOD OF MUCKING: RAIL TO SHAFT HOIST

NUMBER OF SHIFTS / DAY EXCAVATING: 2

METHOD OF PLACING CONCRETE: INVERT

POUR RESTRAINTS: CONTINUOUS PLACEMENT

METHOD OF CONCRETE TRANSPORT: RAIL FROM DROPLINE

NUMBER OF SHIFTS DAY CONCRETE OPERATIONS: 3

NUMBER OF SHIFTS DAY PLACING CONCRETE: 2

PAVEMENT REMOVAL-PERCENT OF WORK AREA: 10

CLEARING CLASS: 1

RESTORATION CLASS: 1

PERCENT OF WORK AREA TO BE PAVED: 10

VENTILATION: CONVENTIONAL

UNDERPINNING

CLASS 1 LIGHT: 0 SF
CLASS 2 MEDIUM: 0 SF
CLASS 3 HEAVY: 8000 SF

Figure 8-8e

CONSTRUCTION COST SUMMARY

CODE: 111233

ITEM	QUANTITY	BASE COST	UNIT COST	ADJ. TOTAL COST
SITE PREPARATION	LS	44120	40352.15	40352
UNDERPINNING	LS	800000	731680.00	731680
DEWATERING	LS	1050673	960946.41	960946
EXCAVATION	8820 LF	18732114	1934.12	17058974
FINAL LINING	8820 LF	1071567	111.13	980187
GROUTING	8820 LF	2528432	262.18	2312504
VENTILATION	LS	1392000	1273123.20	1273123
MECHANICAL & DRAINAGE	LS	1028400	940574.64	940574
RESTORATION	LS	65000	59449.00	59449
TOTAL DIRECT COST (BASE)		26712308		24357791
INDIRECT COST		3351230		3065035
TOTAL COST (GROSS)		30063538		27422827
INSTITUTIONAL FACTOR		3908260		3564967
NET CONSTRUCTION COST		33971799		31331087

Figure 8-8f

ITEM COSTS

CODE: 111233

1. SITE PREPARATION

	QUANTITY	UNIT COST	TOTAL COST
CLEARING	10.0 AC	1500.00	15000
PAVEM'T. REMOVAL	1.0 AC	8000.00	8000
FENCING	2640.0 LF	8.00	21120
TOTAL BASE COST			44120
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.085		-3767
TOTAL DIRECT COST			40352

Figure 8-8g

2. UNDERPINNING

CODE: 111233

	QUANTITY	UNIT COST	TOTAL COST
CLASS 1	0.0 SF	20.00	0
CLASS 2	0.0 SF	50.00	0
CLASS 3	8000.0 SF	100.00	800000
TOTAL BASE COST			800000
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.085		-68320
TOTAL ADJUSTED COST			731680

Figure 8-8h

3. DEWATERING

CODE: 111233

	QUANTITY	UNIT COST	TOTAL COST
EXTERNAL	8820.0 FT	118.02	1041000
TUNNEL	408.6 D	23.67	9673
TOTAL BASE COST			1050673
REGIONAL ADJ.	0.000		0
ESCALATION	-0.085		-89727
TOTAL DIRECT COST			960946

Figure 8-8i

4. EXCAVATION

CODE: 111233

A. PRODUCTION

REACH NO.	LENGTH	ADVANCE RATE PER/DAY	SHIFTS PER DAY	DURATION SHIFTS	DURATION DAYS
1	800 LF	26	2	61.5	30.7
2	2000 LF	18	2	222.2	111.1
3	6020 LF	26	2	463.0	231.5
TOTAL	8820 LF		2	746.8	373.4

4. (B) EXCAVATION COST SUMMARY

CODE 111233

	COST	UNIT QUANTITY	LABOR	EQUIP.	MATERIALS	OTHER	TOTAL
SETUP	295000	LS				295000	295000
HEADING CREW	1828	374 D	684707				684707
U. G. SUPPORT CREW	3145	374 D	1177801				1177801
SUR. SUPPORT CREW	2607	374 D	976424				976424
U. G. EQUIPMENT	3346	374 D		1252880			1252880
SURFACE EQUIPMENT	1901	374 D		711770			711770
STR. STEEL LINER	1310.0	8820 LF			11554200		11554200
RAIL	0.16	17640 LB			84672		84672
RAIL HARDWARE	2.00	17640 LB			35280		35280
SWITCHES	1500.00	10 EA			15000		15000
TRACK TIES	3.00	3529 EA			10587		10587
FANLINE	15.00	9060 LF			135900		135900
DISCHARGE LINE	8.00	9060 LF			72480		72480
AIR LINE	5.00	9060 LF			45300		45300
TEMP. ELECTRIC	40.00	9060 LF			362400		362400
MISC. SUPPLIES	10.00	8820 LF			88200		88200
MUCK HAULING	48.63	8820 LF				428932	428932
SMALL TOOLS	8% OF LABOR				227114		227114
SAFETY EQUIP.	5% OF LABOR				141946		141946
SUBTOTAL-BASE COST			2838933	1964650	12773080	723932	18300596
PAYROLL T. & I.	0.092		261181	0	0	0	261181
MISC. OVERTIME	0.060		170335	0	0	0	170335
SUBTOTAL			3270451	1964650	12773080	723932	18732114
REGIONAL FACTOR	0.000		0	0	0	0	0
REGIONAL FACTOR	0.000		0	0	0	0	0
REGIONAL FACTOR	0.000		0	0	0	0	0
REGIONAL FACTOR	0.000		0	0	0	0	0
ESCALATION FACTOR	-0.073		-238742	0	0	0	-238742
ESCALATION FACTOR	-0.094		0	-184677	0	0	-184677
ESCALATION FACTOR	-0.093		0	0	-1187896	0	-1187896
ESCALATION FACTOR	-0.085		0	0	0	-61823	-61823
TOTAL DIRECT COST	0.000		3031708	1779973	11585183	662109	17058974

Figure 8-8k

5. CONCRETE

CODE: 111233

A. PRODUCTION

	LENGTH	ADVANCE RATE PER/DAY	SHIFTS PER DAY	DURATION SHIFTS	DURATION DAYS
INVERT	8820 FT	250	2	70.5	35.2
TOTALS				70.5	35.2

Figure 8-81

5. B

CONCRETE COST SUMMARY

CODE 111233

	COST	UNIT QUANTITY	LABOR	EQUIP.	MATERIALS	OTHER	TOTAL
SETUP	20000	LS				20000	20000
U. G. INVERT CREW	7237	36 D	260540				260540
SURFACE INVERT CREW	2718	36 D	97850				97850
U. G. INVERT EQUIP.	2191	36 D		78890			78890
SURFACE INVERT EQUIP	1507	36 D		54252			54252
CONC. FOR LINING	21	8820 LF			190498		190498
REINFORCING STEEL	17	8820 LF			152398		152398
OVERRUN CONCRETE	2	8820 LF			19049		19049
CURING COMPOUND	1.00	8820 LF			8820		8820
MISC. SUPPLIES	10	8820 LF			88200		88200
SMALL TOOLS	8% OF LABOR				28671		28671
SAFETY EQUIPMENT	5% OF LABOR				17919		17919
SUB-TOTAL BASE COST			358391	133142	505557	20000	1017091
PAYROLL, T. & I.	0.092		32972				32972
MISC. OVERTIME	0.060		21503				21503
SUBTOTAL			412867	133142	505557	20000	1071567
REGIONAL FACTOR	0.000		0	0	0	0	0
REGIONAL FACTOR	0.000		0	0	0	0	0
REGIONAL FACTOR	0.000		0	0	0	0	0
REGIONAL FACTOR	0.000		0	0	0	0	0
ESCALATION FACTOR	-0.073		-30139	0	0	0	-30139
ESCALATION FACTOR	-0.094		0	-12515	0	0	-12515
ESCALATION FACTOR	-0.093		0	0	-47016	0	-47016
ESCALATION FACTOR	-0.085		0	0	0	-1708	-1708
TOTAL DIRECT COST	0.000		382727	120627	458540	19999	980187

Figure 8-8m

6. GROUTING

CODE: 111233

	QUANTITY	UNIT COST	TOTAL COST
BACKFILL OF LINER	8820.0 LF	286.67	2528432
CONTACT GROUTING	0.0 LF	0.00	0
STABILIZATION GROUTING	0.0 LF	0.00	0
TOTAL BASE COST			2528432
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.085		-215928
TOTAL DIRECT COST			2312504

Figure 8-8n

7. VENTILATION

CODE: 111233

	QUANTITY	UNIT COST	TOTAL COST
STRUCTURES	8820.0 LF	157.82	1392000
TOTAL BASE COST			1392000
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.085		-118876
TOTAL DIRECT COST			1273123

Figure 8-8o

MECHANICAL AND DRAINAGE

CODE: 111233

	QUANTITY	UNIT COST	TOTAL COST
PERMANENT DRAINAGE	8820.0 LF	48.57	428400
VENTTILATION - MECH	8820.0 LF	68.02	600000
TOTAL BASE COST			1028400
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.085		-87825
TOTAL DIRECT COST			940574

Figure 8-8p

9. RESTORATION

CODE: 111233

	QUANTITY	UNIT COST	TOTAL COST
LANDSCAPING	10.0 AC	1500.00	15000
PAVING	4840.0 SY	10.33	50000
TOTAL BASE COST			65000
REGIONAL ADJ.	0.000		0
ESCALATION ADJ.	-0.085		-5551
TOTAL DIRECT COST			59449

Figure 8-8q

9.0 RECOMMENDATIONS

A critical review of the completed program indicates that there are several areas where additional work beyond the present scope would result in significant improvement to the model. These are discussed below.

9.1 PROBABILITY ANALYSIS FEATURE

The history of tunneling rather conclusively shows that hardly a project has been completed by precisely the same construction schedule and methods, and at the same cost, as originally planned and estimated. Geologic conditions may be found to be different than originally forecast, labor rates may change, the required skilled labor may not be available, advance rates may vary from expectations, and a host of other unanticipated events can invalidate original plans and estimates.

Some form of probability analysis might therefore be quite useful in providing an indication to planners, and perhaps contractors also, of possible cost variances due to changed conditions or events. The MIT program represents a very interesting approach to this form of analysis and certain features can be adapted for use in the TSC model.

9.2 "FLASH ESTIMATES"

The model is designed to provide the most accurate cost data possible to estimate, so that it is even suitable for use by contractors in preparing bids. This level of accuracy, however, is not entirely necessary for planners and others involved in making preliminary cost estimates. In some cases, such users may simply want to make a number of iterations by changing say one of the variables in a tunnel design to see what the effects are on cost. For example, it may be desired to determine the effect of various depths on costs, or even the timing of construction operations as a function of industry workload and its effect on project costs. For their use, it would be convenient to have a capability of obtaining "flash" estimates of a lower order of accuracy from simpler inputs, and with less expenditure of computer time. An executive routine can be designed to conveniently handle this type of feature.

9.3 NON-CONSTRUCTION COST ANALYSIS

As indicated in this report certain of the non-construction type costs are not included in the model as their quantification was considered beyond the scope of the present program. The non-construction type costs are listed in Table 9-1, with indication as to whether they are included in the current model or whether future work to analyze their cost parameters is recommended.

9.4 PROGRAM EXPANSION TO INCLUDE CUT AND COVER, STATIONS, IMMERSED TUBE, AND HARD ROCK CONDITIONS

In accordance with limitations on the scope of the current program, mined line sections only have been included in the present model. To accommodate all construction modes for subway systems, the model should be expanded to include cut-and-cover line sections, mined stations, cut-and-cover stations, and immersed tube. The present model is limited to soft ground, and an expansion of the model should include hard rock conditions.

TABLE 9.1 - NON-CONSTRUCTION COST ITEMS

	Included In Current Model	Not Included In Current Model	Needs Added Work	Not a Significant Cost Factor - Eliminate
SCHEDULE SLIPPAGE	X		X	
CHANGE ORDERS	X		X	
INSURANCE	X		X	
UTILITY DENSITY		X		
ENGINEER DESIGN	X		X	
CONSTRUCTION MANAGEMENT	X		X	
BUILDING PERMITS		X		X
NUMBER OF BIDDERS	X		X	
ESCALATION	X		X	
OWNER PURCHASE MATERIALS		X	X	
PAYMENT SCHEDULES		X		X
SIZE OF PROJECT		X	X	
LEGAL		X	X	
ENVIRONMENTAL RESTRICTIONS		X		
TRAFFIC DENSITY		X		
BUILDING DENSITY		X	X	
WEATHER AND CLIMATE		X	X	
RESIDENT ENGINEER		X	X	
STREET MAINTENANCE		X		X
TRAFFIC CONTROL		X		X
FINANCING COSTS	X		X	
OFFICE ADMINISTRATION		X	X	
REAL ESTATE ACQUISITION	X		X	
GEOLOGIC INVESTIGATIONS	X		X	

TABLE 9.1 (continued)

	Included In Current Model	Not Included In Current Model	Needs Added Work	Not a Significant Cost Factor - Eliminate
PROJECT MANAGEMENT	X		X	
BIDDING CLIMATE	X		X	
REGIONAL FACTORS	X		X	
PRODUCTIVITY FACTORS	X		X	
ENVIRONMENTAL & COMMUNITY INTERFACE COSTS		X	X	

10. REFERENCES

1. Harza Engineering Company, May 1970, "A Computer Program for Estimating Costs of Hard Rock Tunneling (COHART)," Contract No. DOT-FR-9-00003, Federal Railroad Administration, PB193-272.
2. Harza Engineering Company, October 1973, "A Computer Program for Estimating Costs of Tunneling (COSTUN)," Report No. FRA-ORD&D-74-16, Federal Railroad Administration.
3. Massachusetts Institute of Technology, May 1974, "Tunnel Cost Model: A Stochastic Simulation Model of Hard Rock Tunneling," National Science Foundation, Research Report No. R74-22.
4. A. J. Birkmyer, D. L. Richardson, Bechtel Corporation, December 1974, "Systems Analysis of Rapid Transit Underground Construction," Vols. I and II, U.S. Department of Transportation, Report No. DOT-TST-75-72.1; UMTA-MA-06-0025-74-11.1.
5. Mass Transit, December 1976, "Construction: Where the Dollars Go," p. MT/10.
6. Gates, Marvin, "Continuing Education Course in Construction Estimating," American Society of Civil Engineers.

APPENDIX A. INPUT DATA SHEET

INSTRUCTIONS

The Input Data Sheet has been so constructed that each question is referenced to pertinent data in the system data bank. It is imperative to the operation of the model that each question be answered. (If information is not known, an assumption may be made until such time as input conditions are fully known.)

The Input Data Sheet should be self-explanatory for the most part, except for the questions addressed below.

Line #4 - Although the occurrence of tunnel shapes other than circular in soft ground is recognized, this study is limited to circular tunnels for now, and condition #1 is mandatory.

Line #7 - Similarly, this study is limited to free air tunnels and condition #1 is imposed.

Line #9 - The tunnel alignment must be analyzed according to the properties of the material through which it passes and sections (reaches) of like or similar properties must be identified.

A. The geological conditons for soft ground tunneling in this model have been classified according to three tunneling properties into five types as defined below.

- Class I - Stiff Cohesive Clay
- Class II - Cohesive Sand and Gravel
- Class III - Non-Cohesive Sand and Gravel
- Class IV - Running Sand, Silt, Gravel
- Class V - Mixed Face (Hard Ground Intrusions)

B. Groundwater Conditions - This is really a judgmental factor relating not only to the soil permeability but to factors such as impervious overlying strata which may inhibit the inflows, depth (or height) of water table, recharge potential from lakes, etc. Therefore groundwater classification may be selected on judgmental basis of potential for inflows.

Class I	Light
Class II	Medium
Class III	Heavy

Line 11.A.2 - The term "Full Round" refers to placing the cast-in-place concrete around the full circumference of the tunnel in one pass, rather than placing the invert first and the arch at a later time.

Line 11.A.3 - "Invert Only" refers to the cases where segment steel or precast concrete tunnel lining functions as both "temporary" (Construction) and final lining.

Line 11.C.5 - The conveyor method of transport is a valid alternate and is recognized as such herein, however its use is not as yet common enought to warrant development of costs in this study. It is acknowledged only a potential subject for future inclusion.

Line 11.D - The shifts per day for concreting operations has been arbitrarily established at 3 shifts/day for this study.

Line 11.E - The shifts per day for placing concrete has been arbitrarily established at 2 shifts per day for this study.

Line 12.B - The classifications for site clearing are defined as follows:

- Class I - Grass, topsoil, few trees
- Class II - 30-50% tree removal, some minor structures
- Class III - Heavy foliage, trees, structures

Line 13.A - Classifications for restoration grading are as follows:

- Class I - Topsoiling/seeding only
- Class II - Seeding, some sodding and shrubs
- Class III - Extensive landscaping and re-planting of shrubs and trees

Line 14.A - Alternate #1 is arbitrarily predetermined for this study.

Line 15 - Underpinning applies only to those structures within the 1:1 influence line of the structure. Classifications are determined as follows:

- Class I - Light - One and two story wooden frame buildings.
- Class II - Medium - Masonry residences and light industrial or commercial buildings.
- Class III - Heavy - Large masonry structures; multi-story buildings; bridges; etc.

Line 16 - Number of Bidders. This is normally a judgmental factor, depending on such conditions as the type, size and location of the project but can reasonably be predicted in an area where similar work is common. For soft ground tunnels in Washington, D.C., a typical number might be 5; in New York City, perhaps 2.

<u>PROJECTED COST OF TUNNEL CONSTRUCTION</u>

<u>INPUT DATA SHEET</u>

PROJECT: ____

RUN NO: __________________ DATE: ________________________

1. <u>Location</u>: (1) Washington, D.C.
   (2) New York City
   (3) Chicago
   (4) Los Angeles _____

2. <u>Projected Start</u>: Select number 0 through 10, corresponding to calendar year in which project is projected to start, subsequent to base date of January 1, 1976. Example: Number (2) would correspond to a start within the calendar year January 1, 1978 to December 31, 1978. (Negative numbers indicate past projects.) _____

3. <u>Length</u>: Enter total length of tunnel in linear feet (l.f.). If twin tubes, enter sum of both tubes. _____l.f.

4. Shape: (1) Circular
   (2) Horseshoe __1__

5. A. <u>Diameter</u>: Enter driven diameter (o.d.) in feet _____ft.
   B. <u>Diameter</u>: (1) 15' to 19' (2) 19' to 24' _____ft.

6. <u>Number of Shafts</u>: _____

7. <u>Air</u>: (1) Free or (2) Compressed __1__

8. <u>Number of tubes</u>: (1) Single or (2) Twin _____

9.

Reach No.	Geology Type	Length	Ave. Depth	Class of Groundwater

INPUT DATA SHEET

10. Excavation and Temporary Support:
    - A. Method of Excavation:
        1. Shield/Hand excavation ____
        2. Shield/Digger arm
        3. Shield/Wheel excavator ____
    - B. Temporary Support:
        1. Ring beams/Liner
        2. Ring beams/Lagging
        3. Structural steel liner
        4. Precast segments ____
    - C. Method of Mucking:
        1. Rubber tire to shaft hoist
        2. Rubber tire to portal
        3. Rail to shaft hoist
        4. Rail to portal
    - D. Number shifts/day excavating: ____
11. Permanent lining; Cast-in-place, reinforced concrete:
    - A. Method of Placing:
        1. Invert and Arch
        2. "Full Round"
        3. Invert only ____
    - B. Pour Restraints:
        1. Bulkhead (50'-100')
        2. Continous placement ____
    - C. Method of Transport
        1. Rubber tire from portal
        2. Rubber tire from dropline
        3. Rail from portal
        4. Rail from dropline
        5. Conveyor
        6. Pump ____

INPUT DATA SHEET

D. Number shifts/Day Concreting Operations: 3

E. Number shifts/Day Placing Concrete: 2

12. Site Preparation:

A. Pavement removal: Approx. amount of work area paved as a percent of total work area. (To nearest 10%) ______

B. Clearing:

1. Class I
2. Class II
3. Class III ______

13. Restoration:

A. Grading and Vegetation of Restored Area:

1. Class I
2. Class II
3. Class III ______

B. Paving: Approximate amount of work area to be paved, expressed as a percent of total work area (To nearest 10%). ______

14. Ventilation:

A. Method:

1. Conventional
2. Other 1

15. Underpinning: Enter area (s.f.) of buildings or portion of buildings within the 45° influence line which falls within each of the following classifications:

A. Class I - Light ______s.f.

B. Class II - Medium ______s.f.

C. Class III - Heavy ______s.f.

16. Anticipated Number of Bidders: ______

APPENDIX B. OUTPUT DATA FORM AND WORKSHEETS

INSTRUCTIONS

Computing the costs of soft ground tunneling with the TSC model is a step-by-step process which involves selecting the appropriate information from the Data Bank "Catalog" as dictated by the given input conditions, transferring that information to the Output Data Form and Worksheets in the appropriate entry form provided and carrying out the designated computations. The following is a list of line-by-line instructions to assist in this procedure.

Page 1. This is a summary sheet for entering final costs computed in other sections and will be referred to later.

Page 2. Again, this is a summary sheet. As construction costs for the various cost items are computed, totals are entered herein.

Page 3. Tunnel Excavation

Item A. Determine the Class Code reference number according to directions.

Item B. Complete the tabulation in the following manner:

Column (a) - Refer to Input Data Sheet, Line (9)

Column (b) - Refer to Input Data Sheet, Line (9)

Column (c) - Refer to Input Data Sheet, Line (9)

Column (d) - Refer to Input Data Sheet, Line (10.D)

Column (e) - Refer to Appendix C-1. and select the table of production rates corresponding to the Class Code computed above. For each reach of tunnel, enter the production rates corresponding to the given geology in the Input Data (Line 9).

Column (f) - For each reach of tunnel, divide the length (Col. c) by the advance rate (Col. e). Round-off fractions to the next highest number.

Total — Total Column (f) and enter the total on Page 4, Lines 1, 2, 3 4, and 5, under the column heading "Quantity".

Page 4. Enter the Class Code in the space provided at the top of the page. Refer to Appendix (C.2) Data Bank and turn to the section corresponding to the Class Code.

Line 1. - "Heading Crew" From the referenced Data Bank, select the table titled "Heading Crew", enter the appropriate total cost per day from this table in the space provided for "Unit Cost. Multiply the Unit Cost by the Quantity and enter the product in the columns for Labor and Total Cost.

Lines 2-5. - Performed in a similar manner.

Line 6. - Set-Up Costs from the same section of Appendix C.2, select the table for set-up cost and enter the Total of these costs in the spaces provided for "Other Costs" and "Total Costs".

Line 7. - Muck Hauling Costs (Offsite) from the same section of Appendix C.2, solve the given cost equation for cost of muck hauling per tunnel foot using given input tunnel diameter and the appropriate Data Bank cost (from Appendix D.3). Enter this cost/tunnel foot on Line 7 under Unit Cost. Enter the total tunnel footage under quantity (Input Data Sheet, Line 3.). Multiply Unit Cost by Quantity and enter the product in the appropriate spaces provided.

<u>Lines 8-26</u>. - These lines are provided for entering the costs of materials. Equations and tables for computing these costs are found in the same section of Appendix C.2 as determined by the Class Code, under the title "Material Costs". Physical conditions are as specified in the Input Data Sheet and prices are found in Appendix D.3, with the one exception that for costs based on a percent of wages, the wages are as determined in Lines 1, 2 and 3 above.

<u>Lines 27 & 28</u>. - Subtotal the item Labor Costs and compute Payroll Burden and Miscellaneous Overtime Allowance as a percent of labor. Use current Payroll Burden percent (Appendix D.1).

<u>Line 30</u>.- Multiplying factors for regional costs are found in Appendix E.1. These factors are applied to the appropriate subtotals on Line 29. The factor for the column "Other Costs" is computed by taking 40% of the labor factor + 40% of equipment factor + 20% of materials factor.

<u>Line 31.</u>- Escalation Costs are computed in a similar manner as Regional Costs. (Refer to the Input Data Sheet, Line 2 in selecting the proper escalation factors from Appendix E.1.)

<u>Line 32</u>.- Total all Cost Columns. Enter the Total Adjusted Cost on Page 2, Line 1.

<u>Page 5</u>. Complete in a manner similar to Page 3, using the Input Data designated and Production Rates from Appendix C.1. Enter the Total Duration in days from Item (B) in the Quantities Column, Page 6, Lines 1-7.

Page 6. Complete in a similar manner as Page 4. Transfer the Total Adjusted Cost from Line 32, to Page 2, Line 2.

Pages 7-12. are Secondary Direct Costs not specifically involved in excavating and lining a tunnel. Appendix C.4 provides equations which are used in conjunction with the Input Data Sheet and Appendix D.4 of Prices, to compute the respective costs. In each case for cost items 3-9, the Total Adjusted Cost so computed is transferred to the respective line on Page 2.

Page 2.

Line 10 - Total Direct Costs are now totaled on Line 10.

Line 11 - Consult Appendix E.2 to determine the Indirect Costs.

Line 12 - Total the Direct and Indirect Costs.

Line 13 - Apply institutional factors from Appendix E.3 to the Gross Total on Line 12.

Line 14 - Total Lines 12 and 13 to compute the Net Construction Cost. Enter this Total on Page 1 and Page 13, Line "A".

Page 13. Compute the Non-Construction Costs from the given equations and the factors in Appendix E.4. Enter the total from Line 11 in the appropriate space on Page 1.

Page 1. Total the Construction Costs and Non-Construction Costs to compute the Total Project Cost.

OUTPUT DATA FORM

PROJECTED COST OF TUNNEL CONSTRUCTION

PROJECT NAME: ____________________

DATE: ____________________

RUN NUMBER: ____________________

TOTAL PROJECT COST SUMMARY

TOTAL CONSTRUCTION COSTS

Page (2), Line 14 $ ____________

TOTAL NON-CONSTRUCTION COSTS $ ____________

____

TOTAL ESTIMATED PROJECT COST $ ____________

CONSTRUCTION COST SUMMARY

ITEM	QUANTITY a.	ADJUSTED TOTAL COST b.
1. Excavation	LF	
2. Final Lining	LF	
3. Site Preparation	LS	
4. Underpinning	LS	
5. Dewatering	LS	
6. Grouting	LF	
7. Ventilation	LS	
8. Mechanical & Drainage	LS	
9. Restoration	LS	
10. TOTAL DIRECT COST 11. INDIRECT COST		
12. TOTAL COST (GROSS) 13. INSTITUTIONAL FACTOR		
14. NET CONSTR. COST *		

*Enter Net Construction Cost on Page 1 and Page 13

1. TUNNEL EXCAVATION

A. <u>CLASS CODE</u>

The Class Code for tunnel excavation is a six digit reference number based on the input conditions, which is used to identify and select the appropriate cost data stored in the Data Banks.

To determine the Class Code, enter the appropriate single digit number from the Input Data Sheet in each of the 6 boxes, A-F below.

A	B	C	D	E	F

Box A----Input Data Sheet, Line 7
Box B----Input Data Sheet, Line 5.B.
Box C----Input Data Sheet, Line 4
Box D----Input Data Sheet, Line 10.A.
Box E----Input Data Sheet, Line 10.B.
Box F----Input Data Sheet, Line 10.C.

a. Reach No.	b. Length	c. Geology	d. Shifts Per Day	e. Advance Rate Per Day	f. Duration Days
TOTAL					

1. C TUNNEL EXCAVATION COST SUMMARY

CLASS CODE:

	Unit Cost	Quantity	Labor	Equipment	Materials	Other	TOTAL
1. HEADING CREW		Days					
2. U.G. SUPPORT CREW		Days					
3. SURFACE SUPPORT CREW		Days					
4. U.G. EQUIPMENT		Days					
5. SURFACE EQUIPMENT		Days					
6. SET-UP COSTS		LS					
7. MUCK HAULING(OFFSITE)		T.F.					
8.							
9.							
10.							
11.							
12.							
13.							
14.							
15.							
16.							
17.							
18.							
19.							
20.							
21.							
22.							
23.							
24.							
25.							
26.							
27. PAYROLL TAX & INS.	(TOT.LAB.)	%					
28. MISC. OVERTIME	(TOT.LAB.)	6%					
29. SUBTOTAL -Base Cost							
30. Regional Factors							
31. Escalation Factors							
32. TOTAL DIRECT COST*							

*Enter this total adjusted cost on page (2), Line (1)

2. CONCRETE

A. <u>CLASS CODE</u>

The Class Code for final tunnel lining is a three digit number based on the input conditions, which is used to identify and select the appropriate cost data stored in the Data Banks.

To Determine the Class Code, enter the appropriate single digit number from the Input Data Sheet in each of the 3 boxes A-C below.

A	B	C

Box A----Input Data Sheet, Line 11A
Box B----Input Data Sheet, Line 11B
Box C----Input Data Sheet, Line 11C

		a. Length	b. Advance Rate/Day	c. Shifts Per Day	d. Duration Days
Invert					
Arch					
TOTAL					

2.C TUNNEL CONCRETE COST SUMMARY

CLASS CODE: ______

	Unit Cost	Quantity	Labor	Equipment	Materials	Other	TOTAL
1. U.G. INVERT CREW		Days					
2. SURFACE INVERT CREW		Days					
3. U.G. ARCH CREW		Days					
4. SURFACE ARCH CREW		Days					
5. U.G. INVERT EQUIPMENT		Days					
6. SURFACE INVERT EQUIP.		Days					
7. U.G. ARCH EQUIPMENT		Days					
8. SURFACE ARCH EQUIPMENT		Days					
9. SET-UP COSTS		LS					
10.							
11.							
12.							
13.							
14.							
15.							
16.							
17.							
18.							
19.							
20.							
21.							
22.							
23.							
24.							
25.							
26.							
27. PAYROLL TAX & INS	(TOT.LAB.)	%					
28. MISC. OVERTIME	(TOT.LAB.)	6 %					
29. SUBTOTAL - Base Cost							
30. Regional Factors							
31. Escalation Factors							
32. TOTAL ADJUSTED COST *							

*Enter this total adjusted cost on Page (2), Line (2)

ITEM COSTS

3. SITE PREPARATION

	Quantity	Unit Cost	Total Cost
Clearing	Ac.	$	$
Pavement Removal	Ac.		
Fencing	LF		
TOTAL BASE COST			
INFLUENCE FACTORS 1. Regional			
2. Escalation			
TOTAL ADJUSTED COST *			*

* Enter Adjusted Total Cost on Page 2, Line 3.

4. UNDERPINNING

	Quantity	Unit Cost	Total Cost
Class I	SF	$	$
Class II	SF		
Class III			
TOTAL BASE COST			
INFLUENCE FACTORS 1. Regional			
2. Escalation			
TOTAL ADJUSTED COST *			*

* Enter Adjusted Total Cost on Page 2, Line 4

ITEM COSTS

5. DEWATERING

	Quantity	Unit Cost	Total Cost
External	lf		
Internal	days		
TOTAL BASE COST			
1. Regional			
2. Escalation			
TOTAL ADJUSTED COST *			*

* Enter Adjusted Total Cost on Page 2, Line 5

6. GROUTING

	Quantity	Unit Cost	Total Cost
Contact Grouting (C_C)	CF		
Backfill Grouting(C_{BF})	CF		
Pregrouting (C_P)	CF		
TOTAL BASE COST			
Regional Adj.			
Escalation Adj.			
TOTAL ADJUSTED COST *			*

* Enter Adjusted Total Cost on Page 2, Line 6

7. VENTILATION

	Quantity	Unit Cost	Total Cost
Fan Shafts	LS		
TOTAL BASE COST			
Regional Adj.			
Escalation Adj.			
TOTAL ADJUSTED COST*			*

* Enter Adjusted Total Cost on Page 2, Line 7

8. MECHANICAL AND DRAINAGE

	Quantity	Unit Cost	Total Cost
Permanent Drainage	LS	-	
Ventilation Mechanical	Shafts		
TOTAL BASE COST			
Regional Adj.			
Escalation Adj.			
TOTAL ADJUSTED COST *			*

* Enter Adjusted Total Cost on Page 2, Line 8

9. RESTORATION

	Quantity	Unit Cost	Total Cost
Landscaping	Acre		
Paving	Acre		
TOTAL BASE COST			
Regional Adj.			
Escalation Adj.			
TOTAL ADJUSTED COST *			*

* Enter Adjusted Total Cost on Page 2, Line 9.

10. NON-CONSTRUCTION COSTS

A. Total Construction Cost (P. 2), Line 14.

$____________________

B. Refer to Appendix E.4

1. Geologic Investigation

$________________ X _____% = ________________

2. Engineering Design

$________________ X _____% = ________________

3. Construction Management

$________________ X _____% = ________________

4. Insurance

$________________ X _____% = ________________

5. Slippage

$________________ X _____% = ________________

6. Change Orders

$________________ X _____% = ________________

7. SUBTOTAL

8. PLUS CONSTRUCTION COST ________________

9. SUBTOTAL

10. PROJECT MANAGEMENT AT ___% = ________________

11. TOTAL NON-CONSTRUCTION COST = ________________

(Line 7 plus Line 10)

APPENDIX C

DATA BANK OF "EFFORT"

C.1 Production Rates
- A. Tunnel Excavation
- B. Final Lining

C.2 Tunnel Excavation - Labor, Equipment and Materials

C.3 Final Tunnel Lining - Labor, Equipment and Materials

NOTE: Appendixes C.1, C.2, and C.3 contain computer run data and other material too voluminous to include in this volume, and are available upon request from the Transportation Systems Center.

C.4 SECONDARY COST FACTORS

SITE PREPARATION COSTS

Site preparation costs are determined from the input conditions and the data bank prices according to the following formulas (assume no demolition).

	Unit Cost (Data Bank)	Total Cost	Per Unit
1. Area Required Office and main yard = 4 acres Plus shaft area 2 acres/shaft X(N)shafts =2(N) acres Total required area (4+2N) acres			
2. Clearing [Unit cost \$(Y)/acre from data bank chart]	\$(Y)/acre	\$(Y)(4+2N)	
3. Pavement Removal Percent paved (P%) from input data sheet Unit cost \$(Y)/acre from data bank	\$(Y)/acre	\$(Y)(P%)(4+2N)	
4. Fencing Unit Cost \$(Y)/LF from data bank Perimeter (ave.) = $4\sqrt{(4+2N)(43,560)}$	\$Y/LF	$\$(Y)4\sqrt{(4+2N)(43,560)}$	
TOTAL COST FOR SITE PREP		$C_c+C_p+C_f$	

UNDERPINNING COSTS

Underpinning costs are determined by the input conditions (structure areas underpinned for each classification) and the unit prices from the data bank.

	Unit Costs (Data Bank)	Total Costs	Per Unit
1. Class I Underpinning (Light) Unit Cost $\$(Y_1)$/SF from data bank area (A_1)SF from input data	$\$(Y_1)$/SF	$\$(Y_1)(A_1)$	LS
2. Class II Underpinning (Medium) Unit Cost $\$(Y_2)$/SF from data bank area (A_2) SF from input data	$\$(Y_2)$/SF	$\$(Y_2)(A_2)$	LS
3. Class III Underpinning (Heavy) Unit cost $\$(Y_3)$/SF from data bank area (A_3) from input data	$\$(Y_3)$/SF	$\$(Y_3)(A_3)$	LS
TOTAL UNDERPINNING COSTS		$\$C_1+C_2+C_3$	LS

DEWATERING COSTS

Dewatering costs are determined from the input conditions and the data bank prices, using the formulas below.

	Unit Cost (Data Bank)	Total Costs	Per Unit
1. External Dewatering (Deep wells, wellpoints, etc.) Unit Cost \$(Y)/LF of tunnel is determined by the data bank chart of prices, according to the input conditions for geology and groundwater. L = Tunnel Length (ft)	\$(Y)/LF	\$(Y)(L)	LS
2. Internal Dewatering of Tunnel* \$(Y) = Cost of initial pumping set-up \$(Z)/day = Cost of operation (D_1) = Duration (days) of tunnel excav. (D_2) = Duration (days) for final lining These durations are determined in the appropriate sections for estimating cost of excavation and final lining.	\$(Y)/tunnel \$(Z)Day	$[(Y)+(Z)(D_1+D_2)]$	LS
TOTAL DEWATERING COSTS		C_1+C_2	LS

*NOTE: Or ground preparation not covered in "Grouting-Consolidation" Section.

GROUTING COSTS

SUMMARY

	Total Grouting Costs	Per Unit
Total Cost Per Tunnel Reach $C_R = C_{BF} + C_C + C_P$ Where C_R = Grouting Cost/Reach C_{BF} = Backfill Grouting Cost/Reach C_C = Contact Grouting Cost/Reach C_P = Ground Treatment Cost/Reach	$C_R = C_{BF} + C_C + C_P$	LS/ Reach
$C_{TOT} = \sum_1^N C_R$ or total tunnel grouting costs (C_{TOT}) = the sum of the costs of each reach	$C_{TOT} = \sum_1^N C_R$	LS/ Reach

GROUTING (con't)

I. Backfill of Liner (Annular Space)

	Unit Cost (Data Bank)	Total Cost	Per Unit
A. Ring Beams and Lagging None required	-	-	-
B. Ring Beams and Liner PL Structural Steel Liner or Precast Liner			
Unit Price = \$(Y)/CF Grout Annular space = 3" (Ave.) Vol/LF of tunnel = (0.25 ft)(π)D Where D = Driven Diameter (From input conditions) L = Length of Tunnel Reach	\$(Y)/CF	\$(Y)(0.25)(πD)L	LS/ Reach

II. Contact Grouting - To fill voids between temporary lining and final cast-in-place concrete lining. Does not apply where structural steel segments or precast concrete segments are used as both temporary and final lining.

	Unit Cost (Data Bank)	Total Cost	Per Unit
1. Ring Beams and Lagging or Ring Beams and Liner Plate			
Unit Price = $(Y)/CF for grout (from data bank)			
Ave Grout take = 4 CF/LF L = length of tunnel reach	$(Y)/CF	$(Y)(4L)	LS Reach
2. Structural Steel Liner or Precast Concrete Liner			
Not applicable	-	-	-

GROUTING (con't)

III. Grouting for Ground Treatment - Pregrouting or consolidation Grouting.

Costs for ground treatment in the presence of groundwater are covered in the section for "Dewatering-External" and may be considered to be total ground treatment costs, regardless of method or combination of methods used (excluding compressed air, freezing, etc.)

The costs in this section, therefore, apply only to Class IV Geology (or Class V with running sand in the upper strata) combined with Class I Groundwater.

	Unit Cost (Data Bank)	Total Cost	Per Unit
Class IV Geology & Class I Groundwater			
Unit Cost = $(Y)/CF Grout (Data Bank)			
L = Length of Tunnel Reach			
Ave Grout Take = 10 CF/LF Tunnel	$(Y)/CF	$(Y)(10L)	LS/ Reach

VENTILATION STRUCTURES

Ventilation shafts are required at a maximum spacing of 2000 LF along centerline or as specified by input conditions.

	Unit Cost (Data Bank)	Total Cost	Per Unit
1. Vent or Fan Shaft Costs			
$C_V = N[\$(Y) + \$(Z)(D)]$			
Where: C_V = Total Cost of Vent Shafts & Structures N = No. shafts required = L/2000 or as specified $(Y) = Base costs of set-up, surface & cross-over structures $(Z) = Cost/VF of Shaft (D) = Average Tunnel Depth (input data)	$(Y)/shaft $(Z)/VF	$N[(Y)+(Z)(D)]	LS/ Tunnel

MECHANICAL AND DRAINAGE

	Unit Cost (Data Bank)	Total Cost	Per Unit
1. Permanent Drainage $C_D = (X)L + N[(Y)+(Z)(D)]$ where: C_D = Total Drainage cost/tunnel N = No. shafts (L/2000 or as specified) L = Total Tunnel Length (Y)=Fixed installation cost/shaft (Z)=Installation Cost/VF shaft (D)=Ave. Depth of tunnel (X)=Installation Cost/LF of tunnel	\$(X)/LF \$(Y)/shaft \$(Z)/VF	(X)(L)+N[(Y)+(Z)(D)]	LS/ Tunnel
2. Ventilation Mechanical $C_{VM} = (V)(N)$ where: C_{VM} = Total Vent Mechanical Costs V = Costs per shaft N = No. shafts (L/2000 or as specified)	\$(V)/shaft	\$(V)(N)	LS
Total Mechanical and Drainage Costs		$C_M = C_D = C_{VM}$	LS

RESTORATION

Restoration costs are determined from the input conditions and the data bank prices by the formulas below.

	Unit Cost (Data Bank)	Total Cost	Per Unit
1. Area Involved - (Same as for clearing) = (4+2N)acres where N = No of shafts			
2. Paving Costs $C_P = (Y_P)(P\%)(4+2N0$ Where: Y_P = Unit Paving costs/ acre (from data bank) P% = Percent of total restored areas which will be paved (from input data) C_P = Total paving cost	$\$(Y_P)$/acre	$\$(Y_P)(P\%)(4+2N)$	LS
3. Grading and Landscaping $C_L = (1-P\%)(Y_L)(4+2N)$ Where: Y_L = Landscaping Unit Cost/ acre C_L = Total cost of grading,etc.	$\$(Y_L)$/acre	$(1-P\%)(Y_L)(4+2N)$	LS
Total Restoration Costs		$C_P + C_L$	LS

APPENDIX D. DATA BANK OF VALUES

D.1 - LABOR RATES

(Including Fringes Effective Jan 1976)

		CODE	RATE/HR
1	SHIFTER	SH	10.23
2	MINER	MI	9.73
3	OPERATOR	OR	11.57
4	MECHANIC	ME	10.94
5	MOTORMAN	MO	11.32
6	DUMPMAN	DM	8.51
7	BRAKEMAN	BM	8.78
8	PUMPMAN	PM	11.32
9	BULLGANG OPERATOR	BO	11.32
10	BULLGANG LABOR	BL	8.78
11	ELECTRICIANS	EL	12.70
12	BULLGANG FOREMAN	BF	10.23
13	HOIST OPERATOR	HO	11.57
14	HOIST OILER	HR	10.94
15	COMPRESSOR OPERATOR	CO	11.32
16	ELEVATOR MAN	EM	8.51
17	DUMPMAN	DP	8.51
18.	MASTER MECHANIC	MM	12.07
19	ELECTRICIAN FOREMAN	EF	13.20
20	TEAMSTER	TM	7.32
21	CRANE OPERATOR	CR	11.57
22	CRANE OILER	CI	10.94
23	IRONWORKER	IW	11.77
24	CARPENTER	CP	10.99
25	LABORER (TOP SIDE)	LR	8.51
26	PUMPMAN (CONC. PUMP)	PC	11.32
27	FOREMAN	FO	9.01
28	OILER	OL	10.94
29	NIPPER	NI	9.08

D.1 - LABOR RATES (con't)

		CODE	RATE/HR
30	CARPENTER FOREMAN	CF	11.49
31	IW FOREMAN	IF	12.10
32	SIGNALMAN	SM	8.78

(Jan 1976 Wage for Payroll T & I = 0.092%)

D.2 - EQUIPMENT RATES

Effective Jan 1976

		CODE	OPER. COST/HR	OWNERSHIP COST/DAY
1	HOIST & HEADFRAME	HH	16.00	200.00
2	MUCK BIN & FEEDER	MF	10.00	30.00
3	966 LOADER	L6	14.00	130.00
4	CHERRY PICKER 20 TON	CH	14.00	130.00
5	CRANE 60 TON	CR	24.00	300.00
6	FLATRACK TRUCK	FT	2.50	10.00
7	COMPRESSOR 1200 CFM	CO	9.00	80.00
8	SHIELD/WHEEL/ERECTOR	SW	80.00	1800.00
9	CONVEYOR/CAR LOADER UNIT	CC	25.00	400.00
10	LOCOMOTIVE	LO	12.00	120.00
11	MUCK CAR	MC	0.20	8.00
12	FLAT CAR	FC	0.20	5.00
13	VENTILATION FAN 25HP	VF	0.80	8.00
14	MANTRIP CAR	MT	0.20	8.00
15	PUMP 6 IN	P6	0.50	5.00
16	PUMP 3 IN	P3	0.30	4.00
17	PUMP 1 IN	P1	0.15	3.00
18	CAR DUMPER	CD	1.50	12.00
19	AIR TUGGER	AT	0.50	5.00
20	CALIFORNIA SWITCH	CS	5.00	25.00
21	SCREED	SD	0.80	34.00
22	CONVEYOR 400 FT	CV	10.00	115.00
23	AGIATATOR CAR	AC	1.00	10.00
24	VIABRATOR 3 IN	VB	0.10	1.00
25	FORMS 50 FT	FR	1.00	150.00
26	FORM TRAVELER (HYDR)	FV	6.50	100.00
27	HIGH CAR	HC	0.50	20.00
28	CONCRETE PUMP	CP	16.00	225.00
29	VIABRATOR FORM	VM	0.10	1.00

D.2 - EQUIPMENT RATES (con't)

		CODE	OPER. COST/HR	OWNERSHIP COST/DAY
30	FAN LINE CAR	FN	2.50	16.00
31	SHIELD/DIGGER ARM	DS	45.00	700.00
32	TRANSITMIX TRUCK	CT	9.00	30.00
33	TRACTOR/HOE	TH	13.00	110.00
34	LOAD/HAUL/DUMP UNIT	LH	19.00	170.00
35	HYD. SHIELD/ERECTOR	SE	45.00	600.00
36	MOTOR GRADER-12E	MG	6.00	72.00
37	TRACTOR/TRAILER	TT	4.00	30.00
38	988 LOADER	L8	17.00	150.00

D.3 - MATERIAL PRICES

Effective Jan 1976

		CODE	UNIT PRICE
1	FANLINE 30 IN	FL	15.00/LF
2	AIRLINE 4 IN	AL	5.00/LF
3	DISCHARGE LINE 8 IN	DL	8.00/LF
4	SMALL TOOLS	ST	8.00% Wages
5	SAFETY EQUIP & SUPPLIES	SE	5.00% Wages
6	TEMP ELECTRIC-HAND MINING	TE	25.00/Tunnel Ft
7	TEMP ELECTRIC-ALL OTHERS	TL	40.00
8	RAIL 90LB/YD	RL	0.16/LB
9	NUTS/BOLTS/SPIKES	NB	1.00/LB
10	SWITCHES	SW	1500.00 each
11	MISC TUNNEL SUPPLIES	MS	10.00/Tunnel Ft
12	R/R TIES	RT	3.00 each
13	CONCRETE	CO	30.00/CY
14	REINFORCING STEEL	RS	0.16/LB
15	FORM LUMBER	FR	0.22/BF
16	BULKHEAD LUMBER	BL	0.22/BF
17	FORM OIL	FO	1.00/Gal
18	CURING COMPOUND	CC	1.00/Gal
19	SLICKLINE 6 IN	SK	12.00/LF
20	DROP HOLES	DH	25.00/VF
21	MUCK HAULING	MH	5.16/BCY
22	INVERT CURING (INVERT ONLY with BULKHEADS)	IC	1.50/Tunnel Ft.

RING BEAMS WITH LINER PLATE

(PRELIMINARY)

GEOLOGY TYPE I

A. Ring Beams @ 4' c-c

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
Size	W6x14	W6x14	W6x14	W6x14	W6x20	W6x20	W6x20	W6x20	W8x20	W8x20
$/Tunnel ft.	50.50	54.00	57.50	61.00	91.90	97.00	102.00	107.00	111.50	116.50

B. Liner PL - 16"

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
Size	¼	¼	¼	¼	¼	¼	¼	5/16	5/16	5/16
$/Tunnel ft.	135.00	139.00	144.00	149.00	154.00	160.00	165.00	185.00	192.00	200.00

RING BEAMS WITH LINER PLATE

(PRELIMINARY)

GEOLOGY TYPE II

A. Ring Beams @ 4' c-c

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
Size	W6x14	W6x14	W6x14	W6x20	W6x20	W6x20	W8x20	W8x20	W8x20	W8x20
$/Tunnel ft.	50.50	54.00	57.50	87.00	91.90	96.50	101.40	106.30	111.50	116.50

B. Liner PL 16"

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
Size	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	5/16	5/16	5/16	5/16
$/Tunnel ft.	135.00	139.00	144.00	149.00	154.00	160.00	179.00	185.00	192.00	200.00

RING BEAMS WITH LINER PLATE

(PRELIMINARY)

GEOLOGY TYPE III

A. Ring Beams @ 4' c-c

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
Size	W6x14	W6x14	W6x20	W6x20	W6x20	W8x20	W8x20	W8x20	W8x24	W8x24
$/Tunnel ft.	50.50	54.00	82.50	87.00	91.90	96.50	101.40	106.30	113.00	118.80

B. Liner PL 16"

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
Size	¼	¼	¼	5/16	5/16	5/16	3/8	3/8	3/8	3/8
$/Tunnel ft	135.00	139.00	144.00	166.00	175.00	186.00	205.00	218.00	228.00	239.00

RING BEAMS WITH LINER PLATE

(PRELIMINARY)

GEOLOGY TYPE IV

A. Ring Beams @ 4' c-c

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
Size	W6x14	W6x14	W6x20	W6x20	W8x20	W8x20	W8x20	W8x24	W8x24	W8x24
$/Tunnel ft.	50.50	54.00	82.50	87.00	91.90	96.50	101.40	109.00	113.00	118.90

B. Liner PL 16"

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
Size	¼	¼	5/16	5/16	5/16	3/8	3/8	3/8	3/8	3/8
$/Tunnel ft	135.00	139.00	161.00	166.00	175.00	196.00	205.00	218.00	228.00	239.00

RING BEAMS WITH LINER PLATE

(PRELIMINARY)

GEOLOGY TYPE V

A. Ring Beams @ 4' c-c

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
Size	W6x20	W6x20	W8x20	W8x20	W8x20	W8x24	W8x24	W8x24	W8x30	W8x30
$/Tunnel ft.	72.00	77.00	81.50	86.00	91.90	98.50	103.00	109.00	121.00	133.00

B. Liner PL 16"

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
Size	5/16	5/16	5/16	3/8	3/8	3/8	3/8	7/16	7/16	7/16
$/Tunnel ft.	151.50	156.00	161.00	178.00	187.00	196.00	205.00	230.00	241.00	254.00

RING BEAMS WITH LAGGING

GEOLOGY TYPE I

A. Ring Beams @ 4' c-c

TUNNEL O.D.

	15'	16'	17'=	18'	19'	20'	21'	22'	23'	24'
Size	W6x14	W6x14	W6x14	W6x14	W6x20	W6x20	W6x20	W6x20	W8x20	W8x20
$/Tunnel ft.	50.50	54.00	57.50	61.00	91.90	97.00	102.00	107.00	111.50	116.50

B. Lagging

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
BF/LF	264	283	302	320	339	358	377	396	557	582
$/LF	58.08	62.26	66.44	70.40	74.58	78.76	82.94	117.04	122.54	128.04

Laggin @ $.022/BF

RING BEAMS WITH LAGGING

GEOLOGY TYPE II

A. Ring Beams @ 4' c-c

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
Size	W6x14	W6x14	W6x14	W6x20	W6x20	W6x20	W8x20	W8x20	W8x20	W8x20
$/Tunnel ft.	50.50	54.00	57.50	87.00	91.90	96.50	101.40	106.30	111.50	116.50

B. Lagging

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
BF/LF	264	283	302	320	339	358	507	532	557	582
$/LF	58.08	62.26	66.44	70.40	74.58	78.76	111.54	117.04	122.54	128.04

RING BEAMS WITH LAGGING

GEOLOGY TYPE III

A. Ring Beams @ 4' c-c

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
Size	W6x14	W6x14	W6x20	W6x20	W6x20	W8x20	W8x20	W8x20	W8x24	W8x24
$/Tunnel ft.	50.50	54.00	82.50	87.00	91.90	96.50	101.40	106.30	113.00	118.90

B. Lagging

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
BF/LF	264	283	302	320	339	482	507	532	557	582
$/LF	58.08	62.26	66.44	70.40	74.58	106.04	111.54	117.04	122.54	128.04

RING BEAMS WITH LAGGING

GEOLOGY TYPE IV

A. Ring Beams @ 4' c-c

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
Size	W6x14	W6x14	W6x20	W6x20	W8x20	W8x20	W8x20	W8x24	W8x24	W8x24
$/Tunnel ft.	50.50	54.00	82.50	87.00	91.90	96.50	101.40	109.00	113.00	118.90

B. Lagging

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
BF/LF	264	283	302	320	456	482	507	532	557	582
$/LF	58.08	62.26	66.44	70.40	100.32	106.04	111.54	117.04	122.54	128.04

RING BEAMS WITH LAGGING

GEOLOGY TYPE V

A. Ring Beams @ 4'c-c

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
Size	W6x20	W6x20	W8x20	W8x20	W8x20	W8x24	W8x24	W8x24	W8x30	W8x30
$/Tunnel ft.	72.00	77.00	81.50	86.00	91.90	98.50	103.00	109.00	121.00	133.00

B. Lagging

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
BF/LF	264	283	406	431	456	482	507	532	557	582
$/LF	58.08	62.26	89.32	94.82	100.32	106.04	111.54	117.04	122.54	128.04

SEGMENTED STRUCTURAL STEEL LINER

GEOLOGY TYPE I

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
$/tunnel ft	1190	1220	1250	1300	1335	1370	1405	1500	1545	1590

SEGMENTED STRUCTURAL STEEL LINER

GEOLOGY TYPE II

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
$/tunnel ft	1190	1220	1260	1310	1335	1370	1420	1530	1570	1610

SEGMENTED STRUCTURAL STEEL LINER

GEOLOGY TYPE III

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
$/tunnel ft	1190	1230	1270	1310	1345	1380	1440	1550	1600	1650

SEGMENTED STRUCTURAL STEEL LINER

GEOLOGY TYPE IV

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
$/tunnel ft	1190	1230	1270	1310	1365	1410	1455	1570	1660	1740

SEGMENTED STRUCTURAL STEEL LINER

GEOLOGY TYPE V

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
$/tunnel ft	1190	1230	1270	1340	1385	1430	1475	1570	1660	1740

PRECAST SEGMENTED CONCRETE LINER

GEOLOGY TYPE I

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
$/tunnel ft	550	565	580	595	610	625	640	655	670	685

PRECAST SEGMENTED CONCRETE LINER

GEOLOGY TYPE II

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
$/tunnel ft	550	565	580	595	610	625	640	655	670	685

PRECAST SEGMENTED CONCRETE LINER

GEOLOGY TYPE III

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
$/tunnel ft	550	565	585	600	620	635	655	675	690	710

PRECAST SEGMENTED CONCRETE LINER

GEOLOGY TYPE IV

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
$/tunnel ft	550	570	590	615	635	655	675	700	720	740

PRECAST SEGMENTED CONCRETE LINER

GEOLOGY TYPE V

TUNNEL O.D.

	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'
$/tunnel ft	550	570	595	620	640	665	690	710	735	760

D.4 - OTHER PRICES (SECONDARY COST ITEMS)

DATA BANK

UNDERPINNING

Class I	(Light)	$20/SF
Class II	(Medium)	$50/SF
Class III	(Heavy)	$100/SF

DATA BANK

DEWATERING COST

I. External dewatering costs (Wellpoints, deepwells, etc.) Per L.F. of tunnel under given ground water and geology conditions are given in the table below.

	GROUNDWATER		
	Class I	Class II	Class III
	$/LF	$/LF	$/LF
Class I	0	0	0
Class II	0	10	50
Class III	0	50	150
Class IV	0	200	350
Class V (Use appropriate costs for over-lying strata)			

II. Internal Dewatering

A. Cost of initial set-up (Y) = $1,500.00

B. Cost per day for operation (Z) = $20/day

GROUTING COSTS

GROUT = $20/C.F.

DATA BANK

CLEARING AND GRUBBING COSTS	
1. Class I - Light-(grass, topsoil, no trees) -	$1,500/Acre
2. Class II - Ave.-30 - 50% Tree removal, some minor structures	$3,000/Acre
3. Class III - Heavy -Foliage, trees, structures	$6,000/Acre
PAVEMENT REMOVAL	$8,000/Acre
GRADING AND VEGATATION OF RESTORED AREA	
1. Class I - Light - Topsoiling/seeding only	$1,500/Acre
2. Class II - Ave. - Seeding, some sodding, and scrubs	$3,000/Acre
3. Class III - Heavy - Landscaping and planting scrubs and trees	$6,000/Acre
PAVING	$50,000/Acre
FENCING	$8.00/L.F.
VENTILATION STRUCTURE PRICES	
1. Cost of set-up, surface and cross-over structures	$(Y)/Shaft= $400,000
2. Cost of shaft per vertical ft (VF)	$(Z)/VF = $800
MECHANICAL AND DRAINAGE PRICES	
1. Drainage	
a. Fixed installation costs (Y)	$80,000/shaft
b. Installation costs in shaft (Z)	$50/VF /shaft
c. Installation costs in tunnel (X)	$20/LF Tunnel
2. Ventilation Mechanical Costs (V)	$200,000/shaft

APPENDIX E. COST FACTORS

E.1 INFLUENCE FACTORS

A. Escalation Factors - Base 1976

YEAR	LABOR	MTLS.	EQUIP.
1977 & Future	(+) 6.5%/yr	(+) 6.0%/yr	+ 7.2%/yr
1976 (Base)	0	0	0
1975 (-1)	(-) 7.3	(-) 9.3	(-) 9.4
1974 (-2)	(-)16.0	(-)29.3	(-)15.2
1973 (-3)	(-)18.8	(-)33.8	(-)21.7
1972 (-4)	(-)25.0	(-)34.8	(-)28.4
1971 (-5)	(-)34.0	(-)36.8	(-)39.9
1970 (-6)	(-)41.9	(-)41.0	(-)41.5
1969 (-7)	(-)47.8	(-)43.6	(-)41.1
1968 (-8)	(-)51.7	(-)46.4	(-)48.2
1967 (-9)	(-)55.1	(-)48.9	(-)49.4
1966 (-10)	(-)57.6	(-)51.4	(-)50.1

NOTE: Prices for items in data bank which are not broken down by labor, equipment and materials (secondary items or those listed as "other") are assumed to involve 40% labor, 40% equipment and 20% materials - escalation should be prorated accordingly.

B. Regional Factors

Direct costs are increased (+) or decreased (-) for regional factors according to the following chart. (Data Base = 0 for Washington, D.C.

	LABOR	EQUIP.	MTLS.	OTHER
Washington, D.C.	0	0	0	0
New York	(+)97%	(+)17%	(+)5%	(+)44%
Chicago	(-)13%	(+)2%	(+)1.4%	(-)4%
Los Angeles	(+)23.8%	(-)5.9%	(-)4.7%	(+)6.5%

E.2 INDIRECT COST FACTORS (MARK-UP)

BASIC INDIRECT & O.H. COSTS
(Before Institutional Factors)

Direct Cost	O.H.	Profit	Total
0 to 1,000,000	15%	8%	23%
Next 9,000,000	10%	5%	15%
Next 10,000,000	8%	3%	11%
Remainder	7%	3%	10%

E.3 INSTITUTIONAL FACTORS

A. Bidding Climate

No. of Bidders	% Added to Technical Estimate
1	48%
2	27%
3	20%
4-5	13%
6-7	6%
8 or more	0%

B. Financing (included in indirect cost factor for present).

C. Productivity (included in regional factor for present).

E-4. NON-CONSTRUCTION COSTS

	Percent of Construction Cost
A. Geologic Investigation	1%
B. Engineering Design	0.5%
C. Construction Management	3.9%
D. Insurance	6%
E. Slippage	6%
F. Change Orders	
For first two contracts of each type	10%
Subsequent Contracts	5%

Percent of
Construction Cost
(con't)

G. Project Management - 4% of project cost, including construction costs and items 1-6 above.

Omitted for this study:

Right-of-Way Costs
Litigation Costs
Environmental and Community Interface Costs

APPENDIX F. EXAMPLES

F.1 PROJECTED COST OF TUNNEL CONSTRUCTION

INPUT DATA SHEET

PROJECT: W MATA F2A

RUN NO: 1 DATE: 2/14/77

1. Location: (1) Washington, D.C.
   (2) New York City
   (3) Chicago
   (4) Los Angeles 1

2. Projected Start: Select number 0 through 10, corresponding to calendar year in which project is projected to start, subsequent to base date of January 1, 1976. Example: Number (2) would correspond to a start within the calendar year January 1, 1978 to December 31, 1978. (Negative numbers indicate past projects.) .... -2

3. Length: Enter total length of tunnel in linear feet (l.f.). If twin tubes, enter sum of both tubes. .... 8820 l.f.

4. Shape: (1) Circular
   (2) Horseshoe 1

5. A. Diameter: Enter driven diameter (o.d.) in feet .... 18 ft.
   B. Diameter: (1) 15' to 19' (2) 19' to 24' .... ft.

6. Number of Shafts: 3

7. Air: (1) Free or (2) Compressed 1

8. Number of tubes: (1) Single or (2) Twin 2

9.

Reach No.	Geology Type	Length	Ave. Depth	Class of Groundwater
1	3	800	80	2
2	4	2000	80	3
3	3	6020	80	2

INPUT DATA SHEET

10. Excavation and Temporary Support:
    - A. Method of Excavation:
        1. Shield/Hand excavation — 2
        2. Shield/Digger arm
        3. Shield/Wheel excavator — 3
    - B. Temporary Support:
        1. Ring beams/Liner
        2. Ring beams/Lagging
        3. Structural steel liner
        4. Precast segments — 3
    - C. Method of Mucking:
        1. Rubber tire to shaft hoist
        2. Rubber tire to portal
        3. Rail to shaft hoist
        4. Rail to portal
    - D. Number shifts/day excavating: — 2
11. Permanent lining; Cast-in-place, reinforced concrete:
    - A. Method of Placing:
        1. Invert and Arch
        2. "Full Round"
        3. Invert only — 3
    - B. Pour Restraints:
        1. Bulkhead (50'-100')
        2. Continous placement — 2
    - C. Method of Transport
        1. Rubber tire from portal
        2. Rubber tire from dropline
        3. Rail from portal
        4. Rail from dropline
        5. Conveyor
        6. Pump — 4

INPUT DATA SHEET

D. Number shifts/Day Concreting Operations: 3

E. Number shifts/Day Placing Concrete: 2

12. Site Preparation:

A. Pavement removal: Approx. amount of work area paved as a percent of total work area. (To nearest 10%) 10

B. Clearing:

1. Class I
2. Class II
3. Class III 1

13. Restoration:

A. Grading and Vegetation of Restored Area:

1. Class I
2. Class II
3. Class III 1

B. Paving: Approximate amount of work area to be paved, expressed as a percent of total work area (To nearest 10%). 10

14. Ventilation:

A. Method:

1. Conventional
2. Other 1

15. Underpinning: Enter area (s.f.) of buildings or portion of buildings within the 45° influence line which falls within each of the following classifications:

A. Class I - Light — s.f.

B. Class II - Medium — s.f.

C. Class III - Heavy 8000 s.f.

16. Anticipated Number of Bidders: 5

F.2 OUTPUT DATA FORM

PROJECTED COST OF TUNNEL CONSTRUCTION

PROJECT NAME: WMATA - SECTION F2A

DATE: 2/14/77

RUN NUMBER: 1

TOTAL PROJECT COST SUMMARY

TOTAL CONSTRUCTION COSTS	
Page F-5, Line 14	$ 31,017,223
TOTAL NON-CONSTRUCTION COSTS	$ 8,466,460
TOTAL ESTIMATED PROJECT COST	$ 39,483,683

CONSTRUCTION COST SUMMARY

ITEM	QUANTITY a.	ADJUSTED TOTAL COST b.
1. Excavation	8820 LF	17,058,951
2. Final Lining	8820 LF	989,318
3. Site Preparation	LS	40,352
4. Underpinning	LS	731,680
5. Dewatering	LS	961,409
6. Grouting	8820 LF	2,281,827
7. Ventilation	LS	1,273,123
8. Mechanical & Drainage	LS	940,574
9. Restoration	LS	58,102
10.. TOTAL DIRECT COST		24,335,336
11. INDIRECT COST		3,113,534
12. TOTAL COST (GROSS)		27,448,870
13. INSTITUTIONAL FACTOR		3,568,353
14. NET CONSTR. COST *		

*Enter Net Construction Cost on pages F-4 and F-16

1. TUNNEL EXCAVATION

A. <u>CLASS CODE</u>

The Class Code for tunnel excavation is a six digit reference number based on the input conditions, which is used to identify and select the appropriate cost data stored in the Data Banks.

To determine the Class Code, enter the appropriate single digit number from the Input Data Sheet in each of the 6 boxes, A-F below.

A	B	C	D	E	F
1	1	1	2	3	3

Box A----Input Data Sheet, Line 7
Box B----Input Data Sheet, Line 5.B.
Box C----Input Data Sheet, Line 4
Box D----Input Data Sheet, Line 10.A.
Box E----Input Data Sheet, Line 10.B.
Box F----Input Data Sheet, Line 10.C.

a. Reach No.	b. Length	c. Geology	d. Shifts Per Day	e. Advance Rate Per Day	f. Duration Days
1	800	3	2	26	31
2	2000	4	2	18	112
3	6020	3	2	26	232
TOTAL					375

1. C TUNNEL EXCAVATION COST SUMMARY

CLASS CODE: 111233

	Unit Cost	Quantity	Labor	Equipment	Materials	Other	TOTAL
1. HEADING CREW	1828	375 Days	685,500				685,500
2. U.G. SUPPORT CREW	3145	375 Days	1,179,375				1,179,375
3. SURFACE SUPPORT CREW	2607	375 Days	977,625				977,625
4. U.G. EQUIPMENT	3346	375 Days		1,254,750			1,254,750
5. SURFACE EQUIPMENT	1901	375 Days		712,875			712,875
6. SET-UP COSTS	295,000	LS				295,000	295,000
7. MUCK HAULING(OFFSITE)	48.63	8820T.F.				428,933	428,933
8. FANLINE	133,500	L.S.			133,500		133,500
9. DISCHARGE LINE	71,200	L.S.			71,200		71,200
10. AIRLINE	44,500	L.S.			44,500		44,500
11. RAIL	9.60	8820 T.F.			84,672		84,672
12. NUTS, BOLTS, SPIKES	4.00	8820.T.F.			35,280		35,280
13. SWITCHES	10,500	L.S.			10,500		10,500
14. R.R. TIES	10,587	L.S.			10,587		10,587
15. TEMP. ELEC.	362,400	L.S.			362,400		362,400
16. MISC. TUNNEL SUPPLIES	88,200	L.S.			88,200		88,200
17. STR STEEL LINER	1310	8820 T.F.			11,554,200		11,554,200
18. SAFETY EQUIP.	(LABOR COST)	8%			142,125		142,125
19. SMALL TOOLS	(LABOR Cost)	5%			227,400		227,400
20.							
21.							
22.							
23.							
24.							
25.							
26.							
27. PAYROLL TAX & INS.	(TOT.LAB.)	9.2%	261,510				261,181
28. MISC. OVERTIME	(TOT.LAB.)	6%	170,550				170,335
29. SUBTOTAL -Base Cost			3,274,560	1,967,625	12,765,564	723,933	18,731,682
30. Regional Factors			0	0	0	0	0
31. Escalation Factors			-(239,043)	-(184,957)	-(1,187,197)	-(61,534)	1,672,731
32. TOTAL DIRECT COST*			3,035,517	1,782,668	11,578,367	662,399	17,058,951

*Enter this total adjusted cost on page F-5, Line (1)

2. CONCRETE

A. <u>CLASS CODE</u>

The Class Code for final tunnel lining is a three digit number based on the input conditions, which is used to identify and select the appropriate cost data stored in the Data Banks.

To Determine the Class Code, enter the appropriate single digit number from the Input Data Sheet in each of the 3 boxes A-C below.

A	B	C
3	2	4

Box A----Input Data Sheet, Line 11A
Box B----Input Data Sheet, Line 11B
Box C----Input Data Sheet, Line 11C

		a. Length	b. Advance Rate/Day	c. Shifts Per Day	d. Duration Days
Invert		8820	250	3	36
Arch					
TOTAL					36

2.C TUNNEL CONCRETE COST SUMMARY

CLASS CODE: 3.2.4. . .

	Unit Cost	Quantity	Labor	Equipment	Materials	Other	TOTAL
1. U.G. INVERT CREW	7237	36 Days	260,532				260,532
2. SURFACE INVERT CREW	2718	36 Days	97,848				97,848
3. U.G. ARCH CREW	—	— Days	—				—
4. SURFACE ARCH CREW	—	— Days	—				—
5. U.G. INVERT EQUIPMENT	2191	36 Days		78,876			78,876
6. SURFACE INVERT EQUIP.	1507	36 Days		54,252			54,252
7. U.G. ARCH EQUIPMENT	—	— Days		—			—
8. SURFACE ARCH EQUIPMENT	—	— Days		—			—
9. SET-UP COSTS		LS				30,000	30,000
10. CONCRETE	21.60	8820 T.F.			190,498		190,498
11. REINFORCING STEEL	17.28	8820 T.F.			152,398		152,398
12. OVERRUN CONC.	2.16	8820 T.F.			19,050		19,050
13. INVERT CURING	1.00	8820 T.F.			8820		8,820
14. MISC. SUPPLIES	10.00	8820 T.F.			88,200		88,200
15. SMALL TOOLS	(LABOR COST)	8%			28,670		28,670
16. SAFETY EQUIP.	(LABOR COST)	5%			17,919		17,919
17.							
18.							
19.							
20.							
21.							
22.							
23.							
24.							
25.							
26.							
27. PAYROLL TAX & INS	(TOT.LAB.)	9.2 %	32,971				32,971
28. MISC. OVERTIME	(TOT.LAB.)	6 %	21,503				21,503
29. SUBTOTAL - Base Cost			412,854	133,128	505,555	30,000	1,081,537
30. Regional Factors			0	0	0	0	0
31. Escalation Factors			-(30,138)	-(12,514)	-(47,017)	-(2,550)	-(92,219)
32. TOTAL ADJUSTED COST *			382,716	120,614	458,538	27,450	989,318

*Enter this total adjusted cost on Page F-5, Line (2)

ITEM COSTS

3. SITE PREPARATION

	Quantity	Unit Cost	Total Cost
Clearing	10 Ac.	$ 1500	$ 15,000
Pavement Removal	1 Ac.	8,000	8,000
Fencing	2640 LF	8.00 L.F.	21,120
TOTAL BASE COST			44,120
INFLUENCE FACTORS 1. Regional			0
2. Escalation			-(3767)
TOTAL ADJUSTED COST *			40,352 *

* Enter Adjusted Total Cost on Page 2, Line 3.

4. UNDERPINNING

	Quantity	Unit Cost	Total Cost
Class I	– SF	$	$
Class II	– SF		
Class III	8000 SF	$100/SF	800,000
TOTAL BASE COST			800,000
INFLUENCE FACTORS 1. Regional			0
2. Escalation			-(68,320)
TOTAL ADJUSTED COST *			731,680 *

* Enter Adjusted Total Cost on Page F-5, Line 4

ITEM COSTS

5. DEWATERING

	Quantity	Unit Cost	Total Cost
External	6820 2000 lf	50.00/LF 350.00/LF	341,000 700,000
Internal	411 days	20/DAY +1500	9720
TOTAL BASE COST			1,050,720
1. Regional			0
2. Escalation			-(89,311)
TOTAL ADJUSTED COST *			961,409*

* Enter Adjusted Total Cost on Page F-5, Line 5

6. GROUTING

	Quantity	Unit Cost	Total Cost
Contact Grouting (C_C)	0 CF		
Backfill Grouting(C_{BF})	124,690 CF	20.00/CF	2,493,800
Pregrouting (C_P)	0 CF		
TOTAL BASE COST			2,493,800
Regional Adj.			0
Escalation Adj.			-(211,973)
TOTAL ADJUSTED COST *			2,281,827 *

* Enter Adjusted Total Cost on Page F-5, Line 6

7. VENTILATION

	Quantity	Unit Cost	Total Cost
Fan Shafts	LS		1,392,000
TOTAL BASE COST			1,392,000
Regional Adj.			0
Escalation Adj.			-(118,876)
TOTAL ADJUSTED COST*			1,273,123*

* Enter Adjusted Total Cost on Page F-5, Line 7

8. MECHANICAL AND DRAINAGE

	Quantity	Unit Cost	Total Cost
Permanent Drainage	LS	-	428,400
Ventilation Mechanical	3 Shafts	200,000	600,000
TOTAL BASE COST			1,028,400
Regional Adj.			0
Escalation Adj.			-(87,825)
TOTAL ADJUSTED COST *			940,574*

* Enter Adjusted Total Cost on Page F-5, Line 8

9. RESTORATION

	Quantity	Unit Cost	Total Cost
Landscaping	9 Acre	1500	13,500
Paving	1 Acre	50,000	50,000
TOTAL BASE COST			63,5000
Regional Adj.			0
Escalation Adj.			-(5,398)
TOTAL ADJUSTED COST *			58,102 *

* Enter Adjusted Total Cost on Page F-5, Line 9

10. NON-CONSTRUCTION COSTS

A. Total Construction Cost p. F-5, Line 14.

$ 31,017,223

B. Refer to Appendix E.4

1. Geologic Investigation

$ 31,017,223 X 1 % = 310,172

2. Engineering Design

$ 31,017,223 X 0.5 % = 155,086

3. Construction Management

$ 31,017,223 X 3.9 % = 1,209,672

4. Insurance

$ 31,017,223 X 6 % = 1,861,033

5. Slippage

$ 31,017,223 X 6 % = 1,861,033

6. Change Orders

$ 31,017,223 X 5 % = 1,550,861

7.	SUBTOTAL	6,947,857
8.	PLUS CONSTRUCTION COST	31,017,223
9.	SUBTOTAL	37,965,080
10.	PROJECT MANAGEMENT AT 4 % =	1,518,603
11.	TOTAL NON-CONSTRUCTION COST =	8,466,460
	(Line 7 plus Line 10)	

APPENDIX G. REPORT OF NEW TECHNOLOGY

A major result has been the development of a model and computer program for calculating tunnel costs for line sections in soil. The model uses units of effort for various tasks which together with unit prices for labor, materials, and equipment may be used to calculate costs.

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