ECONOMIC RISK QUANTIFICATION OF TOLL HIGHWAY PROJECTS

BY

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Abstract

The objectives of this thesis are to model economic and financial performance of user-pay highway facilities, to explore the sensitivity of project performance to changes in primary variables, to measure the uncertainty surrounding user-pay highway facilities, and to explore ways of reducing the uncertainty. Special attention is given to the revenue phase.

The model consists of three levels: work package/revenue stream level; project performance level; and project decision level. The model calculates work package duration, work package cost, and revenue stream for the work package/revenue stream level; project duration, project cost, and project revenue for the project performance level; and project's net present value (NPV) for the project decision level. They are described by their expected value, standard deviation, skewness, and kurtosis.

This model is applied to a numerical example patterned after a Japanese project to carry out a sensitivity and risk analysis, and highly sensitive primary variables are

identified. The case study may be viewed as a comparison of current Japanese deterministic feasibility analysis with a probabilistic one, using the same underlying project model. Risk management strategies are presented, and their impacts on overall project risks are measured.
Results from applying the model to a sample project show that it is very difficult for a highway operator alone to reduce risks. It is suggested that it is very important that risk sharing be negotiated with the government and some guarantee of support be received.

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Chapter 1

Introduction

1.1 General

This thesis describes an application of an analytical method for time and economic risk quantification for large toll highway projects. The methodology facilitates the investigation of the sensitivity of project performance to changes in primary variables for a toll highway project. The goal of this thesis is to model the economic and financial performance of user-pay highway facilities, to measure the uncertainty surrounding such projects, and to explore ways of reducing the uncertainty.

This chapter presents the background of the research, including the toll highway concept and the analytical method for quantification of economic risks, the objectives of the research, and the structure of the thesis.

1.2 Background of the Research

1.2.1 Toll Highway Concept

The concept of toll highway is not new at all. Many economists and researchers (Atkins, Eade, and Fisher, 1972; Beesley and Hensher, 1990; Geltner and Moavenzadeh, 1987; Gittings, 1987; Johansen, 1987; Robertson, 1987; Rusch, 1984; Schneider, 1985; Wuestefeld, 1988; et al) have discussed the toll highway concept for a long time. Many toll highways have been built in a variety of countries, particularly in Italy, France, Spain, and Japan. On the other hand, the former West Germany developed its national highway system without the use of toll financing. It is recognized that toll financing can be an effective method for developing and improving urgently needed highway systems within limited national budgets, although such an approach has unavoidable disadvantages. In addition to using the toll system for the construction of new highways, several countries are also considering toll financing in order to provide funds for the improvement and rehabilitation of existing free highway networks.

The primary objectives of toll financing are described as follows by Rusch(1984):

- to obtain funds for urgently needed projects;
- to shift the burden of capital, operating, and maintenance costs to specific users; and

- to provide an immediate and direct source of revenue to discharge the obligations created.

Potential advantages and disadvantages have been also described by Atkins, Eade, and Fisher(1972); Beesley and Hensher(1990); Geltner and Moavenzadeh (1987); Gittings(1987); Johansen(1987); Robertson(1987); Rusch(1984); Schneider(1985); Wuestefeld (1988) et al as follows.

Advantages include:

- a more precise form of pay-as-you-go financing;
- rapid construction;
- fewer inflationary effects on capital cost;
- better quality maintenance;
- an ability to use toll rates as a form of congestion pricing; and
- a better safety record.

Disadvantages include:

- extra financing costs;
- extra costs of toll collection;
- extra costs for toll collection facilities;
- the payment of a fuel tax while traveling on a toll facility;
- time delays, increased fuel consumption, and worse air quality when motorists are stopped;
- putting more traffic back onto underpriced roads;
- creating an undesirable private monopoly of management; and

- less frequent access.

According to the analysis conducted by the Congressional Budget Office (Gittings, 1987), the benefits of toll-financing may exceed the additional costs if a needed highway facility can be built 4 or more years sooner than would be possible under conventional tax financing. However, if toll financing produces a facility only 2 or fewer years sooner, the use of toll financing is probably not worth the additional costs.

Toll collection systems are generally classified into three basic categories (Gittings, 1987).

(1) Closed (ticket) system

This system limits access to toll-paying motorists. Tollbooths are located at each point of entry and exit. Examples are the New Jersey, Ohio, and Pennsylvania turnpikes.

(2) Open (main-line barrier) systems

This system allows local, short distance traffic to use the facility without paying tolls. Barriers are located intermittently along the main line of the road, and no tollbooth is located on the interchange ramps. All traffic must stop at the barriers to pay the toll. However, local traffic may avoid paying tolls if there is no barrier between entry and exit. Examples are the Connecticut Turnpike and the Bee Line Expressway in Florida.

(3) Hybrid (barrier-ramp) system

This system is a hybrid of the above two systems. There is a closed and an open system. In the closed system, toll barriers are located at intervals along the main line and on most interchange ramps. Every motorist has to pay the toll. An example is the Illinois Tollway. The open system, on the other hand, allows some toll free traffic. Toll barriers are located at the main lines and on selected high-revenue interchange ramps. An example is the Garden State Parkway in New Jersey.

Gittings (1987) mentioned that significant cost savings are dependent on the design of the toll collection system - e.g. type of toll collection system, the number of collection points, the location of collection points - and the degree of automation in the system, and also that toll collection design decisions depend on cost, user access, traffic route choice, toll revenue, safety, and highway financing equity.

There are usually two levels of feasibility studies required: preliminary engineering studies, and more detailed and definitive engineering studies (Rusch, 1984). In preliminary engineering studies, aspects examined include consideration of location, alignment, toll rate, traffic projections, and estimates of construction, operation, maintenance, and financing costs. If preliminary studies indicate project feasibility, more detailed and definitive engineering studies are required in order to produce reliable cost and revenue estimates.

Benefit-cost analysis for highway projects, which includes social benefits and impacts, has been discussed and reported on by many researchers (Andersson, 1985; Campbell and Humphrey, 1988; Christofferson, 1980; Davis and et al, 1953; Sharp, Button, and Deadman, 1986; Waters and Meyers, 1987; Weisbrod and Beckwith, 1992). Atkins, Eade, and Fisher(1972) introduced a computer based model for analysing the financial feasibility of toll roads. However, there seem to be very few academic studies which focus on toll highway projects and the measurement of economic risk.

1.2.2 Analytical Method for Quantification of Economic Risks

This research is based on the Analytical Method for Quantification of Economic Risks, which was developed by Ranasinghe (1990). A brief outline is given below.

By way of background, several probabilistic estimate methods for project decision and performance variables have been developed. They are: Probabilistic Time Methods, Probabilistic Cost Methods, Probabilistic Time/Cost Methods, and Probabilistic Present Value Methods. However, among them, only Probabilistic Present Value Methods, which evaluate a project's net present value (NPV) and internal rate of return (IRR), are suitable for economic

feasibility studies because they employ criteria necessary to the proper evaluation of a project. The Analytical Method for Quantification of Economic Risks belongs in this category.
An engineering project can be described in terms of a hierarchy which consists of three levels, namely, project decision, project performance, and work package/revenue stream.

The project decision level is the highest level, and the individual work package/revenue stream level is the lowest level. At each level, derived variables are described by $Y=g(\underline{X})$, where Y is the derived variable and $\underline{X}$ is a vector of primary variables. Derived variables at the lower level are primary variables at the higher level. See Table 1.1 for the variable hierarchy described.

Level	Primary Variables	Derived Variables
Project Decision	Project Duration Project Cost Project Revenue	NPV IRR
Project Performance	W.P Duration W.P Cost Net Revenue Stream	Project Duration Project Cost Project Revenue
W.P/Revenue Stream	input data	W.P Duration W.P Cost Net Revenue Stream

Table 1.1 Derived Variables at Each Level

The framework for quantifying the uncertainty of a derived variable is based on four assumptions:

(1) The derived and the primary variables are continuous and their probability distributions are approximated by the Pearson family of distributions;

(2) An expert can provide estimates for the percentiles of his subjective prior probability distribution for a primary variable at the input level;

(3) A derived variable can be more accurately estimated from a set of primary variables that are functionally related to it than by direct estimation; and

(4) The correlations between primary variables are linear.

See Ranasinghe (1990) for justification of these assumption. Figure 1.1 shows the flowchart for the analytical approach.

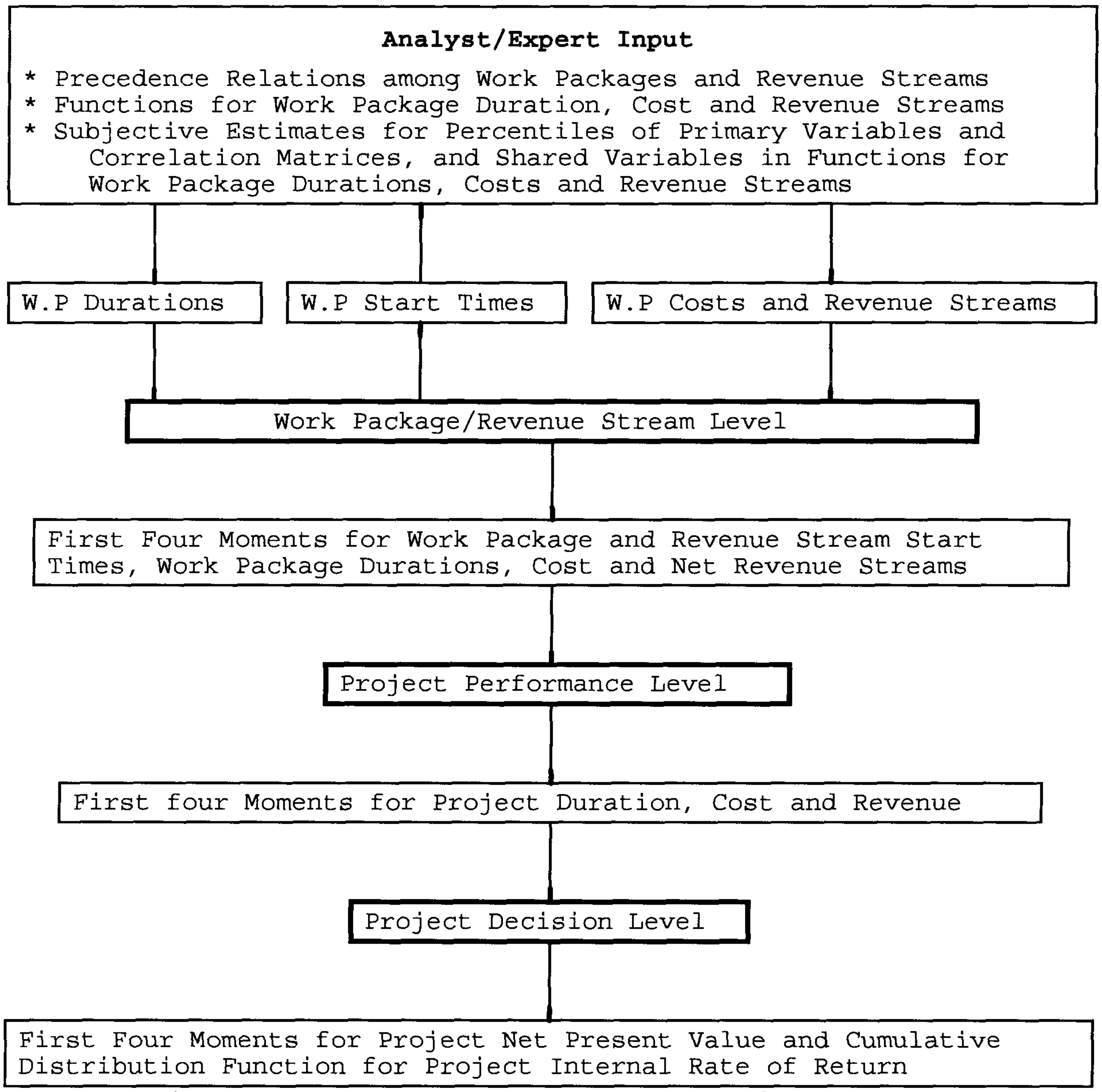

Figure 1.1 Flowchart for the Analytical Approach
(Ranasinghe, 1990)

1.3 Objectives of the Research

The primary objectives of this research are:

1. to model economic and financial performance of user-pay highway facilities, with special emphasis on modeling revenues and costs during the operating phase;
2. to explore the sensitivity of project performance to change in primary variables (input data). Sensitivity analysis for the revenue phase(traffic volume and toll rate) are emphasized;
3. to measure the uncertainty surrounding user-pay highway facilities; and
4. to explore ways of reducing the uncertainty.

The case study presented in chapter 4 is a comparison of current Japanese (Japan Highway Public Corporation) deterministic feasibility analysis with a probabilistic one, using essentially the same underlying project model.
To achieve the objectives of the thesis, extensive work had to be done on the original main frame program developed by Ranasinghe (1990) called TIERA which was converted to a PC based program called AMMA. This program was extensively revised as part of this thesis. It is listed in Appendix D.

Large toll highway projects consume large quantities of time, cost, and resources. The economic failure of a large toll highway project would undoubtedly cause serious damage to both the owner/operator of the highway and to the society in which it has been built. Therefore, it is critical that a detailed feasibility analysis be carried out in order to minimize potential risks. Feasibility analyses for toll highway projects require long-term forecasts of usage and unit rates because of long project durations, especially for the revenue phase. This means that such projects are executed in an environment of high uncertainty. Although many traffic forecast methods are now available (Bushell, 1970; Dalton and Harmelink, 1974; Davinroy, 1962; Duffus, Alfa, and Soliman, 1987; Huber, Boutwell, and Witheford, 1968; Kadiyali, 1983; Morellet, 1981; Neveu, 1982; Newell, 1980; Thomas, 1991; et al), it is difficult to accurately estimate future traffic, because traffic volume is dependent on an uncertain economic environment, changing road network conditions and many other factors. In these situations, risk quantification should be done carefully during feasibility analysis.

1.4 Structure of the Thesis

Chapter 2 develops an analytical model for toll highway projects, with particular emphasis on the revenue phase. The model consists of three levels, work package/revenue stream level (the lowest level), project performance level, and project decision level (the highest level). As they are functionally related, this model requires that primary variables for the work package/revenue stream level only are inputted. This model can be applied to the closed, open, and hybrid systems of toll collection.

Chapter 3 presents a numerical example patterned after a Japanese project. Results from a sensitivity and risk analysis are presented.

Chapter 4 examines strategies for risk management, and explores these impact on overall risks.
Conclusions and recommendations are presented in Chapter 5.

Appendix A contains the mathematical derivation of an equation for discounted work package costs.

Appendix B contains detailed input data required by the model.

Appendix C contains interchange pair traffic volumes and growth parameters for both traffic volumes and toll rates for the sample project.

Appendix D contains source code of the model.

Chapter 2

Analytical Model

2.1 General

This chapter presents an analytical model for the feasibility analysis of a toll highway project. The model is based on an analytical method for time and economic risk quantification developed by Ranasinghe (1990). Extensions are made in the form of generalized revenue and operating cost models which draw on the approach used by the Japan Highway Public Corporation.

Figure 2.1 shows the generalized cash flow diagram for a civil engineering project. However, a modified cash flow diagram, shown in Figure 2.2, is used for this model in order to make it more appropriate to a toll highway project. In this scenario, several basic assumptions have been made in order to simplify the model:

(1) Since a project financing approach where funds are advanced during the construction phase, and repaid during the operation phase is assumed, there is no distinction between interim and permanent financing;

(2) The repayment of financing is assumed to begin after the construction phase is completed, although the model is compatible with projects involving overlapping operation and construction phases as well;

(3) The repayment of financing is assumed to last until the end of the operation phase, but a shorter repayment period or a balloon payment at the end of the revenue phase could also be assumed; and

(4) The repayment profile is assumed to be uniform and to consist of principal and interest.

A more detailed explanation of each cash flow component is given in section 2.2.

Figure 2.3 shows a flow chart of the components of a general feasibility study for a toll highway project used in Japan (Japan Highway Public Corporation, 1983). It is generally divided into seven basic steps as follows.

(1) Traffic Survey

Traffic surveys to elicit base traffic and travel speed for traffic forecasts are carried out. These surveys include a traffic volume survey, a motor vehicle origin-destination (OD) survey, and a travel speed survey.

(2) Traffic Forecast

Traffic forecasts are needed for the first year and years when relevant traffic conditions change - such as a new road opening or a big industrial area being completed. In these 'base years', traffic volume is often discontinuous because

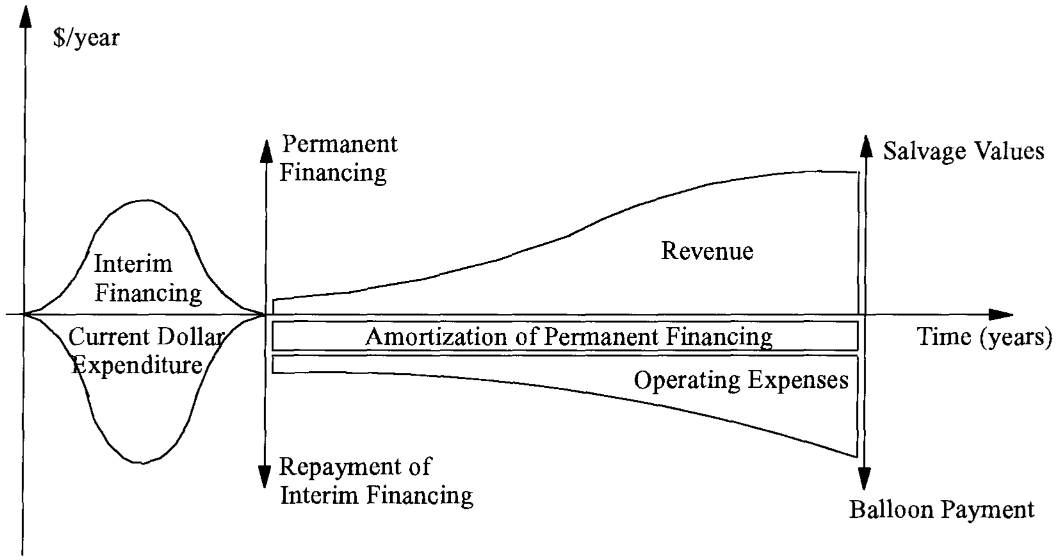

Figure 2.1 Generalized Cash Flow Diagram for an Engineering Project

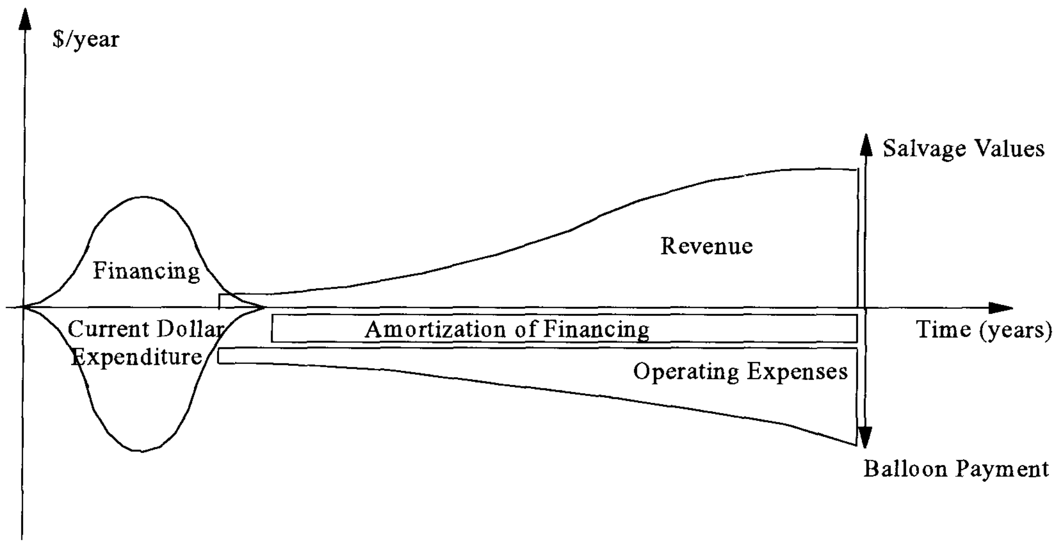

Figure 2.2 Cash Flow Diagram for a Toll Highway Project

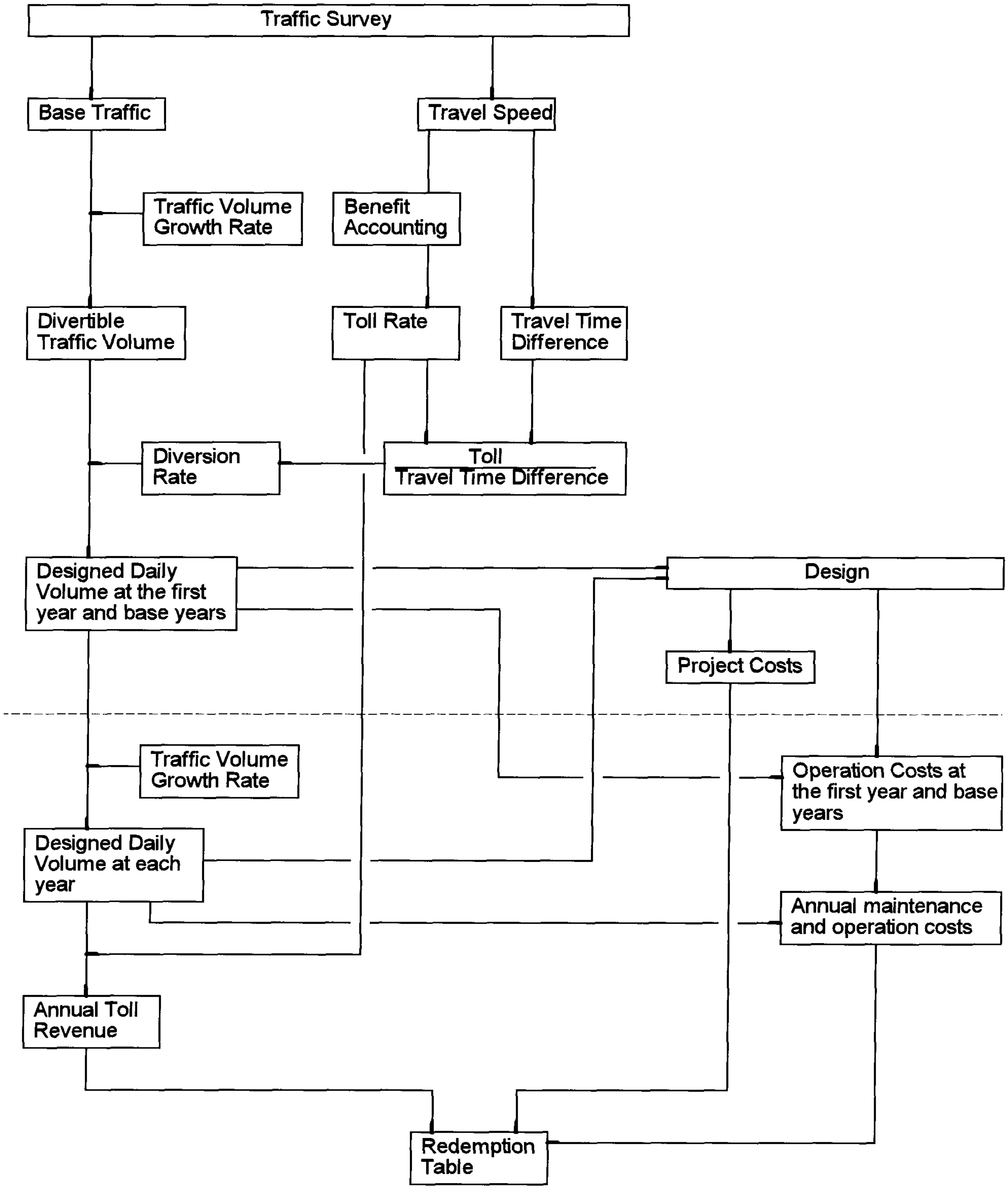

Figure 2.3 Feasibility Study Components for a Toll Highway Project

of discrete additions to capacity or changes in road conditions. See Figure 2.4.

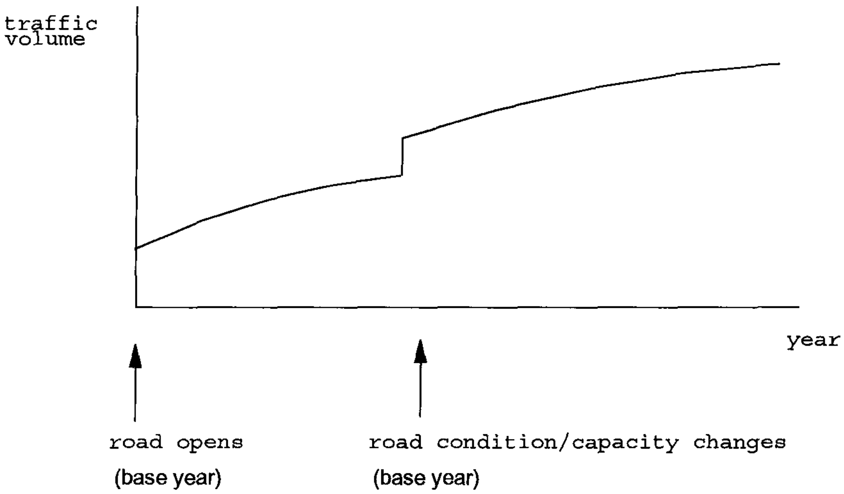

Figure 2.4 general pattern of traffic growth

Future traffic volume is calculated on the basis of toll rates, results of traffic surveys, road length, and the traffic volume growth parameters that are based on future projections of economic conditions, population, road development plans, other national development plans, and so on.

(3) Estimation of Annual Traffic Volume

Annual traffic volume is calculated on the basis of traffic forecasts for the base years. It is not practical to carry out a traffic forecast for every year because of the cost and time involved. Therefore, traffic volume in non-base years is interpolated by parameters.

For example, if traffic volume (Q_o) in a base year is derived from a traffic forecast, traffic volume (Q_i) at year i is:

$$Q_i = k_i / k_o \times Q_o \quad (2.1)$$

where k_o and k_i are parameters, based on economic forecasts, national development plans, and so on. These parameters for the analytical model are described in more detail in section 2.5.

(4) Design

Toll highway facilities are designed on the basis of the traffic volume forecasts, topographical and geological data, political and other factors. Then, construction costs are estimated. The design of toll highway facilities may be dependent not only on traffic volume during base years, but also on that of other years.

(5) Estimation of Annual Revenue

In its simplest form, toll revenue is calculated by multiplying traffic volume by toll rate.

$$\text{toll revenue} = (\text{traffic volume}) \times (\text{toll rate}) \quad (2.2)$$

Complexity arises when consideration has to be given to different vehicle types, volume between interchange points, changing rates versus time, and open versus closed systems.

(6) Estimation of Annual Maintenance and Operation Costs

Annual maintenance and operation costs are calculated on the basis of traffic volume, the toll collection system, the organizational structure adopted, weather conditions, and so on.

(7) Calculation of Project's Future Value (Redemption Table)

The future value of the project at the end of every fiscal year during the construction and revenue phase can be computed in order to measure the project's financial condition. If the projected value at the end of the revenue phase is positive, the project is feasible. This calculation is based on the above-mentioned construction costs, toll revenue, and maintenance and operation costs.

This paper focuses on the procedure followed after traffic forecasts for base years have been completed, and uses the project's net present value as a decision criterion.

The organizational structure required for the administration of a toll road is one important factor that affects project expenses in terms of overheads. The organizational structure assumed for this model is shown in Figure 2.5, and reflects the structure of the Japan Highway Public Corporation (Japan Highway Public Corporation, 1992). Headquarters is in charge of formulating basic plans and policies for execution, setting standards, financing, and auditing. A bureau is an executing body for performing the actual work, such as road construction, operation, etc. Construction Bureaus are mainly in charge of construction, and Operation Bureaus are mainly in charge of executing road operation and collecting tolls. Each Bureau controls several onsite offices: a survey office for performing survey and design of road construction; a construction office in charge of road construction work and negotiations for acquiring rights of way; an operation office in charge of collecting tolls, operating traffic, performing road maintenance work, and management of properties. In addition, a laboratory that performs technical surveys, tests and research and development required for the construction and operation of roads is assumed.

This structure is designed for organizations that operate several toll highway projects simultaneously, but can also be used for organizations that have only a single project.

Overheads are usually allocated to each project in proportion to its construction costs and toll revenue.

The remainder of this chapter is structured as follows: section 2.2 describes the cash flows that this model assumes, section 2.3 presents the structure of the model, section 2.4 describes work packages, section 2.5 describes revenue streams, and section 2.6 describes maintenance and operation costs.

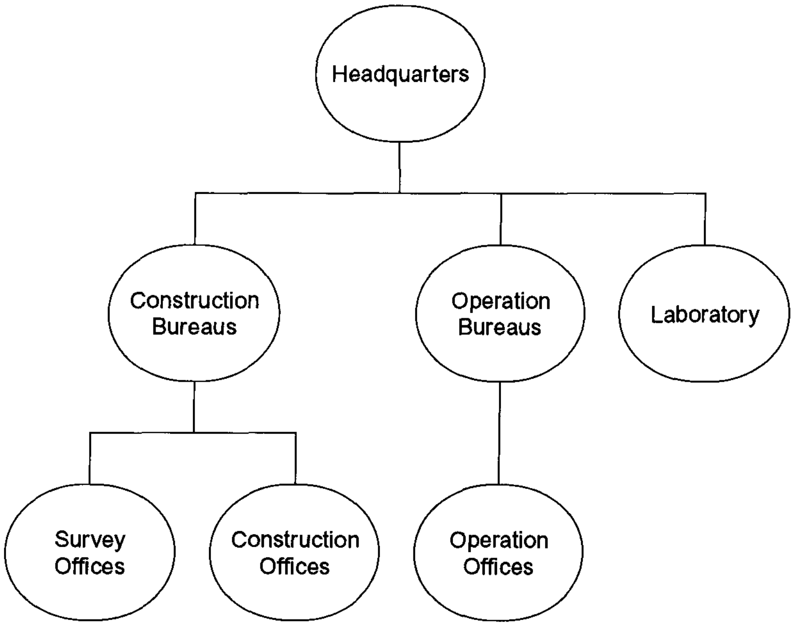

Figure 2.5 Organizational Structure

2.2 Cash Flows

It is assumed that all cash flows are continuous, and the inflation rate, interest rate, and discount rate are invariant with time. The model consists of seven categories of cash flows.

(1) Current Dollar Expenditure

This cash flow category consists of work package costs which include survey and design costs, land acquisition costs, and construction costs.

(2) Financing

In this model, an equity fraction f, which is invariant with time, is assumed. Financing is described as follows:

$$\text{Financing} = (1-f) \times \text{current dollar expenditure of each work package.} \tag{2.3}$$

(3) Revenue

Revenue usually consists of toll revenue and others such as rent from the toll highway's associated facilities, interest, and other miscellaneous revenues. However, this thesis considers toll revenue only. Toll revenues are calculated by using annual traffic volumes and toll rates.

(4) Amortization of Financing

It is assumed that repayment of financing begins after the construction phase is completed, and continues for the remaining operation period (recall that the operation phase could start before the end of construction).

(5) Operating Expenses

Operating expenses consist primarily of two types, maintenance costs and operation costs.

(6) Salvage Values

After the revenue phase expires, toll highway facilities are usually transferred to the government, federal, provincial, or municipal. The salvage values are dependent on the contract, the political environment, and other factors. They are sometimes zero, and sometimes not. This model can be applied to either case.

(7) Balloon Payment

At the end of the revenue phase, the loan balance is discharged by the balloon payment if there is a balance left.

2.3 Structure of the Economic Analysis Model

This analytical model consists of three levels: work package/revenue stream level, project performance level, and project decision level, as well the risk measurement framework. Figure 2.6 shows derived variables at each level.

Derived Variables

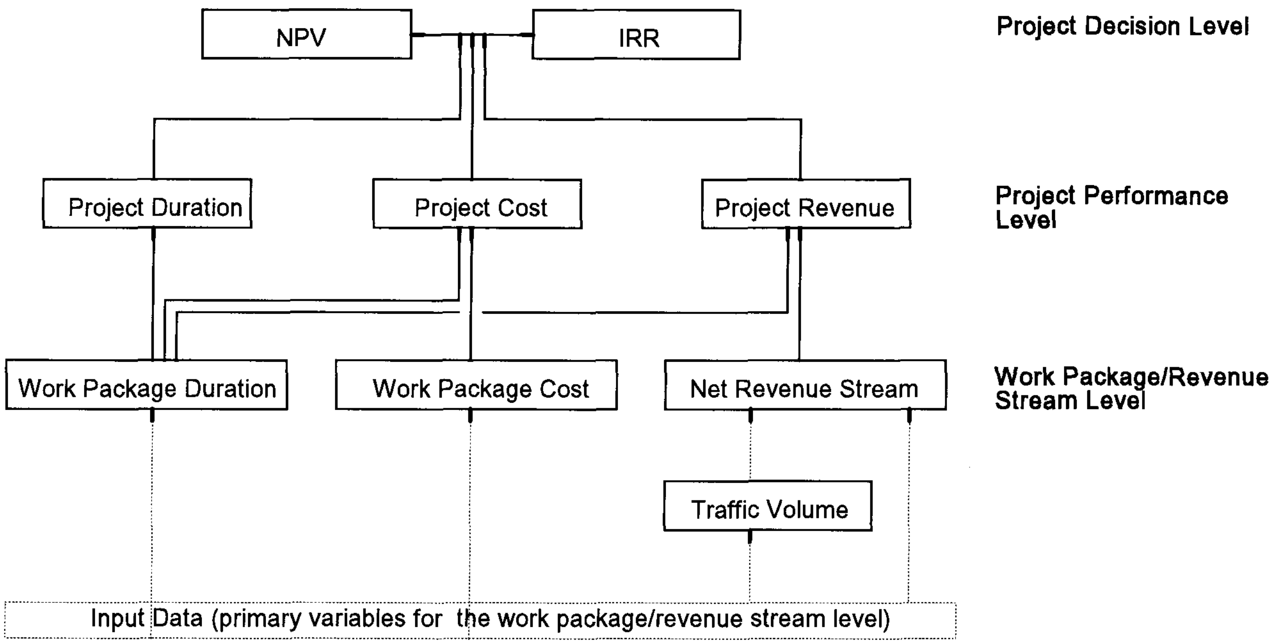

Figure 2.6 Derived Variables at Each Level

2.3 1 Work Package/Revenue Stream Level

This is the lowest level, and each work package and revenue item is linked by way of a precedence network. The work package/revenue stream level has three derived variables: work package duration, work package cost, and net revenue stream including usage (traffic volume).

(1) Work Package Duration

Work package duration can be estimated directly by experts, or derived using functional relationships that are dependent on work scope and productivity. The selection of estimation methods depends on what the model is used for. For preliminary engineering studies or the early stages of feasibility studies, a direct estimate may be chosen. On the other hand, for more detailed and definitive engineering studies and for monitoring a project during the operation phase, a decomposed estimate may be used.

(2) Work Package Cost

Work package cost can also be estimated directly, or derived using a functional relationship in terms of constant, current, or total dollars.

The discounted cost of a typical work package is described as follows. See Appendix A for the detailed derivation.

$$WPC_i = f \cdot e^{(\theta_{ci}-y)\cdot T_{sci}} \cdot \int_0^{T_{ci}} C_{oi}(\tau) \cdot e^{(\theta_{ci}-y)\cdot\tau} d\tau$$

$$+ \int_0^{T_T-T_P} e^{-y\cdot t} dt \cdot e^{-y\cdot T_P} \cdot (1-f) \cdot e^{\theta_{ci}\cdot T_{SCi}} e^{r\cdot(T_p - T_{sci})} \cdot \int_0^{T_{ci}} C_{oi}(\tau) \cdot e^{(\theta_{ci}-r)\cdot\tau} d\tau \,/\, \int_0^{T_T-T_P} e^{-r\cdot t} dt$$

(2.4)

where WPC_i is the discounted cost for the ith work package; $C_{oi}(\tau)$ and $C_i(\tau)$ are the functions for constant dollar cash flow and current dollar cash flow for the ith work package respectively(note: $C_i(\tau) = C_{oi}(\tau) \cdot e^{\theta_{ci}\cdot(T_{sci}+\tau)}$); T_{sci}, T_{ci} are work package start time and duration; T_T, T_p and T_{RT} are total project duration, construction phase finish time, and total revenue phase duration respectively; f is the equity fraction; θ_{ci}, r and y are inflation, interest and discount rates, which are invariant with time, respectively. See figure 2.7 for reference.

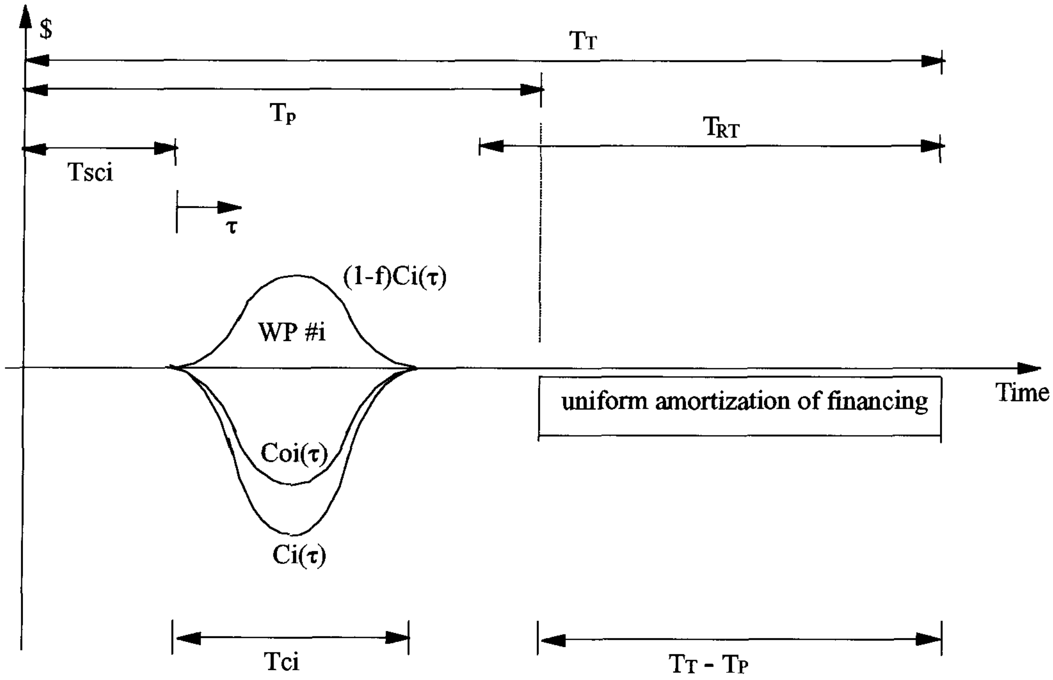

Figure 2.7 Cash Flow Diagram for Work Package

(3) Net Revenue Stream

Net revenue stream can be estimated directly, or derived using functional relationships. However, it is usually derived from traffic volume and toll rate.

A discounted net revenue stream is described as follows:

$$NRSi = e^{-y \cdot T_{SRi}} \int_0^{T_{Ri}} (Ri(\tau) - Mi(\tau)) \cdot e^{-y \cdot \tau} d\tau \qquad (2.5)$$

where NRS_i is the discounted ith net revenue stream; $R_i(\tau)$ is the function for current dollar cash flow for the ith toll revenue; $M_{oi}(\tau)$ and $M_i(\tau)$ are the functions for constant dollar cash flow and current dollar cash flow for the ith operation and maintenance cost respectively (note: $Mi(\tau) = Moi(\tau) \cdot e^{\theta_{Mi} \cdot (T_{SRi} + \tau)}$) ; T_{SRi} and T_{Ri} are revenue stream start time and duration of the revenue stream; θ_{Mi}, r and y are inflation and discount rates respectively. See Figure 2.8 for reference.

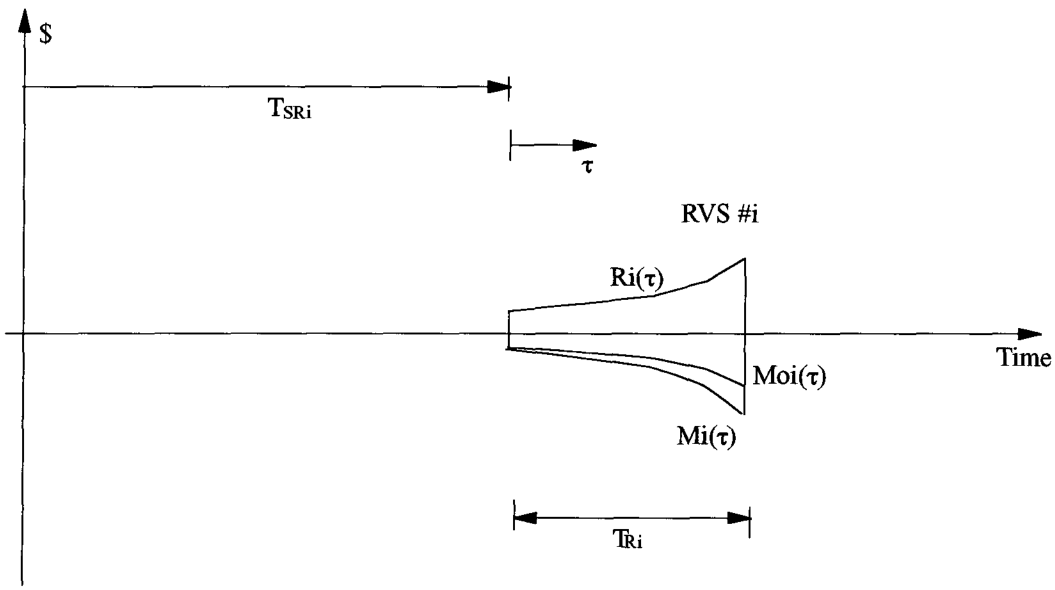

Figure 2.8 Cash Flow Diagram for Net Revenue Stream

Figure 2.9 shows cost and revenue factors at the work package/revenue stream level. They are described in more detail later.

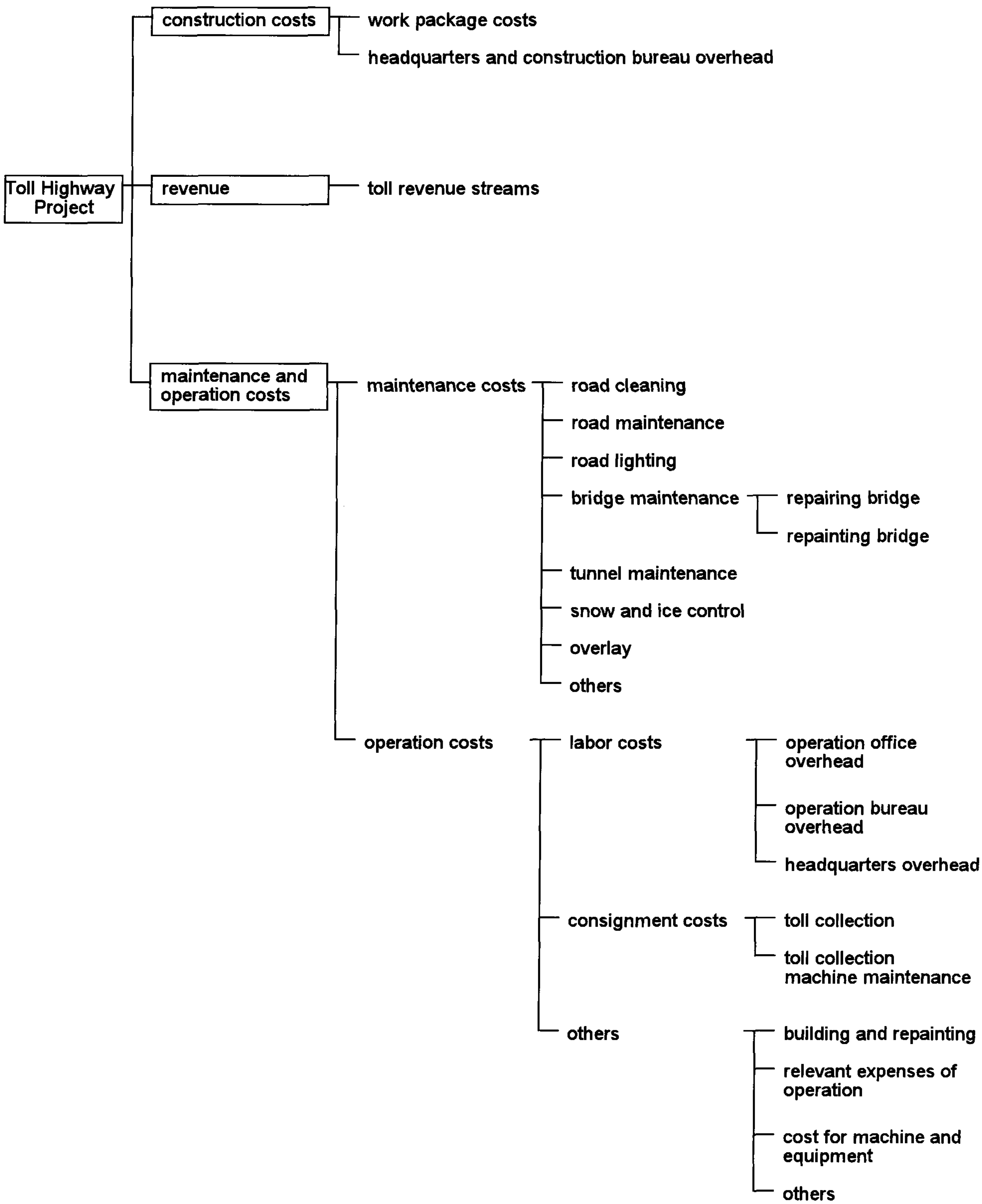

Figure 2.9 Cost/Revenue Components

2.3 2 Project Performance Level

The project performance level has three derived variables, project duration, project cost, and project revenue.

(1) Project duration

The duration of a path is described as follows:

$$T_j = \sum_{i=1}^{n} WPD_{ij} \tag{2.6}$$

where T_j is the duration of the jth path and WPD_{ij} is the duration of the ith work package on the jth path.

For this research, the probability of completing the project in time t, denoted as $p(t)$, is calculated on the basis of the Modified PNET method (Ranasinghe, 1990). Although PNET assumes that the activity durations are statistically independent, two different paths are considered to be correlated as a result of common activities. Then, the correlation between two paths i and j having m common activities is defined as (Ang et al., 1975),

$$\rho_{ij} = \frac{\sum_{k=1}^{m} \sigma^2_{ijk}}{\sigma_i \sigma_j} \tag{2.7}$$

where σ^2_{ijk} is the variance of the k^{th} common activity on paths i and j, σ_i and σ_j are the standard deviations for duration of paths i and j, and ρ_{ij} is the correlation coefficient between paths *i* and *j*. Those paths with $\rho_{ij} \geq \rho$ are represented by path *i* (the longest path) from the assumption that ρ, 0.5 for this research, represents the transition between high and low correlation.

Therefore, the probability, *p(t)* of completing the project in time *t* is given by

$$p(t) = P(T_1 \leq t)P(T_2 \leq t).....P(T_r \leq t) \tag{2.8}$$

where $P(T_1 \leq t)P(T_2 \leq t).....P(T_r \leq t)$ are the probabilities of each representative path completing the project in time *t*, for r representative paths. See Ranasinghe (1990) for a more extensive description.

(2) Project Cost

The discounted project cost is described as follows:

$$\text{Discounted project cost } = \sum_{i=1}^{n} WPC_i \tag{2.9}$$

(3) Project Revenue

The discounted project revenue is described as follows:

$$\text{Discounted project revenue } = \sum_{i=1}^{n} NRS_i \tag{2.10}$$

2.3.3 Project Decision Level

The project decision level has two derived variables, net present value (NPV) and internal rate of return (IRR).

(1) Net Present Value

NPV = Discounted Project Revenue - Discounted Project Cost (2.11)

(2) Internal Rate of Return

IRR = Discount Rate when NPV = 0 (2.12)

2.4 Work Package

A toll highway project consists of a variety of work packages. Therefore, it is not practical to consider every detail of activities such as form work and concrete pouring for a feasibility study, especially at the early stage. Table 2.1 shows factors considered as work packages in this model. Attention has not been placed in this thesis on developing cost estimating relationships for construction related work.

Phase	Work Package
(1) Survey & Design	Survey & Design
(2) Land Acquisition	Land Acquisition
(3) Construction	Earth Work
	Bridge
	Tunnel
	Interchange
	Junction
	Rest Area
	Pavement
	Traffic Control Facility
	Toll Collection Facility
	Building & Repairs
	Overhead
	Others
(4) Revenue Stream (Finish W.P)	Revenue Stream for Different Vehicle Types
	Maintenance Costs
	Operation Costs

Table 2.1 Work Package Components

2.5 Toll Revenue

2.5.1 General

Toll revenue is dependent on the toll collection method, traffic volume, and toll rate. As stated previously, toll collection methods can be classified into three major categories:

(1) closed (ticket) system;

(2) open (main-line barrier) system;

(3) hybrid system.

In addition, each system has several variations such as manual toll collection, automatic toll collection, and non-stop toll collection, e.g. Automatic Vehicle Identification (AVI). This model is designed for all of them.

Each revenue stream is divided by base years. In other words, the first year of each revenue stream is a base year. See Figure 2.10.

The toll revenue of each revenue stream is calculated on the basis of information from the base year and growth parameters. This is described in more detail later.

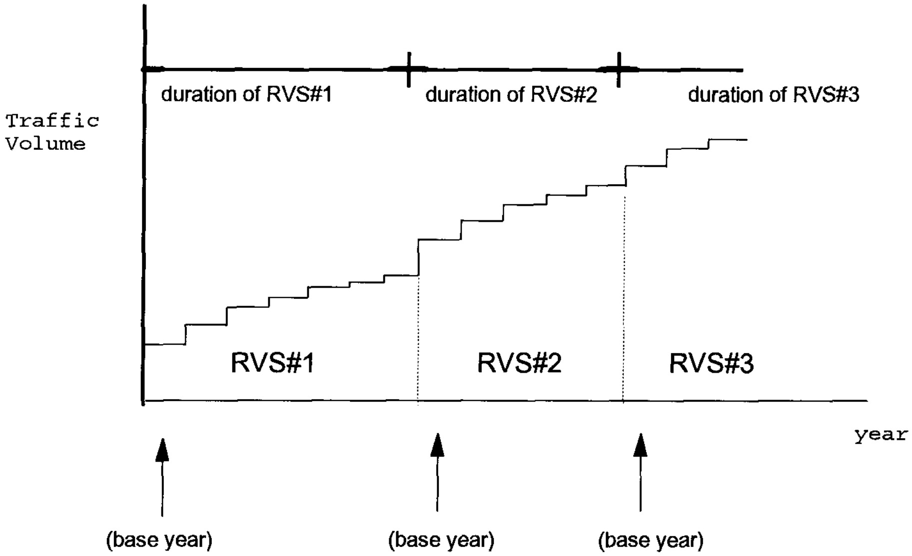

Figure 2.10 Revenue Stream and Base Years

The revenue phase of this model requires three kinds of input data, namely, general information, toll revenue information, and maintenance and operation cost information. Table 2.2 shows these data for a closed system. Deterministic versus probabilistic variables are noted. It is assumed that the physical data for a toll highway, such as the number of interchanges, are deterministic. On the other hand, forecasts of future events such as traffic volume and growth rate are treated as probabilistic. See Appendix D for more detailed input data. Although the number of primary variables for each revenue stream depends on the number of interchanges, toll collection method, revenue stream duration, and the number of vehicle types, it can be over 200. Therefore, in order to simplify the probabilistic treatment of the model, correlation between primary variables for the revenue phase is not considered in the present model.

Input Data Type	Components	
(1) General	the number of revenue streams (= the number of base years) the number of interchanges the number of vehicle types revenue stream duration	D D D P P
(2) Toll Revenue	interchange pair toll toll growth rate interchange pair traffic volume traffic volume growth rate	P P P P
(3) Maintenance and Operation Cost	weather classification periodic overlay periodic bridge repainting maintenance cost estimate criteria operation cost estimate criteria	D D D P P

Table 2.2 Input Data for Revenue Streams

where D : deterministic variable

P : probabilistic variable

In its simplest form, toll revenue is computed as:

$$R = Q \times r \qquad (2.13)$$

where R is toll revenue, Q is traffic volume, and r is toll rate. Q and r are usually described as an interchange pair traffic volume and interchange pair tolls when calculating toll revenue (enter at interchange l, exit at m, pay fare r_{lm}).

For example, if there are 5 interchanges in year i, and interchange pair traffic volume and tolls from vehicle type j are as shown in Tables 2.3 and 2.4, the toll revenue from vehicle type j in year i can be described as in Table 2.5 and equation 2.14.

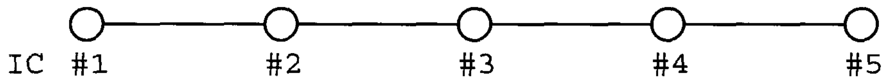

Figure 2.11 Interchanges (Example)

				I.C. #5
			I.C. #4	$Q_{(i,4,5,j)}$
		I.C. #3	$Q_{(i,3,4,j)}$	$Q_{(i,3,5,j)}$
	I.C. #2	$Q_{(i,2,3,j)}$	$Q_{(i,2,4,j)}$	$Q_{(i,2,5,j)}$
I.C. #1	$Q_{(i,1,2,j)}$	$Q_{(i,1,3,j)}$	$Q_{(i,1,4,j)}$	$Q_{(i,1,5,j)}$

Table 2.3 Interchange Pair Daily Traffic Volume

				I.C. #5
			I.C. #4	$r_{(i,4,5,j)}$
		I.C. #3	$r_{(i,3,4,j)}$	$r_{(i,3,5,j)}$
	I.C. #2	$r_{(i,2,3,j)}$	$r_{(i,2,4,j)}$	$r_{(i,2,5,j)}$
I.C. #1	$r_{(i,1,2,j)}$	$r_{(i,1,3,j)}$	$r_{(i,1,4,j)}$	$r_{(i,1,5,j)}$

Table 2.4 Interchange Pair Toll

				I.C. #5
			I.C. #4	$Q_{(i,4,5,j)}\times r_{(i,4,5,j)}\times 365$
		I.C. #3	$Q_{(i,3,4,j)}\times r_{(i,3,4,j)}\times 365$	$Q_{(i,3,5,j)}\times r_{(i,3,5,j)}\times 365$
	I.C. #2	$Q_{(i,2,3,j)}\times r_{(i,2,3,j)}\times 365$	$Q_{(i,2,4,j)}\times r_{(i,2,4,j)}\times 365$	$Q_{(i,2,5,j)}\times r_{(i,2,5,j)}\times 365$
I.C. #1	$Q_{(i,1,2,j)}\times r_{(i,1,2,j)}\times 365$	$Q_{(i,1,3,j)}\times r_{(i,1,3,j)}\times 365$	$Q_{(i,1,4,j)}\times r_{(i,1,4,j)}\times 365$	$Q_{(i,1,5,j)}\times r_{(i,1,5,j)}\times 365$

Table 2.5 Interchange Pair Annual Toll Revenue

$$R_{(i,j)} = \sum_{l=1}^{4} \sum_{m=l+1}^{5} Q_{(i,l,m,j)} \cdot r_{(i,l,m,j)} \tag{2.14}$$

where

$R_{(i,j)}$: toll revenue of vehicle type *j* in year *i*

$Q_{(i,l,m,j)}$: interchange pair traffic volume between interchanges #*l* and #*m* for vehicle type #*j* in year *i*

$r_{(i,l,m,j)}$: interchange pair toll between interchanges #*l* and #*m* for vehicle type #*j* in year *i*

2.5.2 General Input Data

For the closed system, input data required for the computer implementation of this model are:

- the number of revenue streams;
- the number of interchanges;
- the number of vehicle types; and
- revenue stream start time
- revenue stream duration

For the open system, input data required in this model are:

- the number of revenue streams;
- the number of interchanges;
- the number of vehicle types;
- the number of toll gates;
- location of toll gates; and

- revenue stream start time
- revenue stream duration.

For example, if a toll gate is located at interchange #2, the location of the toll gate is indicated by 2. If a toll gate is located between interchanges #2 and #3, the location of the toll gate is indicated by 2.5.

2.5.3 Traffic Volume

As the operation period of a toll highway project is very long, e.g. 30 years, it is very difficult to accurately forecast future traffic volumes, even though many traffic forecasting methods are available (Bushell, 1970; Dalton and Harmelink, 1974; Davinroy, 1962; Duffus, Alfa, and Soliman, 1987; Huber, Boutwell, and Witheford, 1968; Kadiyali, 1983; Morellet, 1981; Neveu, 1982; Newell, 1980; Thomas, 1991; et al). In addition, because each forecasting method has its own characteristics, tendency, and validity, it is important to consider them carefully when the five percentile subjective estimates are done.

The calculation of annual revenue requires information about every interchange-pair traffic volume of every vehicle type for every year during the revenue phase. However, as mentioned previously, it is not practical to carry out a detailed traffic forecast for every year. Therefore, this model requires information on traffic volume for base years only, and traffic volume in non-base years is interpolated by parameters, as described in equation (2.1). As also mentioned previously, traffic growth parameters in equation (2.1) are based on economic forecasts, national development plans, and so on, and the growth rate is not constant. There may be several kinds of the parameters. In this thesis, forecasted annual vehicle-kilometers, which are probabilistic, are used.

This model can deal with any kind of traffic forecasting method as long as it satisfies these requirements. In this thesis, it is assumed that each traffic volume is independent, as mentioned in 2.5.1.

An annual discrete traffic growth model similar to that shown in Figure 2.10 is used for this model in order to calculate annual revenue and expenses.

As mentioned in a later section, estimates related to traffic volume have high uncertainty among the primary variables that describe a toll highway project.

Input data required in this model are:

- every interchange pair traffic volume for every vehicle type in a base year for every revenue stream; and
- a traffic volume growth parameter for every year during the revenue phase.

It is assumed here that the traffic volume growth parameters are the same for each vehicle type. This is based on the current procedure in Japan. Future extensions to the model should facilitate the input of different growth parameters for each vehicle type, thereby rendering the model greater flexibility.

2.5.4 Toll Rate

Toll rates are generally classified into 2 categories, the distance proportional toll rate and the flat(fixed) rate. The general form of the distance proportional toll rate is:

$$r = r_p \times d + r_f \qquad (2.15)$$

where r_p : proportional part of toll rate ($/km)

r_f : fixed part of toll rate ($)

d : travel distance (km)

Tolls are calculated on the basis of the above toll rate and vehicle types. Table 2.16 shows an example of vehicle types and toll ratios between them. This model also considers the long distance discount.

It is very important to discuss whether or not future toll increases are to be considered in a feasibility analysis. Considering future toll increases may cause overestimates of toll revenue, especially if there is no guarantee that

class	description	toll ratio
class 1	Light motor vehicle	a
Class 2	Ordinary motor vehicle	1.00
class 3	Medium-sized motor vehicle	b
class 4	Large-sized motor vehicle	c
class 5	Special large-sized motor vehicle	d

Table 2.6 Vehicle Type and Toll Ratio

toll rates can be increased over time. However, in some cases, it is more realistic to take them into account. Therefore, this model is applicable in both cases.

Two kinds of toll increase considered in this model are shown in Figure 2.12 and 2.13. Figure 2.12 shows toll rates that increase annually, and Figure 2.13 shows toll rates that increase every several years. Figure 2.13 tends to reflect common practice because annual toll increases are often met by public opposition.

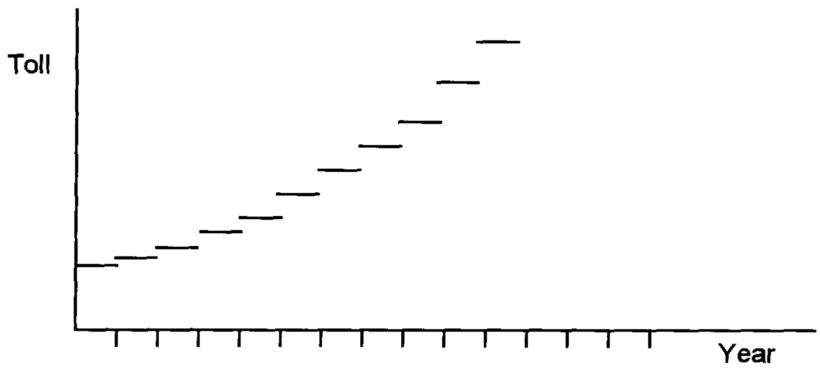

Figure 2.12 toll rate increase (case-1)

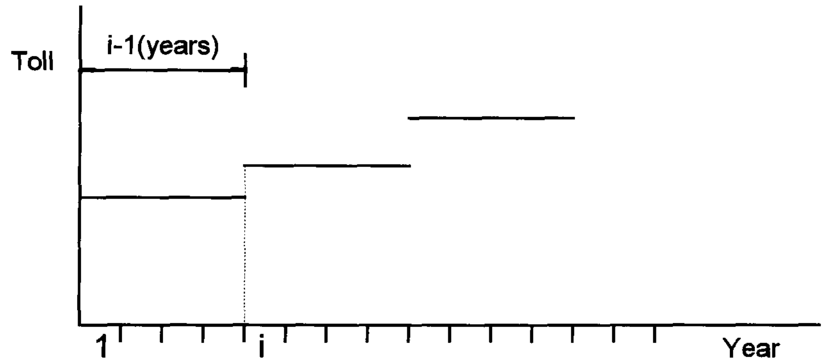

Figure 2.13 toll rate increase (case-2)

For both cases, the toll rate is described as:

$$toll_i = \alpha_i \cdot toll_1 \quad (2.16)$$

where $toll_1$ and $toll_i$ are the toll rates in base year and year i respectively, and α_i is a toll growth parameter for year i.

Along with traffic growth parameters, a toll growth parameter is assigned to every year during the revenue phase as input data. It is not necessary that the parameter be constant because this parameter is also dependent on economic conditions, government policies, and so on. α_i are sometimes described as $\alpha_i = (1+\alpha)^{i-1}$, where α is average annual growth rate.

α_i for both cases looks like Figures 2.14 and 2.15.

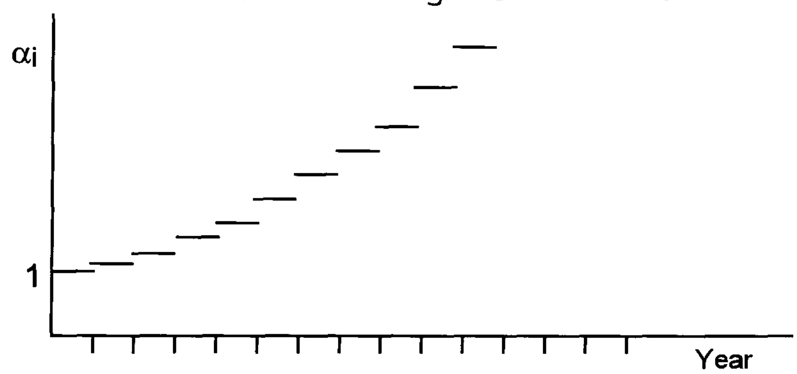

Figure 2.14 toll growth parameters (case-1)

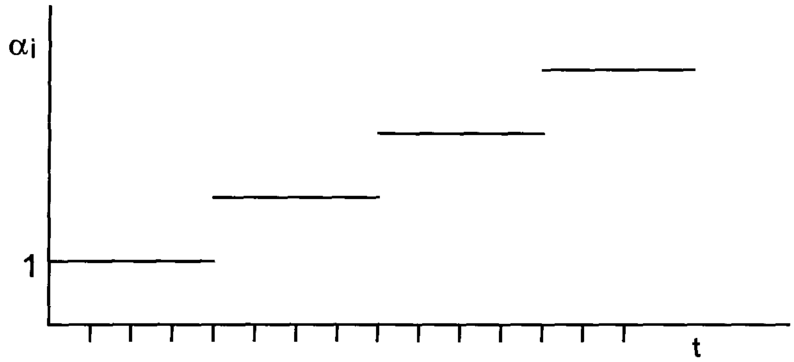

Figure 2.15 toll growth parameters (case-2)

When toll rates increase, traffic volume theoretically decreases(Japan Highway Public Corporation, 1993; et al). No attempt is made to model this phenomenon here, however, because of a lack of data with which to attempt the derivation of an empirical model.

In this model, input data for the distance proportional toll are:

- proportional part of toll rate for ordinary motor vehicle;
- fixed part of toll rate (constant for all vehicle types);
- interchange pair distances;
- toll ratio between vehicle types;
- long distance discount information; and
- a toll growth parameter for every year during the revenue phase.

In this model, input data for the fixed toll are:

- every interchange pair toll for every vehicle type in base year for every revenue stream; and
- a toll growth parameter for every year during the revenue phase.

2.5.5 General Form of Toll Revenue

The constant dollar toll revenue is described as follows.

$$\begin{aligned} P_{TOLL} &= \sum_{i=1}^{nrv} \sum_{j=1}^{rvd(i)} \sum_{k=1}^{nic(i)-1} \sum_{l=k+1}^{nic(i)} \sum_{m=1}^{nvt(i)} R_{(i,j,k,l,m)} \\ &= \sum_{i=1}^{nrv} \sum_{j=1}^{rvd(i)} \sum_{k=1}^{nic(i)-1} \sum_{l=k+1}^{nic(i)} \sum_{m=1}^{nvt(i)} Q_{(i,k,l,m)} \cdot \frac{k_{(i,j)}}{k_{(i,1)}} \cdot r_{(i,k,l,m)} \cdot q_{(i,j)} \times 365 \end{aligned} \tag{2.17}$$

where

P_{TOLL} : constant dollar toll revenue of the project

nrv : the number of revenue streams

$rvd_{(i)}$: duration of RVS #*i*

$nic_{(i)}$: the number of interchanges for RVS #*i*

$nvt_{(i)}$: the number of vehicle types for RVS #*i*

$R_{(i,j,k,l,m)}$: annual revenue interchanges #*k* and #*l* for vehicle type #*m* in *j*th year for RVS #*i*

$Q_{(i,k,l,m)}$: daily traffic volume between interchanges #*k* and #*l* for vehicle type #*m* in base year for RVS #*i*

$k_{(i,j)}$: traffic growth parameter of year *j* for RVS #*i*

$k_{(i,1)}$: traffic growth parameter of base year for RVS #*i*

$r_{(i,k,l,m)}$: toll between interchanges #*k* and #*l* for vehicle type #*m* in base year for RVS #*i*

$q_{(i,j)}$: toll growth rate parameter in year *j* for RVS #*i*

A simple example is shown below.

nrv	2
$rvd_{(1)}$	2
$rvd_{(2)}$	3
$nic_{(1)}$	2
$nic_{(2)}$	3
$nvt_{(1)}$	2
$nvt_{(2)}$	2
$Q_{(1,k,l,1)}$	See Table 2. 7.
$Q_{(1,k,l,2)}$	See Table 2. 8.
$Q_{(2,k,l,1)}$	See Table 2.11.
$Q_{(2,k,l,2)}$	See Table 2.12.
$k_{(1,1)}$	5156
$k_{(1,2)}$	5350
$k_{(2,1)}$	5480
$k_{(2,2)}$	5610
$k_{(2,3)}$	5740
$r_{(1,k,l,1)}$	See Table 2. 9.
$r_{(1,k,l,2)}$	See Table 2.10.
$r_{(2,k,l,1)}$	See Table 2.13.
$r_{(2,k,l,2)}$	See Table 2.14.
$q_{(1,1)}$	1.00
$q_{(1,2)}$	1.020 (1.02^1)
$q_{(2,1)}$	1.040 (1.02^2)
$q_{(2,2)}$	1.061 (1.02^3)
$q_{(2,3)}$	1.082 (1.02^4)

Table 2.7 Input Data for Toll Revenue (Example)

	I.C.#2
I.C.#1	8,000

Table 2.8
Daily Traffic Volume
(vehicles/day)
$Q_{(1,k,l,1)}$

	I.C.#2
I.C.#1	12,000

Table 2.9
Daily Traffic Volume
(vehicles/day)
$Q_{(1,k,l,2)}$

	I.C.#2
I.C.#1	5

Table 2.10 Toll ($)
$r_{(1,k,l,1)}$

	I.C.#2
I.C.#1	7

Table 2.11 Toll ($)
$r_{(1,k,l,2)}$

		I.C.#3
	I.C.#2	5,000
I.C.#1	10,000	14,000

Table 2.12
Daily Traffic Volume
(vehicles/day)
$Q_{(2,k,l,1)}$

		I.C.#3
	I.C.#2	7,000
I.C.#1	14,000	15,000

Table 2.13
Daily Traffic Volume
(vehicles/day)
$Q_{(2,k,l,2)}$

		I.C.#3
	I.C.#2	3
I.C.#1	5	8

Table 2.14 Tolls ($)
$r_{(2,k,l,1)}$

		I.C.#3
	I.C.#2	4
I.C.#1	7	10

Table 2.15 Tolls ($)
$r_{(2,k,l,2)}$

According to equation (2.18), toll revenues are shown in Tables (2.16) to (2.26)

Revenue Stream #1:

	I.C.#2
I.C.#1	14.60

Table 2.16
Annual Revenue ($ million)
$R_{(1,1,k,l,1)}$

	I.C.#2
I.C.#1	30.66

Table 2.17
Annual Revenue ($ million)
$R_{(1,1,k,l,2)}$

	I.C.#2
I.C.#1	15.45

Table 2.18
Annual Revenue ($ million)
$R_{(1,2,k,l,1)}$

	I.C.#2
I.C.#1	32.45

Table 2.19
Annual Revenue ($ million)
$R_{(1,2,k,l,2)}$

Revenue Stream #2:

		I.C.#3
	I.C.#2	5.69
I.C.#1	18.98	42.52

Table 2.20
Annual Revenue ($ million)
$R_{(2,1,k,l,1)}$

		I.C.#3
	I.C.#2	10.63
I.C.#1	37.20	56.94

Table 2.21
Annual Revenue ($ million)
$R_{(2,1,k,l,2)}$

		I.C.#3
	I.C.#2	5.95
I.C.#1	19.82	44.40

Table 2.22
Annual Revenue ($ million)
$R_{(2,2,k,l,1)}$

		I.C.#3
	I.C.#2	11.10
I.C.#1	38.85	59.47

Table 2.23
Annual Revenue ($ million)
$R_{(2,2,k,l,2)}$

		I.C.#3
	I.C.#2	6.21
I.C.#1	20.68	46.33

Table 2.24
Annual Revenue ($ million)
$R_{(2,3,k,l,1)}$

		I.C.#3
	I.C.#2	11.58
I.C.#1	40.54	62.05

Table 2.25
Annual Revenue ($ million)
$R_{(2,3,k,l,2)}$

Then, total revenues are:

Total Revenue of RVS #1	$ 93.16 million
Total Revenue of RVS #2	$ 538.94 million
Total	$ 632.10 million

Table 2.26 Total Revenues for an Example

2.6 Maintenance and Operation Cost Model

Maintenance and operation costs are dependent on road structures, toll collection systems, traffic volumes, weather conditions, organizational structures, and other factors.

This model assumes that maintenance costs are mainly dependent on road structure, while operation costs are dependent on the others. Components of each group are shown in Tables 2.27 and 2.28. See sections 2.6.1 and 2.6.2 for more detail. Maintenance and operation costs are written in constant dollar form. It is assumed that constant dollar maintenance and operation costs are constant during the operation phase because the highway is maintained properly.

The same inflation rate is used for all components, because of the difficulty in identifying differences between inflation rates for each component.

road cleaning	
road maintenance	
road lighting	
bridge maintenance	bridge repair
	bridge repainting
tunnel maintenance	
snow and ice maintenance	
overlay	
others	

Table 2.27 Maintenance Costs

labor costs	operation office overhead
	operation bureau overhead
	headquarters overhead
consignment costs	toll collection
	toll collection machine maintenance
others	building and repairs
	relevant expenses of operation
	cost of machine and equipment
	others

Table 2.28 Operation costs

2.6.1 Maintenance Costs

In this model, maintenance costs are calculated on the basis of road length and the number of lanes. Therefore, this information should be input.

	2 Lanes	4 lanes	6 lanes	Total
Bridge	l_{B2}	l_{B4}	l_{B6}	$l_B = l_{B2} + l_{B4} + l_{B6}$
Tunnel	l_{T2}	l_{T4}	l_{T6}	$l_T = l_{T2} + l_{T4} + l_{T6}$
earthwork	l_{E2}	l_{E4}	l_{E6}	$l_E = l_{E2} + l_{E4} + l_{E6}$
Total	$l_2 = l_{B2} + l_{T2} + l_{E2}$	$l_4 = l_{B4} + l_{T4} + l_{E4}$	$l_6 = l_{B6} + l_{T6} + l_{E6}$	$l = l_B + l_T + l_E$ $l = l_2 + l_4 + l_6$

Table 2.29 Road Length

no ventilation	jet fan	others	total
l_{Tn}	l_{Tj}	l_{To}	l_T

Table 2.30 Tunnel Length by Ventilation Methods

For example, if the road structure shown in Figure 2.16 is assumed, Tables 2.29 and 2.30 become Tables 2.31 and 2.32.

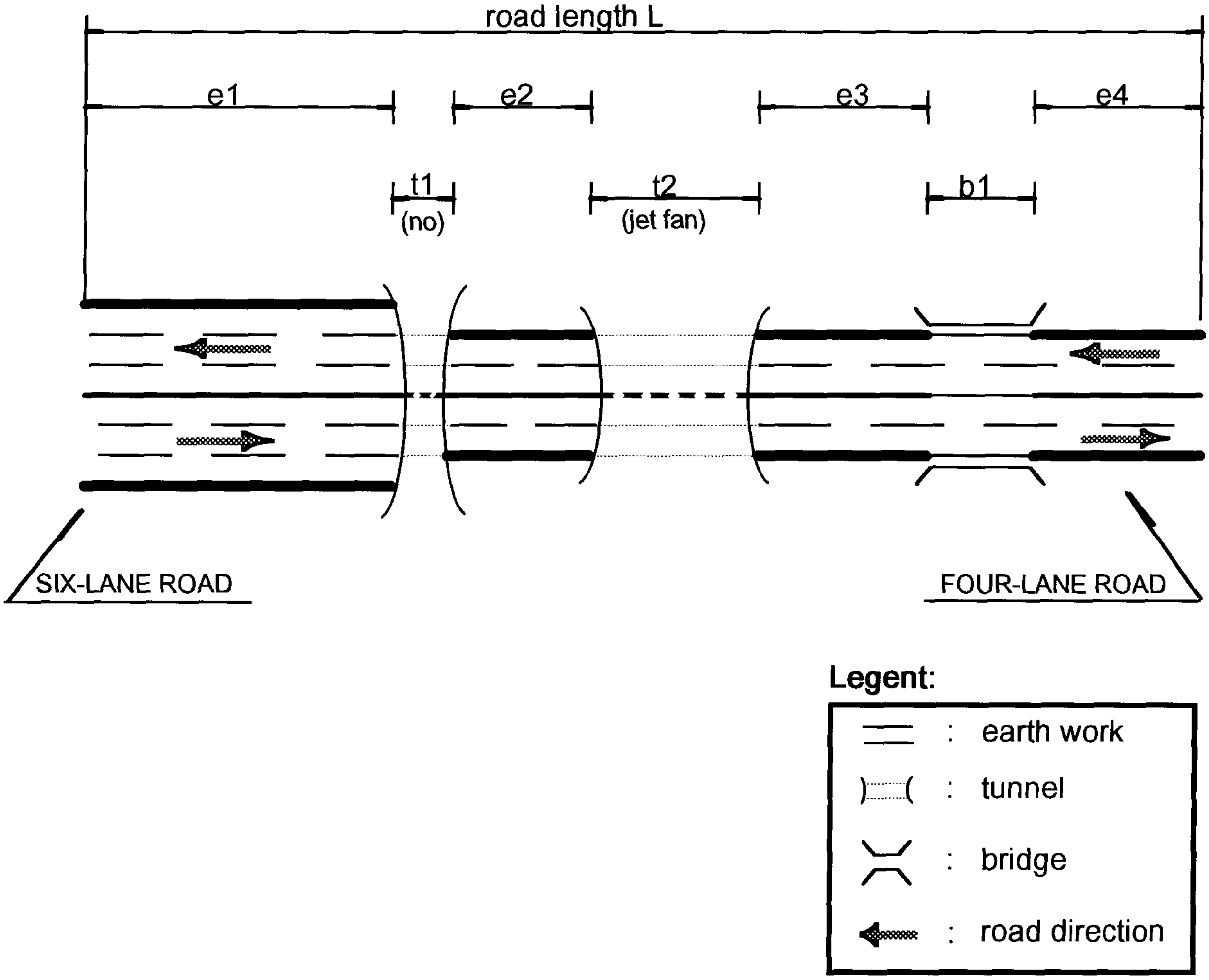

Figure 2.16 Road Structure (Example)

	2 Lanes	4 lanes	6 lanes	Total
Bridge	0	b1	0	b1
Tunnel	0	t1+t2	0	t1+t2
earthwork	0	e2+e3+e4	e1	e1+e2+e3+e4
Total	0	b1+t1+t2+e2+e3+e4	e1	L

Table 2.31 Road Length (Example)

no ventilation	jet fan	others	total
t1	t2	0	t1+t2

Table 2.32 Tunnel Length by Ventilation Methods (Example)

Maintenance costs consist of nine factors.

(1) Road Cleaning Costs

Road cleaning costs are calculated on the basis of the road length and the number of lanes.

Input data are as follows.

the number of lanes	cost ($/km)
2	c_{c2}
4 or more	c_{c4}

Table 2.33 Road cleaning Costs

$$\text{Road Cleaning Costs} = c_{c2} \times l_2 + c_{c4} \times (l_4 + l_6) \tag{2.18}$$

(2) Road Maintenance Costs

Road maintenance costs are calculated on the basis of the earth work length and the number of lanes. These include pavement repair, road marking, roadside maintenance, planting, and so on.

earth work length

= road length - bridge and tunnel length (2.19)

Input data are as follows.

the number of lanes	cost ($/km)
2	c_{m2}
4	c_{m4}
6	c_{m6}

Table 2.34 Road Maintenance Costs

road maintenance costs = $c_{m2} \times l_{E2} + c_{m4} \times l_{E4} + c_{m6} \times l_{E6}$ (2.20)

(3) Road Lighting Costs

Road lighting costs are calculated on the basis of the earth work and bridge length and the number of lanes. Input data are as follows.

the number of lanes	cost ($/km)
1 or 2	c_{l1}
4 or 6	c_{l4}

Table 2.35 Road Lighting Costs

road lighting costs = $c_{l1} \times (l_{B2} + l_{E2}) + c_{l4} \times \{(l_{B4} + l_{B6}) + (l_{E4} + l_{E6})\}$ (2.21)

(4) Bridge Maintenance (Repair) Costs

Bridge repair costs are calculated on the basis of the bridge length and the number of lanes. These costs include joint repair, shoe repair, handrail repair, and so on.

Input data are as follows.

the number of lanes	cost ($/km)
2	c_{r2}
4	c_{r4}
6	c_{r6}

Table 2.36 Bridge Maintenance (Repairing) Costs

bridge repair costs = $c_{r2} \times l_{B2} + c_{r4} \times l_{B4} + c_{r6} \times l_{B6}$ (2.22)

(5) Bridge Maintenance (Repainting) Costs

Bridge repainting costs are calculated on the basis of the bridge length and the number of lanes. Bridge repainting is performed at intervals of specific years, which depend on the owner's standards, weather conditions, etc. In this model, it is assumed that bridge repainting is performed every n1 years (for this thesis, n1 equals 7).

Input data are as follows.

the number of lanes	cost ($/km)
2	c_{p2}
4	c_{p4}
6	c_{p6}

Table 2.37 Bridge Maintenance (Repainting) Costs

bridge repaint costs = $c_{p2} \times l_{B2} + c_{p4} \times l_{B4} + c_{p6} \times l_{B6}$ (2.23)

(6) Tunnel Maintenance Costs

Tunnel maintenance costs are calculated on the basis of tunnel length and the ventilation methods. They include:

- cleaning costs of interior finish boards and lights,
- replacement costs of light bulbs,
- maintenance costs of independent electric power plants and cables,
- repair costs of tunnel bodies, interior finish boards, and inspection steps,
- electric fees,
- traffic control costs, etc.

Input data are as follows.

		cost ($/km)
ventilation	no ventilation	c_{tn}
methods	jet fan	c_{tj}
	others	c_{to}

Table 2.38 Tunnel Maintenance Costs

tunnel maintenance = $2(c_{tn} \times l_{Tn} + c_{tj} \times l_{Tj} + c_{to} \times l_{To})$ (2.24)

(7) Snow and Ice Control Costs

Snow and ice control costs are calculated on the basis of the road length, the number of lanes, and the weather conditions.

Input data are as follows.

weather condition	cost ($/km/2lanes)
area of heavy snowfall (1)	c_{Sh}
area of ordinary snowfall (2)	c_{So}

Table 2.39 Snow and Ice Control Costs

snow and ice control = $c_{Sh} \times (l_2 + 2l_4 + 3l_6)$ or,

$$c_{So} \times (l_2 + 2l_4 + 3l_6) \qquad (2.25)$$

(8) Overlay Costs

Overlay costs are calculated on the basis of the road length and the number of lanes. These include scarification costs. Overlay is performed at intervals of specific years, which depend on the owner's standards, weather conditions, etc.. In this model, it is assumed that overlay is performed every n2 years (for this thesis, n2 equals 12).

Input data are as follows.

the number of lanes	cost ($/km)
2	c_{O2}
4	c_{O4}
6	c_{O6}

Table 2.40 Overlay Costs

overlay : $l_2 \times c_{O2} + l_4 \times c_{O4} + l_6 \times c_{O6}$ (2.26)

(9) Other Indirect Maintenance Costs

Other Indirect Maintenance Costs

$$\{\text{total of costs for (1) to (6)}\} \times \beta \qquad (2.27)$$

where

β : parameter for other indirect maintenance costs

2.6.2 Operation Costs

In this model, operation costs are mainly calculated on the basis of traffic volume and labour costs, and take the form of a step function as labour/equipment must be added in discrete units.

Operation costs consist of six factors. This model assumes that toll collection work and toll collection machine maintenance are performed by subcontractors.

(1) Labor Costs (Operation Office Overhead)

These are labor costs for operation offices, and are calculated on the basis of traffic volume, toll collection method, and the number of toll gates.

Input data are as follows.

traffic volume (vehicles/day)	A	B	C	D	E	sum
0 to t_{01}	a_1	b_1	c_1	d_1	e_1	s_1
t_{01} to t_{02}	a_2	b_2	c_2	d_2	e_2	s_2
t_{02} to t_{03}	a_3	b_3	c_3	d_3	e_3	s_3
t_{03} to t_{04}	a_4	b_4	c_4	d_4	e_4	s_4
t_{04} to t_{05}	a_5	b_5	c_5	d_5	e_5	s_5
t_{05} or more	a_6	b_6	c_6	d_6	e_6	s_6

Table 2.41 Manpower Required for Operation Office

a. closed system

Traffic volume is half of the total traffic volume that each toll gate deals with.

b. open system

Traffic volume is the total of traffic volume that each toll gate deals with.

		cost ($/person)
A	director	c_{pa}
B	vice-director	c_{pb}
C	chief	c_{pc}
D	clerk or engineer	c_{pd}
E	worker	c_{pe}

Table 2.42 Labour Cost for Operation Office

For example, if traffic volume is between t_{03} and t_{04}, toll collection costs = $a_4 \times c_{pa} + b_4 \times c_{pb} + c_4 \times c_{pc} + d_4 \times c_{pd} + e_4 \times c_{pe}$ (2.28)

(2) Labor Costs (Operation Bureau Overhead)

These are labor costs for operation bureaus.

$$\text{Operation Bureau Overhead} = R \times \alpha_2 \tag{2.29}$$

where

α_2 : parameter for labor costs (operation bureau overhead)

(3) Labor Costs (Headquarters Overhead)

These are labor costs for headquarters.

$$\text{Headquarters Overhead} = R \times \alpha_3 \tag{2.30}$$

where

α_3 : parameter for labour costs (headquarters overhead)

(4) Consignment Costs (Toll Collection)

Consignments costs for toll collection work are calculated on the basis of traffic volume, toll collection method, and the number of toll gates.

Input data are as follows.

c_{to} :labour cost ($/person)

α_5 :(closed system) parameter for consignment costs (toll collection)

α_6 :(open system) parameter for consignment costs (toll collection)

(per toll gate)

closed system		open system	
traffic volume (vehicles/day)	clerk	traffic volume (vehicles/day)	clerk
0 to t_{11}	x_1	0 to t_{31}	y_1
t_{11} to t_{12}	x_2	t_{31} to t_{32}	y_2
t_{12} to t_{13}	x_3	t_{32} to t_{33}	y_3
t_{13} to t_{14}	x_4	t_{33} to t_{34}	y_4
t_{14} to t_{15}	x_5	t_{34} to t_{35}	y_5
t_{15} to t_{16}	x_6	t_{35} to t_{36}	y_6
t_{16} to t_{17}	x_7	t_{36} to t_{37}	y_7
t_{17} to t_{18}	x_8	t_{37} to t_{38}	y_8
t_{18} to t_{19}	x_9	t_{38} to t_{39}	y_9
t_{19} to t_{20}	x_{10}	t_{39} to t_{40}	y_{10}
t_{20} to t_{21}	x_{11}	t_{40} to t_{41}	y_{11}
t_{21} to t_{22}	x_{12}	t_{41} to t_{42}	y_{12}
t_{22} to t_{23}	x_{13}	t_{42} to t_{43}	y_{13}
t_{23} to t_{24}	x_{14}	t_{43} to t_{44}	y_{14}
t_{24} to t_{25}	x_{15}	t_{44} to t_{45}	y_{15}
t_{25} to t_{26}	x_{16}	t_{45} to t_{46}	y_{16}
t_{26} to t_{27}	x_{17}	t_{46} to t_{47}	y_{17}
t_{27} or more	x_{18}	t_{47} to t_{48}	y_{18}
		t_{48} or more	y_{19}

Table 2.43 Manpower Required for Toll Collection

a. closed system

Consignment Costs (Toll Collection)

$$= \{\Sigma(\text{the number of clerks}) \times c_{to}\} \times \alpha_5 \qquad (2.31)$$

b. open system

Consignment Costs (Toll Collection)

$$= \{\Sigma(\text{the number of clerks}) \times c_{to}\} \times \alpha_6 \qquad (2.32)$$

(5) Consignment Costs (Toll Collection Machine Maintenance)

Consignment costs of toll collection machine maintenance are calculated on the basis of consignment costs of toll collection work and, toll collection method.

(closed system)

Consignment Costs (Toll Collection Machine Maintenance)

$$= \text{Consignment Costs (Toll Collection)} \times \alpha_7 \quad (2.33)$$

(open system)

Consignment Costs (Toll Collection Machine Maintenance)

$$= \text{Consignment Costs (Toll Collection)} \times \alpha_8 \quad (2.34)$$

where

α_7 : (closed system)
parameter for consignment costs
(toll collection machine maintenance)

α_8 : (open system)
parameter for consignment costs
(toll collection machine maintenance)

(6) Other Operation Costs

These include:

- building and repair expenses,
- operational expenses,
- cost for machine and equipment, and
- others.

The total of (6) to (9)

$$= \{c_{op} \times (o_s + t_s) + c_{of}\} \tag{2.35}$$

where

o_s : the number of operation office personnel

t_s : the number of toll collection clerks

c_{op} : parameter for other operation costs

c_{of} : parameter for other operation costs

In addition, inflation rates for maintenance and operation costs are required.

2.6.4 General Form of Maintenance and Operation Costs

The constant dollar maintenance and operation costs are described as follows.

$$P_{M\&O} = \sum_{i=1}^{nrv}\sum_{j=1}^{nm}\sum_{k=1}^{no}(M_{(i,j)} + O_{(i,k)}) \tag{2.36}$$

where

$P_{M\&O}$: constant dollar maintenance and operation costs

nrv : the number of revenue streams

nm : the number of items required for maintenance cost estimates (= 9 in this model)

no : the number of items required for operation cost estimates (= 6 in this model)

$M_{(i,j)}$: maintenance cost of item #j for RVS #i

$O(i,j)$: operation cost of item #j for RVS #i

Chapter 3

Application

3.1 General

This chapter applies the analytical model described in Chapter 2 to an actual deterministic feasibility study for a large toll highway project. Section two describes the sample project, and sections three and four present results from a sensitivity and risk analysis.

The data for this example were obtained from an actual deterministic feasibility analysis conducted for a toll highway in Japan.

3.2 Sample Project

3.2.1 Sample Project General Information

This toll highway is being constructed in northern Japan as a bypass road intended to ease traffic congestion in an urban area. Because this highway passes near an urban area, high construction costs and large traffic volumes are expected.

The general details are shown in Table 3.1.

Road Length	20.8 Km
Road Structure	
Earth Work	16.8 Km
Bridge and Viaduct	4.0 Km
Tunnel	-
Number of Lanes	2 and 4
Number of Interchanges	6
Toll Collection System	Closed System (Manual Collection)
Number of Vehicle Types	5
Toll Rate	34 cents/Km (Ordinary Motor Vehicle)
(toll ratio) Light motor vehicle Ordinary motor vehicle Medium-sized motor vehicle Large-sized motor vehicle Special large-sized motor vehicle	 0.80 1.00 1.06 1.55 2.75
Construction Period	10.5 years
Operation Period	30 years
Construction Costs	$753 million
Rest Facility	-

Table 3.1 General Features of the Sample Project

This highway project is divided into three sections, each with a different opening date. However, to simplify the model, amortization of financing is assumed to start when the last segment opens.

For illustrative purposes, uniform constant dollar expenditure profiles for work package costs, uniform constant dollar annual expenditure profiles for operating costs, and uniform constant dollar annual revenue profiles for revenue streams are assumed. See Figures 3.1 and 3.2.

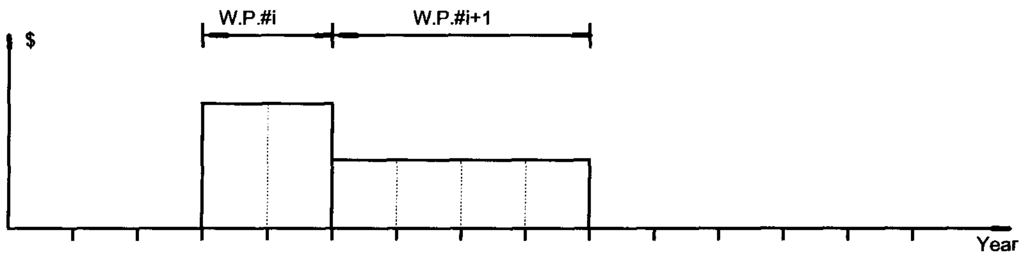

Figure 3.1 Expenditure Profiles for the Construction Phase

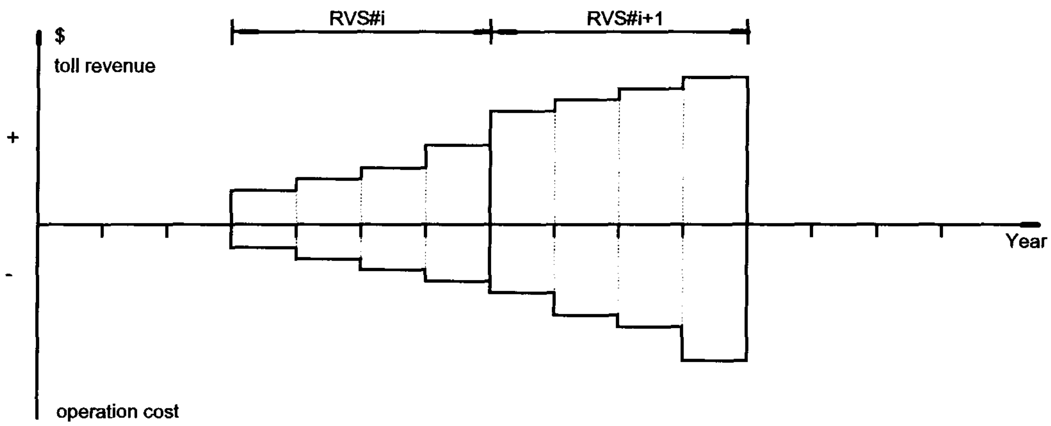

Figure 3.2 Expenditure and Revenue Profiles for the Revenue Phase

In addition, constant interest and inflation rates are assumed. The values assumed for the inflation rate(θ_c and θ_M), the interest rate (r), the discount rate (y), and the equity fraction (f) are shown in Table 3.2. All construction work packages are assumed to have identical inflation rates.

	Mean	σ	$\sqrt{\beta_1}$	β_2
θ_c	4.311%	1.093%	2.0	9.4
θ_M	4.311%	1.093%	2.0	9.4
r	6.500%	0.163%	0.1	5.9
y	6.500%	-	-	-
f	0.000	-	-	-

Table 3.2 Statistical Data for Inflation, Interest, Discount Rates, and Equity Fraction

$\sqrt{\beta_1}$ and β_2 are the moments ratios that describe the Pearson family of distributions.

This analysis follows the procedures described in Figure 1.1 and assumes that the Pearson family of distributions will provide a good fit to most "real life" distributions (Ranasinghe, 1990). Therefore, all probabilistic primary variables and derived variables here are assumed to approximate to the Pearson family of distributions.

Figure 3.3 shows a time line for the sample project. For the base years of revenue streams #1, #2, and #5, the highway is assumed to open in stages, and in the other base years, changes to conditions on related roads are predicted.

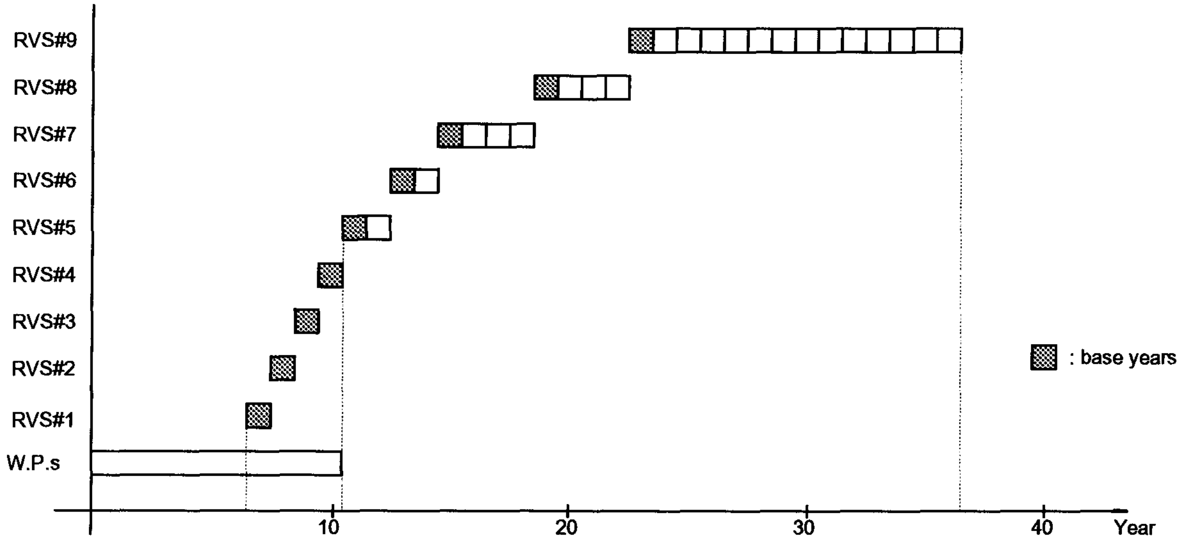

Figure 3.3 Time Line for a Sample Project

For the purpose of this thesis, the project's net present value (NPV) is dealt with as a derived variable at the decision level.

3.2.2 Work Packages

The starting point for the analysis is at the work package level. The original construction program has been modified into that described in Figure 3.4 and Table 3.5. According to Table 3.5, work package durations and work package costs seem not to be correlated. This often happens because each work package does not have the same technical complexity.

The analytical model requires the five percentile estimates for every probabilistic primary variable, and allows each work package to have a different distribution. However, to simplify the analysis for this sample project, work packages are classified into categories and the five percentile estimate parameters for a quasi normalized distribution are assigned to each category. The shapes of the distribution function for all of the work packages in one category are assumed to be identical. Such an assumption should not be made when modeling actual projects, as there can be significant differences in technical complexity amongst work packages in the same category. For example, for the category survey and design, there are 6 work packages (W.P.#2 to W.P.#7), and they have the same distribution function. The normalized distributions correspond to the Pearson family of distributions.

Table 3.3 shows the five percentile estimate parameters for W.P. duration. Land acquisition has high uncertainty and is skewed to the right because of probable difficulties in negotiating with land owners and residents. Earth work, Interchange, and appurtenant work also have higher uncertainty than survey and design, bridge, and others because of the greater possibility of external intervention and the complicated nature of the work.

For example, if deterministic W.P. duration for one paving job is 1 year, the estimates for 2.5, 5.0, 50.0, 95.0, and 97.5 percentiles are 0.90, 0.91, 1.00, 1.09, 1.10 years respectively.

category	2.5%	5.0%	50.0%	95.0%	97.5%	$\sqrt{\beta_1}$	β_2
survey & design	0.900	0.910	1.000	1.180	1.200	0.6	2.4
land acquisition	0.900	0.910	1.000	1.500	1.650	2.0	8.0
earth work	0.850	0.870	1.000	1.450	1.500	0.9	2.8
bridge	0.900	0.910	1.000	1.180	1.200	0.6	2.4
pavement	0.900	0.910	1.000	1.090	1.100	0.0	2.2
IC	0.850	0.870	1.000	1.450	1.500	0.9	2.8
ancillary facilities	0.900	0.910	1.000	1.090	1.100	0.0	2.2
appurtenant work	0.900	0.910	1.000	1.450	1.500	1.1	3.2
building & repairing	0.900	0.910	1.000	1.090	1.100	0.0	2.2
overhead	0.900	0.910	1.000	1.180	1.200	0.6	2.4
revenue	0.900	0.910	1.000	1.090	1.100	0.0	2.2

Table 3.3 Five Percentile Estimate Parameters for W.P. Duration

There are also the five percentile estimate parameters for W.P. costs. Table 3.4 shows the five percentile estimate parameters for W.P. cost. These parameters have similar shape to those of W.P. duration. In addition, the inflation rate is expected to be highly uncertain.

category	2.5%	5.0%	50.0%	95.0%	97.5%	$\sqrt{\beta_1}$	β_2
survey & design	0.950	0.952	1.000	1.350	1.410	1.6	5.2
land acquisition	0.920	0.930	1.000	1.500	1.650	2.0	7.6
earth work	0.900	0.920	1.000	1.550	1.700	2.0	7.8
bridge	0.920	0.930	1.000	1.250	1.300	1.2	4.0
pavement	0.920	0.930	1.000	1.250	1.300	1.2	4.0
IC	0.900	0.910	1.000	1.500	1.560	1.2	3.6
ancillary facilities	0.850	0.870	1.000	1.250	1.300	0.8	3.3
appurtenant work	0.850	0.860	1.000	1.650	1.850	2.0	8.3
building & repairing	0.800	0.810	1.000	1.180	1.200	0.0	2.1
overhead	0.700	0.710	1.000	1.580	1.600	0.5	2.1
interest rate	0.950	0.960	1.000	1.040	1.050	0.0	5.6
inflation rate	0.800	0.820	1.000	1.300	1.400	1.4	7.7

Table 3.4 Five Percentile Estimate Parameters for W.P. Costs

Once again, these parameters are used to simplify the example. In actual practice, however, it is recommended that each component be estimated independently.

Tables 3.5, and 3.6 show statistics for work package durations and constant dollar costs used for the original deterministic feasibility analysis respectively, and Table 3.7 shows discounted work package costs based on them.

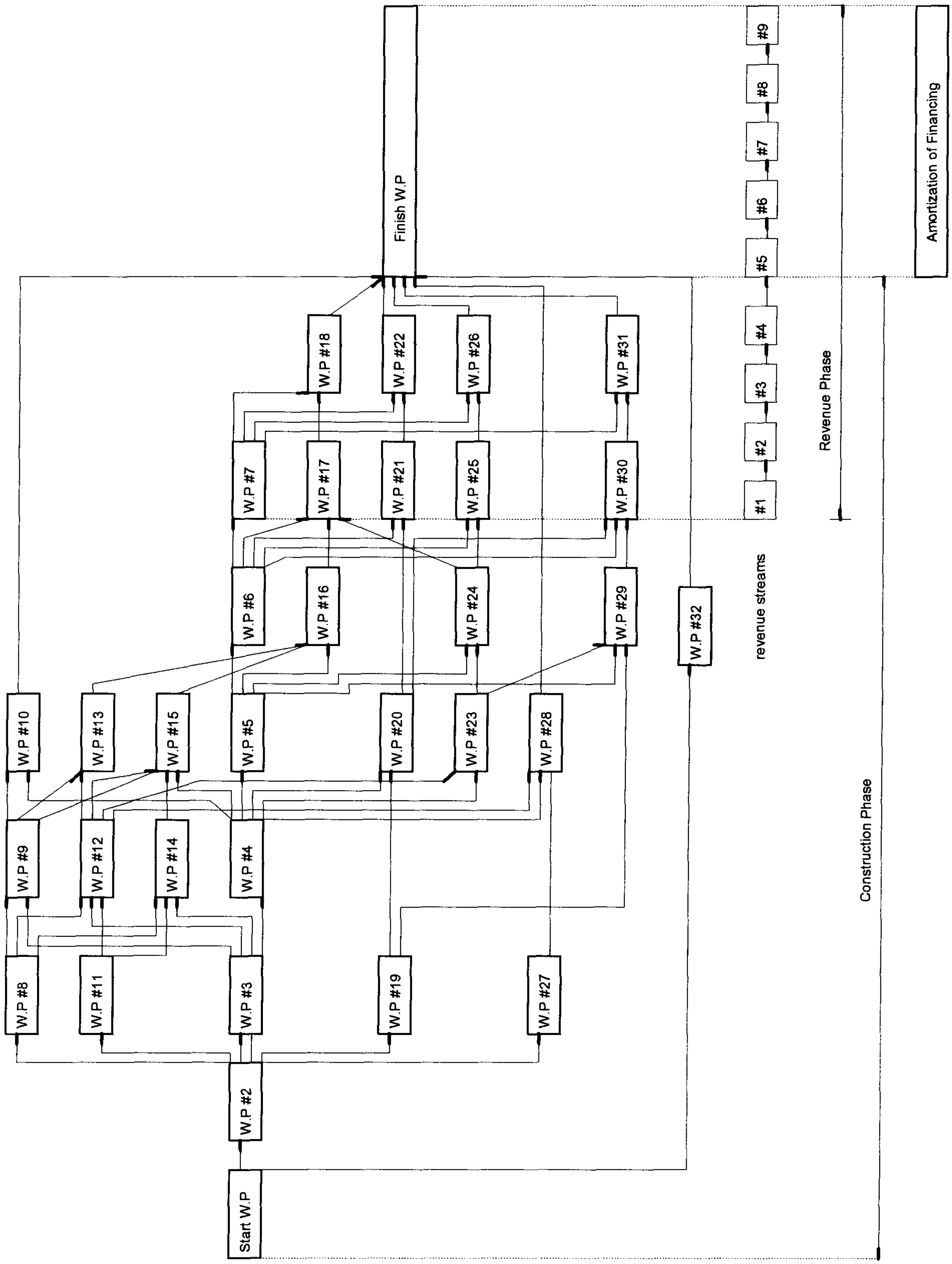

Figure 3.4 Precedence Network for the Sample Project

WP#	Work Package description	Duration (year)	Cost ($)
1	Start Work Package	-	-
2	Survey and design (1)	1.0	2,325,600
3	Survey and design (2)	0.5	1,162,800
4	Survey and design (3)	2.0	3,488,400
5	Survey and design (4)	2.0	6,201,600
6	Survey and design (5)	1.0	3,876,000
7	Survey and design (6)	2.5	2,325,600
8	Land Acquisition (1)	0.5	6,866,100
9	Land Acquisition (2)	2.0	143,043,750
10	Land Acquisition (3)	2.0	78,960,150
11	Earth Work (1)	0.5	1,256,500
12	Earth Work (2)	3.0	57,172,200
13	Earth Work (3)	1.5	67,224,400
14	Bridge (1)	3.0	46,589,500
15	Bridge (2)	1.5	82,825,900
16	Pavement (1)	1.0	30,064,700
17	Pavement (2)	1.5	6,906,700
18	Pavement (3)	1.5	3,656,500
19	Interchange (1)	2.5	17,600,300
20	Interchange (2)	3.0	34,435,400
21	Interchange (3)	1.5	15,304,600
22	Interchange (4)	1.5	9,182,800
23	Ancillary Facility (1)	0.5	8,570,100
24	Ancillary Facility (2)	1.0	16,767,700
25	Ancillary Facility (3)	1.5	7,452,300
26	Ancillary Facility (4)	1.5	4,471,400
27	Appurtenant Work (1)	2.5	18,373,100
28	Appurtenant Work (2)	3.0	22,456,000
29	Building and Repairs (1)	1.0	15,347,600
30	Building and Repairs (2)	1.5	4,514,000
31	Building and Repairs (3)	1.5	2,708,400
32	Overhead	10.5	32,099,500
33	Finish Work Package (Revenue Phase)	26.0	-
	Total Base Estimate	10.5	753,229,600

Table 3.5 Deterministic Values for Work Package Durations and Costs

WP#	Duration (year)				Constant Dollar Cost ($)			
	E[WPD]	σ_{WPD}	$\sqrt{\beta_1}$	β_2	E[C_o]	σ_{WPD}	$\sqrt{\beta_1}$	β_2
1	-	-	-	-	-	-	-	-
2	1.017	0.085	0.6	2.4	2,455,530	300,516	1.6	5.2
3	0.508	0.042	0.6	2.4	1,227,770	150,258	1.6	5.2
4	2.033	0.170	0.6	2.4	3,683,300	450,774	1.6	5.2
5	2.033	0.170	0.6	2.4	6,548,080	801,376	1.6	5.2
6	1.017	0.085	0.6	2.4	4,092,550	500,860	1.6	5.2
7	2.543	0.211	0.6	2.5	2,455,530	300,516	1.6	5.2
8	0.539	0.104	2.0	8.0	7,412,300	1,369,470	2.0	7.6
9	2.152	0.410	2.0	8.0	154,423,000	28,530,600	2.0	7.6
10	2.152	0.410	2.0	8.0	85,241,400	15,748,900	2.0	7.6
11	0.530	0.094	0.9	2.8	1,365,790	274,652	2.0	7.8
12	3.178	0.565	0.9	2.8	62,143,300	12,496,600	2.0	7.8
13	1.591	0.282	0.9	2.8	73,069,600	14,693,900	2.0	7.8
14	3.050	0.255	0.6	2.4	48,141,000	4,840,470	1.2	4.0
15	1.526	0.126	0.6	2.4	85,584,000	8,605,280	1.2	4.0
16	1.000	0.055	0.0	2.2	31,065,800	3,123,600	1.2	4.0
17	1.502	0.082	0.0	2.2	7,136,740	717,584	1.2	4.0
18	1.502	0.082	0.0	2.2	3,778,280	379,898	1.2	4.0
19	2.650	0.471	0.9	2.8	18,935,300	3,371,490	1.2	3.6
20	3.178	0.565	0.9	2.8	37,047,300	6,596,390	1.2	3.6
21	1.591	0.282	0.9	2.8	16,465,500	2,931,730	1.2	3.6
22	1.591	0.282	0.9	2.8	9,879,280	1,759,040	1.2	3.6
23	0.500	0.027	0.0	2.2	8,760,390	1,021,340	0.8	3.3
24	1.000	0.055	0.0	2.2	17,139,900	1,998,280	0.8	3.3
25	1.502	0.082	0.0	2.2	7,617,730	888,125	0.8	3.3
26	1.502	0.082	0.0	2.2	4,570,640	532,875	0.8	3.3
27	2.668	0.438	1.1	3.2	20,106,600	5,019,960	2.0	8.3
28	3.200	0.526	1.1	3.2	24,574,700	6,135,510	2.0	8.3
29	1.000	0.055	0.0	2.2	15,319,200	1,726,440	0.0	2.1
30	1.502	0.082	0.0	2.2	4,505,650	507,775	0.0	2.1
31	1.502	0.082	0.0	2.2	2,703,390	304,665	0.0	2.1
32	10.676	0.891	0.6	2.4	33,821,600	8,787,020	0.5	2.1
33	26.000	1.422	0.0	2.2	801,271,150	-	-	-

Table 3.6 Statistics for Work Package Durations and Costs

WP#	Discounted W.P. cost ($)
1	-
2	2,296,771
3	1,127,032
4	3,277,390
5	5,542,311
6	3,336,191
7	1,916,290
8	6,654,896
9	134,391,152
10	70,565,928
11	1,217,880
12	53,053,544
13	58,959,172
14	43,233,280
15	72,642,408
16	25,556,122
17	5,690,555
18	2,865,718
19	16,640,328
20	30,396,242
21	12,768,268
22	7,196,808
23	7,610,584
24	14,432,428
25	6,217,264
26	3,504,348
27	17,370,926
28	19,332,550
29	13,210,146
30	3,765,920
31	2,122,653
32	28,232,106
33	-
Total	675,127,211

Table 3.7 Discounted Work Package Costs

3.2.3 Revenue Streams

In this example, revenue streams, like work packages, are calculated using the five percentile estimate parameters. Table 3.8 shows the five percentile estimate parameters for revenue streams. Traffic volumes and inflation rates are assigned high uncertainty because of the difficulty in forecasting them. In contrast, toll growth rates involve less uncertainty than other factors because they can be controlled by the highway operators to a certain extent.

category	2.5%	5.0%	50.0%	95.0%	97.5%	$\sqrt{\beta_1}$	β_2
traffic volume	0.350	0.500	1.000	1.350	1.400	-1.0	5.9
RVS duration	0.900	0.910	1.000	1.090	1.100	0.0	2.2
toll	0.900	0.910	1.000	1.180	1.200	0.6	2.4
toll growth rate	0.800	0.850	1.000	1.050	1.060	-2.0	10.2
traffic growth rate	0.700	0.750	1.000	1.090	1.100	-1.0	3.4
road length	0.920	0.930	1.000	1.070	1.080	0.0	2.4
inflation rate	0.800	0.820	1.000	1.300	1.400	1.40	7.7
(maintenance cost)							
maintenance unit costs	0.920	0.930	1.000	1.250	1.300	1.2	4.0
cost parameter	0.900	0.910	1.000	1.250	1.300	1.0	3.4
(operation cost)							
labour cost	0.900	0.910	1.000	1.250	1.300	1.0	3.4
traffic range	0.900	0.910	1.000	1.250	1.300	1.0	3.4
number of workers	0.900	1.910	1.000	1.090	1.100	0.0	2.2
cost parameter	0.900	0.910	1.000	1.250	1.300	1.0	3.4

Table 3.8 Five Percentile Estimate Parameters for Revenue Streams

In this example, vehicles are classified into five categories: light motor vehicle, ordinary motor vehicle, medium-sized motor vehicle, large-sized motor vehicle, and special large-sized motor vehicle. Deterministic toll ratios between vehicle types are shown in Table 3.1. It is assumed that the numbers for all vehicle types grow at the same rate, and have the same distribution. In real life, for example, when a big industrial area is developed, the number of trucks may increase more than that of other vehicle types. However, in this example, this possible difference is not considered because, at least in Japan, differential traffic volume increases due to local development are not considered for feasibility analyses for regional highways, in order to avoid overestimating future traffic volumes (Japan Highway Public Corporation, 1983). However, in the model, it is possible to set different growth rates and distributions for each vehicle type.

Interchange distances are shown in Table 3.9; tolls for each vehicle type are shown in Tables 3.10 to 3.14; and spot traffic volumes are shown in Tables 3.15 to 3.19 and Figures 3.5 to 3.9 (▲ indicates base years).

(Unit : km)

					I.C. #6
				I.C. #5	4.4
			I.C. #4	3.0	7.4
		I.C. #3	6.7	9.7	14.1
	I.C. #2	3.3	10.0	13.0	17.4
I.C. #1	3.4	6.7	13.4	16.4	20.8

Table 3.9 Interchange Distances

(Unit : Dollar)

					I.C. #6
				I.C. #5	1.0
			I.C. #4	1.0	2.0
		I.C. #3	2.0	2.5	3.5
	I.C. #2	1.0	2.5	3.5	4.5
I.C. #1	1.0	2.0	3.5	4.5	5.5

Table 3.10 Toll for Light Motor Vehicle

(Unit : Dollar)

					I.C. #6
				I.C. #5	1.5
			I.C. #4	1.0	2.5
		I.C. #3	2.5	3.5	5.0
	I.C. #2	1.0	3.5	4.5	6.0
I.C. #1	1.5	2.5	4.5	5.5	7.0

Table 3.11 Toll for Ordinary Motor Vehicle

(Unit : Dollar)

					I.C. #6
				I.C. #5	1.5
			I.C. #4	1.0	2.5
		I.C. #3	2.5	3.5	5.0
	I.C. #2	1.0	3.5	4.5	6.0
I.C. #1	1.5	2.5	5.0	6.0	7.5

Table 3.12 Toll for Medium-sized Motor Vehicle

(Unit : Dollar)

					I.C. #6
				I.C. #5	2.5
			I.C. #4	1.5	4.0
		I.C. #3	3.5	5.0	7.5
	I.C. #2	1.5	5.0	6.5	9.0
I.C. #1	2.0	3.5	7.0	8.5	11.0

Table 3.13 Toll for Large-sized Motor Vehicle

(Unit : Dollar)

					I.C. #6
				I.C. #5	4.0
			I.C. #4	3.0	7.0
		I.C. #3	6.0	9.0	13.0
	I.C. #2	3.0	9.0	12.0	16.0
I.C. #1	3.0	6.0	12.0	15.0	19.0

Table 3.14 Toll for Special Large-sized Motor Vehicle

The toll rate is assumed to increase every three years in proportion to one half of the inflation rate, giving an increase of approximately 2% per year.

Year	RVS #	Daily Traffic Volume (vehicles/day)
1	1	0
2	2	0
3	3	0
4	4	0
5	5	11,266
6		11,419
7	6	12,084
8		12,340
9	7	15,246
10		15,556
11		15,844
12		16,179
13	8	31,337
14		31,912
15		32,429
16		33,011
17	9	33,090
18		33,510
19		33,884
20		34,362
21		34,786
22		35,167
23		35,590
24		36,010
25		36,442
26		36,862
27		37,284
28		37,666
29		38,082
30		38,559

Table 3.15 Spot Traffic Volume between Interchange #1 and #2

Year	RVS #	Daily Traffic Volume (vehicles/day)
1	1	0
2	2	12,200
3	3	18,769
4	4	20,512
5	5	26,247
6		26,601
7	6	27,985
8		28,583
9	7	31,293
10		31,936
11		32,536
12		33,232
13	8	46,416
14		47,274
15		48,064
16		48,933
17	9	49,717
18		50,363
19		50,938
20		51,668
21		52,324
22		52,908
23		53,558
24		54,205
25		54,857
26		55,509
27		56,156
28		56,741
29		57,381
30		58,112

Table 3.16 Spot Traffic Volume between Interchange #2 and #3

Year	RVS #	Daily Traffic Volume (vehicles/day)
1	1	17,462
2	2	20,271
3	3	24,307
4	4	26,114
5	5	30,098
6		30,500
7	6	32,233
8		32,928
9	7	35,348
10		36,076
11		36,760
12		37,545
13	8	49,423
14		50,342
15		51,185
16		52,110
17	9	52,385
18		53,068
19		53,686
20		54,457
21		55,146
22		55,772
23		56,456
24		57,146
25		57,837
26		58,534
27		59,217
28		59,838
29		60,519
30		61,293

Table 3.17 Spot Traffic Volume between Interchange #3 and #4

Year	RVS #	Daily Traffic Volume (vehicles/day)
1	1	22,212
2	2	24,960
3	3	28,421
4	4	30,591
5	5	32,386
6		32,819
7	6	34,763
8		35,518
9	7	39,651
10		40,475
11		41,251
12		42,137
13	8	53,704
14		54,712
15		55,640
16		56,647
17	9	57,008
18		57,768
19		58,441
20		59,290
21		60,052
22		60,733
23		61,487
24		62,246
25		63,007
26		63,775
27		64,530
28		65,215
29		65,964
30		66,808

Table 3.18 Spot Traffic Volume between Interchange #4 and #5

Year	RVS #	Daily Traffic Volume (vehicles/day)
1	1	22,943
2	2	24,572
3	3	28,740
4	4	31,723
5	5	33,716
6		34,174
7	6	35,470
8		36,213
9	7	44,827
10		45,731
11		46,571
12		47,546
13	8	56,263
14		57,298
15		58,241
16		59,276
17	9	60,356
18		61,127
19		61,812
20		62,681
21		63,451
22		64,148
23		64,916
24		65,679
25		66,475
26		67,246
27		68,010
28		68,708
29		69,471
30		70,338

Table 3.19 Spot Traffic Volume between Interchange #5 and #6

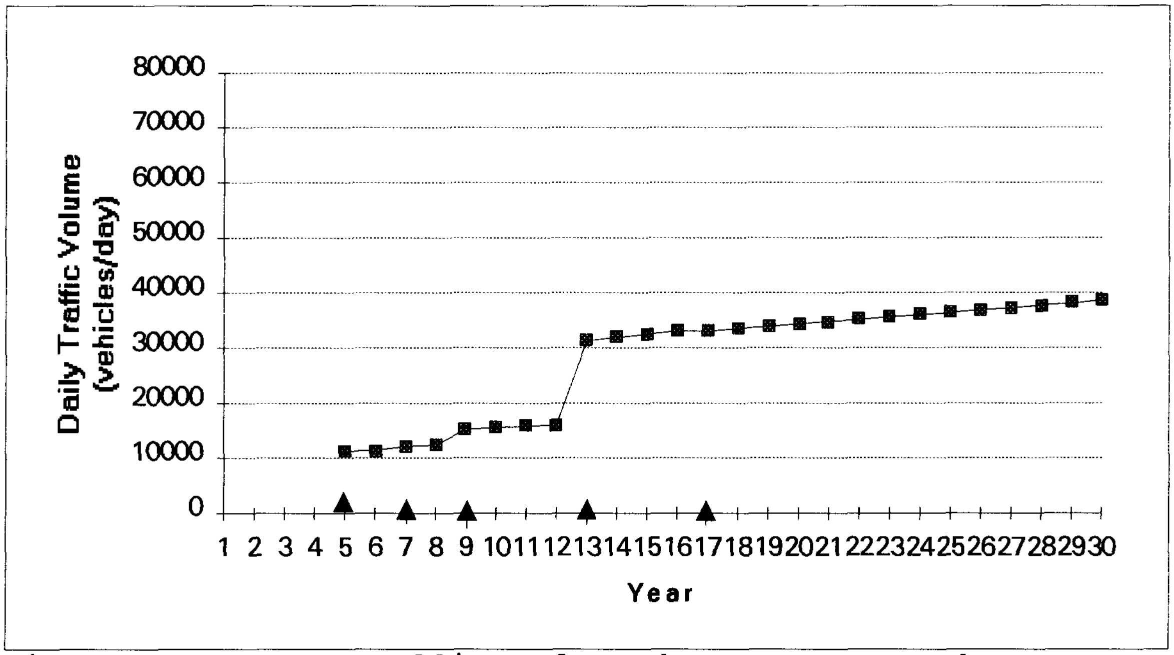

Figure 3.5 Spot Traffic Volume between Interchange #1 and #2

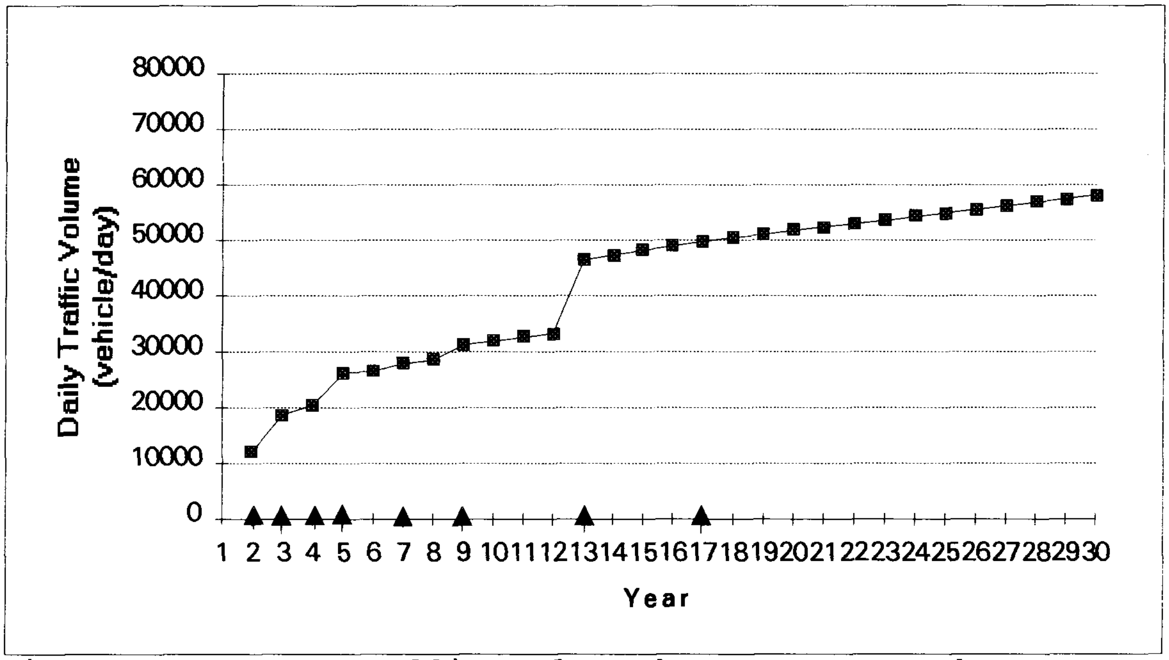

Figure 3.6 Spot Traffic Volume between Interchange #2 and #3

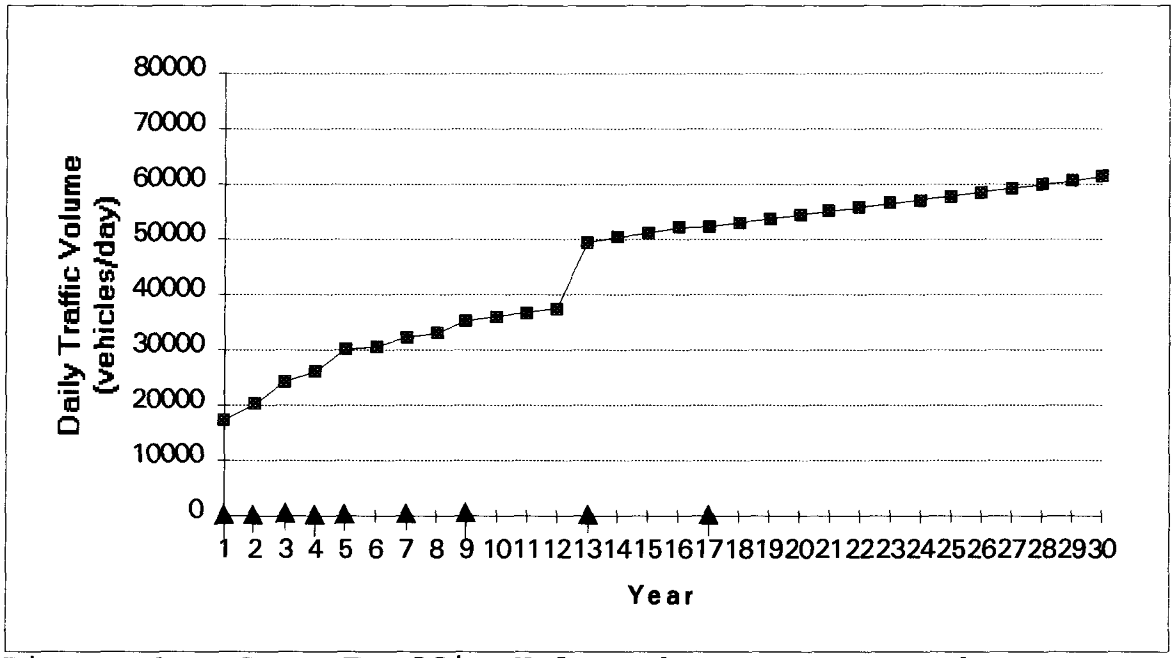

Figure 3.7 Spot Traffic Volume between Interchange #3 and #4

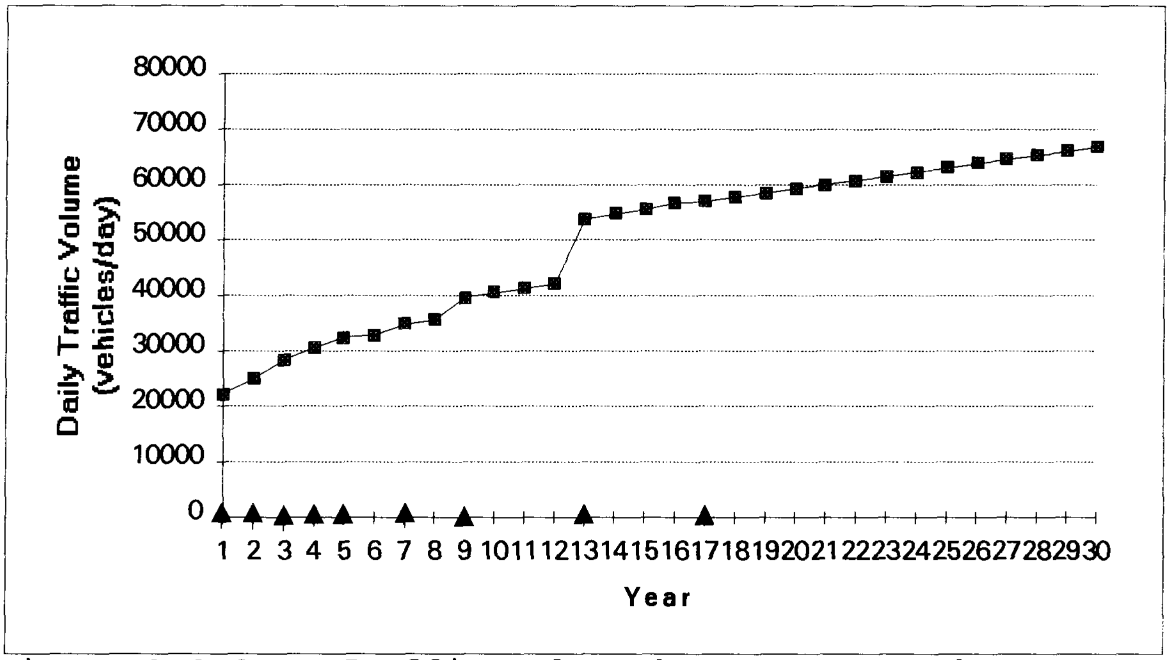

Figure 3.8 Spot Traffic Volume between Interchange #4 and #5

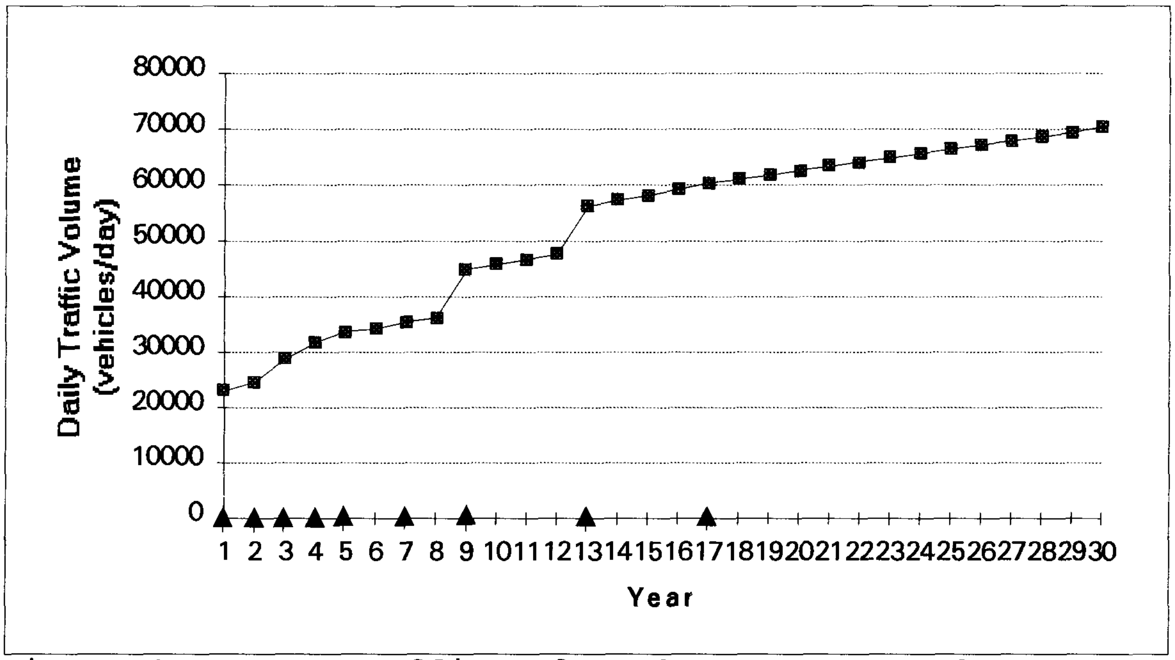

Figure 3.9 Spot Traffic Volume between Interchange #5 and #6

Appendix C contains interchange pair traffic volumes in base years, traffic volume growth parameters, and toll rate growth parameters. Appendix B contains other more detailed input data.

Table 3.20 shows deterministic annual revenues and annual maintenance and operating costs (constant dollar). A total of nine revenue streams corresponding to nine different base years are used to describe the project. Each revenue stream includes all vehicle types and all increases in traffic volumes and toll rates for that revenue stream's duration. Table 3.21 shows the deterministic discounted revenues which form parts of the conventional analysis. They will be used later to compare with the probabilistic results.

RVS #	year	annual revenues($)	annual operation costs ($)
1	1	36,241,000	6,908,380
2	1	45,332,800	8,011,250
3	1	54,980,500	9,091,350
4	1	62,667,200	9,370,250
5	1	74,931,300	10,534,000
	2	75,820,300	10,549,100
6	1	84,904,900	11,049,400
	2	86,729,300	16,780,200
7	1	98,677,500	12,799,500
	2	106,880,000	13,087,200
	3	108,875,000	13,121,100
	4	111,036,000	16,405,300
8	1	162,106,000	15,211,800
	2	164,962,000	15,556,800
	3	168,057,000	15,905,900
	4	181,374,000	22,029,700
9	1	182,462,000	16,546,000
	2	184,958,000	16,786,100
	3	198,918,000	17,023,400
	4	201,567,000	17,068,500
	5	203,951,000	17,109,000
	6	219,245,000	17,698,200
	7	222,056,000	18,042,400
	8	224,866,000	27,284,400
	9	241,621,000	19,017,300
	10	244,604,000	19,068,000
	11	247,587,000	19,118,700
	12	265,904,000	19,430,100
	13	268,753,000	19,478,500
	14	271,918,000	19,532,400
Total		4,801,984,800	469,614,230

Table 3.20 Deterministic Annual Revenues and Annual Maintenance and Operating Costs (Constant Dollar)

RVS #	Discounted Revenues ($)
1	17,197,658
2	20,396,808
3	23,375,566
4	25,423,164
5	55,608,140
6	51,585,960
7	108,936,328
8	137,441,792
9	341,720,064
Total	781,685,480

Table 3.21 Discounted Revenues for the Original Feasibility Analysis

3.2 4 Calculation Results

Tables 3.22 to 3.24 show the statistics evaluated from the analytical approach.

WP#	Discounted Work Package Costs ($)			
	E[Cost]	σ_{WPD}	skewness	kurtosis
1	-	-	-	-
2	2,426,922	307,731	1.441	4.531
3	1,191,287	150,934	1.445	4.542
4	3,466,470	440,294	1.436	4.492
5	5,868,715	754,482	1.397	4.343
6	3,536,048	461,781	1.356	4.207
7	2,033,763	272,631	1.302	4.035
8	7,189,650	1,348,819	1.909	7.139
9	145,033,968	27,284,032	1.895	7.057
10	75,812,112	14,369,514	1.856	6.844
11	1,324,929	269,923	1.923	7.392
12	57,561,288	11,775,636	1.898	7.265
13	63,972,888	13,181,744	1.862	7.055
14	44,655,704	4,762,571	1.019	3.246
15	74,626,536	8,225,747	0.966	3.121
16	26,237,010	2,963,008	0.949	3.080
17	5,850,180	678,961	0.941	3.062
18	2,967,196	359,682	0.953	3.090
19	17,908,290	3,250,705	1.132	3.537
20	32,546,888	5,980,267	1.099	3.450
21	13,645,265	2,546,414	1.070	3.375
22	7,766,000	1,478,051	1.046	3.314
23	7,775,125	965,464	0.687	2.596
24	14,761,998	1,853,530	0.691	2.573
25	6,365,913	814,869	0.691	2.572
26	3,606,331	483,579	0.712	2.609
27	19,014,506	4,794,670	1.944	7.957
28	2,111,917	5,374,707	1.890	7.655
29	13,193,518	1,609,108	0.057	2.004
30	3,731,328	469,362	0.108	2.014
31	2,128,250	278,937	0.208	2.052
32	29,856,906	7,878,655	0.479	2.275
33	-	-	-	-

Table 3.22 Statistics for Discounted Work Package Costs

RS#	Discounted Revenues ($)			
	E[Revenue]	σ_{WPD}	skewness	kurtosis
1	16,309,014	3,070,476	-0.579	2.402
2	19,234,812	3,085,872	-0.576	2.398
3	22,230,906	3,676,449	-0.565	2.384
4	23,743,590	3,901,506	-0.557	2.372
5	50,141,572	8,278,854	-0.111	2.015
6	46,100,320	8,457,769	-0.106	2.013
7	98,181,080	18,919,314	0.252	2.076
8	124,448,704	23,890,288	0.210	2.053
9	305,117,600	69,715,768	0.246	2.073

Table 3.23 Statistics for Discounted Revenues

	Mean	σ_{WPD}	skewness	kurtosis
Project Duration (month)	135.77	7.21	0.700	3.600
Project Cost ($)	717,174,144	39,283,612	0.876	4.100
Project Revenue ($)	705,507,584	77,309,352	0.190	1.411
NPV($)	-11,666,560	86,717,576	0.053	2.043

Table 3.24 Statistics for Project Duration, Discounted Project Cost, Project Revenue, and Project Net Present Value(NPV)

Cumulative probabilities of derived variables at the project performance level and the project decision level are described below.

(1) Project Duration

Table 3.25 and Figure 3.10 present the cumulative probability of the project duration.

According to the original deterministic estimate, the project duration was 126 months. However, this analytical model indicates that the expected project duration is 135.77 months, and the standard deviation is 7.21 months. The project duration is projected to be about 10 months longer than was indicated by the original deterministic feasibility analysis.

Cumulative Probability(%)	Project Duration (month)
0.25	121.69
0.50	122.31
1.00	123.05
2.50	124.32
5.00	125.57
10.00	127.22
25.00	130.49
50.00	134.89
75.00	140.11
90.00	145.47
95.00	148.97
97.50	152.16
99.00	156.04
99.50	158.77
99.75	161.38

Table 3.25 Cumulative Probability of Project Duration

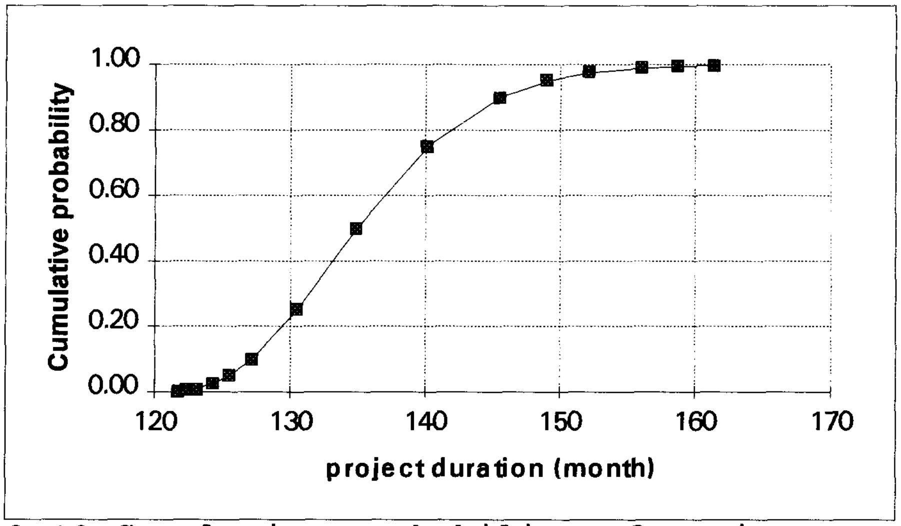

Figure 3.10 Cumulative Probability of Project Duration

(2) Project Costs

Table 3.26 and Figure 3.11 present the cumulative probability of the project cost.

According to the original deterministic estimate, the discounted project cost was $675,127,211. However, this analytical model indicates that the expected project cost is $717,174,144, and the standard deviation is $39,283,612. The project cost is projected to be about $42,000,000 more than was indicated by the original deterministic feasibility analysis.

Cumulative Probability(%)	Project Cost ($)
0.25	606905024.00
0.50	615987392.00
1.00	625788672.00
2.50	640178240.00
5.00	652556544.00
10.00	666828288.00
25.00	690677376.00
50.00	717174144.00
75.00	743670912.00
90.00	767520000.00
95.00	781791744.00
97.50	794170048.00
99.00	808559616.00
99.50	818360896.00
99.75	827443264.00

Table 3.26 Cumulative Probability of Project Cost

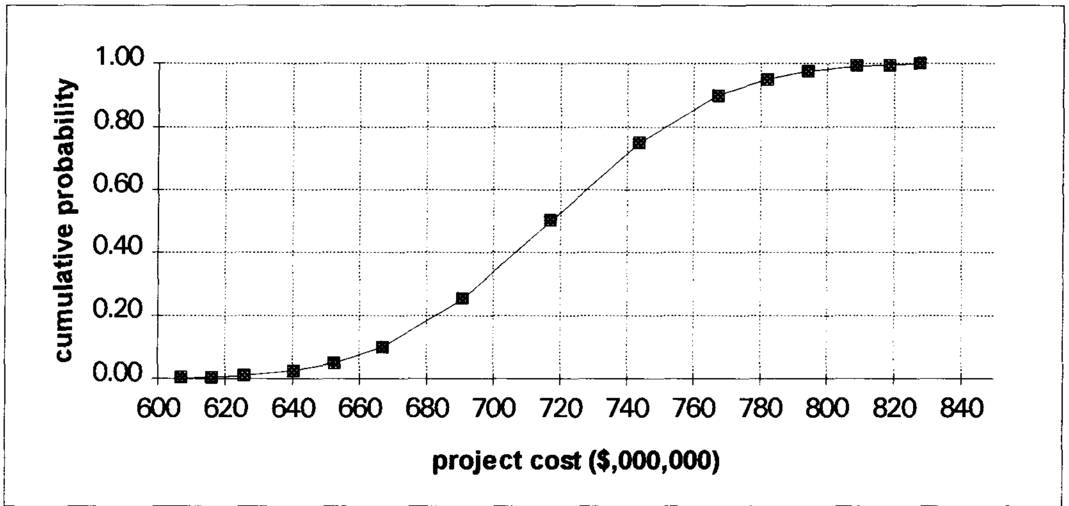

Figure 3.11 Cumulative Probability of Project Cost

(3) Project Revenue

Table 3.27 and Figure 3.12 present the cumulative probability of the project revenue.

According to the original deterministic estimate, the discounted project revenue was $781,685,480. However, this analytical model indicates that the expected project revenue is $705,507,584, and the standard deviation is $77,309,352.

The project revenue is projected to be about $76,000,000 less than was indicated by the original deterministic feasibility analysis.

Cumulative Probability(%)	Project Revenue ($)
0.25	488500224.00
0.50	506374144.00
1.00	525662848.00
2.50	553981248.00
5.00	578341440.00
10.00	606427904.00
25.00	653362432.00
50.00	705507584.00
75.00	757652736.00
90.00	804587264.00
95.00	832673728.00
97.50	857033920.00
99.00	885352320.00
99.50	904641024.00
99.75	922514944.00

Table 3.27 Cumulative Probability of Project Revenue

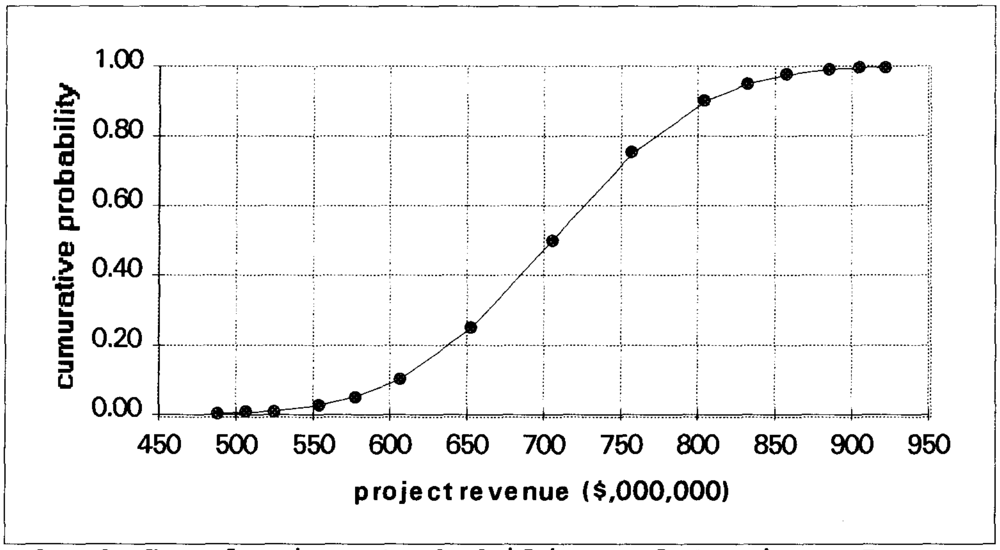

Figure 3.12 Cumulative Probability of Project Revenue

(4) Net Present Value

Table 3.28 and Figure 3.13 present the cumulative probability of the Project Net Present Value (NPV).

According to the original deterministic estimate, the NPV was $106,558,269. However, this analytical model indicates that the expected NPV is -$11,666,560, and the standard deviation is $86,717,576.

The NPV is projected to be about $118,000,000 less than was indicated by the original deterministic feasibility analysis.

Cumulative Probability(%)	NPV ($)
0.25	-255082800.00
0.50	-235033696.00
1.00	-213397664.00
2.50	-181633008.00
5.00	-154308304.00
10.00	-122803808.00
25.00	-70157568.00
50.00	-11666560.00
75.00	46824444.00
90.00	99470688.00
95.00	130975184.00
97.50	158299888.00
99.00	190064544.00
99.50	211700576.00
99.75	231749680.00

Table 3.28 Cumulative Probability of Project Net Present Value

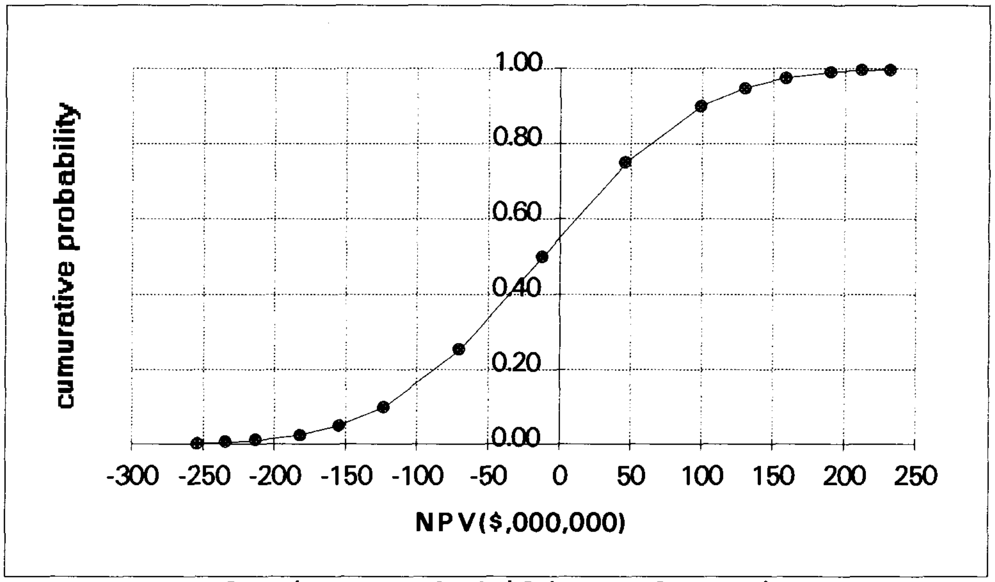

Figure 3.13 Cumulative Probability of Project Net Present Value

3.3 Sensitivity Analysis

3.3.1 Results

This section describes the sensitivity analysis for the sample project. The analytical model requires subjective estimates of primary variables whose accuracy can affect the entire analysis. Therefore, it is important to identify the sensitivity of each primary variable, and to be very careful when highly sensitive variables are estimated. The purpose of sensitivity analysis is to identify how much a change in a primary variable affects the derived variable. In this section, the focus is on revenue streams.

The sensitivity of a primary variable is measured by the total sensitivity coefficient for that variable. The general idea of sensitivity analysis is as follows.

The sensitivity of the derived variable whose functional form is given by $Y = g(X)$ is described as (Russell, 1992),

$$\frac{\Delta Y}{Y} \cong \sum_i S_i \frac{\Delta X_i}{X_i} \tag{3.1}$$

where $\frac{\Delta Y}{Y}$ and $\frac{\Delta X_i}{X_i}$ are the percent changes in Y and X_i respectively, and S_i is the total sensitivity coefficient, which is defined as (Russell, 1992),

$$Si = \frac{\partial Y}{\partial X_i} \frac{X_i}{Y} \tag{3.2}$$

where $\frac{\partial Y}{\partial X_i}$ is the sensitivity coefficient of Y with respect to X_i.

Because moment analysis is based on the truncated Taylor series expansion of $g(X)$, the partial derivatives with respect to primary variables are evaluated. However, since the analytical method transforms the primary variables X to Z and $g(X)$ to $G(Z)$ prior to using the Taylor series expansion, the sensitivity coefficients are evaluated with respect to the transformed variables.

$$\frac{\Delta Y}{Y} \cong \sum_i S_i \frac{\Delta Z_i}{Z_i} \tag{3.3}$$

$$Si = \frac{\partial Y}{\partial Z_i} \frac{Z_i}{Y} \tag{3.4}$$

In this section, revenue streams are considered as derived variables. Highly sensitive primary variables for each derived variable are shown in Tables 3.29 to 3.37.

(Deterministic Duration Estimate : 1 year)

Ranking	Primary Variable	S_i
1	parameter (toll rate growth)	1.32811
2	RVS early start time	-0.526802
3	toll(Ic#3-#6, vehicle-2)	0.453709
3	traffic volume (Ic#3-#6, vehicle-2)	0.453709
5	parameter (consignment cost of toll collection)	-0.185005
6	labor cost (toll collection)	-0.185002
7	toll(Ic#3-#5, vehicle-2)	0.135406
7	traffic volume (Ic#3-#5, vehicle-2)	0.135406
9	toll(Ic#3-#6, vehicle-1)	0.106513
9	toll(Ic#3-#6, vehicle-1)	0.106513
11	inflation rate	-0.104595

Table 3.29 Total sensitivity Coefficients for RVS #1

(Deterministic Duration Estimate : 1 year)

Ranking	Primary Variable	S_i
1	parameter (toll rate growth)	1.32186
2	RVS early start time	-0.606351
3	toll (Ic#2-#6, vehicle-2)	0.274935
3	traffic volume (Ic#2-#6, vehicle-2)	0.274935
5	labor cost (toll collection)	-0.180724
5	parameter (consignment cost of toll collection)	-0.180724
7	toll(Ic#3-#6, vehicle-2)	0.172023
7	traffic volume (Ic#3-#6, vehicle-2)	0.172023
9	inflation rate	-0.117903
10	the number of toll collection clerks	-0.114262
11	toll(Ic#2-#5, vehicle-2)	0.108815
11	traffic volume (Ic#2-#5, vehicle-2)	0.108815

Table 3.30 Total sensitivity Coefficients for RVS #2

(Deterministic Duration Estimate : 1 year)

Ranking	Primary Variable	S_i
1	parameter (toll rate growth)	1.28879
2	RVS early start time	-0.675688
3	toll (Ic#2-#6, vehicle-2)	0.325839
3	traffic volume (Ic#2-#6, vehicle-2)	0.325839
5	labor cost (toll collection)	-0.166774
5	parameter (consignment cost of toll collection)	-0.166774
7	toll (Ic#2-#5, vehicle-2)	0.125868
7	traffic volume (Ic#2-#5, vehicle-2)	0.125868
9	toll (Ic#3-#6, vehicle-2)	0.123317
9	traffic volume toll (Ic#3-#6, vehicle-2)	0.123317
11	inflation rate	-0.120515

Table 3.31 Total sensitivity Coefficients for RVS #3

(Deterministic Duration Estimate : 1 year)

Ranking	Primary Variable	S_i
1	parameter (toll rate growth)	1.28737
2	RVS early start time	-0.755225
3	toll (Ic#2-#6, vehicle-2)	0.313043
3	traffic volume (Ic#2-#6, vehicle-2)	0.313043
5	labor cost (toll collection)	-0.169169
5	parameter (consignment cost of toll collection)	-0.169169
7	inflation rate	-0.133920
8	toll (Ic#2-#5, vehicle-2)	0.125191
8	traffic volume (Ic#2-#5, vehicle-2)	0.125191
10	toll (Ic#3-#6, vehicle-2)	0.105923
10	traffic volume (Ic#3-#6, vehicle-2)	0.105923

Table 3.32 Total sensitivity Coefficients for RVS #4

(Deterministic Duration Estimate : 2 year)

Ranking	Primary Variable	S_i
1	RVS early start time	-0.884902
2	parameter (toll rate growth) the first year	0.659903
3	parameter (traffic growth) the first year	-0.624994
4	parameter (toll rate growth) the second year	0.624937
5	parameter (traffic growth) the second year	0.624933
6	traffic volume (Ic#2-#6, vehicle-2)	0.228876
7	toll (Ic#2-#6, vehicle-2)	0.228872
8	parameter (consignment cost of toll collection)	-0.168755
9	labor cost (toll collection)	-0.168751
10	inflation rate	-0.162603
11	toll (Ic#1-#6, vehicle-2)	0.117991
11	traffic volume (Ic#1-#6, vehicle-2)	0.117991

Table 3.33 Total sensitivity Coefficients for RVS #5

(Deterministic Duration Estimate : 2 year)

Ranking	Primary Variable	S_i
1	RVS early start time	-1.10177
2	parameter (toll rate growth) the first year	0.710231
3	parameter (traffic growth) the first year	-0.679008
4	parameter (toll rate growth) the second year	0.678934
5	parameter (traffic growth) the second year	0.678929
6	inflation rate	-0.255841
7	traffic volume (Ic#2-#6, vehicle-2)	0.237182
8	toll (Ic#2-#6, vehicle-2)	0.237177
9	parameter (consignment cost of toll collection)	-0.179586
10	labor cost (toll collection)	-0.179581
11	toll(Ic#1-#6, vehicle-2)	0.124552
12	traffic volume (Ic#1-#6, vehicle-2)	0.124552

Table 3.34 Total sensitivity Coefficients for RVS #6

(Deterministic Duration Estimate : 4 year)

Ranking	Primary Variable	S_i
1	RVS early start time	-1.23521
2	parameter (traffic growth) the first year	-0.992122
3	parameter (traffic growth) the second year	0.346556
4	parameter (toll rate growth) the second year	0.346552
5	parameter (toll rate growth) the first year	0.341947
6	parameter (traffic growth) the third year	0.330304
7	parameter (toll rate growth) the third year	0.330300
8	parameter (toll rate growth) the fourth year	0.315163
8	parameter (traffic growth) the fourth year	0.315163
10	inflation rate	-0.272465
11	traffic volume (Ic#2-#6, vehicle-2)	0.203149
12	toll (Ic#2-#6, vehicle-2)	0.203153
13	labor cost (toll collection)	-0.192027
13	parameter (consignment cost of toll collection)	-0.192027
15	toll (Ic#1-#6, vehicle-2)	0.136613
15	traffic volume (Ic#1-#6, vehicle-2)	0.136613

Table 3.35 Total sensitivity Coefficients for RVS #7

(Deterministic Duration Estimate : 4 year)

Ranking	Primary Variable	S_i
1	RVS early start time	-1.52193
2	parameter (traffic growth) the first year	-0.942056
3	parameter (toll rate growth) the first year	0.339475
4	parameter (toll rate growth) the second year	0.323165
4	parameter (traffic growth) the second year	0.323165
6	parameter (traffic growth) the fourth year	0.310871
7	parameter (toll rate growth) the fourth year	0.310868
8	parameter (traffic growth) the third year	0.307962
9	parameter (toll rate growth) the third year	0.307955
10	inflation rate	-0.295489
11	traffic volume (Ic#1-#6, vehicle-2)	0.179443
12	toll (Ic#1-#6, vehicle-2)	0.179440
13	labor cost (toll collection)	-0.162416
13	parameter (consignment cost of toll collection)	-0.162416
15	toll (Ic#2-#6, vehicle-2)	0.126082
15	traffic volume (Ic#2-#6, vehicle-2)	0.126082
17	toll (Ic#1-#6, vehicle-4)	0.126033
17	traffic volume (Ic#1-#6, vehicle-4)	0.126033

Table 3.36 Total sensitivity Coefficients for RVS #8

(Deterministic Duration Estimate : 14 year)

Ranking	Primary Variable	S_i
1	RVS early start time	-1.91796
2	parameter (traffic growth) the first year	-1.21835
3	inflation rate	-0.520859
4	labor cost (toll collection)	-0.210106
4	parameter (consignment cost of toll collection)	-0.210106
6	traffic volume (Ic#1-#6, vehicle-2)	0.181898
6	toll (Ic#1-#6, vehicle-2)	0.181898
8	toll (Ic#2-#6, vehicle-2)	0.133843
8	traffic volume (Ic#2-#6, vehicle-2)	0.133843
10	toll (Ic#1-#6, vehicle-4)	0.122000
10	traffic (Ic#1-#6, vehicle-4)	0.122000
12	parameter (toll rate growth) the first year	0.118742
13	parameter (toll rate growth) the second year	0.112559
13	parameter (traffic growth) the second year	0.112559
15	parameter (toll rate growth) the third year	0.113193
15	parameter (traffic growth) the third year	0.113193
17	parameter (toll rate growth) the fourth year	0.107248
17	parameter (traffic growth) the fourth year	0.107248
19	toll (Ic#1-#5, vehicle-4)	0.102694
19	traffic volume (Ic#1-#5, vehicle-4)	0.102694
21	parameter (toll rate growth) the fifth year	0.101456
21	parameter (traffic growth) the fifth year	0.101456
23	parameter (toll rate growth) the sixth year	0.101953
23	parameter (traffic growth) the sixth year	0.101953

Table 3.37 Total sensitivity Coefficients for RVS #9

3.3.2 Summary of Sensitivity Analysis

Although there are some differences between the revenue streams, it can be said that the following factors demonstrate high sensitivity in most cases:

- revenue stream early start time;
- toll rate growth parameter;
- traffic volume growth parameter;
- tolls and traffic volume;
- inflation rate; and
- parameter for consignment cost of toll collection.

In addition to the above, revenue stream durations affect the sensitivity coefficients of toll rate growth and traffic volume growth parameters.

3.4 Summary

This chapter applied the analytical model to a real deterministic feasibility study for a large toll highway project. The project NPV of the original deterministic feasibility study indicated that this project was feasible. However, the analytical model indicates the likelihood of delay and cost overrun, and shows negative NPV. This project should be reexamined and reconsidered.

Because this model has the capacity to measure uncertainty, and to investigate the sensitivity of the project performance to changes in primary variables for a toll highway project, it is useful for feasibility analyses both in the preliminary and detailed stages of analysis.

Chapter 4

Risk Management

4.1 General

This chapter examines strategies for risk management and explores their impact on overall project risks. In order to manage risks, it is important for the private sector and/or quasi-public corporations to negotiate risk sharing with the government. Beesley and Hensher (1990) describe some of risks that should be considered.

They are:

- termination risks that involve negotiating the residual value and takeback date when the project is handed over to the government;
- regulation risks that primarily involve consideration of possible changes such as ones in existing regulations and the political ideology of the government which affects price control;
- construction risks which include the usual engineering risks associated with construction; and

- information risks that concern the reliability of traffic forecasts.

Among these risks, only economic risks are addressed here, and the focus is on risk management for the revenue phase.

Uncertainty surrounding estimates for the revenue phase is related to:

- time estimates for work packages and revenue streams (e.g. productivity and quantity);
- revenue estimates (e.g. interchange pair traffic volume for different vehicle types, toll rate, and operating costs); and
- prediction of economic factors (e.g. inflation rate and interest rate).

Section two presents possible ways of reducing the uncertainty; section three attempts to quantify their effects; and section four presents conclusions.

4.2 Strategies for Risk Management

One of the most effective ways of decreasing risk seems to be to reduce the uncertainty of variables that performance (e.g. net present value) is highly sensitive to. According to the results of the sensitivity analysis in chapter 3, they are:

(1) revenue stream early start time;

(2) toll rate growth parameters;

(3) traffic volume growth parameters;

(4) tolls;

(5) traffic volume;

(6) inflation rate; and

(7) parameter for consignment cost of toll collection.

In this section, strategies for tightening distributions for the above variables are discussed, and the effects of tighter distributions on overall project risks are examined. The range of each distribution is decreased by half. As mentioned in chapter 3, the five percentile estimate parameters are used for this sample project. Therefore, the range of each distribution is indicated by the parameters. For convenience, the original sample project is called case-1. In each case except case-9, the distribution of variables changes in one category only in order to examine an individual effect. Cumulative effects are not considered until case-9.

4.2.1 Revenue Stream Early Start Time (case-2)

A tightening of the distribution describing revenue stream early start time is considered here. The following are possible strategies for tightening the distributions for revenue stream early start time:

- to use modern construction management techniques for better time management of the design and construction phase; and

- to add clauses such as penalty clauses for delays, in order to encourage contractors to meet deadlines in contracts.

Table 4.1 shows the parameters for case-1, and Table 4.2 shows ones for case-2.

category	2.5%	5.0%	50.0%	95.0%	97.5%	$\sqrt{\beta_1}$	β_2
survey & design	0.900	0.910	1.000	1.180	1.200	0.6	2.4
land acquisition	0.900	0.910	1.000	1.500	1.650	2.0	8.0
earth work	0.850	0.870	1.000	1.450	1.500	0.9	2.8
bridge	0.900	0.910	1.000	1.180	1.200	0.6	2.4
pavement	0.900	0.910	1.000	1.090	1.100	0.0	2.2
IC	0.850	0.870	1.000	1.450	1.500	0.9	2.8
ancillary facilities	0.900	0.910	1.000	1.090	1.100	0.0	2.2
appurtenant work	0.900	0.910	1.000	1.450	1.500	1.1	3.2
building & repairing	0.900	0.910	1.000	1.090	1.100	0.0	2.2
overhead	0.900	0.910	1.000	1.180	1.200	0.6	2.4
revenue phase duration	0.900	0.910	1.000	1.090	1.100	0.0	2.2

Table 4.1 Five Percentile Estimate Parameters for W.P. Durations (case-1)

category	2.5%	5.0%	50.0%	95.0%	97.5%	$\sqrt{\beta_1}$	β_2
survey & design	0.950	0.955	1.000	1.090	1.100	0.6	2.4
land acquisition	0.950	0.955	1.000	1.280	1.325	1.5	4.8
earth work	0.925	0.930	1.000	1.200	1.250	1.4	5.3
bridge	0.950	0.955	1.000	1.090	1.100	0.6	2.4
pavement	0.950	0.955	1.000	1.045	1.050	0.0	2.2
IC	0.925	0.930	1.000	1.200	1.250	1.4	5.3
ancillary facilities	0.950	0.955	1.000	1.045	1.050	0.0	2.2
appurtenant work	0.950	0.960	1.000	1.200	1.250	1.7	6.3
building & repairing	0.950	0.955	1.000	1.045	1.050	0.0	2.2
overhead	0.950	0.955	1.000	1.090	1.10	0.6	2.4
revenue phase duration	0.950	0.955	1.000	1.045	1.050	0.0	2.2

Table 4.2 Five Percentile Estimate Parameters for W.P. Durations (case-2)

Tables 4.3, 4.4, and Figure 4.1 show the comparison between the two cases in terms of the project revenue, and Tables 4.5, 4.6, and Figure 4.2 show the comparison between the two cases in terms of the project NPV. Mean value and standard deviation of the early start time of the first revenue for case-1 are 7.56 years and 0.523 years respectively, and those for case-2 are 7.25 years and 0.258 years respectively.

case	mean	σ	skewness	kurtosis
1	705,507,584	77,309,352	0.190	1.411
2	729,199,360	74,547,520	0.241	1.495

Table 4.3 Comparison of the Project Revenue (case-1 and case-2)

cumulative probability(%)	Case 1 ($,000,000)	Case 2 ($,000,000)
0.25	488.5	519.9
0.50	506.4	537.2
1.00	525.7	555.8
2.50	554.0	583.1
5.00	578.3	606.6
10.00	606.4	633.7
25.00	653.4	678.9
50.00	705.5	729.2
75.00	757.7	779.5
90.00	804.9	824.7
95.00	832.7	851.8
97.50	857.0	875.3
99.00	885.4	902.6
99.50	904.6	921.2
99.75	922.5	938.5

Table 4.4 Cumulative Probability of the Project Revenue (case-1 and case-2)

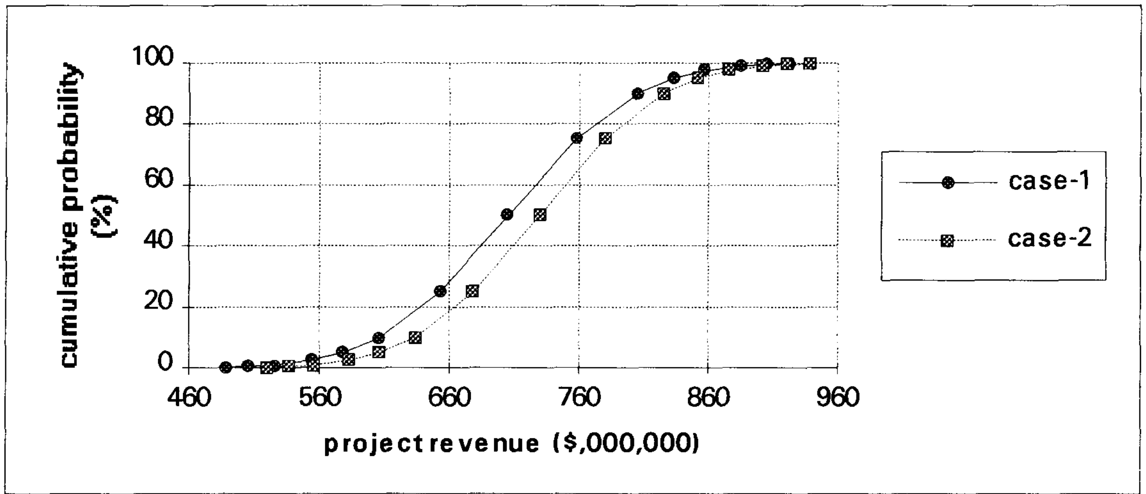

Figure 4.1 Cumulative Probability of the Project Revenue (case-1 and case-2)

case	mean	σ	skewness	kurtosis
1	-11,666,560	86,717,576	0.053	2.043
2	9,563,840	84,254,624	0.078	2.131

Table 4.5 Comparison of the Project NPV (case-1 and case-2)

Cumulative Probability (%)	Case 1 ($,000,000)	Case 2 ($,000,000)
0.25	-255.1	-226.9
0.50	-235.0	-207.5
1.00	-213.4	-186.4
2.50	-181.6	-155.6
5.00	-154.3	-129.0
10.00	-122.8	-98.4
25.00	-70.2	-47.3
50.00	-11.7	9.6
75.00	46.8	66.4
90.00	99.5	117.5
95.00	131.0	148.2
97.50	158.3	174.7
99.00	190.1	205.6
99.50	211.7	226.6
99.75	231.7	246.1

Table 4.6 Cumulative Probability of the Project NPV (case-1 and case-2)

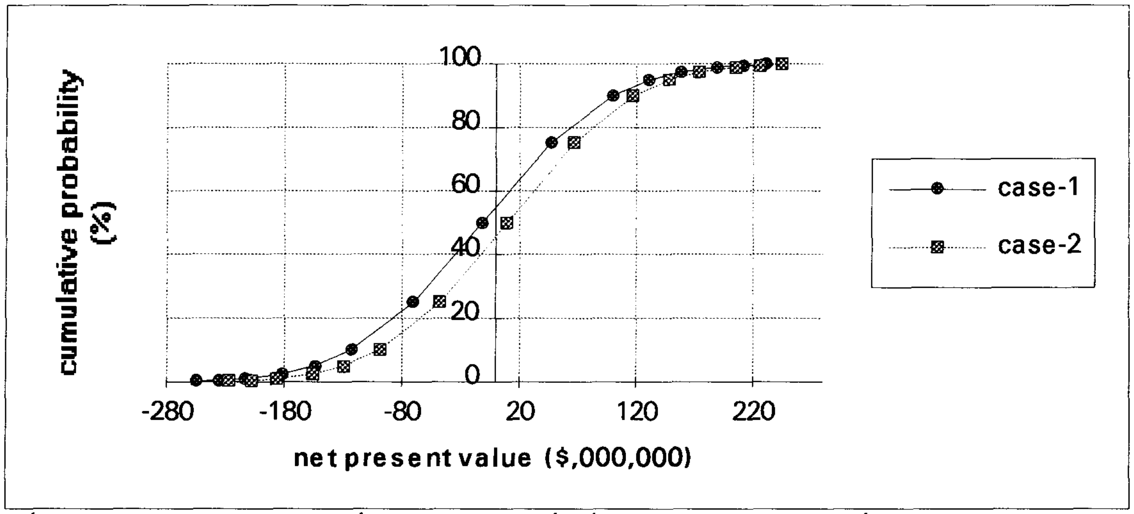

Figure 4.2 Cumulative Probability of the Project NPV (case-1 and case-2)

A tightening of the distribution describing revenue stream early start time improves expected project revenue and net present value significantly but does not reduce the uncertainty as measured by σ, by much. Clearly, efforts to fast track or accelerate a project can have a significant effect on expected NPV, although possibly at the price of increased risk.

4.2.2 Toll Rate Growth Parameters (case-3)

A tightening up of the distribution describing toll rate growth parameters, described by α_t in 2.5.4, is considered here. Toll rate growth parameters can be controlled by road operators even though they are affected by inflation. The following are possible strategies for reducing the uncertainty:

- to negotiate a long-term pricing policy; and

- to require that the project be feasible without increases in toll rate.

Tables 4.7 and 4.8 describe the parameters for case-1 and case-3

	2.5%	5.0%	50.0%	95.0%	97.5%
case-1	0.800	0.850	1.000	1.050	1.060
case-3	0.900	0.910	1.000	1.028	1.030

Table 4.7 Five Percentile Estimate Parameters for Toll Rate Growth Parameters

	Mean	Standard Deviation	$\sqrt{\beta_1}$	β_2
case-1	0.9815	0.0703	-2.0	10.2
case-3	0.9885	0.0383	-0.9	2.8

Table 4.8 Statistics Information of Five Percentile Estimate Parameters for Toll Rate Growth Parameters

Tables 4.9, 4.10, and Figure 4.3 show the comparison between case-1 and case-3 in terms of the project revenue, and Tables 4.11, 4.12, and Figure 4.4 show the comparison between the two cases in terms of the project NPV.

case	mean	σ	skewness	kurtosis
1	705,507,584	77,309,352	0.190	1.411
3	715,485,760	77,054,544	0.200	1.396

Table 4.9 Comparison of the Project Revenue (case-1 and case-3)

cumulative probability(%)	Case 1 ($,000,000)	Case 3 ($,000,000)
0.25	488.5	499.2
0.50	506.4	517.0
1.00	525.7	536.2
2.50	554.0	564.5
5.00	578.3	588.7
10.00	606.4	616.7
25.00	653.4	663.5
50.00	705.5	715.5
75.00	757.7	767.5
90.00	804.9	814.2
95.00	832.7	842.2
97.50	857.0	866.5
99.00	885.4	894.7
99.50	904.6	914.0
99.75	922.5	931.8

Table 4.10 Cumulative Probability of the Project Revenue
(case-1 and case-3)

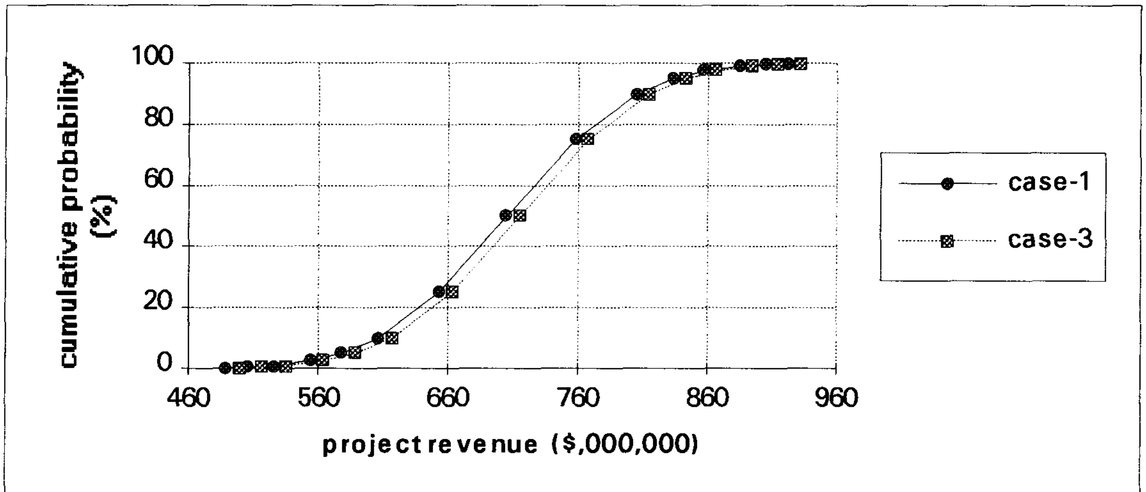

Figure 4.3 Cumulative Probability of the Project Revenue
(case-1 and case-3)

case	mean	σ	skewness	kurtosis
1	-11,666,560	86,717,576	0.053	2.043
3	-1,688,384	86,490,488	0.060	2.036

Table 4.11 Comparison of the Project NPV
(case-1 and case-3)

Cumulative Probability (%)	Case 1 ($,000,000)	Case 3 ($,000,000)
0.25	-255.1	-244.5
0.50	-235.0	-224.5
1.00	-213.4	-202.9
2.50	-181.6	-171.2
5.00	-154.3	-144.0
10.00	-122.8	-112.5
25.00	-70.2	-60.0
50.00	-11.7	-1.7
75.00	46.8	56.6
90.00	99.5	109.2
95.00	131.0	140.6
97.50	158.3	167.8
99.00	190.1	199.5
99.50	211.7	221.1
99.75	231.7	241.1

Table 4.12 Cumulative Probability of the Project NPV (case-1 and case-3)

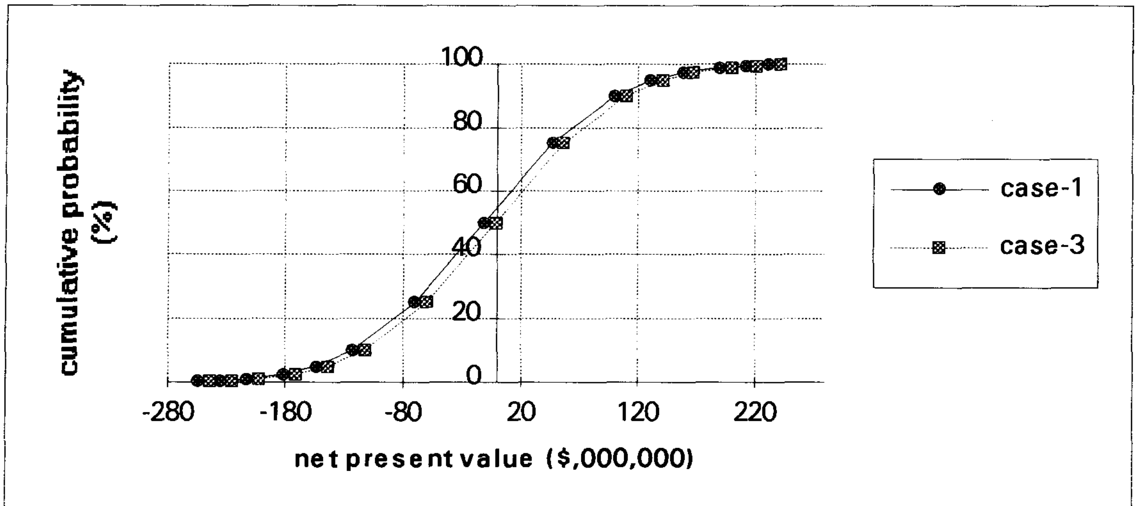

Figure 4.4 Cumulative Probability of the Project NPV (case-1 and case-3)

A tightening of the distribution describing toll rate growth parameters shifts project revenue and net present value in a positive direction, but it does little to reduce uncertainty.

4.2.3 Traffic Volume Growth Parameters (case-4)

A tightening of the distribution describing traffic volume growth parameters, described as *k* in section 2.1, is considered here. It is very difficult to control the distribution for traffic volume growth parameters. A possible way is to review past data of similar highway projects, and to analyze information about development plans, road capacity, economic condition, and so on. Tables 4.13 and 4.14 describe the parameters for case-1 and case-4

	2.5%	5.0%	50.0%	95.0%	97.5%
case-1	0.700	0.750	1.000	1.090	1.100
case-4	0.850	0.870	1.000	1.045	1.050

Table 4.13 Five Percentile Estimate Parameters for traffic volume growth parameters

	Mean	Standard Deviation	$\sqrt{\beta_1}$	β_2
case-1	0.9704	0.1104	-1.0	3.4
case-4	0.9843	0.0568	-0.9	2.9

Table 4.14 Statistics Information of Five Percentile Estimate Parameters for Traffic Volume Growth Parameters

Tables 4.15, 4.16, and Figure 4.5 show the comparison between case-1 and case-4 in terms of the project revenue, and Tables 4.17, 4.18, and Figure 4.6 show the comparison between the two cases in terms of the project NPV.

case	mean	σ	skewness	kurtosis
1	705,507,584	77,309,352	0.190	1.411
4	702,523,968	61,274,760	-0.170	1.383

Table 4.15 Comparison of the Project Revenue (case-1 and case-4)

cumulative probability(%)	Case 1 ($,000,000)	Case 4 ($,000,000)
0.25	488.5	530.5
0.50	506.4	544.7
1.00	525.7	560.0
2.50	554.0	582.4
5.00	578.3	601.7
10.00	606.4	624.0
25.00	653.4	661.2
50.00	705.5	702.5
75.00	757.7	743.9
90.00	804.9	781.1
95.00	832.7	803.3
97.50	857.0	822.6
99.00	885.4	845.1
99.50	904.6	860.4
99.75	922.5	874.5

Table 4.16 Cumulative Probability of the Project Revenue (case-1 and case-4)

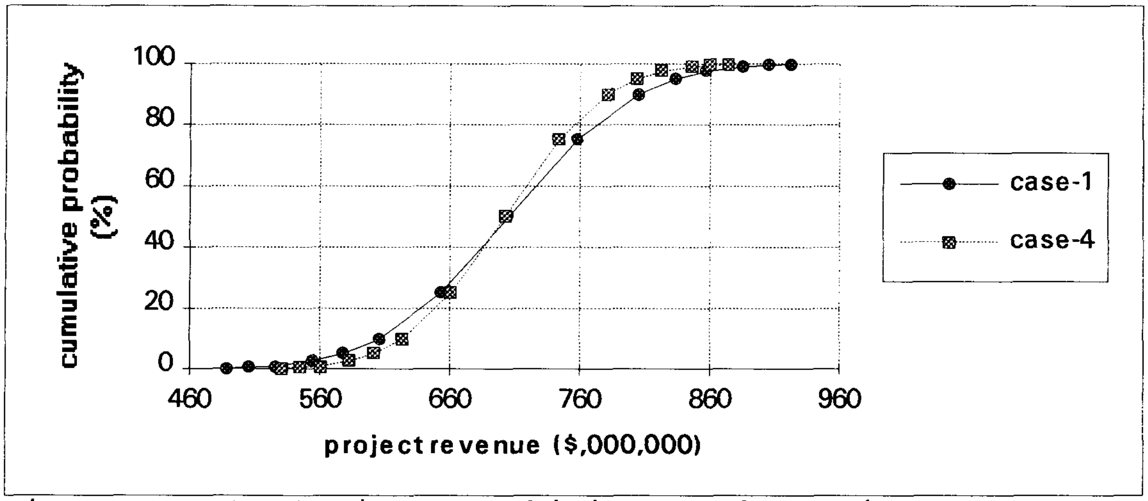

Figure 4.5 Cumulative Probability of the Project Revenue (case-1 and case-4)

case	mean	σ	skewness	kurtosis
1	-11,666,560	86,717,576	0.053	2.043
4	-14,650,176	72,785,976	-0.239	2.281

Table 4.17 Comparison of the Project NPV (case-1 and case-4)

Cumulative Probability (%)	Case 1 ($,000,000)	Case 4 ($,000,000)
0.25	-255.1	-219.0
0.50	-235.0	-202.1
1.00	-213.4	-184.0
2.50	-181.6	-157.3
5.00	-154.3	-134.4
10.00	-122.8	-107.9
25.00	-70.2	-63.7
50.00	-11.7	-14.7
75.00	46.8	34.4
90.00	99.5	78.6
95.00	131.0	105.1
97.50	158.3	128.0
99.00	190.1	154.7
99.50	211.7	172.8
99.75	231.7	189.7

Table 4.18 Cumulative Probability of the Project NPV (case-1 and case-4)

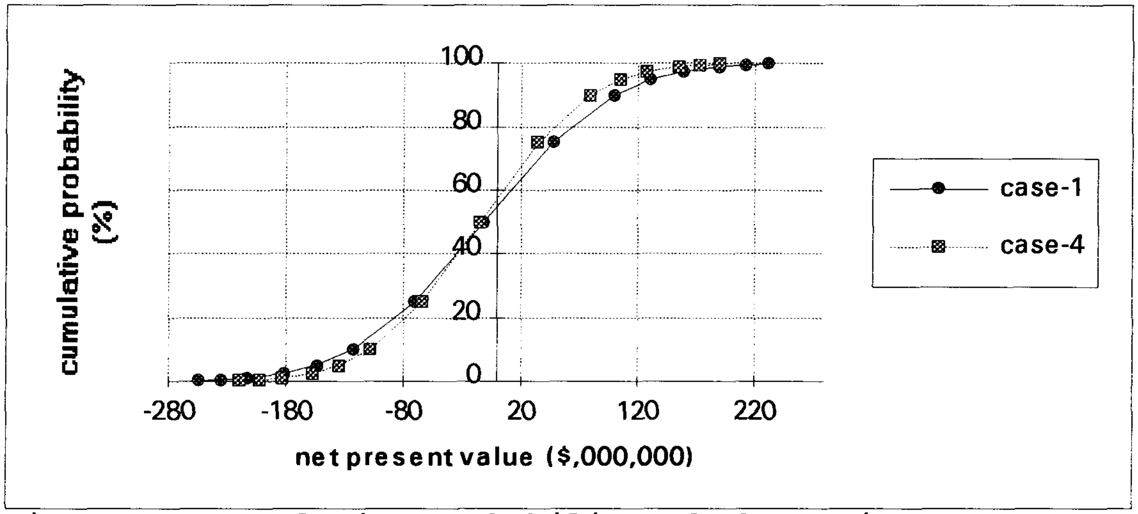

Figure 4.6 Cumulative Probability of the Project NPV (case-1 and case-4)

A tightening of the distribution describing traffic volume growth parameters significantly reduces the uncertainty of an overall project; mean values of project revenue and net present value, however, are decreased.

4.2.4 Tolls (case-5)

The effects of tightening the distribution of base toll rates are considered in this section. In general, toll rates are decided on the basis of benefit-cost principles, in which the tolls charged to the various road users should not exceed the benefit normally received by them for using the highway. Practically, the uncertainty surrounding base tolls disappears near the end of the construction phase, or earlier, if the concession structure dictates the base toll rate. An example of where the uncertainty in the toll rate persists to the commissioning phase of a project is the recently completed English Chunnel project.

Tables 4.19 and 4.20 describe the parameters for case-1 and case-5.

	2.5%	5.0%	50.0%	95.0%	97.5%
case-1	0.900	0.910	1.000	1.180	1.200
case-5	0.950	0.955	1.000	1.09	1.100

Table 4.19 Five Percentile Estimate Parameters for Tolls

	Mean	Standard Deviation	$\sqrt{\beta_1}$	β_2
case-1	1.0167	0.0850	0.6	2.4
case-5	1.0083	0.0425	0.6	2.4

Table 4.20 Statistics Information of Five Percentile Estimate Parameters for Tolls

Tables 4.21, 4.22, and Figure 4.7 show the comparison between case-1 and case-5 in terms of the project revenue, and Tables 4.23, 4.24, and Figure 4.8 show the comparison between the two cases in terms of the project NPV.

case	mean	σ	skewness	kurtosis
1	705,507,584	77,309,352	0.190	1.411
5	699,348,992	76,269,088	0.192	1.419

Table 4.21 Comparison of the Project Revenue (case-1 and case-5)

cumulative probability(%)	Case 1 ($,000,000)	Case 5 ($,000,000)
0.25	488.5	485.3
0.50	506.4	502.9
1.00	525.7	521.9
2.50	554.0	549.9
5.00	578.3	573.9
10.00	606.4	601.6
25.00	653.4	647.9
50.00	705.5	699.3
75.00	757.7	750.8
90.00	804.9	797.1
95.00	832.7	824.8
97.50	857.0	848.8
99.00	885.4	876.8
99.50	904.6	895.8
99.75	922.5	913.4

Table 4.22 Cumulative Probability of the Project Revenue (case-1 and case-5)

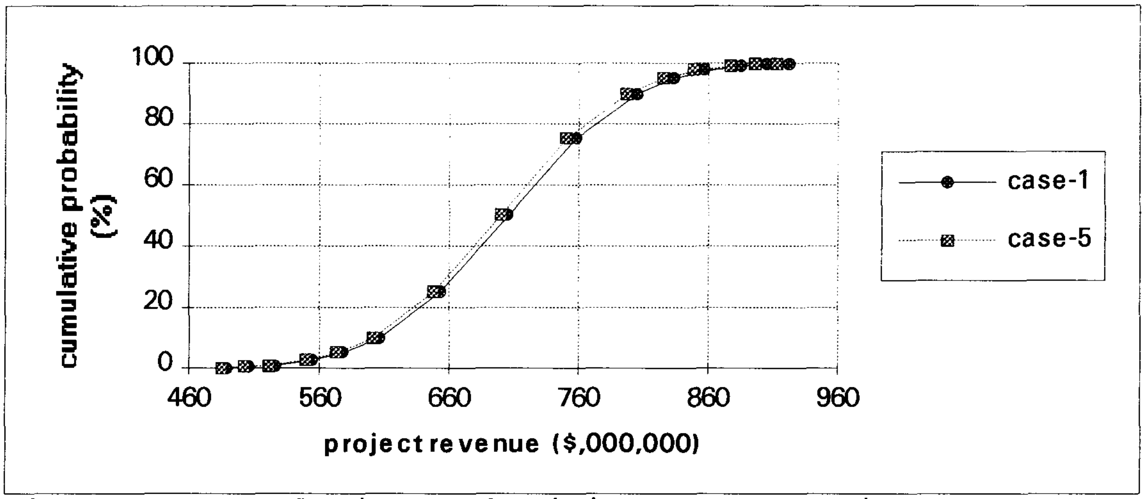

Figure 4.7 Cumulative Probability of the Project Revenue
(case-1 and case-5)

case	mean	σ	skewness	kurtosis
1	-11,666,560	86,717,576	0.053	2.043
5	-17,825,152	85,791,464	0.051	2.061

Table 4.23 Comparison of the Project NPV
(case-1 and case-5)

Cumulative Probability (%)	Case 1 ($,000,000)	Case 5 ($,000,000)
0.25	-255.1	-258.6
0.50	-235.0	-238/.8
1.00	-213.4	-217.4
2.50	-181.6	-186.0
5.00	-154.3	-158.9
10.00	-122.8	-127.8
25.00	-70.2	-75.7
50.00	-11.7	-17.8
75.00	46.8	40.0
90.00	99.5	92.1
95.00	131.0	123.3
97.50	158.3	150.3
99.00	190.1	181.8
99.50	211.7	203.2
99.75	231.7	223.0

Table 4.24 Cumulative Probability of the Project NPV
(case-1 and case-5)

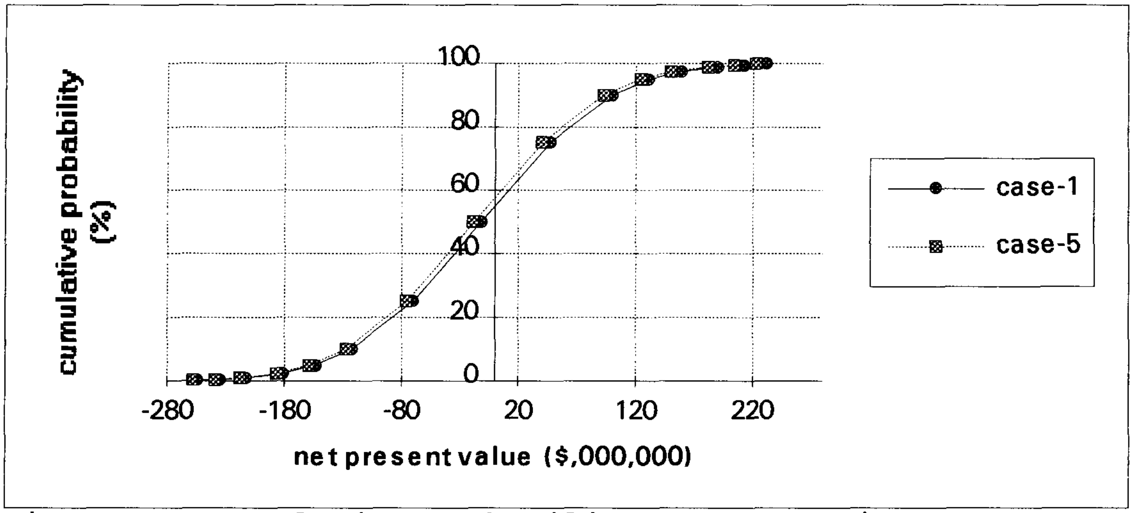

Figure 4.8 Cumulative Probability of the Project NPV (case-1 and case-5)

A tightening of the distribution describing base toll rates does not significantly reduce overall uncertainty. A small negative impact on the expected value is observed.

4.2.5 Traffic Volume (case-6)

A tightening of the distribution of base traffic volume is considered here. It is also difficult to achieve in practice. It may be obtained, in part, through detailed traffic surveys, and more detailed traffic forecasts. Tables 4.25 and 4.26 describe the parameters for case-1 and case-6

	2.5%	5.0%	50.0%	95.0%	97.5%
case-1	0.350	0.500	1.000	1.350	1.400
case-6	0.675	0.700	1.000	1.180	1.200

Table 4.25 Five Percentile Estimate Parameters for Traffic Volume

	Mean	Standard Deviation	$\sqrt{\beta_1}$	β_2
case-1	0.9723	0.2667	-1.0	5.9
case-6	0.9778	0.1488	-0.4	2.2

Table 4.26 Statistics Information of Five Percentile Estimate Parameters for Traffic Volume

Tables 4.27, 4.28, and Figure 4.9 show the comparison between case-1 and case-6 in terms of the project revenue, and Tables 4.29, 4.30, and Figure 4.10 show the comparison between the two cases in terms of the project NPV.

case	mean	σ	skewness	kurtosis
1	705,507,584	77,309,352	0.190	1.411
6	712,278,592	73,196,800	0.249	1.472

Table 4.27 Comparison of the Project Revenue (case-1 and case-6)

cumulative probability(%)	Case 1 ($,000,000)	Case 6 ($,000,000)
0.25	488.5	506.8
0.50	506.4	523.7
1.00	525.7	542.0
2.50	554.0	568.8
5.00	578.3	591.9
10.00	606.4	618.5
25.00	653.4	662.9
50.00	705.5	712.3
75.00	757.7	761.6
90.00	804.9	806.1
95.00	832.7	832.7
97.50	857.0	855.7
99.00	885.4	882.6
99.50	904.6	900.8
99.75	922.5	917.7

Table 4.28 Cumulative Probability of the Project Revenue (case-1 and case-6)

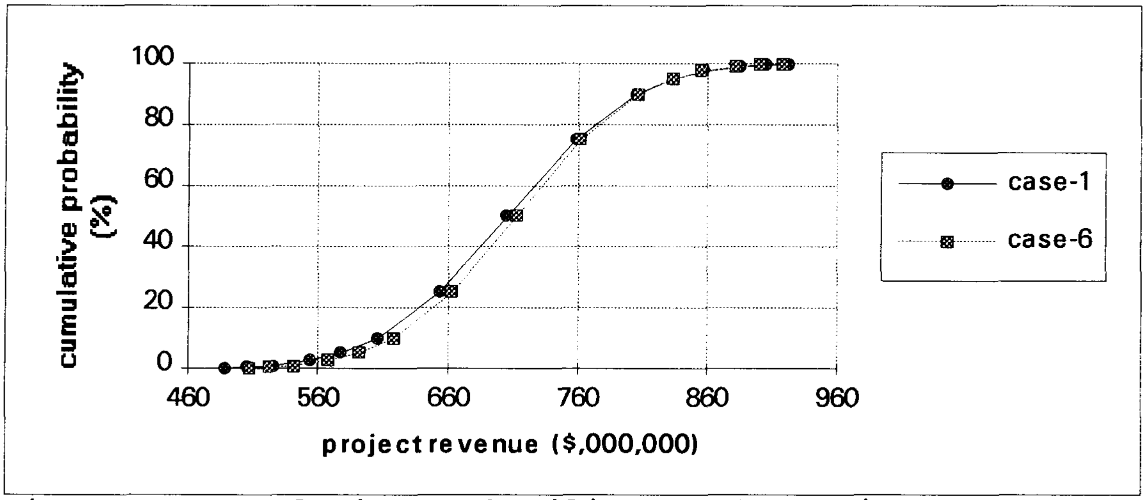

Figure 4.9 Cumulative Probability of the Project Revenue (case-1 and case-6)

case	mean	σ	skewness	kurtosis
1	-11,666,560	8,6717,576	0.053	2.043
6	-4,895,552	7,3196,800	0.249	1.472

Table 4.29 Comparison of the Project NPV (case-1 and case-6)

Cumulative Probability (%)	Case 1 ($,000,000)	Case 6 ($,000,000)
0.25	-255.1	-238.1
0.50	-235.0	-218.9
1.00	-213.4	-198.1
2.50	-181.6	-167.7
5.00	-154.3	-141.5
10.00	-122.8	-111.4
25.00	-70.2	-60.9
50.00	-11.7	-4.9
75.00	46.8	51.1
90.00	99.5	101.6
95.00	131.0	131.7
97.50	158.3	157.9
99.00	190.1	188.4
99.50	211.7	209.1
99.75	231.7	228.3

Table 4.30 Cumulative Probability of the Project NPV (case-1 and case-6)

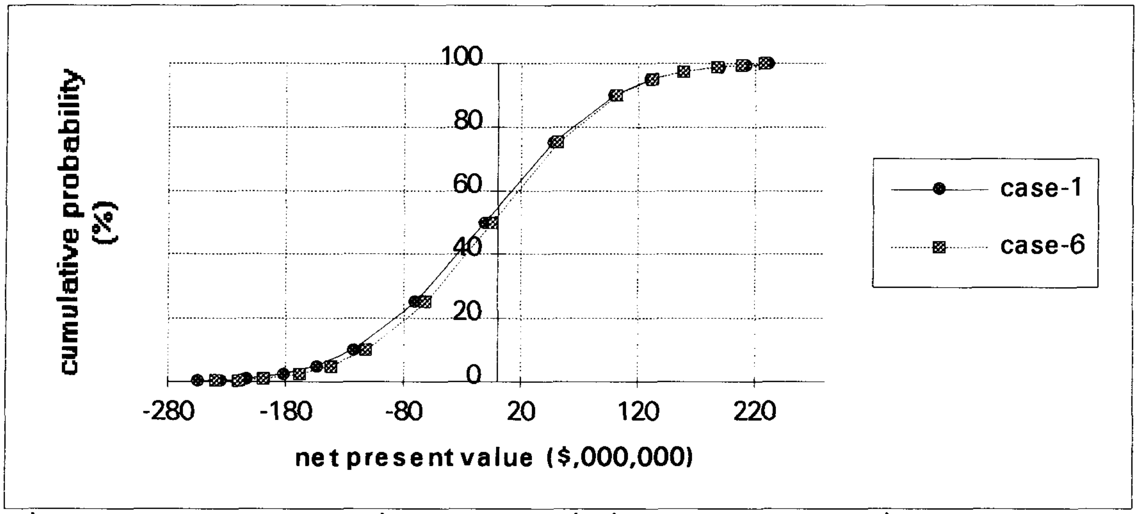

Figure 4.10 Cumulative Probability of the Project NPV (case-1 and case-6)

This tightening has no significant effect on reducing the uncertainty of an overall project.

4.2.6 Inflation Rate (case-7)

A tightening of the distribution for the inflation rate that applies to operating costs only is considered here. It cannot be controlled by road operators although it is necessary to observe economic conditions and to forecast its trend carefully to reduce the uncertainty.

Tables 4.31 and 4.32 describe the parameters for case-1 and case-7.

	2.5%	5.0%	50.0%	95.0%	97.5%
case-1	0.800	0.820	1.000	1.300	1.400
case-7	0.900	0.910	1.000	1.180	1.200

Table 4.31 Five Percentile Estimate Parameters for Inflation Rate

	Mean	Standard Deviation	$\sqrt{\beta_1}$	β_2
case-1	1.0222	0.1540	1.4	7.7
case-7	1.0167	0.0850	0.6	2.4

Table 4.32 Statistics Information of Five Percentile Estimate Parameters for Inflation Rate

Tables 4.33, 4.34, and Figure 4.11 show the comparison between case-1 and case-7 in terms of the project revenue, and Tables 4.35, 4.36, and Figure 4.12 show the comparison between the two cases in terms of the project NPV.

case	mean	σ	skewness	kurtosis
1	705,507,584	77,309,352	0.190	1.411
7	709,877,120	73,241,816	0.334	1.491

Table 4.33 Comparison of the Project Revenue (case-1 and case-7)

cumulative probability(%)	Case 1 ($,000,000)	Case 7 ($,000,000)
0.25	488.5	504.3
0.50	506.4	521.2
1.00	525.7	539.5
2.50	554.0	566.3
5.00	578.3	589.4
10.00	606.4	616.0
25.00	653.4	660.5
50.00	705.5	709.9
75.00	757.7	759.3
90.00	804.9	803.7
95.00	832.7	830.4
97.50	857.0	853.4
99.00	885.4	880.3
99.50	904.6	898.5
99.75	922.5	915.5

Table 4.34 Cumulative Probability of the Project Revenue (case-1 and case-7)

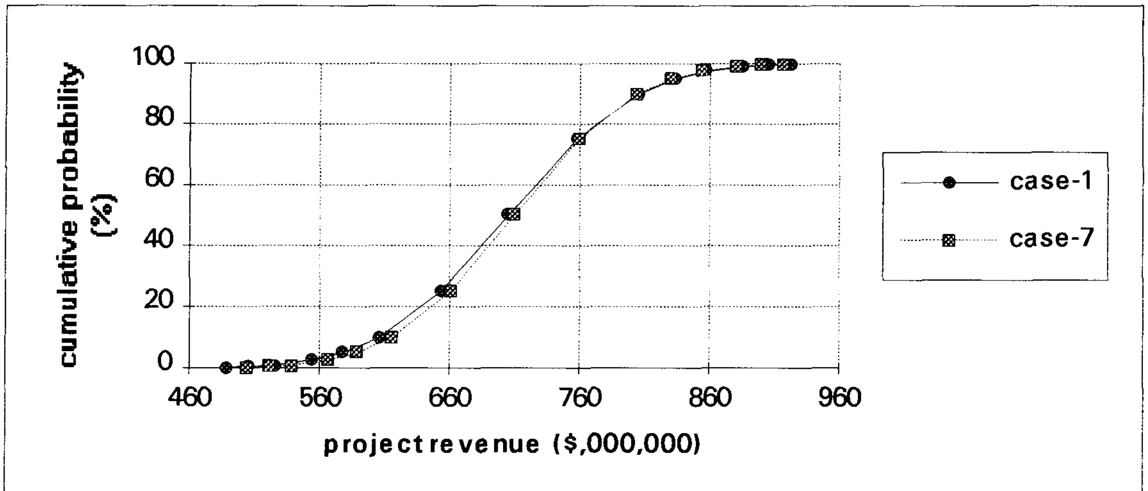

Figure 4.11 Cumulative Probability of the Project Revenue (case-1 and case-7)

case	mean	σ	skewness	kurtosis
1	-11,666,560	86,717,576	0.053	2.043
7	-6,317,120	82,959,512	0.137	2.139

Table 4.35 Comparison of the Project NPV (case-1 and case-7)

Cumulative Probability (%)	Case 1 ($,000,000)	Case 7 ($,000,000)
0.25	-255.1	-239.2
0.50	-235.0	-220.0
1.00	-213.4	-199.3
2.50	-181.6	-168.9
5.00	-154.3	-142.8
10.00	-122.8	-112.6
25.00	-70.2	-62.3
50.00	-11.7	-6.3
75.00	46.8	49.6
90.00	99.5	100.0
95.00	131.0	130.1
97.50	158.3	156.3
99.00	190.1	186.7
99.50	211.7	207.4
99.75	231.7	226.6

Table 4.36 Cumulative Probability of the Project NPV (case-1 and case-7)

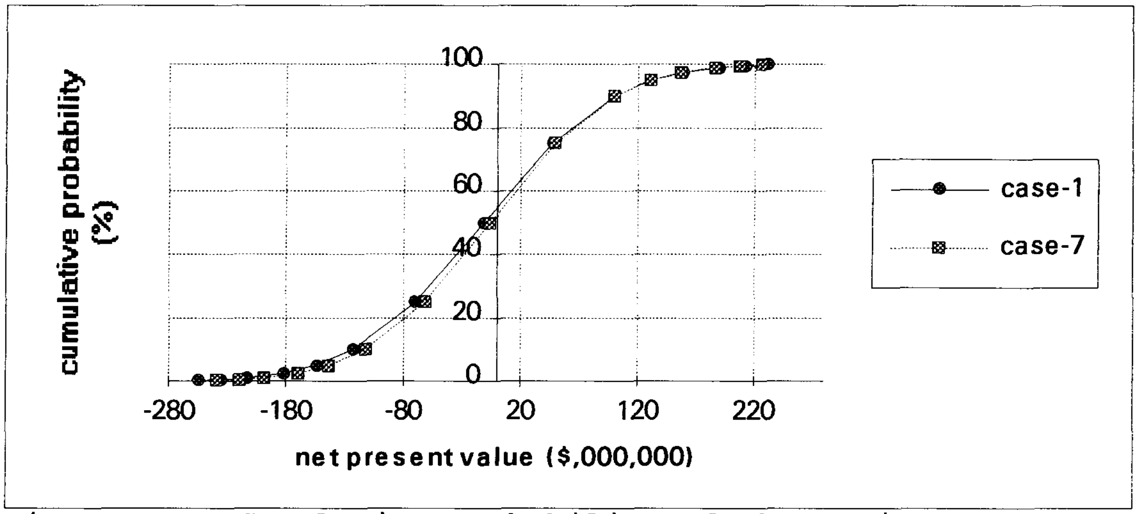

Figure 4.12 Cumulative Probability of the Project NPV (case-1 and case-7)

This tightening has no significant effect on reducing the uncertainty for the overall project.

4.2.7 Parameter for Consignment Cost of Toll Collection (case-8)

A tightening of the distribution of the parameter for the consignment cost of toll collection is examined here. This can be controlled, in part, by road operators.

Tables 4.37 and 4.38 describe the parameters for case-1 and case-8.

	2.5%	5.0%	50.0%	95.0%	97.5%
case-1	0.900	0.910	1.000	1.250	1.300
case-8	0.950	0.955	1.000	1.120	1.150

Table 4.37 Five Percentile Estimate Parameters for Parameter for Consignment Cost of Toll Collection

	Mean	Standard Deviation	$\sqrt{\beta_1}$	β_2
case-1	1.0296	0.1104	1.0	3.4
case-7	1.0139	0.0539	1.4	5.6

Table 4.38 Statistics Information of Five Percentile Estimate Parameters for Parameter for Consignment Cost of Toll Collection

Tables 4.39, 4.40, and Figure 4.13 show the comparison between case-1 and case-8 in terms of the project revenue, and Tables 4.41, 4.42, and Figure 4.14 show the comparison between the two cases in terms of the project NPV.

case	mean	σ	skewness	kurtosis
1	705,507,584	77,309,352	0.190	1.411
8	708,981,504	76,916,008	0.197	1.420

Table (4.39) Comparison of the Project Revenue (case-1 and case-8)

cumulative probability(%)	Case 1 ($,000,000)	Case 8 ($,000,000)
0.25	488.5	493.1
0.50	506.4	510.9
1.00	525.7	530.1
2.50	554.0	558.2
5.00	578.3	582.5
10.00	606.4	610.4
25.00	653.4	657.1
50.00	705.5	709.0
75.00	757.7	760.9
90.00	804.9	807.6
95.00	832.7	835.5
97.50	857.0	859.7
99.00	885.4	887.9
99.50	904.6	907.1
99.75	922.5	924.9

Table 4.40 Cumulative Probability of the Project Revenue (case-1 and case-8)

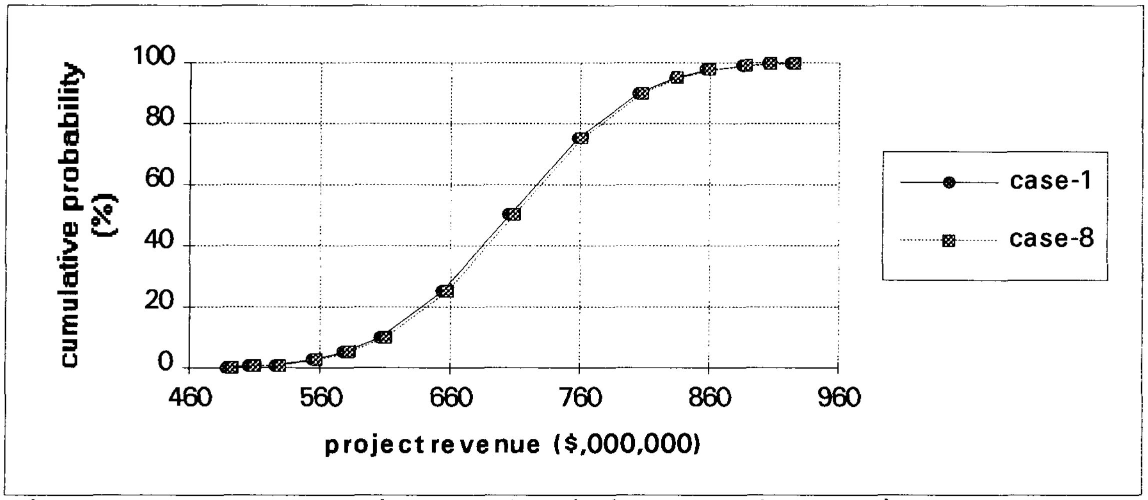

Figure 4.13 Cumulative Probability of the Project Revenue (case-1 and case-8)

case	mean	σ	skewness	kurtosis
1	-11,666,560	86,717,576	0.053	2.043
8	-8,192,640	86,367,096	0.056	2.053

Table 4.41 Comparison of the Project NPV (case-1 and case-8)

Cumulative Probability (%)	Case 1 ($,000,000)	Case 8 ($,000,000)
0.25	-255.1	-250.6
0.50	-235.0	-230.7
1.00	-213.4	-209.1
2.50	-181.6	-177.5
5.00	-154.3	-150.3
10.00	-122.8	-118.9
25.00	-70.2	-66.4
50.00	-11.7	-8.2
75.00	46.8	50.1
90.00	99.5	102.5
95.00	131.0	133.9
97.50	158.3	161.1
99.00	190.1	192.7
99.50	211.7	214.3
99.75	231.7	234.2

Table 4.42 Cumulative Probability of the Project NPV (case-1 and case-8)

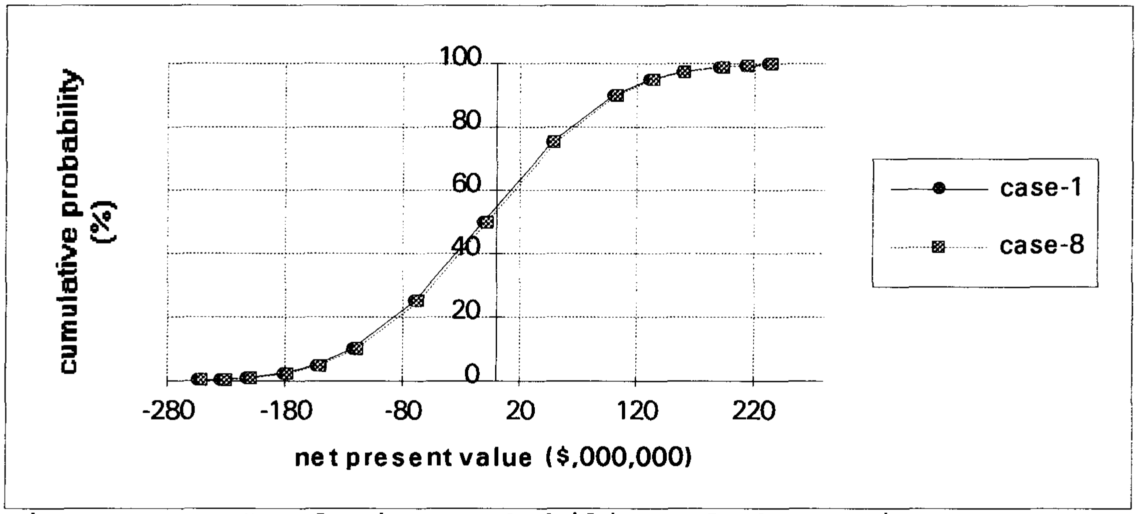

Figure 4.14 Cumulative Probability of the Project NPV (case-1 and case-8)

This tightening has no significant effect on reducing the uncertainty for the overall project.

4.2.8 Combination of Case-2 to Case-8 (case-9)

The total effect of all the distribution tightenings described in case-2 to case-8 is considered here.

Tables 4.43, 4.44, and Figure 4.15 show the comparison between case-1 and case-9 in terms of the project revenue, and Tables 4.45, 4.46, and Figure 4.16 show the comparison between the two cases in terms of the project NPV.

case	mean	σ	skewness	kurtosis
1	705,507,584	77,309,352	0.190	1.411
8	733,059,648	40,677,744	0.161	1.355

Table 4.43 Comparison of the Project Revenue (case-1 and case-9)

cumulative probability(%)	Case 1 ($,000,000)	Case 9 ($,000,000)
0.25	488.5	618.9
0.50	506.4	628.3
1.00	525.7	638.4
2.50	554.0	653.3
5.00	578.3	666.1
10.00	606.4	680.9
25.00	653.4	705.6
50.00	705.5	733.1
75.00	757.7	760.5
90.00	804.9	785.2
95.00	832.7	800.0
97.50	857.0	812.8
99.00	885.4	827.7
99.50	904.6	837.8
99.75	922.5	847.2

Table 4.44 Cumulative Probability of the Project Revenue (case-1 and case-9)

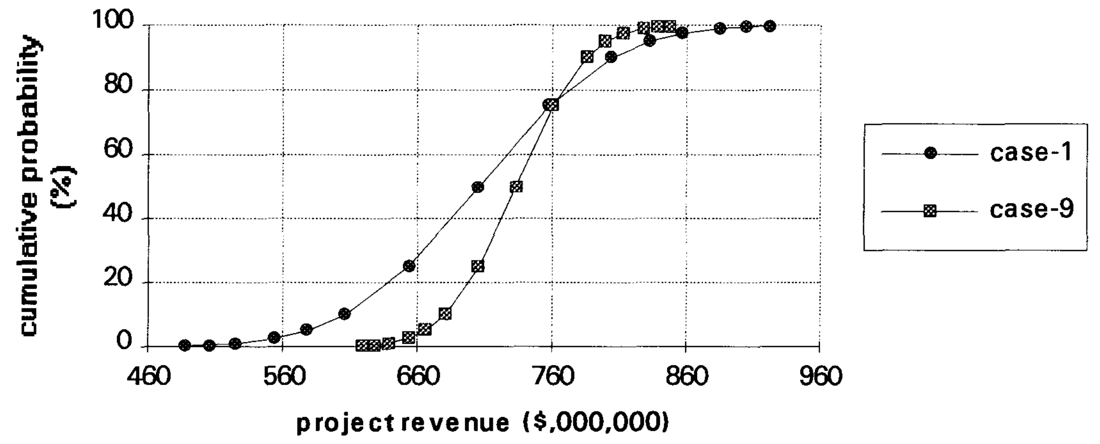

Figure 4.15 Cumulative Probability of the Project Revenue
(case-1 and case-9)

case	mean	σ	skewness	kurtosis
1	-11,666,560	86,717,576	0.053	2.043
9	13,424,128	56,534,840	-0.236	2.819

Table 4.45 Comparison of the Project NPV
(case-1 and case-9)

Cumulative Probability (%)	Case 1 ($,000,000)	Case 9 ($,000,000)
0.25	-255.1	-145.3
0.50	-235.0	-132.2
1.00	-213.4	-118.1
2.50	-181.6	-97.4
5.00	-154.3	-79.6
10.00	-122.8	-59.0
25.00	-70.2	-24.7
50.00	-11.7	13.4
75.00	46.8	51.6
90.00	99.5	85.9
95.00	131.0	106.4
97.50	158.3	124.2
99.00	190.1	144.9
99.50	211.7	159.0
99.75	231.7	172.1

Table 4.46 Cumulative Probability of the Project NPV
(case-1 and case-9)

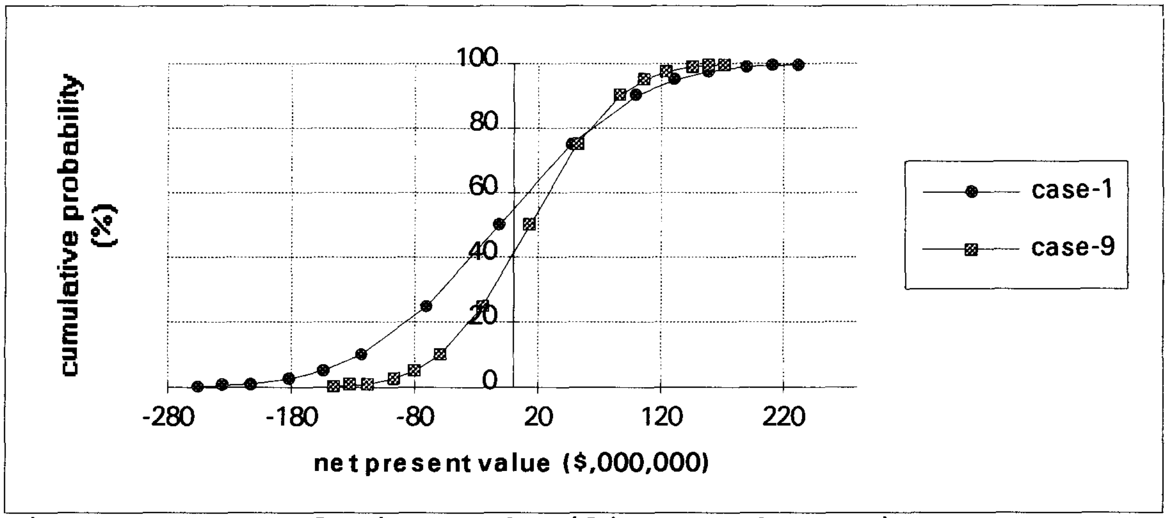

Figure 4.16 Cumulative Probability of the Project NPV (case-1 and case-9)

In this case, significant improvements for both reducing the uncertainty and increasing the project's expected net present value are observed. In practice, many of tightenings described may not be achievable, but the process is clear - examine each variable in turn, determine how its uncertainty can be reduced, and then determine the residual uncertainty. The goal is to achieve the type of result shown in Figure 4.16 - tighten or steepen the distribution, and shift it in the positive direction. Even if the tightening examined could be achieved, the example project would still , in all likelihood, be infeasible because there is a 40% chance of not obtaining the minimum attractive rate of return. Thus, additional strategies would be required to further reduce risk.

4.3 Conclusions

As suggested in the previous section, even when the range of the distribution of highly sensitive primary variables is decreased by half, the effect on overall project risks is not significant except when considered in combination (case-9). On a variable-variable basis, improvements are found only in case-4 (traffic volume growth rate). However, in practice, it is very difficult to tighten up the distribution for traffic volume growth parameters, because they are related to uncertain economic conditions, road development plans, and many other factors.
This indicates that it is very difficult for a highway operator alone to reduce risks . Therefore, it would seem that it is very important that risk sharing be negotiated with the government and some guarantee of support be received. For example, if the government guarantees a certain traffic volume, the situation improves as indicated below in case-10.

Although parameters for traffic volume should be deterministic for case-10, the model requires probabilistic values for primary variables. Therefore, very tight distributions for the parameters are used. Tables 4.47 and 4.48 describe the parameters for case-1 and case-10.

	2.5%	5.0%	50.0%	95.0%	97.5%
case-1	0.350	0.500	1.000	1.350	1.400
case-10	0.9996	0.9997	1.000	1.0003	1.0004

Table 4.47 Five Percentile Estimate Parameters for Traffic Volume

	Mean	Standard Deviation	$\sqrt{\beta_1}$	β_2
case-1	0.9723	0.2667	-1.0	5.9
case-10	1.0000	0.0002	0.0	9.0

Table 4.48 Statistics Information of Five Percentile Estimate Parameters for Traffic Volume

Tables 4.49, 4.50, and Figure 4.17 show the comparison between case-1 and case-9 in terms of the project revenue, and Tables 4.51, 4.52, and Figure 4.18 show the comparison between the two cases in terms of the project NPV.

case	mean	σ	skewness	kurtosis
1	705,507,584	77,309,352	0.190	1.411
10	729,600,320	72,625,800	0.276	1.518

Table 4.49 Comparison of the Project Revenue (case-1 and case-10)

cumulative probability(%)	Case 1 ($,000,000)	Case 9 ($,000,000)
0.25	488.5	525.7
0.50	506.4	542.5
1.00	525.7	560.7
2.50	554.0	587.3
5.00	578.3	610.1
10.00	606.4	636.5
25.00	653.4	680.6
50.00	705.5	729.6
75.00	757.7	778.6
90.00	804.9	822.7
95.00	832.7	849.1
97.50	857.0	871.9
99.00	885.4	898.5
99.50	904.6	916.7
99.75	922.5	933.5

Table 4.50 Cumulative Probability of the Project Revenue (case-1 and case-10)

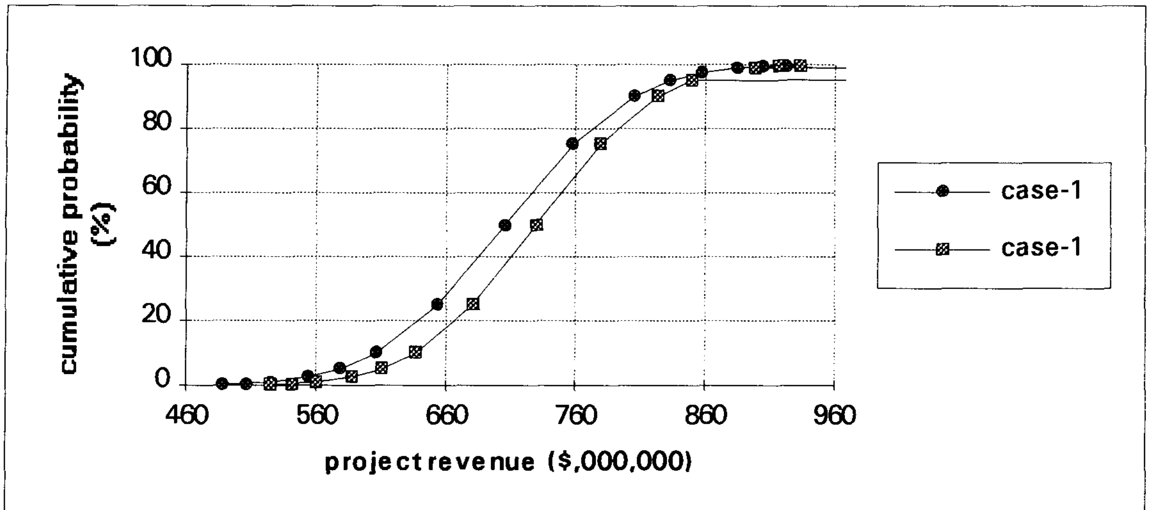

Figure 4.17 Cumulative Probability of the Project Revenue (case-1 and case-10)

case	mean	σ	skewness	kurtosis
1	-11,666,560	86,717,576	0.053	2.043
8	12,426,176	82,569,424	0.094	2.169

Table 4.51 Comparison of the Project NPV
(case-1 and case-10)

Cumulative Probability (%)	Case 1 ($,000,000)	Case 9 ($,000,000)
0.25	-255.1	-219.3
0.50	-235.0	-200.3
1.00	-213.4	-179.7
2.50	-181.6	-149.4
5.00	-154.3	-123.4
10.00	-122.8	-93.4
25.00	-70.2	-43.3
50.00	-11.7	12.4
75.00	46.8	68.1
90.00	99.5	118.2
95.00	131.0	148.2
97.50	158.3	174.3
99.00	190.1	204.5
99.50	211.7	225.1
99.75	231.7	244.2

Table 4.52 Cumulative Probability of the Project NPV
(case-1 and case-10)

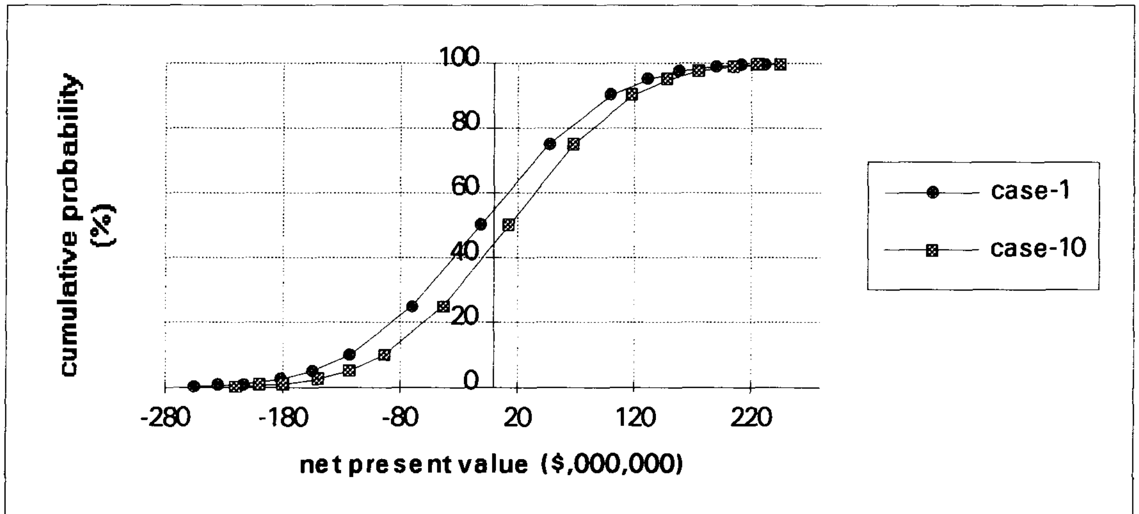

Figure 4.18 Cumulative Probability of the Project NPV
(case-1 and case-10)

In case-10, there is no obvious improvement on the uncertainty of overall project risks. However, its profitability clearly improves. Therefore, obtaining certain guarantees concerning such factors as traffic volume must be recognized as possible and almost essential risk management strategies.

Chapter 5

Conclusions and Recommendations

5.1 Conclusions

The primary objectives of this thesis were to model economic and financial performance of user-pay highway facilities and to explore the sensitivity of project performance to changes in primary variables, uncertainty surrounding such projects, and ways of reducing the uncertainty.

The analytical model developed requires three kinds of input data: work package duration; work package costs; and revenue streams. Special attention was given to the revenue phase.

The general features of the analytical model are as follows.

1. This model consists of three levels: work package/revenue stream level; project performance level; and project decision level.

2. The work package/revenue stream level involves three derived variables: work package duration; work package cost; and revenue stream.
3. The project performance level also involves three derived variables: project duration; project cost; and project revenue.
4. The project decision level involves two derived variables: project net present value (NPV); and project internal rate of return (IRR).
5. Each derived variable is described by its expected value, standard deviation, skewness, and kurtosis.
6. This model can be applied to closed toll collection systems (manual or automatic collection), closed toll collection systems (manual or automatic collection), and their hybrids.
7. The model is dependent on traffic volume forecast, and can also deal with any traffic volume forecasting method as long as it provides the interchange pair traffic volume for each vehicle type in base years.

The results of a sensitivity and risk analysis of a Japanese project and which focused mainly on the revenue phase are as follows.

1. In most cases, the highly sensitive primary variables are as follows:
   (1) revenue stream early start time;
   (2) toll rate growth parameters;

(3) traffic volume growth parameters;

(4) tolls;

(5) traffic volume;

(6) inflation rate; and

(7) parameter for consignment cost of toll collection.

2. However, even if the uncertainty of these sensitive variables is decreased, their impacts on overall project risks are not great except in the case of traffic volume growth rate.
3. One of the most effective risk management strategies is to negotiate risk sharing with the government and to receive some guarantee of support.

5.2 Recommendations for Future Work

Recommendations for future work are presented in three categories: computer programs; correlation between primary variables for revenue streams; and deterministic input for primary variables.

5.2.1 Computer Programs

One of the primary objectives of this thesis was to model economic and financial performance of user-pay highway facilities. This model is based on the program "AMMA", which is a modified version of "TIERA" (Ranasinghe, 1990). "AMMA", unlike "TIERA", can be used on personal computers.

It was planned to be used in conjunction with the program "TERQ", a more user-friendly program capable of creating input data files with relative ease. However, since "TERQ" has not been completed yet, the analytical model requires users to do a lot of work creating input data files. It is strongly recommended that "TERQ" be completed as soon as possible. The analytical model, namely "AMMA", uses 2.5, 5.0, 50.0, 95.0, and 97.5 percentile estimates. However, because of the difficulty in assessing the 2.5 and 97.5 percentiles subjectively, 5.0, 25.0, 50.0, 75.0, and 95.0 percentile estimates seem to be more suitable for the model.

5.2.2 Correlation between Primary Variables for Revenue Streams

The analytical model can theoretically deal with correlation between primary variables. However, since there are many primary variables, e.g. the smallest revenue stream has 181 primary variables, and the biggest revenue stream has 297 primary variables for the sample project, this thesis sets all correlation coefficients to zero. However, especially in the revenue phase, many primary variables are correlated with each other, e.g. interchange pair traffic volumes, and volumes in different years. Therefore, it is recommended that the correlation between primary variables be considered, and their impacts be measured.

5.2.3 Deterministic Input for Primary Variables

As mentioned in chapter four, the model requires probabilistic values for most primary variables. However, in order to examine risk management strategies, it is sometimes necessary to set some deterministic variables . Therefore, it is recommended that the model be modified to accept both deterministic and probabilistic values.

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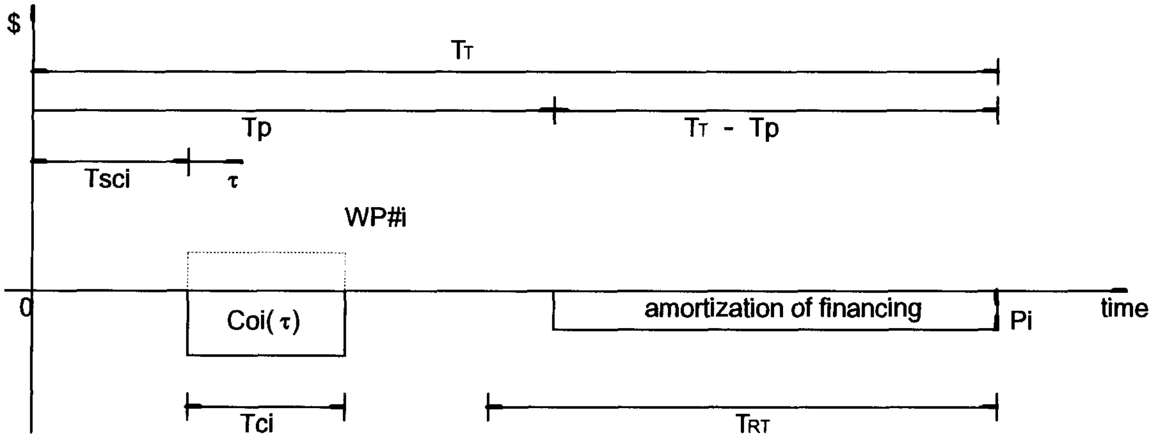
Appendix A

Discounted Work Package Cost

The following figure shows a cash flow diagram of work Package #i. Uniform repayment of financing is assumed.



WPC_i is the discounted *i*th work package cost

$C_{oi}(\tau)$ is the function for constant dollar cash flow for the *i*th work package

T_{sci} is start time of Work Package#i

T_{ci} is work package duration

T_P is construction phase duration

T_T is total project duration (construction and operation phase)

T_{RT} is operation phase duration

f is the equity fraction,

θ_{ci}, r and y are inflation, interest and discount rates respectively which are invaried with time.

First, figure out the amount of annual repayment for *i*th work package, P_i.

FW at end of WP#i is:

$$(1-f)\cdot\int_0^{T_{ci}} e^{\theta_{ci}\cdot T_{SCi}}\cdot C_{oi}(\tau)\cdot e^{\theta_{ci}\cdot\tau}\cdot e^{(T_c-\tau)\cdot r}d\tau$$

$$=(1-f)\cdot e^{\theta_{ci}\cdot T_{SCi}}\cdot e^{T_{ci}\cdot r}\cdot\int_0^{T_{ci}} C_{oi}(\tau)\cdot e^{(\theta_{ci}-r)\cdot\tau}d\tau$$

FW at T_P is :

$$(1-f)\cdot e^{\theta_{ci}\cdot T_{SCi}}\cdot e^{T_{ci}\cdot r}\cdot\int_0^{T_{ci}} C_{oi}(\tau)\cdot e^{(\theta_{ci}-r)\cdot\tau}d\tau\cdot e^{r\cdot(T_p-T_{sci}-T_{ci})}$$

$$=(1-f)\cdot e^{\theta_{ci}\cdot T_{SCi}}\cdot e^{r\cdot(T_p-T_{sci})}\cdot\int_0^{T_{ci}} C_{oi}(\tau)\cdot e^{(\theta_{ci}-r)\cdot\tau}d\tau$$

FW at T_P is also described as:

$$\int_0^{T_T-T_P} P_i\cdot e^{-r\cdot t}dt$$

Therefore,

$$P_i=(1-f)\cdot e^{\theta_{ci}\cdot T_{SCi}}e^{r\cdot(T_p-T_{sci})}\cdot\int_0^{T_{ci}} C_{oi}(\tau)\cdot e^{(\theta_{ci}-r)\cdot\tau}d\tau\Big/\int_0^{T_T-T_P} e^{-r\cdot t}dt$$

Then, discounted *i*th work package cost is,

$$WPC_i = f \cdot e^{(\theta_{ci}-y)\cdot T_{sci}} \int_0^{T_{ci}} C_{oi}(\tau) \cdot e^{(\theta_{ci}-y)\cdot\tau} d\tau + \int_0^{T_T-T_P} P_i \cdot e^{-y\cdot t} dt \cdot e^{-y\cdot T_P}$$

$$= f \cdot e^{(\theta_{ci}-y)\cdot T_{sci}} \cdot \int_0^{T_{ci}} C_{oi}(\tau) \cdot e^{(\theta_{ci}-y)\cdot\tau} d\tau$$

$$+ \int_0^{T_T-T_P} e^{-y\cdot t} dt \cdot e^{-y\cdot T_P} \cdot (1-f) \cdot e^{\theta_{ci}\cdot T_{SCi}} e^{r\cdot(T_P-T_{sci})} \cdot \int_0^{T_{ci}} C_{oi}(\tau) \cdot e^{(\theta_{ci}-r)\cdot\tau} d\tau \;/\; \int_0^{T_T-T_P} e^{-r\cdot t} dt$$

Appendix B

Input Data for Revenue Stream

The following tables shows input data for revenue streams.

B.1 Closed System (Fixed Toll Rate)

	Input Data	
nAL	the number of interchanges(IC)	deterministic
nP	the number of vehicle types	deterministic
nWC	weather classification	deterministic
nOL	periodic overlay	deterministic
nBR	periodic bridge repainting	deterministic
	(General Data)	
iby	start time of the revenue stream	automatically calculated
ird	revenue stream duration	
	(Data related to Toll Rate)	
fee(1,J,K,L)	toll rate of vehicle type L between IC #J and #K at the first year	
ptr(I)	toll growth rate parameter at year I	
	(Data related to Traffic Volume)	
ptv(I)	traffic volume growth rate parameter at year I	
traf(1,J,K,L)	traffic volume of vehicle type L between IC #J and #K at the first year	

	(Maintenance Cost)	
lb2	2 lane bridge length	
lb4	4 lane bridge length	
lb6	6 lane bridge length	
lt2	2 lane tunnel length	
lt4	4 lane tunnel length	
lt6	6 lane tunnel length	
le2	2 lane earthwork section length	
le4	4 lane earthwork section length	
le6	6 lane earthwork section length	
ltn	length of tunnel with no ventilation	
ltj	length of tunnel with jet fan	
lto	length of tunnel with other ventilation	
cc2	road cleaning cost (2 lanes)	
cc4	(4 lanes or more)	
cm2	road maintenance cost (2 lanes)	
cm4	(4 lanes)	
cm6	(6 lanes)	
cl1	lighting cost (1 or 2 lanes)	
cl4	(4 or 6 lanes)	
cr2	bridge repair cost (2 lanes)	
cr4	(4 lanes)	
cr6	(6 lanes)	
cp2	bridge paint cost (2 lanes)	
cp4	(4 lanes)	
cp6	(6 lanes)	
ctn	tunnel maintenance cost (no ventilation)	
ctj	tunnel maintenance cost (jet fan)	
cto	tunnel maintenance cost (others)	
csh	snow and ice control cost (heavy snow area))	
cso	(ordinary snow area)	
co2	overlay cost (2 lanes)	
co4	(4 lanes)	
co6	(6 lanes)	
pcot	other maintenance cost parameter	
	(Operation Cost)	
ldir	labor cost of operation office (director)	
lvdir	(vice director)	

lchi	(chief)	
leng	(clerk or engineer)	
lwor	(worker)	
t1	traffic volume(boundary-1)	
ita1	the number of directors needed for less traffic volume than t1	
itb1	the number of vice directors needed	
itc1	the number of chiefs needed	
itd1	the number of clerks and engineers needed	
ite1	the number of workers needed	
t2	traffic volume(boundary-2)	
ita2	the number of directors needed for less traffic volume than t2	
itb2	the number of vice directors needed	
itc2	the number of chiefs needed	
itd2	the number of clerks and engineers needed	
ite2	the number of workers needed	
t3	traffic volume(boundary-3)	
ita3	the number of directors needed for less traffic volume than t3	
itb3	the number of vice directors needed	
itc3	the number of chiefs needed	
itd3	the number of clerks and engineers needed	
ite3	the number of workers needed	
t4	traffic volume(boundary-4)	
ita4	the number of directors needed for less traffic volume than t4	
itb4	the number of vice directors needed	
itc4	the number of chiefs needed	
itd4	the number of clerks and engineers needed	
ite4	the number of workers needed	
t5	traffic volume(boundary-5)	
ita5	the number of directors needed for less traffic volume than t5	
itb5	the number of vice directors needed	
itc5	the number of chiefs needed	
itd5	the number of clerks and engineers needed	
ite5	the number of workers needed	
ita6	the number of directors needed for more traffic volume than t5	
itb6	the number of vice directors needed	

itc6	the number of chiefs needed	
itd6	the number of clerks and engineers needed	
ite6	the number of workers needed	
ltc	labor cost of toll collection (clerk)	
tc1	traffic volume(boundary-1)	
itct1	the number of clerks needed for less traffic volume than t1	
tc2	traffic volume(boundary-2)	
itct2	the number of toll collection clerks needed for less traffic volume than t2	
tc3	traffic volume(boundary-3)	
itct3	the number of toll collection clerks needed for less traffic volume than t3	
tc4	traffic volume(boundary-4)	
itct4	the number of toll collection clerks needed for less traffic volume than t4	
tc5	traffic volume(boundary-5)	
itct5	the number of toll collection clerks needed for less traffic volume than t5	
tc6	traffic volume(boundary-6)	
itct6	the number of toll collection clerks needed for less traffic volume than t6	
tc7	traffic volume(boundary-7)	
itct7	the number of toll collection clerks needed for less traffic volume than t7	
tc8	traffic volume(boundary-8)	
itct8	the number of toll collection clerks needed for less traffic volume than t8	
tc9	traffic volume(boundary-9)	
itct9	the number of toll collection clerks needed for less traffic volume than t9	
tc10	traffic volume(boundary-10)	
itct10	the number of toll collection clerks needed for less traffic volume than t10	
tc11	traffic volume(boundary-11)	
itct11	the number of toll collection clerks needed for less traffic volume than t11	
tc12	traffic volume(boundary-12)	
itct12	the number of toll collection clerks needed for less traffic volume than t12	
tc13	traffic volume(boundary-13)	

itct13	the number of toll collection clerks needed for less traffic volume than t13	
tc14	traffic volume(boundary-14)	
itct14	the number of toll collection clerks needed for less traffic volume than t14	
tc15	traffic volume(boundary-15)	
itct15	the number of toll collection clerks needed for less traffic volume than t15	
tc16	traffic volume(boundary-16)	
itct16	the number of toll collection clerks needed for less traffic volume than t16	
tc17	traffic volume(boundary-17)	
itct17	the number of toll collection clerks needed for less traffic volume than t17	
itct18	the number of toll collection clerks needed for more traffic volume than t17	
ptct	(consigment costs of toll collection) are (toll collection labor costs) * ptct(parameter)	
ptcm	toll collection machine maintenance costs) are (consigment costs of toll collection) * ptcm(parameter)	
ibrco1	cost parameter of building and repainting expenses etc.	
ibrco2	cost parameter of building and repainting expenses etc.	
pobo	operation bureau overhead parameter	
pho	headquarters overhead	
flr	inflation rate (maintenance and operation costs)	

Table B.1 Closed System (Fixed Toll Rate)

B.2 Closed System (Distance Proportional Toll Rate)

	Input Data	
nAL	the number of interchanges(IC)	deterministic
nP	the number of vehicle types	deterministic
nWC	weather classification	deterministic
nOL	periodic overlay	deterministic
nBR	periodic bridge repainting	deterministic
	(General Data)	
iby	start time of the revenue stream	automatically calculated
ird	revenue stream duration	
	(Data related to Toll Rate)	
disc1	toll discount boundary-1 (distance)	
rate1	toll discount rate-1	
disc2	toll discount boundary-2 (distance)	
rate2	toll discount rate-2	
perKm	toll rate (distance proportional part) of ordinary motor vehicle	
entFee	toll rate (fixed part) of ordinary motor vehicle	
al(I)	distance between IC #I-1 and #I	
p(K)	toll ratios compared between ordinary motor vehicle and vehicle type K	
ptr(I)	toll growth rate parameter at year I	
	(Data related to Traffic Volume)	
ptv(I)	traffic volume growth rate parameter at year I	
traf(1,J,K,L)	traffic volume of vehicle type L between IC #J and #K at the first year	
	(Maintenance Cost)	
lb2	2 lane bridge length	
lb4	4 lane bridge length	
lb6	6 lane bridge length	
lt2	2 lane tunnel length	
lt4	4 lane tunnel length	
lt6	6 lane tunnel length	
le2	2 lane earthwork section length	
le4	4 lane earthwork section length	

le6	6 lane earthwork section length	
ltn	length of tunnel with no ventilation	
ltj	length of tunnel with jet fan	
lto	length of tunnel with other ventilation	
cc2	road cleaning cost (2 lanes)	
cc4	(4 lanes or more)	
cm2	road maintenance cost (2 lanes)	
cm4	(4 lanes)	
cm6	(6 lanes)	
cl1	lighting cost (1 or 2 lanes)	
cl4	(4 or 6 lanes)	
cr2	bridge repair cost (2 lanes)	
cr4	(4 lanes)	
cr6	(6 lanes)	
cp2	bridge paint cost (2 lanes)	
cp4	(4 lanes)	
cp6	(6 lanes)	
ctn	tunnel maintenance cost (no ventilation)	
ctj	tunnel maintenance cost (jet fan)	
cto	tunnel maintenance cost (others)	
csh	snow and ice control cost (heavy snow area))	
cso	(ordinary snow area)	
co2	overlay cost (2 lanes)	
co4	(4 lanes)	
co6	(6 lanes)	
pcot	other maintenance cost parameter	
	(Operation Cost)	
ldir	labor cost of operation office (director)	
lvdir	(vice director)	
lchi	(chief)	
leng	(clerk or engineer)	
lwor	(worker)	
t1	traffic volume(boundary-1)	
ita1	the number of directors needed for less traffic volume than t1	
itb1	the number of vice directors needed	
itc1	the number of chiefs needed	
itd1	the number of clerks and engineers needed	
ite1	the number of workers needed	

t2	traffic volume(boundary-2)	
ita2	the number of directors needed for less traffic volume than t2	
itb2	the number of vice directors needed	
itc2	the number of chiefs needed	
itd2	the number of clerks and engineers needed	
ite2	the number of workers needed	
t3	traffic volume(boundary-3)	
ita3	the number of directors needed for less traffic volume than t3	
itb3	the number of vice directors needed	
itc3	the number of chiefs needed	
itd3	the number of clerks and engineers needed	
ite3	the number of workers needed	
t4	traffic volume(boundary-4)	
ita4	the number of directors needed for less traffic volume than t4	
itb4	the number of vice directors needed	
itc4	the number of chiefs needed	
itd4	the number of clerks and engineers needed	
ite4	the number of workers needed	
t5	traffic volume(boundary-5)	
ita5	the number of directors needed for less traffic volume than t5	
itb5	the number of vice directors needed	
itc5	the number of chiefs needed	
itd5	the number of clerks and engineers needed	
ite5	the number of workers needed	
ita6	the number of directors needed for more traffic volume than t5	
itb6	the number of vice directors needed	
itc6	the number of chiefs needed	
itd6	the number of clerks and engineers needed	
ite6	the number of workers needed	
ltc	labor cost of toll collection (clerk)	
tc1	traffic volume(boundary-1)	
itct1	the number of clerks needed for less traffic volume than t1	
tc2	traffic volume(boundary-2)	
itct2	the number of toll collection clerks needed for less traffic volume than t2	

tc3	traffic volume(boundary-3)	
itct3	the number of toll collection clerks needed for less traffic volume than t3	
tc4	traffic volume(boundary-4)	
itct4	the number of toll collection clerks needed for less traffic volume than t4	
tc5	traffic volume(boundary-5)	
itct5	the number of toll collection clerks needed for less traffic volume than t5	
tc6	traffic volume(boundary-6)	
itct6	the number of toll collection clerks needed for less traffic volume than t6	
tc7	traffic volume(boundary-7)	
itct7	the number of toll collection clerks needed for less traffic volume than t7	
tc8	traffic volume(boundary-8)	
itct8	the number of toll collection clerks needed for less traffic volume than t8	
tc9	traffic volume(boundary-9)	
itct9	the number of toll collection clerks needed for less traffic volume than t9	
tc10	traffic volume(boundary-10)	
itct10	the number of toll collection clerks needed for less traffic volume than t10	
tc11	traffic volume(boundary-11)	
itct11	the number of toll collection clerks needed for less traffic volume than t11	
tc12	traffic volume(boundary-12)	
itct12	the number of toll collection clerks needed for less traffic volume than t12	
tc13	traffic volume(boundary-13)	
itct13	the number of toll collection clerks needed for less traffic volume than t13	
tc14	traffic volume(boundary-14)	
itct14	the number of toll collection clerks needed for less traffic volume than t14	
tc15	traffic volume(boundary-15)	
itct15	the number of toll collection clerks needed for less traffic volume than t15	
tc16	traffic volume(boundary-16)	

itct16	the number of toll collection clerks needed for less traffic volume than t16	
tc17	traffic volume(boundary-17)	
itct17	the number of toll collection clerks needed for less traffic volume than t17	
itct18	the number of toll collection clerks needed for more traffic volume than t17	
ptct	(consigment costs of toll collection) are (toll collection labor costs) * ptct(parameter)	
ptcm	toll collection machine maintenance costs) are (consigment costs of toll collection) * ptcm(parameter)	
ibrco1	cost parameter of building and repainting expenses etc.	
ibrco2	cost parameter of building and repainting expenses etc.	
pobo	operation bureau overhead parameter	
pho	headquarters overhead	
flr	inflation rate (maintenance and operation costs)	

Table D.2 Closed System (Distance Proportional Toll Rate)

B.3 Open System (Fixed Toll Rate)

	Input Data	
nAL	the number of interchanges(IC)	deterministic
nP	the number of vehicle types	deterministic
nTG	the number of toll gates	deterministic
TGL(J)	locations of toll gates	deterministic
nWC	weather classification	deterministic
nOL	periodic overlay	deterministic
nBR	periodic bridge repaintingr	deterministic
	(General Data)	
iby	start time of the revenue stream	automatically calculated
ird	revenue stream duration	
	(Data related to Toll Rate)	
Fee	toll rate of ordinary motor vehicle	
p(K)	toll ratios compared between ordinary motor vehicle and vehicle type K	
ptr(I)	toll growth rate parameter at year I	
	(Data related to Traffic Volume)	
ptv(I)	traffic volume growth rate parameter at year I	
traf(1,J,K,L)	traffic volume of vehicle type L between IC #J and #K at the first year	
	(Maintenance Cost)	
lb2	2 lane bridge length	
lb4	4 lane bridge length	
lb6	6 lane bridge length	
lt2	2 lane tunnel length	
lt4	4 lane tunnel length	
lt6	6 lane tunnel length	
le2	2 lane earthwork section length	
le4	4 lane earthwork section length	
le6	6 lane earthwork section length	
ltn	length of tunnel with no ventilation	
ltj	length of tunnel with jet fan	
lto	length of tunnel with other ventilation	

cc2	road cleaning cost (2 lanes)	
cc4	(4 lanes or more)	
cm2	road maintenance cost (2 lanes)	
cm4	(4 lanes)	
cm6	(6 lanes)	
cl1	lighting cost (1 or 2 lanes)	
cl4	(4 or 6 lanes)	
cr2	bridge repair cost (2 lanes)	
cr4	(4 lanes)	
cr6	(6 lanes)	
cp2	bridge paint cost (2 lanes)	
cp4	(4 lanes)	
cp6	(6 lanes)	
ctn	tunnel maintenance cost (no ventilation)	
ctj	tunnel maintenance cost (jet fan)	
cto	tunnel maintenance cost (others)	
csh	snow and ice control cost (heavy snow area))	
cso	(ordinary snow area)	
co2	overlay cost (2 lanes)	
co4	(4 lanes)	
co6	(6 lanes)	
pcot	other maintenance cost parameter	
	(Operation Cost)	
ldir	labor cost of operation office (director)	
lvdir	(vice director)	
lchi	(chief)	
leng	(clerk or engineer)	
lwor	(worker)	
t1	traffic volume(boundary-1)	
ita1	the number of directors needed for less traffic volume than t1	
itb1	the number of vice directors needed	
itc1	the number of chiefs needed	
itd1	the number of clerks and engineers needed	
ite1	the number of workers needed	
t2	traffic volume(boundary-2)	
ita2	the number of directors needed for less traffic volume than t2	
itb2	the number of vice directors needed	

itc2	the number of chiefs needed	
itd2	the number of clerks and engineers needed	
ite2	the number of workers needed	
t3	traffic volume(boundary-3)	
ita3	the number of directors needed for less traffic volume than t3	
itb3	the number of vice directors needed	
itc3	the number of chiefs needed	
itd3	the number of clerks and engineers needed	
ite3	the number of workers needed	
t4	traffic volume(boundary-4)	
ita4	the number of directors needed for less traffic volume than t4	
itb4	the number of vice directors needed	
itc4	the number of chiefs needed	
itd4	the number of clerks and engineers needed	
ite4	the number of workers needed	
t5	traffic volume(boundary-5)	
ita5	the number of directors needed for less traffic volume than t5	
itb5	the number of vice directors needed	
itc5	the number of chiefs needed	
itd5	the number of clerks and engineers needed	
ite5	the number of workers needed	
ita6	the number of directors needed for more traffic volume than t5	
itb6	the number of vice directors needed	
itc6	the number of chiefs needed	
itd6	the number of clerks and engineers needed	
ite6	the number of workers needed	
ltc	labor cost of toll collection (clerk)	
tc1	traffic volume(boundary-1)	
itct1	the number of clerks needed for less traffic volume than t1	
tc2	traffic volume(boundary-2)	
itct2	the number of toll collection clerks needed for less traffic volume than t2	
tc3	traffic volume(boundary-3)	
itct3	the number of toll collection clerks needed for less traffic volume than t3	
tc4	traffic volume(boundary-4)	

itct4	the number of toll collection clerks needed for less traffic volume than t4	
tc5	traffic volume(boundary-5)	
itct5	the number of toll collection clerks needed for less traffic volume than t5	
tc6	traffic volume(boundary-6)	
itct6	the number of toll collection clerks needed for less traffic volume than t6	
tc7	traffic volume(boundary-7)	
itct7	the number of toll collection clerks needed for less traffic volume than t7	
tc8	traffic volume(boundary-8)	
itct8	the number of toll collection clerks needed for less traffic volume than t8	
tc9	traffic volume(boundary-9)	
itct9	the number of toll collection clerks needed for less traffic volume than t9	
tc10	traffic volume(boundary-10)	
itct10	the number of toll collection clerks needed for less traffic volume than t10	
tc11	traffic volume(boundary-11)	
itct11	the number of toll collection clerks needed for less traffic volume than t11	
tc12	traffic volume(boundary-12)	
itct12	the number of toll collection clerks needed for less traffic volume than t12	
tc13	traffic volume(boundary-13)	
itct13	the number of toll collection clerks needed for less traffic volume than t13	
tc14	traffic volume(boundary-14)	
itct14	the number of toll collection clerks needed for less traffic volume than t14	
tc15	traffic volume(boundary-15)	
itct15	the number of toll collection clerks needed for less traffic volume than t15	
tc16	traffic volume(boundary-16)	
itct16	the number of toll collection clerks needed for less traffic volume than t16	
tc17	traffic volume(boundary-17)	
itct17	the number of toll collection clerks needed for less traffic volume than t17	

tc18	traffic volume(boundary-18)	
itct18	the number of toll collection clerks needed for less traffic volume than t18	
itct19	the number of toll collection clerks needed for more traffic volume than t18	
ptct	(consigment costs of toll collection) are (toll collection labor costs) * ptct(parameter)	
ptcm	toll collection machine maintenance costs) are (consigment costs of toll collection) * ptcm(parameter)	
ibrco1	cost parameter of building and repainting expenses etc.	
ibrco2	cost parameter of building and repainting expenses etc.	
pobo	operation bureau overhead parameter	
pho	headquarters overhead	
flr	inflation rate (maintenance and operation costs)	

Table D.3 Open System (Fixed Toll Rate)

Appendix C

Interchange Pair Traffic Volume and Traffic Volume and Toll Rate Growth Parameters

C.1 Interchange Pair Traffic Volume

Tables C.1 to C.9 shows interchange pair traffic volume for the sample project.
They are described by daily traffic volume, and their units are vehicles/day.

vehicle type-1
(light motor vehicle)

					I.C. #6
				I.C. #5	1,636
			I.C. #4	449	853
		I.C. #3	660	756	2,275
	I.C. #2				
I.C . #1					

vehicle type-2
(ordinary motor vehicle)

					I.C. #6
				I.C. #5	4,585
			I.C. #4	1,846	2,660
		I.C. #3	1,400	2,892	6,785
	I.C. #2				
I.C . #1					

vehicle type-3
(medium-sized motor vehicle)

					I.C. #6
				I.C. #5	723
			I.C. #4	278	448
		I.C. #3	176	187	1,099
	I.C. #2				
I.C . #1					

vehicle type-4
(large-sized motor vehicle)

					I.C. #6
				I.C. #5	505
			I.C. #4	183	346
		I.C. #3	141	117	862
	I.C. #2				
I.C . #1					

vehicle type-5
(special large-sized motor vehicle)

					I.C. #6
				I.C. #5	44
			I.C. #4	39	37
		I.C. #3	12	15	85
	I.C. #2				
I.C . #1					

(total)

					I.C. #6
				I.C. #5	7,493
			I.C. #4	2,795	4,344
		I.C. #3	2,389	3,967	11,106
	I.C. #2	0	0	0	0
I.C . #1	0	0	0	0	0

Table C.1: Interchange Pair Traffic Volume at Base Year for RVS #1.

vehicle type-1
(light motor vehicle)

					I.C. #6
				I.C. #5	1,676
			I.C. #4	469	880
		I.C. #3	333	333	955
	I.C. #2	7	411	610	1,536
I.C . #1					

vehicle type-2
(ordinary motor vehicle)

					I.C. #6
				I.C. #5	4,751
			I.C. #4	1,923	2,740
		I.C. #3	704	1,495	3,233
	I.C. #2	22	947	2,272	4,306
I.C . #1					

vehicle type-3
(medium-sized motor vehicle)

					I.C. #6
				I.C. #5	727
			I.C. #4	306	461
		I.C. #3	26	154	396
	I.C. #2	6	156	104	881
I.C . #1					

vehicle type-4
(large-sized motor vehicle)

					I.C. #6
				I.C. #5	506
			I.C. #4	198	358
		I.C. #3	19	96	304
	I.C. #2	6	120	69	672
I.C . #1					

vehicle type-5
(special large-sized motor vehicle)

					I.C. #6
				I.C. #5	46
			I.C. #4	43	39
		I.C. #3	2	17	41
	I.C. #2	0	10	5	64
I.C . #1					

(total)

					I.C. #6
				I.C. #5	7,706
			I.C. #4	2,939	4,478
		I.C. #3	1,084	2,095	4,929
	I.C. #2	41	1,644	3,060	7,459
I.C . #1	0	0	0	0	0

Table C.2: Interchange Pair Traffic Volume at Base Year for RVS #2.

vehicle type-1
(light motor vehicle)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #5					1,969
I.C. #4				401	983
I.C. #3			328	269	823
I.C. #2		351	552	836	2,086
I.C . #1					

vehicle type-2
(ordinary motor vehicle)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #5					5,493
I.C. #4				1,647	3,084
I.C. #3			703	1,112	2,883
I.C. #2		991	1,414	3,269	6,348
I.C . #1					

vehicle type-3
(medium-sized motor vehicle)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #5					770
I.C. #4				270	490
I.C. #3			27	110	344
I.C. #2		72	192	169	1,138
I.C . #1					

vehicle type-4
(large-sized motor vehicle)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #5					538
I.C. #4				173	382
I.C. #3			19	62	262
I.C. #2		38	152	119	925
I.C . #1					

vehicle type-5
(special large-sized motor vehicle)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #5					51
I.C. #4				41	44
I.C. #3			2	11	41
I.C. #2		6	12	13	86
I.C . #1					

(total)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #5					8,821
I.C. #4				2,532	4,983
I.C. #3			1,079	1,564	4,353
I.C. #2		1,458	2,322	4,406	10,583
I.C . #1	0	0	0	0	0

Table C.3: Interchange Pair Traffic Volume at Base Year for RVS #3.

vehicle type-1
(light motor vehicle)

					I.C. #6
				I.C. #5	2,144
			I.C. #4	402	1,058
		I.C. #3	341	327	810
	I.C. #2	402	562	883	2,234
I.C . #1					

vehicle type-2
(ordinary motor vehicle)

					I.C. #6
				I.C. #5	6,008
			I.C. #4	1,651	3,353
		I.C. #3	727	1,447	2,716
	I.C. #2	1,128	1,439	3,566	6,689
I.C . #1					

vehicle type-3
(medium-sized motor vehicle)

					I.C. #6
				I.C. #5	1,344
			I.C. #4	277	534
		I.C. #3	28	131	331
	I.C. #2	87	195	244	1,396
I.C . #1					

vehicle type-4
(large-sized motor vehicle)

					I.C. #6
				I.C. #5	923
			I.C. #4	183	399
		I.C. #3	19	76	264
	I.C. #2	44	154	175	1,160
I.C . #1					

vehicle type-5
(special large-sized motor vehicle)

					I.C. #6
				I.C. #5	150
			I.C. #4	41	59
		I.C. #3	2	14	36
	I.C. #2	6	13	20	115
I.C . #1					

(total)

					I.C. #6
				I.C. #5	10,569
			I.C. #4	2,554	5,403
		I.C. #3	1,117	1,995	4,157
	I.C. #2	1,667	2,363	4,888	11,594
I.C . #1	0	0	0	0	0

Table C.4: Interchange Pair Traffic Volume at Base Year for RVS #4.

vehicle type-1
(light motor vehicle)

					I.C. #6
				I.C. #5	2,326
			I.C. #4	422	743
		I.C. #3	352	327	817
	I.C. #2	428	486	424	1,597
I.C . #1	75	285	303	628	1,113

vehicle type-2
(ordinary motor vehicle)

					I.C. #6
				I.C. #5	6,671
			I.C. #4	1,745	2,251
		I.C. #3	752	1,438	2,736
	I.C. #2	1,181	1,127	1,798	5,859
I.C . #1	290	1,055	787	2,462	2,589

vehicle type-3
(medium-sized motor vehicle)

					I.C. #6
				I.C. #5	1,543
			I.C. #4	292	518
		I.C. #3	29	136	277
	I.C. #2	112	125	132	991
I.C . #1	38	143	163	123	434

vehicle type-4
(large-sized motor vehicle)

					I.C. #6
				I.C. #5	1,076
			I.C. #4	188	411
		I.C. #3	20	78	208
	I.C. #2	60	76	86	815
I.C . #1	29	90	135	99	366

vehicle type-5
(special large-sized motor vehicle)

					I.C. #6
				I.C. #5	169
			I.C. #4	43	53
		I.C. #3	2	14	40
	I.C. #2	10	10	14	85
I.C . #1	3	11	11	6	28

(total)

					I.C. #6
				I.C. #5	11,785
			I.C. #4	2,690	3,976
		I.C. #3	1,155	1,993	4,078
	I.C. #2	1,791	1,824	2,454	9,347
I.C . #1	435	1,584	1,399	3,318	4,530

Table C.5: Interchange Pair Traffic Volume at Base Year for RVS #5.

vehicle type-1
(light motor vehicle)

					I.C. #6
				I.C. #5	2,529
			I.C. #4	464	782
		I.C. #3	376	446	755
	I.C. #2	460	518	490	1,652
I.C . #1	80	302	318	688	1,164

vehicle type-2
(ordinary motor vehicle)

					I.C. #6
				I.C. #5	7,235
			I.C. #4	1,956	2,357
		I.C. #3	802	2,128	2,497
	I.C. #2	1,267	1,199	2,124	5,996
I.C . #1	312	1,134	832	2,745	2,699

vehicle type-3
(medium-sized motor vehicle)

					I.C. #6
				I.C. #5	1,837
			I.C. #4	315	557
		I.C. #3	31	159	283
	I.C. #2	120	135	148	1,032
I.C . #1	42	151	173	134	474

vehicle type-4
(large-sized motor vehicle)

					I.C. #6
				I.C. #5	1,290
			I.C. #4	203	443
		I.C. #3	22	94	213
	I.C. #2	65	84	97	855
I.C . #1	31	96	142	111	393

vehicle type-5
(special large-sized motor vehicle)

					I.C. #6
				I.C. #5	205
			I.C. #4	49	61
		I.C. #3	2	15	42
	I.C. #2	10	11	16	91
I.C . #1	4	13	12	7	28

(total)

					I.C. #6
				I.C. #5	13,096
			I.C. #4	2,987	4,200
		I.C. #3	1,233	2,842	3,790
	I.C. #2	1,922	1,947	2,875	9,626
I.C . #1	469	1,696	1,477	3,685	4,758

Table C.6: Interchange Pair Traffic Volume at Base Year for RVS #6.

vehicle type-1
(light motor vehicle)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #5					3,528
I.C. #4				558	950
I.C. #3			437	482	875
I.C. #2		586	534	493	1,624
I.C . #1	110	437	371	770	1,419

vehicle type-2
(ordinary motor vehicle)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #5					10,366
I.C. #4				2,205	3,690
I.C. #3			922	2,215	2,946
I.C. #2		1,627	1,241	1,915	6,216
I.C . #1	457	1,706	960	3,081	3,583

vehicle type-3
(medium-sized motor vehicle)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #5					2,286
I.C. #4				309	774
I.C. #3			34	217	354
I.C. #2		141	146	83	953
I.C . #1	50	91	189	83	722

vehicle type-4
(large-sized motor vehicle)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #5					1,677
I.C. #4				201	599
I.C. #3			24	136	289
I.C. #2		93	97	45	785
I.C . #1	38	130	156	68	634

vehicle type-5
(special large-sized motor vehicle)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #5					266
I.C. #4				47	111
I.C. #3			5	24	39
I.C. #2		14	12	12	91
I.C . #1	6	19	13	3	50

(total)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #5					18,123
I.C. #4				3,320	6,124
I.C. #3			1,422	3,074	4,503
I.C. #2		2,461	2,030	2,548	9,669
I.C . #1	661	2,383	1,689	4,005	6,408

Table C.7: Interchange Pair Traffic Volume at Base Year for RVS #7.

vehicle type-1
(light motor vehicle)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #6					
I.C. #5					4,002
I.C. #4				636	980
I.C. #3			497	542	1,009
I.C. #2		617	602	538	1,580
I.C . #1	195	829	402	1,114	2,177

vehicle type-2
(ordinary motor vehicle)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #5					11,532
I.C. #4				2,496	3,815
I.C. #3			1,051	2,497	3,448
I.C. #2		1,656	1,386	2,052	5,858
I.C . #1	908	3,315	1,093	4,944	7,146

vehicle type-3
(medium-sized motor vehicle)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #5					2,063
I.C. #4				350	759
I.C. #3			40	239	420
I.C. #2		155	156	98	744
I.C . #1	119	346	196	387	3,667

vehicle type-4
(large-sized motor vehicle)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #5					1,491
I.C. #4				229	603
I.C. #3			28	147	324
I.C. #2		90	93	51	608
I.C . #1	88	267	169	309	3,194

vehicle type-5
(special large-sized motor vehicle)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #5					239
I.C. #4				55	107
I.C. #3			5	31	55
I.C. #2		16	14	14	71
I.C . #1	10	35	17	39	371

(total)

	I.C. #2	I.C. #3	I.C. #4	I.C. #5	I.C. #6
I.C. #5					19,327
I.C. #4				3,766	6,264
I.C. #3			1,621	3,456	5,256
I.C. #2		2,534	2,251	2,753	8,861
I.C . #1	1,320	4,792	1,877	6,793	16,555

Table C.8: Interchange Pair Traffic Volume at Base Year for RVS #8.

vehicle type-1
(light motor vehicle)

					I.C. #6
				I.C. #5	4,443
			I.C. #4	709	1,075
		I.C. #3	560	572	1,109
	I.C. #2	705	679	601	1,732
I.C . #1	219	967	441	1,193	2,287

vehicle type-2
(ordinary motor vehicle)

					I.C. #6
				I.C. #5	12,614
			I.C. #4	2,768	4,194
		I.C. #3	1,183	2,657	3,811
	I.C. #2	1,888	1,559	2,339	6,322
I.C . #1	1,035	3,846	1,200	5,290	7,364

vehicle type-3
(medium-sized motor vehicle)

					I.C. #6
				I.C. #5	2,319
			I.C. #4	387	826
		I.C. #3	44	214	464
	I.C. #2	177	176	105	803
I.C . #1	146	460	215	314	3,562

vehicle type-4
(large-sized motor vehicle)

					I.C. #6
				I.C. #5	1,684
			I.C. #4	256	659
		I.C. #3	32	125	365
	I.C. #2	104	1,208	58	664
I.C . #1	106	357	188	264	3,143

vehicle type-5
(special large-sized motor vehicle)

					I.C. #6
				I.C. #5	276
			I.C. #4	61	114
		I.C. #3	6	31	62
	I.C. #2	17	15	17	79
I.C . #1	15	46	20	27	385

(total)

					I.C. #6
				I.C. #5	21,336
			I.C. #4	4,181	6,868
		I.C. #3	1,825	3,599	5,811
	I.C. #2	2,891	3,637	3,120	9,600
I.C . #1	1,521	5,676	2,064	7,088	16,741

Table C.9: Interchange Pair Traffic Volume at Base Year for RVS #9.

C.2 Traffic Volume Growth Parameters

Table C.10 shows traffic volume growth parameters used for deterministic feasibility analysis.

RVS #	Year in RVS	Parameter
1	1	559
2	1	567
3	1	574
4	1	582
5	1	590
	2	597
6	1	605
	2	618
7	1	630
	2	643
	3	655
	4	668
8	1	681
	2	693
	3	706
	4	718
9	1	731
	2	741
	3	751
	4	761
	5	770
	6	780
	7	790
	8	800
	9	810
	10	820
	11	830
	12	840
	13	849
	14	859

Table C.10 Traffic Volume Growth Parameters

C.3 Toll Rate Growth Parameters

Table C.11 shows toll rate growth parameters used for deterministic feasibility analysis.

RVS #	Year in RVS	Parameter
1	1	1.0000
2	1	1.0000
3	1	1.0000
4	1	1.0404
5	1	1.0404
	2	1.0404
6	1	1.1041
	2	1.1041
7	1	1.1041
	2	1.1717
	3	1.1717
	4	1.1717
8	1	1.2434
	2	1.2434
	3	1.2434
	4	1.3195
9	1	1.3195
	2	1.3195
	3	1.4002
	4	1.4002
	5	1.4002
	6	1.4859
	7	1.4859
	8	1.4859
	9	1.5769
	10	1.5769
	11	1.5769
	12	1.6734
	13	1.6734
	14	1.6734

Table C.11 Toll Rate Growth Parameters

Appendix D

Source Code of the Model

Appendix D shows source code of the model.

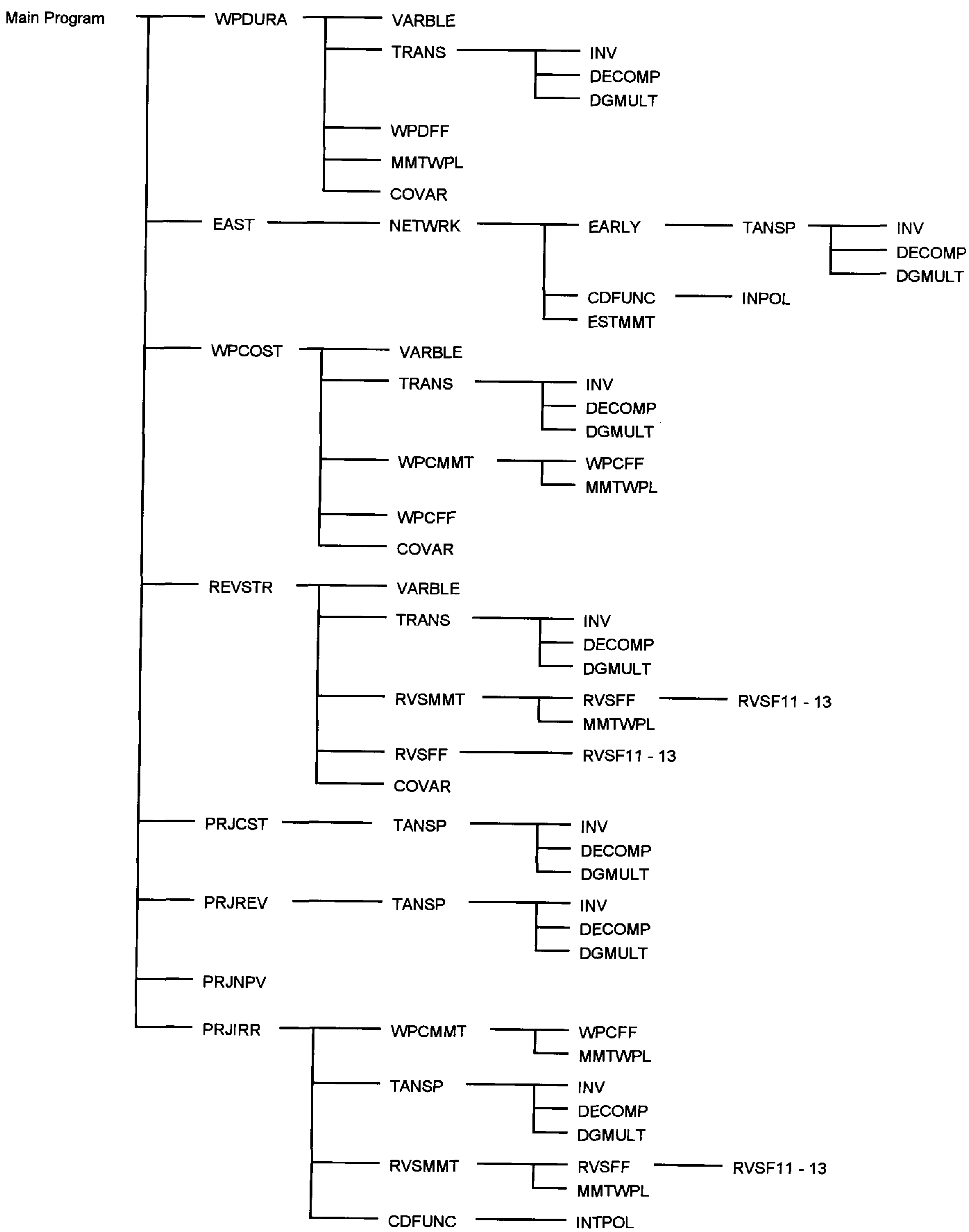


Figure D.1 Program Structure

main program	AMMA	
sub-routine	WPDURA	evaluate the first four moments of the work package duration.
	EAST	evaluate the first four moments of the early start time of work packages. obtain the calendar month of the early start time.
	WPCOST	evaluate the first four moments of the work package cost.
	REVSTR	evaluate the first four moments of the net revenue stream.
	PRJCST	approximate the first four moments of the project cost at the MARR.
	PRJREV	approximate the first four moments of the project revenue at the MARR.
	PRJNPV	approximate the first four moments of the project NPV at the MARR.
	PRJIRR	approximate the cumulative distribution function and the first four moments of the project IRR.
	CDFUNC	obtain values of cumulative distribution function of a dependent variable approximated by a pearson typed distribution.
	INTPOL	interpolate the beta1 and beta2 values of the pearson table by a method of linear interpolation.
	VARBLE	approximate a variable to a pearson type distribution by using five percentile estimates.
	TRANS	transform a set of correlated variables to a set of uncorrelated variables.
	TANSP	transform correlated work package costs/revenue streams to uncorrelated work package costs/revenue.
	WPDFF	check the type of functional form for work package duration. estimate the function at the mean values of the transformed variables.
	WPCMMT	evaluate the first four moments of the work package cost for different discount rates.

	RVSMMT	evaluate the first four moments of the revenue streams for different discount rates.
	WPCFF	check the type of functional form for work package cost. estimate the function at the mean values of the transformed variables.
	RVSFF	check the type of functional form for revenue streams. estimate the function at the mean values of the transformed variables.
	MMTWPL	approximate the first four moments of a dependent variables at work package/revenue stream level (by Taylor series).
	COVAR	approximate the correlation between two dependent variables by using information between the primary variables and their partial derivatives.
	NETWRK	evaluate the first four moments of work package early start time (by PNET).
	EARLY	evaluate the first four moments of a path early start time by uncorrelating the work package durations.
	ESTMMT	approximate the first four moments for early start time (if PNET is used).
	INV	invert a matrix
	DECOMP	decompose A to A=L*Ltranspose (by Choleski method).
	DGMULT	calculate matrix * matrix e.g. transformation matrix ($\mathbf{L}^{-1} \times \mathbf{D}^{-1}$)
	RVSF11 - 13	the functional forms for revenue streams for toll highway projects
	SPARSE	save huge arrays that contain mainly zero.
	FOO1	called by "RVSF12"
	TRACE	trace the procedure

Table D.1 Program List

```
C Amma.FOR

C modified by Toshiaki Hatakama in July 1994 in order to adjust
C the program to toll highway projects that require a lot of primary
C variables (e.g. 200) for revenue streams.

C However, this program limits the number of primary variables to 300
C due to memory capacity.

C For example, if the number of interchanges is 6, the number of
C vehicle types is 5, toll collection system is closed system (fixed
C toll rates), and a revenue stream duration is 14 years, the number
C of primary variables of the revenue stream is 297.  This is almost
C the limit.  If you have big enough RAM, you can increase this
C number.

C AMMA is capable of dealing with correlations between variables.
C However, due to memory capacity, correlation coefficients for
C revenue streams are automatically calculated as zero.  In other
C words, work package duration and cost input files should include
C correlation coefficients, but revenue stream input file does not
C include them.

C In addition, save memory spaces, subroutine SPARSE is used.  Most
C correlation coefficients are often zero.  SPARSE can save these
C spaces.  See source code.

C Common blocks in the original program (written in 1990) are
C replaced by Dummy Arguments.

C This program requires 2.5, 5.0, 50.0, 95.0, and 97.5 percentile
C estimates (note : not 5.0, 25.0, 50.0, 75.0, 95.0).

C Step functions are used for operation cost estimates, there is a
C problem when partial derivatives are calculated.  Even small
C changes in some primary variables may cause big differences because
C their ranks sometimes change.  See operation cost estimates in
C RVSF11, 12, and 13.inc for reference.  Therefore, AMMA uses a trick
C to deal with this, namely, parameters KT and KP.  See REVSTR,
C RVSMMT, and RVSF11, 12, and 13.inc.


C=============================================================
==
      PROGRAM AMMA
C=============================================================

      IMPLICIT REAL*4 (A-H,O-Z)
      CHARACTER*64 FNAME


C if you have 16M or more Ram, choose "enough" = 1.
C if not, choose any number but 1.

$DEFINE enough = 0
```

```
      REAL*4 PEARSN (:,:)
      ALLOCATABLE PEARSN

      REAL*4 WPTIME (:,:), CORRD (:,:), ESTART (:,:)

      INTEGER IWPC (:), NWPCF (:), NDVR (:)
      INTEGER NRVSF (:), NDRV (:)

      REAL*4 XUCOST (:,:,:), TRIWPC (:,:,:), COST (:,:), CORRC (:,:)

      REAL*4 BOTTLE (:,:), XUREV (:,:,:), REV (:,:), CORRR (:,:)

$IF enough .EQ. 1
      REAL*4 TRIRVS (:,:,:)
$ELSE
      REAL*4 TRIRVS (:)
$ENDIF

      REAL*4 PCOST (4), PREV (4)

      ALLOCATABLE WPTIME, CORRD, ESTART
      ALLOCATABLE IWPC, NWPCF, NDVR, NRVSF, NDRV, BOTTLE
      ALLOCATABLE XUCOST, TRIWPC, COST, CORRC
      ALLOCATABLE XUREV, TRIRVS, REV, CORRR

      INCLUDE 'DEBUG.CMN'

      CALL TRACE (1, 'MAIN', 'Amma 2.0 begins execution.')

C get certain parameters from a startup file, such as

      OPEN (UNIT=1, FILE='AMMA.INI', STATUS='UNKNOWN')
      READ (1, *) NPEARS      ! the size of the pearson table (always
                              ! 2655)
      READ (1, *) MAXDVC      ! max # of variables for COST (~25)
      READ (1, *) MAXDVR      ! max # of variables for REVENUE (~300)
      READ (1, *) IDEBUG      ! 0=silent, 1=enter/exit, 2=more...
      CLOSE (UNIT=1)

C Read in the Pearson Distribution Definition and store in an array.
C the pearson table should REALLY be (17,NPEARS).
C that way, you don't have to refer to NPEARS all the time.

      ALLOCATE (PEARSN (NPEARS, 17))
      OPEN (UNIT=1, FILE='PEARSON', STATUS='UNKNOWN')
      DO 10 I=1,2655
   10    READ (1,9901) (PEARSN(I,J), J=1,17)
      CLOSE (UNIT=1)


C Get all the input file names from the Pipe between Terq and AMMA
C fName is read into as many times as is required to get at the
C actual data (the program 'comments' the parameters...

      OPEN (UNIT=90, FILE='TERQAMMA.PIP', STATUS='UNKNOWN')
      READ (90,*) fName
```

```
      READ (90,*) fName
      READ (90,*) fName

      READ (90,*) fName
      READ (90,*) fName      ! LR filename, usually 'tTerq.LR'
       OPEN (UNIT=10, FILE=fName, STATUS='UNKNOWN' )

      READ (90,*) fName
      READ (90,*) fName      ! D filename, usually 'tTerq.D'
       OPEN (UNIT=11, FILE=fname, STATUS='UNKNOWN' )

      READ (90,*) fName
      READ (90,*) fName      ! C filename, usually 'tTerq.C'
       OPEN (UNIT=12, FILE=fName, STATUS='UNKNOWN' )

      READ (90,*) fName
      READ (90,*) fName      ! R filename, usually 'tTerq.R'
       OPEN (UNIT=13, FILE=fName, STATUS='UNKNOWN' )

      READ (90,*) fName
      READ (90,*) fName      ! Output filename, usually 'tTerq.OUT'
       OPEN (UNIT=7, FILE=fName, STATUS='UNKNOWN' )
       CALL TRACE (1, 'MAIN', fName)

      CLOSE (UNIT=90)


C EXCEL.CSV is a 'Comma Separated Value' file for EXCEL to play
C with...
C This file is used to draw cumulative probability distributions.

      OPEN (UNIT=20, FILE='AMMA.CSV', STATUS='UNKNOWN')

      READ (11, 9902)
     +  NWP    ! number of Work Packages, inc. start/fin.

      ALLOCATE (WPTIME (4, NWP))
      ALLOCATE (CORRD (NWP, NWP))

C set the global error variable to 0.
C if there is a problem, this gets set to something other than 0,
C and the program jumps to the STOP statement.

      IERR = 0

      CALL TRACE (1, 'MAIN', 'calling Work Package DURAtion.')
       CALL WPDURA (PEARSN, WPTIME, CORRD)
C            READ from unit 11 (correlation of primary variables)
C            CALLs VARBLE, TRANS, WPDFF, MMTWPL & COVAR (the reader!)

      IF (0 < IERR) THEN
         CALL TRACE (1, 'MAIN', 'WPDURA set IERR, exiting.')
         GO TO 1000
      ENDIF

      ALLOCATE (ESTART (4, NWP))
```

```
      CALL TRACE (1, 'MAIN', 'calling EArly STart.')
       CALL EAST (PEARSN, WPTIME, CORRD, ESTART)
C            READ from unit 10, just one line with system parameters
C            CALLs NETWRK, which CALLs EARLY, CDFUNC & ESTMMT

      IF (0 < IERR) THEN
         CALL TRACE (1, 'MAIN', 'EAST set IERR, exiting.')
         GO TO 1000
      ENDIF

      READ (12, 9903)
     +  DR,     ! minimum attractive rate of return
     +  FRA     ! equity fraction

      READ (13, 9904)
     +  NRS     ! the number of revenue streams

      ALLOCATE (IWPC (NWP))
      ALLOCATE (NWPCF (NWP))
      ALLOCATE (NDVR (NWP))
      ALLOCATE (XUCOST (4, NWP, MAXDVC))
      ALLOCATE (TRIWPC (NWP, NWP, NWP))
      ALLOCATE (COST (4, NWP))
      ALLOCATE (CORRC (NWP, NWP))

      CALL TRACE (1, 'MAIN', 'calling Work Package COST.')
       CALL WPCOST (DR, FRA,
     +              PEARSN,
     +              WPTIME,
     +              ESTART,
     +              IWPC, NWPCF, NDVR,
     +              COST,
     +              XUCOST, TRIWPC,
     +              CORRC)
C            READ from unit 12, alot of work package stuff
C            CALLs VARBLE, TRANS, WPCMMT, WPCFF & COVAR (the reader!)
      IF (0 < IERR) THEN
         CALL TRACE (1, 'MAIN', 'WPCOST set IERR, exiting.')
         GO TO 1000
      ENDIF

      ALLOCATE (NRVSF (NRS))
      ALLOCATE (NDRV (NRS))
      ALLOCATE (XUREV (4, NRS, MAXDVR))

C this is a sparse array, so go figure...

$IF enough .EQ. 1
      ALLOCATE (TRIRVS (NRS, MAXDVR, MAXDVR))
$ELSE
      NSIZ = (MAXDVR * 3 * NRS) + 6
      NSIZ = 10002 ! and this is an optimal patch for the time
being...
      ALLOCATE (TRIRVS (NSIZ))
      CALL SPA_INIT3 (TRIRVS, NSIZ, NRS, MAXDVR, MAXDVR)
$ENDIF
```

```
      ALLOCATE (REV (4, NRS))
      ALLOCATE (CORRR (NRS,NRS))
      ALLOCATE (BOTTLE (NRS, 30))


      CALL TRACE (1, 'MAIN', 'calling REVenue STReam.')
       CALL REVSTR (PEARSN,
     +              DR,
     +              WPTIME,
     +              ESTART,
     +              NRVSF, NDRV,
     +              XUREV, TRIRVS,
     +              REV, CORRR,
     +              BOTTLE)
C           READ from unit 13, tons of data into NRVSF, etc.
C           CALLs VARBLE, TRANS, RVSMMT, RVSFF & COVAR
      IF (0 < IERR) THEN
         CALL TRACE (1, 'MAIN', 'REVSTR set IERR, exiting.')
         GO TO 1000
      ENDIF

      DEALLOCATE (WPTIME, CORRD)
      DEALLOCATE (ESTART)


C THE PROJECT PERFORMANCE LEVEL


      CALL TRACE (1, 'MAIN', 'calling PRoJect CoST.')
       CALL PRJCST (DR,
     +              COST,
     +              CORRC,
     +              PCOST)
C           CALLs TANSP


      CALL TRACE (1, 'MAIN', 'calling PRoJect REVenue.')
       CALL PRJREV (DR,
     +              REV,
     +              CORRR,
     +              PREV)
C           CALLs TANSP


C if (constant, current or total dollars = 0), then we're done.

      IF (DR == 0.0D0) THEN
         CALL TRACE (1, 'MAIN', 'minumum attractive rate=0,
     +                exiting.')
         GO TO 1000
      ENDIF


C THE PROJECT DECISION LEVEL


      CALL TRACE (1, 'MAIN', 'calling PRoJect Net Present Value.')
```

```
       CALL PRJNPV (DR,
     +              PCOST,
     +              PREV)


C If you are trying to run a huge toll highway project, stop here.
C You need to modify the program to IRR, because it may take 20
C minutes per discount rate.


      CALL TRACE (1, 'MAIN', 'calling PRoJect Internal Rate of
     +            Return!')
       CALL PRJIRR (PEARSN,FRA,
     +              IWPC, NWPCF, NDVR,
     +              CORRC, TRIWPC,
     +              XUCOST, COST,
     +              NRVSF, NDRV,
     +              CORRR, TRIRVS,
     +              XUREV, REV,
     +              BOTTLE)
C           CALLs WPCMMT, TANSP, RVSMMT, CDFUNC


      DEALLOCATE (IWPC, NWPCF, NDVR, NRVSF, NDRV)
      DEALLOCATE (CORRC, XUCOST, COST)
      DEALLOCATE (CORRR, XUREV, REV)
      DEALLOCATE (BOTTLE)


      CALL TRACE (1, 'MAIN', 'that''s all, folks!')
1000  STOP


 990  CALL TRACE (1, 'MAIN', 'damn.')
      GOTO 1000


9901  FORMAT (8F8.4,7F7.4,2F4.1)
9902  FORMAT (I3)
9903  FORMAT (2F8.3)
9904  FORMAT (I3)

      END

      INCLUDE 'TRACE.MJW'
      INCLUDE 'ANSI.MJW'

$IF enough .NE. 1
      INCLUDE 'SPARSE.MJW'
$ENDIF
```

```
C WpDura.FOR
C modified by Toshiaki Hatakama in July, 1994.

C THE ROUTINE TO EVALUATE THE FIRST FOUR MOMENTS OF THE WORK
C PACKAGE DURATION BY APPLYING THE FRAMEWORK

C=================================================================
      SUBROUTINE WPDURA (PEARSN,
     +                  WPTIME,CORRD)
C=================================================================

      IMPLICIT REAL*4(A-H,O-Z)

      INCLUDE 'DEBUG.CMN'

      REAL*4 PEARSN (2655, 17)
      REAL*4 WPTIME (4, *), CORRD (NWP, *)

      INTEGER IWPD(:),NWPDF(:),NDVR(:)
      ALLOCATABLE IWPD,NWPDF,NDVR

      REAL*4 PRCEST(:,:)
      REAL*4 CALC(:,:)
      ALLOCATABLE PRCEST,CALC

      REAL*4 X(:),Z(:),SZ(:),GZS(:),GZL(:)
      REAL*4 XWPD(:,:,:), ZWPD(:,:,:)
      ALLOCATABLE X,Z,SZ,GZS,GZL,XWPD,ZWPD

      REAL*4 WPDCO(:,:,:), PWPD1(:), PWPD2(:), PWPDX(:,:)
      REAL*4 TRIWPD(:,:), STFO(:)
      ALLOCATABLE WPDCO,PWPD1,PWPD2,PWPDX,TRIWPD, STFO

      CALL TRACE (2, 'WPDURA', 'starting.')

      ALLOCATE (IWPD(NWP))
      ALLOCATE (NWPDF(NWP))
      ALLOCATE (NDVR(NWP))
      ALLOCATE (PRCEST(5,NWP))
      ALLOCATE (CALC(4,NWP))
      ALLOCATE (X(MAXDVC))
      ALLOCATE (Z(MAXDVC))
      ALLOCATE (SZ(MAXDVC))
      ALLOCATE (GZS(MAXDVC))
      ALLOCATE (GZL(MAXDVC))
      ALLOCATE (XWPD(4,NWP,MAXDVC))
      ALLOCATE (ZWPD(4,NWP,MAXDVC))
      ALLOCATE (WPDCO(NWP,MAXDVC,MAXDVC))
      ALLOCATE (PWPD1(MAXDVC))
      ALLOCATE (PWPD2(MAXDVC))
      ALLOCATE (PWPDX(NWP,MAXDVC))
      ALLOCATE (TRIWPD (MAXDVC, MAXDVC))
      ALLOCATE (STFO(NWP))


C initialize the first four moments of the start work package
```

```
      DO 2 K=1,4
    2    WPTIME(K,1) = 0.D0

C basic data about the work packages

      DO 150 INWP=2,NWP


C type of work package duration : holistic or decomposed
C IWPD(I) = 1, detailed estimate
C IWPD(I) = 2, holistic
C IWPD(I) = 3, ???
C IWPD(I) = 4, direct input

         READ(11,10)IWPD(INWP)
  10     FORMAT(I2)

         SELECT CASE (IWPD(INWP))


C detailed estimate
         CASE (1)

C NWPDF(I) = type of functional form
C NDVR(I) = number of discrete primary variables

         READ (11,20) NWPDF(INWP), NDVR(INWP)
  20     FORMAT(I2,I3)

C approximate the primary variables in the functional forms
C for work package durations to pearson type distributions
C to obtain the first four moments for them.

C NNVR = number of primary variables...
C why are we getting an array dimension from something we just
C read in that is specific to only one data set? something funny
C is going on here.
         NNVR = NDVR(INWP)
         IF (NNVR .GT. MAXDVC) THEN
            CALL TRACE (1, 'WPDURA', 'MAXDVC exceeded.')
            IERR = 1
            GOTO 1000
         ENDIF

         DO 50 JPV=1,NNVR

C subjective estimates for each variable in the
C functional form for the work package duration.


            READ (11, 8001)      A,B,C,D,E
            CALL VARBLE (PEARSN, A,B,C,D,E, C1,C2,C3,C4)
            IF (IERR .EQ. 1) GOTO 9001
            XWPD (1, INWP, JPV) = C1
            XWPD (2, INWP, JPV) = C2
            XWPD (3, INWP, JPV) = C3
            XWPD (4, INWP, JPV) = C4
```

```
  50     CONTINUE

C correlation coefficients between the primary variables in
C the work package. correlation matrix is positive definite.

         DO 90 JPV = 1,NNVR
            JPV1 = JPV+1
            IF (JPV1.LE.NNVR) THEN
               READ(11,70) (WPDCO(INWP,JPV,K),K=JPV1,NNVR)
  70           FORMAT(20F6.2)

               DO 80 K=JPV1,NNVR
  80              WPDCO(INWP,K,JPV) = WPDCO(INWP,JPV,K)
            ENDIF
  90     CONTINUE


C calculate the first four moments for a WP duration when
C the duration is estimated holistically.
C why are there TWO ways to do this???
         CASE (2,3)

         JPV = 1


         READ (11, 8001) A,B,C,D,E
         CALL VARBLE (PEARSN, A,B,C,D,E, C1,C2,C3,C4)
         IF (IERR .EQ. 1) GOTO 9002
         WPTIME (1, INWP) = C1
         WPTIME (2, INWP) = C2
         WPTIME (3, INWP) = C3
         WPTIME (4, INWP) = C4

C moments of the work package durations are entered directly
         CASE (4)

         READ(11,125) (WPTIME(K,INWP),K=1,4)
 125     FORMAT(4F25.6)

         END SELECT
 150  CONTINUE


C correlation between work package durations?
C looks to me like defining some zeros in the matrix...
C making the matrix triangular?

      NWPM1 = NWP-1
      DO 170 INWP=2,NWPM1
         INWP1 = INWP+1
         IF (INWP1 .LE. NWPM1) THEN
            DO 160 J = INWP1, NWPM1
               CORRD (INWP,J) = 0.0D0
 160           CORRD (J,INWP) = 0.0D0
         ENDIF
 170  CONTINUE
```

```
C WHEN DURATIONS ARE ESTIMATED WHOLISTICALLY OR FROM MOMENTS.

      DO 200 INWP=2,NWPM1
         IF (IWPD(INWP).GE.2) THEN
            INWP1 = INWP+1
            IF (INWP1 .LE. NWPM1) THEN
               DO 190 J=INWP1,NWPM1
                  IF (IWPD(J).GE.2) THEN
                     READ(11,180) CORRD(INWP,J)
 180                 FORMAT(F6.2)
                     CORRD(J,INWP) = CORRD(INWP,J)
                  ENDIF
 190           CONTINUE
            ENDIF
         ENDIF
 200  CONTINUE

C THE FIRST FOUR MOMENTS OF THE WORK PACKAGE DURATION WHEN THE
C DURATION IS ESTIMATED FROM A DECOMPOSITION.

      DO 300 INWP=2,NWP

C WHEN WORK PACKAGE DURATIONS ARE ESTIMATED WHOLISTICALLY
C OR FOR THE WORK PACKAGES TO PHASE PROJECTS WITH A TIME
C LAG OR FOR THE FINISH WORK PACKAGE.

         IF (IWPD(INWP).EQ.1) THEN

C TRANSFORM CORRELATED VARIABLES TO UNCORRELATED VARIABLES.
C ONLY THE LINEAR CORRELATION IS CONSIDERED.


            NNVR = NDVR (INWP)
            CALL TRANS (INWP,NNVR,NWP,MAXDVC,
     +                  XWPD,ZWPD,WPDCO,TRIWPD)
            IF (0 < IERR) GO TO 1000

C ESTIMATE G(Z) FROM THE g(X) GIVEN BY THE USER AT THE MEAN
C VALUES OF Z (THE TRANSFORMED VARIABLES) AND THE PARTIAL
C DERATIVES WITH RESPECT TO THE TRANSFORMED VARIABLES.

            DO 210 JPV=1,NNVR
 210           Z(JPV) = ZWPD(1,INWP,JPV)

            DO 220 JPV=1,NNVR
               X(JPV) = 0.0D0
               DO 220 KSV=1,NNVR
 220              X(JPV) = X(JPV) + TRIWPD(JPV,KSV) * Z(KSV)

C THE VALUE OF G(Z) AT THE MEAN VALUES OF Z


            CALL WPDFF(NWPDF (INWP), X, GZ)

C THE PARTIAL DERAVATIVES OF THE TRANSFORMED VARIABLES
C JPV is the primary variable index
```

```
C KSV is the secondary variable index
C KTV is the tertiary (third) variable index...
C i think....

            DO 290 JPV=1,NNVR
               Z(JPV)  = ZWPD(1,INWP,JPV) * 0.99D0
               SZ(JPV) = ZWPD(1,INWP,JPV) * 0.01D0
               DO 240 KSV=1,NNVR
                  X(KSV) = 0.0D0
                  DO 240 LTV=1,NNVR
 240                 X(KSV) = X(KSV) + TRIWPD(KSV,LTV) * Z(LTV)

C THE VALUE FOR G(Z) WHEN Z(J) IS LESS THAN THE MEAN VALUE
C (NEGATIVE INCREMENT)


               CALL WPDFF(NWPDF (INWP), X, GZS (JPV))

               Z(JPV)  = ZWPD(1,INWP,JPV) * 1.01D0
               DO 260 KSV=1,NNVR
                  X(KSV) = 0.0D0
                  DO 260 LTV=1,NNVR
                     X(KSV) = X(KSV) + TRIWPD(KSV,LTV) * Z(LTV)
 260                 CONTINUE

C THE VALUE FOR G(Z) WHEN Z(J) IS MORE THAN THE MEAN VALUE
C (POSITIVE INCREMENT)


               CALL WPDFF(NWPDF (INWP), X, GZL(JPV))

C 1st & 2nd partial derivatives wrt Z(J)

               PWPD1(JPV) = (GZL(JPV) - GZS(JPV)) / (2.0D0 * SZ(JPV))
               PWPD2(JPV) = (GZL(JPV) + GZS(JPV) - 2.0D0 * GZ)
     +                      / (SZ(JPV)**2)

               Z(JPV) = ZWPD(1,INWP,JPV)
 290        CONTINUE

C the first four moments for the work package duration


            CALL MMTWPL (INWP,NNVR,
     +                   NWP,ZWPD,
     +                   GZ,PWPD1,PWPD2,
     +                   WPTIME,STFO(INWP))
         ENDIF
 300  CONTINUE

C APPROXIMATE THE CORRELATION BETWEEN THE WORK PACKAGES FOR
C MOMENT APPROXIMATIONS AT THE PROJECT LEVEL.

C ESTIMATE g(X) GIVEN BY THE USER AT MEAN OF X AND THE FIRST
C PARTIAL DERAVATIVE WITH RESPECT TO THE CORRELATED VARIABLES.

      NWPM1 = NWP-1
```

```
      DO 350 INWP=2,NWPM1
         IF (IWPD(INWP).EQ.1) THEN
            NNVR = NDVR(INWP)

C as kludgy as this may seem, WPDFF can potentially make
C a reference to ALL elements of X....
            DO 330 JPV=1,NNVR
 330           X(JPV) = XWPD(1,INWP,JPV)

C THE FIRST PARTIAL DERAVATIVE OF THE CORRELATED VARIABLES

            DO 340 JPV=1,NNVR
               X(JPV)  = XWPD(1,INWP,JPV) * 0.99D0
               SZ(JPV) = XWPD(1,INWP,JPV) * 0.01D0

C THE VALUE FOR g(X) WHEN X(J) IS LESS THAN THE MEAN VALUE
C (NEGATIVE INCREMENT)


               CALL WPDFF (NWPDF (INWP), X, GZS (JPV))

               X(JPV)  = XWPD(1,INWP,JPV) * 1.01D0

C THE VALUE FOR g(X) WHEN X(J) IS MORE THAN THE MEAN VALUE
C (POSITIVE INCREMENT)


               CALL WPDFF(NWPDF (INWP), X, GZL (JPV))

C THE FIRST PARTIAL DERAVATIVE WITH RESPECT TO Z(J)

               PWPDX(INWP,JPV) = (GZL(JPV) - GZS(JPV)) /
     +                   (2.0D0 * SZ(JPV))
               X(JPV) = XWPD(1,INWP,JPV)
 340        CONTINUE
         ENDIF
 350  CONTINUE

C ESTIMATE THE CORRELATION BETWEEN TWO WORK PACKAGE DURATIONS.

      JU = 11
      NN = NWP-1
      DO 380 INWP=2,NN
         IF (IWPD(INWP) .EQ. 1) THEN
            NI = NDVR(INWP)
            INWP1 = INWP+1
            IF (INWP1 .LE. NN) THEN
               DO 370 JWP=INWP1,NN
                  IF (IWPD(JWP) .EQ. 1) THEN
                     NJ = NDVR(JWP)

C MJW moved this read out of COVAR,
C 'cause why make the call if you do NADA? ("Nothing")

                     READ (JU, *) NDCV
                     IF (NDCV == 0) THEN
                        CORRD (INWP, JWP) = 0.0D0
```

```
                        CORRD (JWP, INWP) = 0.0D0
                     ELSE
                        CALL COVAR(JU, NDCV, INWP,JWP,NI,NJ,
     +  PWPDX,
     +  XWPD,
     +  WPDCO,
     +  STFO(INWP),STFO(JWP),
     +  CORRD)
                     ENDIF
                  ENDIF
370            CONTINUE
            ENDIF
         ENDIF
380   CONTINUE

1000  DEALLOCATE (IWPD, NWPDF, NDVR)
      DEALLOCATE (PRCEST, CALC)
      DEALLOCATE (X, Z, SZ, GZS, GZL)
      DEALLOCATE (XWPD, ZWPD)
      DEALLOCATE (WPDCO)
      DEALLOCATE (PWPD1, PWPD2, PWPDX)
      DEALLOCATE (TRIWPD,STFO)

      CALL TRACE (2, 'WPDURA', 'exiting.')

      RETURN

8001  FORMAT(5F20.4)

9001  WRITE (7, 9901) INWP, JPV
9901  FORMAT (/,'WP#(',I3,') var(',I2,') != Pearson Type.',/)
      GOTO 1000

9002  WRITE (7, 9902) INWP
9902  FORMAT (/,'WP#(',I3,').Duration != Pearson Dist.',/)
      GOTO 1000


      END
```

```
C East.FOR
C modified by Toshiaki Hatakama in July, 1994.

C ROUTINE TO EVALUATE THE FIRST FOUR MOMENTS OF THE EARLY START
C TIME OF WORK PACKAGES USING A PRECEDENCE NETWORK AND OBTAIN
C THE CALENDAR MONTH OF THE EARLY START TIME.

C=================================================================
      SUBROUTINE EAST (PEARSN, WPTIME, CORRD, ESTART)
C=================================================================

      IMPLICIT REAL*4(A-H,O-Z)
      INCLUDE 'DEBUG.CMN'

      REAL*4 PEARSN (NPEARS, *)
      REAL*4 WPTIME (4, *), CORRD (NWP, *)
      REAL*4 ESTART (4, *)

      CHARACTER*3 LM (:)
      INTEGER LY (:)
      REAL*4 SDET(:), SKET(:), AKET(:), AMEET(:)
      ALLOCATABLE LM, LY, SDET, SKET, AKET, AMEET

C this is ment to ease the burden of calculating some of the days.
C the last index is 1=7 day ww, 2=6 day ww, 3=5 day ww.

      INTEGER DAYS (13, 3)
      CHARACTER*3 MONTHS (12)

      DATA DAYS/
     + 0,22,42,64, 86,108,130,151,173,195,217,239,261,   ! 5 day week
     + 0,27,51,77,103,130,156,182,209,235,261,287,313,   ! 6 day week
     + 0,31,59,90,120,151,181,212,243,273,304,334,365/   ! 7 day week

      DATA MONTHS/
     + 'JAN','FEB','MAR','APR','MAY','JUN',
     + 'JUL','AUG','SEP','OCT','NOV','DEC'/

C START AND FINISH DATES IN CALENDAR TIME AND THE TIME UNIT
C IDS = day start
C IMS = month start
C IYS = year start
C IDF = day finish
C IMF = month finish
C IYF = year finish
C NUNT = time unit (1=day, 2=month, 3=year)
C NWW = (5,6,7) = number of days in work week.

      CALL TRACE (2, 'EAST', 'starting.')

      ALLOCATE (LM (NWP), LY (NWP))
      ALLOCATE (SDET (NWP), SKET (NWP), AKET (NWP), AMEET (NWP))

      READ (10, 9910) IDS, IMS, IYS, IDF, IMF, IYF, NUNT, NWW
      IF (NWW < 5 .OR. 7 < NWW) THEN
         IERR = 1
         WRITE (7, 9901)
```

```
         GO TO 1000
      ENDIF

      IF (IYS == 0) THEN
         SDATE = 0.0D0
         GO TO 400
      ENDIF

      IWW = NWW - 4

      IYB  = 1988
      ICHS = IYS - IYB
      ND   = ICHS * DAYS (13, IWW)
      NDS  = ND + IDS + DAYS (IMS, IWW)


      IF (0 < ICHS) GO TO 180
      IF (IMS < 3) GO TO 200

  180 NDS = NDS + 1
      JS = IFIX (ICHS / 4.)
      IF (2 < IMS) GO TO 190
      NDS = NDS + JS - 1
      GO TO 200

  190 NDS = NDS + JS
  200 SELECT CASE (NUNT)
             CASE (1)
                  SDATE = FLOAT (NDS)
             CASE (2)
                  SDATE = FLOAT (NDS) / 30.4167D0
             CASE (3)
                  SDATE = FLOAT (NDS) / 365.0D0
      END SELECT

      IF (IYF == 0) GO TO 400
      ICHF = IYF - IYB
      NF = ICHF * DAYS (13, IWW)
      NDF = NF + IDF + DAYS (IMF, IWW)

      IF (0 < ICHF) GO TO 380
      IF (IMF < 3) GO TO 400

  380 NDF = NDF + 1
      JF = IFIX (ICHF / 4.)
      IF (2 < IMF) THEN
         NDF = NDF + JF
      ELSE
         NDF = NDF + JF - 1
      ENDIF


  400 CALL NETWRK (PEARSN, WPTIME, CORRD, ESTART, TRCOR)
      IF (0 < IERR) GO TO 1000

C the work package durations in the specified time unit
```

```
      WRITE (7, 9911)
      WRITE (7, 9912)

      DO 1590 I = 1, NWP
         IF (WPTIME (2, I) == 0.0D0) THEN
            SDTME = 0.0D0
            SKTME = 0.0D0
            AKTME = 0.0D0
         ELSE
            SDTME = WPTIME (2, I) ** 0.5D0
            SKTME = WPTIME (3, I) / (WPTIME (2, I) ** 1.5D0)
            ASKT  = 1.2D0 * (SKTME ** 2)+2.0
            AKTME = WPTIME (4, I) / (WPTIME (2, I) ** 2)
            IF (AKTME < ASKT) THEN
               AKTME = ASKT
            ENDIF
         ENDIF

         SELECT CASE (NUNT)
                CASE (1)
                     AMTME = WPTIME (1, I)   / 30.4167D0
                     SDTME = SDTME           / 30.4167D0
                CASE (2)
                     AMTME = WPTIME (1, I)
                     SDTME = SDTME
                CASE (3)
                     AMTME = WPTIME (1, I)   * 12.0D0
                     SDTME = SDTME           * 12.0D0
         END SELECT

 1570    WRITE (7, 9913) I, AMTME, SDTME, SKTME, AKTME
 1590 CONTINUE

      WRITE (7, 9914) TRCOR
      WRITE (7, 9915)

      DO 2250 I = 1, NWP
         IF (ESTART (2, I) == 0.0D0) THEN
            SDET (I) = 0.0D0
            SKET (I) = 0.0D0
            AKET (I) = 0.0D0
         ELSE
            SDET (I) = ESTART (2, I) ** 0.5D0
            SKET (I) = ESTART (3, I) / (ESTART (2, I) ** 1.5D0)
            AKET (I) = ESTART (4, I) / (ESTART (2, I) ** 2)
         ENDIF


C convert the early start time of a work package to calendar
C time from absolute time.

         SELECT CASE (NWW + NUNT - 1)
C 7 day ww, daily
                CASE (7)
                     AMST       = ESTART (1, I) + SDATE
                     AMEET (I)  = ESTART (1, I) / 30.4167D0
                     SDET  (I)  = SDET      (I) / 30.4167D0
```

```
C 7 day ww, monthly
                CASE (8)
                     AMST       = (ESTART (1, I) + SDATE) * 30.4167D0
                     AMEET (I) =  ESTART (1, I)
                     SDET  (I) =  SDET       (I)
C 7 day ww, yearly
                CASE (9)
                     AMST       = (ESTART (1, I) + SDATE) * 365.0D0
                     AMEET (I) =  ESTART (1, I) * 12.0D0
                     SDET  (I) =  SDET       (I) * 12.0D0
C 5 day ww (daily)
                CASE (5)
                     AMST       = ESTART (1, I)
                     SDET  (I) = SDET       (I) / 21.75D0
C 6 day ww (daily)
                CASE (6)
                     AMST       = ESTART (1, I)
                     SDET  (I) = SDET       (I) / 26.0833D0
         END SELECT

         LYY   = IFIX (AMST / DAYS (13, IWW))
         LY(I) = IYB + LYY

         LDC = IFIX (AMST)
         LDD = MOD (LDC, DAYS (13, IWW))
         IF (0 < LYY) GO TO 1710
         IF (LDD < DAYS (2, IWW)) GO TO 1730

 1710    JJ  = IFIX (LYY / 4.)
         IF (DAYS (2, IWW) < LDD) GO TO 1720
         LDD = LDD - JJ + 1
         GO TO 1730

 1720    LDD = LDD - JJ

 1730    ITEMP = 1
         DO 1731, WHILE ( (DAYS (ITEMP + 1,IWW) <= LDD) .AND.
     +                    ITEMP < 12 )
 1731       ITEMP = ITEMP + 1

 2250    LM (I) = MONTHS (ITEMP)

C the early start times of the work packages

      DO 2300 I = 1, NWP
 2300    WRITE (7, 9916) I, LM (I), LY (I),
     +         AMEET (I), SDET (I), SKET (I), AKET(I)

C the project duration : E.S.T of the Nth work package

      WRITE (7, 9917) TRCOR
      WRITE (7, 9918)

      SELECT CASE (NUNT)
            CASE (1)
                 AMP = ESTART (1, NWP) / 30.4167D0
            CASE (2)
```

```
                 AMP = ESTART (1, NWP)
            CASE (3)
                 AMP = ESTART (1, NWP) * 12.0D0
      END SELECT

      SDP = SDET (NWP)
      SKP = SKET (NWP)
      AKP = AKET (NWP)

      WRITE (7, 9903) LM (NWP), LY (NWP), AMP, SDP, SKP, AKP

      CALL CDFUNC (PEARSN, AMP, SDP, SKP, AKP,
     +     V1,V2,V3,V4,V5,V6,V7, V8, V9,V10,V11,V12,V13,V14,V15)

      WRITE (20, 9930)
     +     V1,V2,V3,V4,V5,V6,V7, V8, V9,V10,V11,V12,V13,V14,V15

 1000 CALL TRACE (2, 'EAST', 'exiting.')
      DEALLOCATE (LM, LY)
      DEALLOCATE (SDET, SKET, AKET, AMEET)
      RETURN

 9901 FORMAT ('EAST: Work Week should be 5, 6 or 7 days.')
C 9902 FORMAT ('***** WHEN WORK WEEK =(5,6), TIME UNIT sb DAYS.')
 9903 FORMAT (A3,' / ',I4,4F15.2)

 9910 FORMAT (2I3,I5,2I3,I5,2I2)

 9911 FORMAT (/,'Work Package Durations',/,'The TIME UNIT is
MONTHS.')
 9912 FORMAT ('W.P.#      Exp.Value===== ',
     +                   'S.Dev.======== Skewness Kurtosis')
 9913 FORMAT (I4,6X,2F15.3,2F8.2)

 9914 FORMAT (/,'Work Package Early Start Times for a Transitional ',
     +          'Correlation of', F5.2,/,'The TIME UNIT is MONTHS.')
 9915 FORMAT ('W.P.#      Exp.Month===== Exp.Value===== ',
     +                   'S.Dev========= Skewness Kurtosis')
 9916 FORMAT (I4,7X,A3,' / ',I4,4X,2F15.2,2F8.2)

 9917 FORMAT (/,'The Project Duration for a Transitional ',
     +          'Correlation of', F5.2,/,'The TIME UNIT is MONTHS.')
 9918 FORMAT ('Month      Exp.Value===== ',
     +                   'S.Dev========= Skewness Kurtosis')

 9930 FORMAT (' Project Duration export for EXCEL',
     +          /,' ',F20.2,', 0.25',
     +          /,' ',F20.2,', 0.50',
     +          /,' ',F20.2,', 1.00',
     +          /,' ',F20.2,', 2.50',
     +          /,' ',F20.2,', 5.00',
     +          /,' ',F20.2,',10.00',
     +          /,' ',F20.2,',25.00',
     +          /,' ',F20.2,',50.00',
     +          /,' ',F20.2,',75.00',
     +          /,' ',F20.2,',90.00',
     +          /,' ',F20.2,',95.00',
```

```
     +          /,' ',F20.2,',97.50',
     +          /,' ',F20.2,',99.00',
     +          /,' ',F20.2,',99.50',
     +          /,' ',F20.2,',99.75')

      END
```

```
C WpCost.FOR
C modified by Toshiaki Hatakama in July, 1994.

C THE ROUTINE TO EVALUATE THE FIRST FOUR MOMENTS OF THE WORK
C PACKAGE COST BY APPLYING THE FRAMEWORK

C==============================================================
      SUBROUTINE WPCOST (DR,FRA,PEARSN,
     +                   WPTIME,
     +                   ESTART,
     +                   IWPC, NWPCF, NDVR,
     +                   COST,
     +                   XUCOST, TRIWPC,
     +                   CORRC)
C==============================================================

      IMPLICIT REAL*4(A-H,O-Z)
      INCLUDE 'DEBUG.CMN'
      REAL*4 PEARSN (NPEARS, *)
      REAL*4 WPTIME (4, *)
      REAL*4 ESTART (4, *)
      INTEGER IWPC (*), NWPCF (*), NDVR (*)
      REAL*4 XUCOST (4, NWP, *), TRIWPC (NWP, NWP, *)
      REAL*4 COST (4, *), CORRC (NWP, *)

      INTEGER NNVR, NTYP (50)

      REAL*4 X(25), SZ(25), GZS(25), GZL(25)

      REAL*4 XCOST (:,:,:), WPCCO (:,:,:), PWPCX (:,:)
      ALLOCATABLE XCOST, WPCCO, PWPCX

      REAL*4 STFO (:), TRI (:,:)
      ALLOCATABLE STFO, TRI

      CALL TRACE (2, 'WPCOST', 'starting.')

      ALLOCATE (STFO (NWP))
      ALLOCATE (TRI (MAXDVC, MAXDVC))
      ALLOCATE (XCOST (4, NWP, MAXDVC))
      ALLOCATE (WPCCO (NWP, MAXDVC, MAXDVC))
      ALLOCATE (PWPCX (NWP, MAXDVC))

C the first four moments of the start work package

      COST (1, 1) = 0.D0
      COST (2, 1) = 0.D0
      COST (3, 1) = 0.D0
      COST (4, 1) = 0.D0

C basic data about the work packages

      IWPC (1) = 0
      NWPCF (1) = 0
      NDVR (1) = 0
      NTYP (1) = 0
```

```
      DO 300 I=2,NWP

         READ (12, 8020)
     +     IWPC(I)      ! type of work package cost
                        ! 1=decomposed
                        ! 2=wholistic
                        ! 3=direct input

         GOTO (10, 150, 200) IWPC(I)
         GOTO 9003  ! something's worng


C type of functional form and the number of primary variables

  10     READ (12, 8030) NWPCF (I), NDVR (I), NTYP (I)
         NNVR = NDVR (I)


C DURATION AND EARLY FINISH TIME ARE PRIMARY VARIABLES IN
C ALL THE FUNCTIONAL FORMS FOR WORK PACKAGE COST. (THE LINK
C BETWEEN TIME AND COST BECAUSE COST IS TIME DEPENDENT).

C Var#1 is the duration of the work package

         XCOST (1, I, 1) = WPTIME (1, I)
         XCOST (2, I, 1) = WPTIME (2, I)
         XCOST (3, I, 1) = WPTIME (3, I)
         XCOST (4, I, 1) = WPTIME (4, I)

C Var#2 is the early finish time

         XCOST (1, I, 2) = ESTART (1, I) + WPTIME (1, I)
         XCOST (2, I, 2) = ESTART (2, I) + WPTIME (2, I)
         XCOST (3, I, 2) = ESTART (3, I) + WPTIME (3, I)
         XCOST (4, I, 2) = ESTART (4, I) + WPTIME (4, I)

C Var#3 is the project duration, aka the time at which the loan is
due.

         XCOST (1, I, 3) = ESTART (1, NWP)
         XCOST (2, I, 3) = ESTART (2, NWP)
         XCOST (3, I, 3) = ESTART (3, NWP)
         XCOST (4, I, 3) = ESTART (4, NWP)

C Var#4 is the revenue phase duration, which equals the finish
C work package duration.

         IF (11 <= NWPCF (I)) THEN

            XCOST (1, I, 4) = WPTIME (1, NWP)
            XCOST (2, I, 4) = WPTIME (2, NWP)
            XCOST (3, I, 4) = WPTIME (3, NWP)
            XCOST (4, I, 4) = WPTIME (4, NWP)

            DO 35 J=1,4
               JJ = J+1
               DO 34 K=JJ,NNVR
```

```
                 WPCCO(I,J,K) = 0.0D0
                 WPCCO(I,K,J) = 0.0D0
 34           CONTINUE
 35         CONTINUE

C APPROXIMATE THE PRIMARY VARIABLES IN THE FUNCTIONAL FORMS
C FOR WORK PACKAGE COST TO PEARSON TYPE DISTRIBUTIONS TO
C OBTAIN THE FIRST FOUR MOMENTS FOR THEM.

            DO 40 J=5,NNVR
               IF (1 < NTYP (I)) THEN ! direct read the moments
                  READ (12, 37) (XCOST (K, I, J), K = 1, 4)
 37               FORMAT (4F30.5)
               ELSE
                  READ (12, 8010)       A,B,C,D,E
                  CALL VARBLE (PEARSN, A,B,C,D,E, C1, C2, C3, C4)
                  IF (IERR == 1) GO TO 9001
                  XCOST (1, I, J) = C1
                  XCOST (2, I, J) = C2
                  XCOST (3, I, J) = C3
                  XCOST (4, I, J) = C4

               ENDIF
 40         CONTINUE

C CORRELATION COEFFICIENTS BETWEEN THE PRIMARY VARIABLES IN
C THE WORK PACKAGE. CORRELATION MATRIX IS POSITIVE DEFINITE.

            DO 45 J = 5,NNVR
               JJ = J+1
               IF (NNVR < JJ) GO TO 45
               READ (12, 41) (WPCCO (I, J, K), K = JJ, NNVR)
 41            FORMAT(20F6.2)
               DO 42 K=JJ,NNVR
                  WPCCO(I,K,J) = WPCCO(I,J,K)
 42            CONTINUE
 45         CONTINUE
         ELSE
            DO 50 J=1,3
               JJ = J+1
               DO 50 K=JJ,NNVR
                  WPCCO(I,J,K) = 0.0D0
 50               WPCCO(I,K,J) = 0.0D0


C APPROXIMATE THE PRIMARY VARIABLES IN THE FUNCTIONAL FORMS
C FOR WORK PACKAGE COST TO PEARSON TYPE DISTRIBUTIONS TO
C OBTAIN THE FIRST FOUR MOMENTS FOR THEM.

C SUBJECTIVE ESTIMATES FOR OTHER VARIABLES IN THE
C FUNCTIONAL FORM FOR THE WORK PACKAGE COST.

            DO 100 J=4,NNVR
               IF (1 < NTYP (I)) THEN
                  READ (12, 70) (XCOST (K, I, J), K = 1, 4)
 70               FORMAT (4F30.5)
               ELSE
```

```
                    READ (12, 8010)      A,B,C,D,E
                    CALL VARBLE (PEARSN, A,B,C,D,E, C1,C2,C3,C4)
                    IF (IERR == 1) GO TO 9001
                    XCOST (1, I, J) = C1
                    XCOST (2, I, J) = C2
                    XCOST (3, I, J) = C3
                    XCOST (4, I, J) = C4
                 ENDIF
 100          CONTINUE

C CORRELATION COEFFICIENTS BETWEEN THE PRIMARY VARIABLES IN
C THE WORK PACKAGE. CORRELATION MATRIX IS POSITIVE DEFINITE.

              DO 140 J = 4,NNVR
                 JJ = J+1
                 IF (JJ <= NNVR) THEN
                    READ (12, 110) (WPCCO (I,J,K),K=JJ,NNVR)
 110                FORMAT (20F6.2)
                    DO 120 K=JJ,NNVR
 120                   WPCCO (I,K,J) = WPCCO (I,J,K)
                 ENDIF
 140          CONTINUE
           ENDIF
           GO TO 300

C THE FIRST FOUR MOMENTS FOR A WORK PACKAGE COST WHEN THE
C COST IS ESTIMATED WHOLISTICALLY.

 150       J = 1
           READ (12, 8010)      A,B,C,D,E
           CALL VARBLE (PEARSN, A,B,C,D,E, C1,C2,C3,C4)
           IF (0 < IERR) GO TO 9002

           COST (1, I) = C1
           COST (2, I) = C2
           COST (3, I) = C3
           COST (4, I) = C4

C************************************************

           XUCOST (1, I, 1) = C1
           XUCOST (2, I, 1) = C2
           XUCOST (3, I, 1) = C3
           XUCOST (4, I, 1) = C4

C************************************************

           GO TO 300


C MOMENTS OF THE WORK PACKAGE DURATIONS ARE ENTERED DIRECTLY

 200       READ (12, 210) (COST (K, I),K=1,4)
 210       FORMAT (4F25.6)

 300   CONTINUE   ! Go back and get the next work package info.
```

```
C CORRELATION BETWEEN WORK PACKAGE COSTS.

      NN = NWP-1
      DO 320 I=2,NN
         JJ = I+1
         IF (JJ <= NN) THEN
            DO 310 J=JJ,NN
               CORRC(I,J) = 0.0D0
 310           CORRC(J,I) = 0.0D0
         ENDIF
 320  CONTINUE

C WHEN WORK PACKAGE COSTS ARE INPUT AS MOMENTS.

      DO 350 I=2,NN
         IF (2 < IWPC(I)) THEN
            JJ = I+1
            IF (NN < JJ) GO TO 350
            DO 340 J=JJ,NN
               IF (2 < IWPC(J)) THEN
                  READ(12,330) CORRC(I,J)
 330              FORMAT(F6.2)
                  CORRC(J,I) = CORRC(I,J)
               ENDIF
 340        CONTINUE
         ENDIF
 350  CONTINUE

C THE FIRST FOUR MOMENTS OF THE WORK PACKAGE COST WHEN THE COST
C IS ESTIMATED FROM A DECOMPOSITION.
C WHEN WORK PACKAGE COST ARE ESTIMATED WHOLISTICALLY OR FOR
C THE FINISHED WORK PACKAGE,
C TRANSFORM CORRELATED VARIABLES TO UNCORRELATED VARIABLES.
C ONLY THE LINEAR CORRELATION IS CONSIDERED.

      DO 400 I = 2, NWP
         IF (IWPC(I) == 1) THEN
            NNVR = NDVR(I)
            CALL TRANS (I, NNVR, NWP, MAXDVC,
     +                  XCOST,
     +                  XUCOST,
     +                  WPCCO, TRI)
            IF (IERR == 1) GO TO 1000


C THE TRANSFORMATION MATRIX FOR A WORK PACKAGE

            DO 360 J=1,NNVR
               DO 360 K=1,NNVR
                  TRIWPC(I,J,K) = TRI(J,K)
                  TRIWPC(I,K,J) = TRI(K,J)

 360        CONTINUE

C this is the only place where COST is affected
C by anything when IWPC(I) = 1...
```

```
            CALL WPCMMT (I, DR, FRA,
     +  NWPCF, NDVR,
     +  XUCOST, TRIWPC,
     +  COST,
     +  STFO (I))
          ENDIF
 400  CONTINUE

C APPROXIMATE THE CORRELATION BETWEEN THE WORK PACKAGES FOR
C MOMENT APPROXIMATIONS AT THE PROJECT LEVEL.

C ESTIMATE g(X) GIVEN BY THE USER AT MEAN OF X AND THE FIRST
C PARTIAL DERAVATIVE WITH RESPECT TO THE CORRELATED VARIABLES.

      NN = NWP-1
      DO 450 I=2,NN
         IF (1 < IWPC(I)) GO TO 450
         NNVR = NDVR(I)
         DO 430 J=1,NNVR
            X(J) = XCOST (1, I, J)
 430     CONTINUE

C THE FIRST PARTIAL DERAVATIVE OF THE CORRELATED VARIABLES

         DO 440 J=1,NNVR
            X(J)  = XCOST (1, I, J) * 0.99D0
            SZ(J) = XCOST (1, I, J) * 0.01D0

C THE VALUE FOR g(X) WHEN X(J) IS LESS THAN THE MEAN VALUE
C (NEGATIVE INCREMENT)


C *********************

            CALL WPCFF(NWPCF(I),DR,FRA,X,GZS(J))
            X(J)  = XCOST (1, I, J) * 1.01D0

C THE VALUE FOR g(X) WHEN X(J) IS MORE THAN THE MEAN VALUE
C (POSITIVE INCREMENT)


C ***********************

            CALL WPCFF(NWPCF(I),DR,FRA,X,GZL(J))

C THE FIRST PARTIAL DERAVATIVE WITH RESPECT TO Z(J)

            PWPCX(I,J) = (GZL(J) - GZS(J)) / (2.0D0 * SZ(J))
            X(J) = XCOST (1, I, J)
 440     CONTINUE
 450  CONTINUE


C ESTIMATE THE CORRELATION BETWEEN TWO WORK PACKAGE COSTS.
C COVAR does something to the SECOND set of values of XCOST.
C check this carefully.
```

```
      JU = 12
      NN = NWP-1
      DO 500 I = 2, NN
         IF (IWPC(I) == 1) THEN
            NI = NDVR (I)
            JJ = I+1
            IF (JJ <= NN) THEN
               DO 470 J=JJ,NN
                  IF (IWPC(J) == 1) THEN
                     NJ = NDVR (J)
                     READ (JU, *) NDCV
                     IF (NDCV == 0) THEN
                        CORRC (I, J) = 0.0D0
                        CORRC (J, I) = 0.0D0
                     ELSE
                        CALL COVAR (JU,NDCV, I,J,NI,NJ,
     +  PWPCX,
     +  XCOST,
     +  WPCCO,
     +  STFO (I),STFO(J),
     +  CORRC)
                     ENDIF
                  ENDIF
 470           CONTINUE
            ENDIF
         ENDIF
 500  CONTINUE

 1000 DEALLOCATE (XCOST, WPCCO, STFO, TRI)
      CALL TRACE (2, 'WPCOST', 'exiting.')
      RETURN

 8010 FORMAT(5F20.4)
 8020 FORMAT(I2)
C 8030 FORMAT (I2, I3, I2)
 8030 FORMAT (I4, I4, I4)

 9001 WRITE (7,9901) I, J
 9901 FORMAT ('WPCOST: WP(',I3,').Var(',I2,') is not PEARSON.')
      GOTO 1000

 9002 WRITE (7, 9902) I
 9902 FORMAT ('WPCOST: WP(',I3,') is not PEARSON.')
      GOTO 1000

 9003 WRITE (7, *) 'What Gives! Type greater than 3?'
      GOTO 1000

      END
```

```
C RevStr.FOR
C modified by Toshiaki Hatakama in July, 1994.

C THE ROUTINE TO EVALUATE THE FIRST FOUR MOMENTS OF THE NET
C REVENUE STREAM BY APPLYING THE FRAMEWORK TO THE WP/RS LEVEL.
C calls VARBLE, RVSMMT

C=================================================================
      SUBROUTINE REVSTR (PEARSN,
     +                   DR,
     +                   WPTIME,
     +                   ESTART,
     +                   NRVSF, NDRV,
     +                   XUREV,
     +                   TRIRVS,
     +                   REV, CORRR,
     +                   BOTTLE)
C=================================================================

C if you have 16M Ram, chhose "enough" = 1.
C if not, choose any number but 1.

$DEFINE enough = 0

      IMPLICIT REAL*4 (A-H,O-Z)
      INCLUDE 'DEBUG.CMN'

      REAL*4 PEARSN (NPEARS, *)
      REAL*4 WPTIME (4, *)
      REAL*4 ESTART (4, *)
      INTEGER NRVSF (*), NDRV (*)
      REAL*4 BOTTLE (NRS, *)

$IF enough .EQ. 1
      REAL*4 XUREV (4, NRS, *), TRIRVS (NRS, MAXDVR, *)
$ELSE
      REAL*4 XUREV (4, NRS, *), TRIRVS (*)
$ENDIF

      REAL*4 REV (4, *), CORRR(NRS, *)

      REAL*4 X (300), SZ, GZS, GZL
      REAL*4 XREV (:,:,:), RVSCO(:,:,:), PRVSX(:,:)
      ALLOCATABLE XREV, RVSCO, PRVSX

      REAL*4 STFO(:), TRI(:,:)
      ALLOCATABLE STFO, TRI

C basic data about the revenue streams

      CALL TRACE (1, 'REVSTR', 'starting.')

      ALLOCATE (STFO (NRS))
      ALLOCATE (XREV (4, NRS, MAXDVR))

C Only 1 Multi-Megabyte Array per application, please....
C we can't get rid of this because TRANS & COVAR do alot of work with
```

```
C it.

      ALLOCATE (RVSCO (NRS, MAXDVR, MAXDVR))
      ALLOCATE (PRVSX (NRS, MAXDVR))

      DO 100 INRS = 1, NRS

         PRINT *, 'Reading in REVenue STReam #', INRS
         READ (13, 9901)
     +        NRVSF (INRS),   ! type of functional form
     +        NDRV (INRS),    ! number of primary variables
     +        LL,             ! the work package number
     +        PERT            ! the fraction of the duration after
                              ! which
                              ! the revenue begins...

C if this is a toll highway project, read more basic data.
C we have to pass extra info to our custom RVSFF functions,
C so we're going to do it in X, our WONDER-VECTOR.
C the first element of X tells how many elements are sacred to
C RVSFnn.


         SELECT CASE (NRVSF (INRS))
         CASE (11) ! 'closed' toll highway (one toll booth per gate)
              READ (13, 9905)
     +              BOTTLE (INRS, 1),    ! nAL = # of interchanges
     +              BOTTLE (INRS, 2)     ! nP  = # of vehicle types

              READ (13, 9906)
     +              BOTTLE (INRS, 3)     ! nWC = weather
                                         ! class(1,2,...)

              READ (13, 9906)
     +              BOTTLE (INRS, 4)     ! nOL = overlay
                                         ! years(0,1,2,..)

              READ (13, 9906)
     +              BOTTLE (INRS, 5)     ! nBR = bridge repaint
                                         ! year(0,1,2,...)

         CASE (12) ! 'open' toll highway (some may not have gates)
              READ (13, 9907)
     +              BOTTLE (INRS, 1),    ! nAL = # of interchanges
     +              BOTTLE (INRS, 2),    ! nP  = # of vehicle types
     +              BOTTLE (INRS, 6)     ! nTG = # of toll gates

              DO 50 J = 1, BOTTLE (INRS, 6)
 50              READ (13, 9908)
     +              BOTTLE (INRS, (J + 6))  ! toll gate location

              READ (13, 9906)
     +              BOTTLE (INRS, 3)     ! nWC = weather class
                                         ! (1,2,...)

              READ (13, 9906)
     +              BOTTLE (INRS, 4)     ! nOL = overlay
```

```
                                        ! years(0,1,2,..)

            READ (13, 9906)
     +           BOTTLE (INRS, 5)      ! nBR = bridge repaint
                                        ! year(0,1,2,...)

         CASE (13) ! 'closed' toll highway (fixed toll)
            READ (13, 9905)
     +           BOTTLE (INRS, 1),     ! nAL = # of interchanges
     +           BOTTLE (INRS, 2)      ! nP  = # of vehicle types

            READ (13, 9906)
     +           BOTTLE (INRS, 3)      ! nWC = weather class
                                        ! (1,2,...)

            READ (13, 9906)
     +           BOTTLE (INRS, 4)      ! nOL = overlay
                                        ! years(0,1,2,..)

            READ (13, 9906)
     +           BOTTLE (INRS, 5)      ! nBR = bridge repaint
                                        ! year(0,1,2,...)

         END SELECT

         NNVR = NDRV (INRS)

C the start time of the revenue stream is a primary variable
C in all the functional forms for a revenue stream. the link
C between time and revenue because revenue is time dependent.
C variable#1 is the start time of the revenue stream.

         XREV (1, INRS, 1) = ESTART (1, LL) + PERT * WPTIME (1, LL)
         XREV (2, INRS, 1) = ESTART (2, LL) + PERT * WPTIME (2, LL)
         XREV (3, INRS, 1) = ESTART (3, LL) + PERT * WPTIME (3, LL)
         XREV (4, INRS, 1) = ESTART (4, LL) + PERT * WPTIME (4, LL)

C approximate the primary variables in the functional forms
C for revenue streams to pearson type distributions to
C obtain the first four moments for them.

         DO 65 J = 1, NNVR
            DO 60 K = 1, NNVR
               RVSCO (INRS, J, K) = 0.0D0
 60         CONTINUE
            RVSCO (INRS, J, J) = 1.0D0
 65      CONTINUE

         DO 90 J = 2, NNVR

C subjective estimates for other variables in the
C functional form for the revenue streams.

            READ (13, 9902)      A,B,C,D,E  ! 5%ile estimate
            CALL VARBLE (PEARSN, A,B,C,D,E,
     +                   XREV (1, INRS, J),
     +                   XREV (2, INRS, J),
```

```
     +                   XREV (3, INRS, J),
     +                   XREV (4, INRS, J))

 90         IF (0 < IERR) GOTO 9000

  100 CONTINUE

C the first four moments of the revenue stream.
C DR is fixed.
C in PRJIRR, we will vary DR to get a desired ... IRR.

      ALLOCATE (TRI (MAXDVR, MAXDVR))

      OPEN (UNIT = 121, FILE = 'REV1.SEN', STATUS = 'UNKNOWN')
      OPEN (UNIT = 122, FILE = 'REV2.SEN', STATUS = 'UNKNOWN')

      DO 300 INRS = 1, NRS

C transform correlated variables to uncorrelated variables.

         NNVR = NDRV(INRS)
         CALL TRANS (INRS, NNVR, NRS, MAXDVR,
     +               XREV, XUREV, RVSCO, TRI)
         IF (IERR == 1) GO TO 1000

C the transformation matrix for a revenue stream

         DO 200 J = 1, NNVR
            DO 200 K = 1, NNVR

$IF enough .EQ. 1
               TRIRVS (INRS, J, K) = TRI (J, K)
$ELSE
               CALL SPA_SET3 (TRIRVS, TRI (J, K), INRS, J, K)
$ENDIF

 200     CONTINUE

         WRITE (121, *) 'sensitivity coefficient1 for RVS #',INRS
         WRITE (122, *) 'sensitivity coefficient2 for RVS #',INRS

         CALL RVSMMT (INRS, DR, BOTTLE,
     +                NRVSF, NDRV,
     +                XUREV, TRIRVS,
     +                REV, STFO (INRS))

 300  CONTINUE
      DEALLOCATE (TRI)

C approximate the correlation between the revenue streams for
C moment approximations at the project level.

C estimate g(x) given by the user at mean of X and the first
C partial derivative with respect to the correlated variables.

      DO 450 INRS = 1,NRS
         NNVR = NDRV(INRS)
```

```
         DO 430 J=1,NNVR
            X(J) = XREV (1, INRS, J)
 430     CONTINUE

C ROCK (-1%) AND ROLL (+1%) THE VARIABLES TO GET THE PARTIALS

         DO 440 J=1,NNVR
            SZ     = XREV (1, INRS, J) * 0.01D0 ! the increment...

            X (J) = XREV (1, INRS, J) * 0.99D0 ! rock
             CALL RVSFF (NRVSF (INRS), J, 1, DR, BOTTLE, INRS, X,
     +                   GZS)

            X (J) = XREV (1, INRS, J) * 1.01D0 ! roll
             CALL RVSFF (NRVSF (INRS), J, 3, DR, BOTTLE, INRS, X,
     +                   GZL)

            X (J) = XREV (1, INRS, J)            ! reset

            PRVSX (INRS, J) = (GZL - GZS) / (2.0D0 * SZ)
 440     CONTINUE
 450  CONTINUE


C ESTIMATE THE CORRELATION BETWEEN TWO REVENUE STREAMS.
C COVAR does something to the SECOND set of values of XREV.
C check this carefully.

      JU = 13
      PRINT *, 'about to call COVAR, many times...'
      DO 500 INRS = 1, NRS

            NI = NDRV (INRS)
            JJ = INRS + 1
            IF (JJ <= NRS) THEN
               DO 470 J=JJ,NRS
                     NJ = NDRV (J)
                     READ (JU, *) NDCV
                     IF (NDCV == 0) THEN
                        CORRR (INRS, J) = 0.0D0
                        CORRR (J, INRS) = 0.0D0
                     ELSE
                        CALL COVAR (JU,NDCV, INRS,J,NI,NJ,
     +                              PRVSX,
     +                              XREV,
     +                              RVSCO,
     +                              STFO (INRS), STFO (J),
     +                              CORRR)
                     ENDIF

 470           CONTINUE

            ENDIF

 500  CONTINUE

 1000 DEALLOCATE(XREV, RVSCO, STFO)
```

```
      CALL TRACE (2, 'REVSTR', 'exiting.')
      RETURN

 9000 WRITE (6, *) INRS, J, '--> Bogositude to the max.'
      WRITE (6, *) A,B,C,D,E
      WRITE (7, 9909) INRS, J
      GOTO 1000

 9901 FORMAT (I4,I4,I4,F10.5)
 9902 FORMAT (5F20.4)
 9905 FORMAT (2I4)
 9906 FORMAT (I2)
 9907 FORMAT (3I4)
 9908 FORMAT (F10.2)

 9909 FORMAT (/,'RS(',I3,').VAR(',I4,') is NOT pearson dist.',/)

      END
```

```
C PrjCst.FOR
C modified by Toshiaki Hatakama in July, 1994.

C ROUTINE TO APPROXIMATE THE FIRST FOUR MOMENTS OF THE PROJECT
C COST AT THE MINIMUM ATTRACTIVE RATE OF RETURN (OR IN TOTAL
C DOLLARS WHEN THE MARR IS EQUAL TO ZERO).

C===============================================================
      SUBROUTINE PRJCST (DR,
     +                   COST,
     +                   CORRC,
     +                   PCOST)
C================================================================

      IMPLICIT REAL*4(A-H,O-Z)
      INCLUDE 'DEBUG.CMN'
      REAL*4 COST (4, *), CORRC (NWP, *), PCOST (*)
      REAL*4 X (:,:), Z (:,:), TRI (:,:), COR (:,:), PD (:)
      ALLOCATABLE X, Z, TRI, COR, PD

      CALL TRACE (2, 'PRJCST', 'starting.')

      ALLOCATE (X (4, NWP))
      ALLOCATE (Z (4, NWP))
      ALLOCATE (TRI (NWP-2, NWP-2))
      ALLOCATE (COR (NWP-2, NWP-2))
      ALLOCATE (PD (NWP))

      IF (DR /= 0.0D0) THEN
      WRITE (7, 9901) DR
      ELSE
      WRITE (7, 9902)
      ENDIF
      WRITE (7, 9903)

      DO 100 I = 1, NWP

      IF (COST (2, I) == 0.0D0) THEN
         SDWPC = 0.0D0
         SKWPC = 0.0D0
         AKWPC = 0.0D0
      ELSE
         SDWPC = COST (2, I) ** 0.5D0
         SKWPC = COST (3, I) / (COST (2, I) ** 1.5D0)
         ASKP  = 1.2D0* (SKWPC ** 2) + 2.0D0
         AKWPC = COST (4, I) / (COST (2, I) ** 2)
         IF (AKWPC .LT. ASKP) AKWPC = ASKP
      ENDIF
 100    WRITE (7, 9904) I, COST (1, I), SDWPC, SKWPC, AKWPC

C first four moments of the project cost at MARR

      PCOST (1) = 0.0D0
      PCOST (2) = 0.0D0
      PCOST (3) = 0.0D0
```

```
      PCOST (4) = 0.0D0

C all this segment is here for is to move the variables into a
C slightly different place for the benefit of TANSP....
C TANSP needs to take an offset of some sort. later.

      DO 120 I = 2, (NWP - 1)
       K = I - 1
       X (1, K) = COST (1, I)
       X (2, K) = COST (2, I)
       X (3, K) = COST (3, I)
       X (4, K) = COST (4, I)
       IF (I < (NWP - 1)) THEN
          DO 110 J = (I + 1), (NWP - 1)
             L = J - 1
             TEMP = CORRC (I, J)
             COR (K, L) = TEMP
 110            COR (L, K) = TEMP
       ENDIF
 120  CONTINUE

C transform the correlated W.P costs to uncorrelated W.P costs
C hand TANSP another parameter, namely where to start work?

      CALL TANSP ((NWP - 2),
     +            X,
     +            Z,
     +            COR,TRI)
      IF (0 < IERR) GO TO 500

C first partial deravatives of the transformed W.P costs. second
C partial deravative is zero because the function is linear.

      DO 150 I = 2, (NWP - 1)
       PD (I) = 0.0D0
       DO 150 J = 2, (NWP - 1)
 150        PD (I) = PD (I) + TRI (J - 1, I - 1)

      DO 200 I = 2, (NWP - 1)
       PCOST (1) = PCOST (1) + PD (I)      * Z (1, I - 1)
       PCOST (2) = PCOST (2) + PD (I) ** 2 * Z (2, I - 1)
       PCOST (3) = PCOST (3) + PD (I) ** 3 * Z (3, I - 1)
       FC    = 0.0D0
       IF (I < (NWP - 1)) THEN
          DO 180 J = (I + 1), (NWP - 1)
 180           FC = FC + 6.0D0 *
     +              (PD (I) * PD (J)) ** 2 * Z (2, I - 1) * Z (2, J -
     +               1)
       ENDIF
 200     PCOST (4) = PCOST (4) + FC + PD (I) ** 4 * Z (4, I - 1)

C standard deviation, skewness and kurtosis of project cost

      SDPC = PCOST (2) ** 0.5D0
      SKPC = PCOST (3) / (PCOST (2) ** 1.5D0)
      AKPC = PCOST (4) / (PCOST (2) ** 2)
```

```
      IF (DR == 0.0D0) THEN
       WRITE (7, 9906)
      ELSE
       WRITE (7, 9905)DR
      ENDIF
      WRITE (7, 9907)
      WRITE (7, 9908) PCOST (1), SDPC, SKPC, AKPC

      CALL CDFUNC (PEARSN, PCOST (1), SDPC, SKPC, AKPC,
     +     V1,V2,V3,V4,V5,V6,V7, V8, V9,V10,V11,V12,V13,V14,V15)

      WRITE (20, 9910)
     +     V1,V2,V3,V4,V5,V6,V7, V8, V9,V10,V11,V12,V13,V14,V15


  500 CALL TRACE (2, 'PRJCST', 'exiting.')
      DEALLOCATE (X, Z, TRI, COR, PD)
      RETURN

 9901 FORMAT (/,'WP Costs (Discount rate of ', F6.3, ')')
 9902 FORMAT (/,'WP Costs (Total Dollars)')
 9903 FORMAT ('W.P.#      Exp.Value===== S.Dev========= ',
     +                    'Skewness====== Kurtosis======')
 9904 FORMAT (I4,6X,4F15.3)


 9905 FORMAT (/,'The Project Cost (discount rate of Return
of',F6.3,')')
 9906 FORMAT (/,'The Project Cost (Total Dollars)')
 9907 FORMAT ('           Exp.Value===== S.Dev========= ',
     +                    'Skewness====== Kurtosis======')
 9908 FORMAT (10X,4F15.3)

 9910 FORMAT (' Project Cost export for EXCEL',
     +        /,' ',F20.2,', 0.25',
     +        /,' ',F20.2,', 0.50',
     +        /,' ',F20.2,', 1.00',
     +        /,' ',F20.2,', 2.50',
     +        /,' ',F20.2,', 5.00',
     +        /,' ',F20.2,',10.00',
     +        /,' ',F20.2,',25.00',
     +        /,' ',F20.2,',50.00',
     +        /,' ',F20.2,',75.00',
     +        /,' ',F20.2,',90.00',
     +        /,' ',F20.2,',95.00',
     +        /,' ',F20.2,',97.50',
     +        /,' ',F20.2,',99.00',
     +        /,' ',F20.2,',99.50',
     +        /,' ',F20.2,',99.75')

      END
```

```
C PrjRev.FOR
C modified by Toshiaki Hatakama in July, 1994.

C ROUTINE TO APPROXIMATE THE FIRST FOUR MOMENTS OF THE PROJECT
C REVENUE AT THE MINIMUM ATTRACTIVE RATE OF RETURN (OR IN TOTAL
C DOLLARS WHEN THE MARR IS EQUAL TO ZERO).

C================================================================
      SUBROUTINE PRJREV (DR,
     +                   REV,
     +                   CORRR,
     +                   PREV)
C================================================================

      IMPLICIT REAL*4 (A-H,O-Z)
      REAL*4 REV (4, *), PREV (4), CORRR (NRS, *)
      REAL*4 Z (:,:), TRI (:,:), PD (:)
      ALLOCATABLE Z, TRI, PD

      INCLUDE 'DEBUG.CMN'

      CALL TRACE (2, 'PRJREV', 'starting.')

      ALLOCATE (Z (4, NRS))
      ALLOCATE (TRI (NRS, NRS))
      ALLOCATE (PD (NRS))


      IF (DR == 0.0D0) THEN
         WRITE(7,9901)
      ELSE
         WRITE(7,9902)DR
      ENDIF
      WRITE(7,9903)

      DO 80 I = 1, NRS

         IF (REV (2, I) == 0.0D0) THEN
            SDRVS = 0.0D0
            SKRVS = 0.0D0
            AKRVS = 0.0D0
         ELSE
            SDRVS = REV (2, I) ** 0.5D0
            SKRVS = REV (3, I) / (REV (2, I) ** 1.5D0)
            ASKR  = 1.2D0 * (SKRVS ** 2) + 2.0D0
            AKRVS = REV (4, I) / (REV (2, I) ** 2)
            IF (AKRVS < ASKR) THEN
               AKRVS = ASKR
            ENDIF
         ENDIF

 80      WRITE (7, 9904) I, REV (1, I), SDRVS, SKRVS, AKRVS

C first four moments of the project revenue at MARR
```

```
      PREV (1) = 0.0D0
      PREV (2) = 0.0D0
      PREV (3) = 0.0D0
      PREV (4) = 0.0D0

C transform the correlated RVS to uncorrelated RVS

      CALL TANSP (NRS,
     +            REV,
     +            Z,
     +            CORRR,
     +            TRI)
       IF (IERR > 0) GO TO 500

C first partial derivatives of the transformed RVS.
C second partial derivatives are zero because the function is linear.

      DO 150 I = 1, NRS
         PD(I) = 0.0D0
         DO 150 J = 1, NRS
 150        PD (I) = PD (I) + TRI (J, I)


      DO 200 I = 1, NRS
         PREV (1) = PREV (1) + PD (I)      * Z (1, I)
         PREV (2) = PREV (2) + PD (I) ** 2 * Z (2, I)
         PREV (3) = PREV (3) + PD (I) ** 3 * Z (3, I)
         FR = 0.0D0
         IF (I < NRS) THEN
            DO 180 J = I + 1, NRS
               IF (NRS < J) THEN
                  PRINT *, 'why are we here...?'
                  PRINT *,
                  PRINT *,
               ENDIF
               FR = FR + 6.0D0 * (PD (I) * PD(J)) ** 2 *
     *              Z (2, I) * Z (2, J)
 180        CONTINUE
         ENDIF
 200     PREV (4) = PREV (4) + FR + PD (I) ** 4 * Z (4, I)

C standard deviation, skewness and kurtosis of project revenue

      SDPR = PREV (2) ** 0.5D0
      SKPR = PREV (3) / (PREV (2) ** 1.5D0)
      AKPR = PREV (4) / (PREV (2) ** 2)

      IF (DR == 0.0D0) THEN
         WRITE (7, 9905)
      ELSE
         WRITE (7, 9906)DR
      ENDIF
      WRITE (7, 9907)
      WRITE (7, 9908) PREV(1), SDPR, SKPR, AKPR

      CALL CDFUNC (PEARSN, PREV (1), SDPR, SKPR, AKPR,
     +     V1,V2,V3,V4,V5,V6,V7, V8, V9,V10,V11,V12,V13,V14,V15)
```

```
      WRITE (20, 9910)
     +     V1,V2,V3,V4,V5,V6,V7, V8, V9,V10,V11,V12,V13,V14,V15

 500  DEALLOCATE (Z, TRI, PD)
      CALL TRACE (2, 'PRJREV', 'exiting.')
      RETURN


 9901 FORMAT (/,'Net Revenue Streams in Total $s')
 9902 FORMAT (/,'Net Revenue Streams (Discount Rate',F6.3,')')

 9903 FORMAT ('RevStr#    Exp.Value===== S.Dev========= ',
     +                   'Skewness====== Kurtosis======')
 9904 FORMAT (I4,6X,4F15.3)

 9905 FORMAT (/,'The Project Revenue in Total Dollars')
 9906 FORMAT (/,'The Project Revenue (Discount Rate',F6.3,')')
 9907 FORMAT ('             Exp.Value===== S.Dev========= ',
     +                   'Skewness====== Kurtosis======')
 9908 FORMAT (10X,4F15.3)

 9910 FORMAT (' Project Revenue export for EXCEL',
     +         /,' ',F20.2,', 0.25',
     +         /,' ',F20.2,', 0.50',
     +         /,' ',F20.2,', 1.00',
     +         /,' ',F20.2,', 2.50',
     +         /,' ',F20.2,', 5.00',
     +         /,' ',F20.2,',10.00',
     +         /,' ',F20.2,',25.00',
     +         /,' ',F20.2,',50.00',
     +         /,' ',F20.2,',75.00',
     +         /,' ',F20.2,',90.00',
     +         /,' ',F20.2,',95.00',
     +         /,' ',F20.2,',97.50',
     +         /,' ',F20.2,',99.00',
     +         /,' ',F20.2,',99.50',
     +         /,' ',F20.2,',99.75')

      END
```

```
C PrjNPV.FOR
C modified by Toshiaki Hatakama in July, 1994

C ROUTINE TO APPROXIMATE THE FIRST FOUR MOMENTS OF THE PROJECT
C NET PRESENT VALUE AT THE MINIMUM ATTRACTIVE RATE OF RETURN
C (OR IN TOTAL DOLLARS WHEN THE MARR IS EQUAL TO ZERO).

C==============================================================
      SUBROUTINE PRJNPV (DR,
     +                   PCOST,
     +                   PREV)
C==============================================================

      IMPLICIT REAL*4(A-H,O-Z)
      REAL*4 PCOST(4), PREV(4), NPV (4)

C the first four moments of project net present value

      CALL TRACE (2, 'PRJNPV', 'starting.')

      NPV (1) = PREV (1) - PCOST (1)
      NPV (2) = PREV (2) + PCOST (2)
      NPV (3) = PREV (3) - PCOST (3)
      NPV (4) = PREV (4) + PCOST (4) + 6.0D0 * PREV (2) * PCOST (2)

C standard deviation, skewness and kurtosis of project NPV

      SDNPV = NPV (2) **0.5D0
      SKNPV = NPV (3) / (NPV (2) ** 1.5D0)
      AKNPV = NPV (4) / (NPV (2) ** 2)

      WRITE (7, 9901) DR
      WRITE (7, 9902)
      WRITE (7, 9903) NPV (1), SDNPV, SKNPV, AKNPV

      CALL CDFUNC (PEARSN, NPV (1), SDNPV, SKNPV, AKNPV,
     +     V1,V2,V3,V4,V5,V6,V7, V8, V9,V10,V11,V12,V13,V14,V15)

      WRITE (20, 9910)
     +     V1,V2,V3,V4,V5,V6,V7, V8, V9,V10,V11,V12,V13,V14,V15

      CALL TRACE (2, 'PRJNPV', 'exiting.')
      RETURN

 9901 FORMAT (/,'The Project NPV at a Discount Rate of',F6.3)
 9902 FORMAT ('           Exp.Value===== S.Dev========= ',
     +                   'Skewness====== Kurtosis======')
 9903 FORMAT (10X,4F15.3)

 9910 FORMAT (' Project Net Present Value export for EXCEL',
     +        /,' ',F20.2,', 0.25',
     +        /,' ',F20.2,', 0.50',
     +        /,' ',F20.2,', 1.00',
     +        /,' ',F20.2,', 2.50',
     +        /,' ',F20.2,', 5.00',
```

```
     +          /,'  ',F20.2,',10.00',
     +          /,'  ',F20.2,',25.00',
     +          /,'  ',F20.2,',50.00',
     +          /,'  ',F20.2,',75.00',
     +          /,'  ',F20.2,',90.00',
     +          /,'  ',F20.2,',95.00',
     +          /,'  ',F20.2,',97.50',
     +          /,'  ',F20.2,',99.00',
     +          /,'  ',F20.2,',99.50',
     +          /,'  ',F20.2,',99.75')
      END
```

```
C PrjIrr.FOR
C modified by Toshiaki Hatakama in July, 1994.
C in order to calculate IRR, it is necessary to improve this
C subroutine, because, it takes too long.



C ROUTINE TO APPROXIMATE THE CUMULATIVE DISTRIBUTION FUNCTION
C AND THE FIRST FOUR MOMENTS OF PROJECT INTERNAL RATE OF RETURN.

C=================================================================
      SUBROUTINE PRJIRR (PEARSN, FRA,
     +                   IWPC, NWPCF, NDVR,
     +                   CORRC, TRIWPC,
     +                   XUCOST, COST,
     +                   NRVSF, NDRV,
     +                   CORRR, TRIRVS,
     +                   XUREV, REV,
     +                   BOTTLE)
C=================================================================

C if you have 16M RAM, chhose "enough" = 1.
C if not, choose any number but 1.


$DEFINE enough = 0

      IMPLICIT REAL*4(A-H,O-Z)
      INCLUDE 'DEBUG.CMN'

      PARAMETER (JSZ=50,ISZ=10)

      REAL*4 PEARSN (NPEARS, *)
      INTEGER IWPC (*), NWPCF (*), NDVR (*), NRVSF (*), NDRV (*)
      REAL*4 CORRC (NWP, *), TRIWPC (NWP, NWP, *)
      REAL*4 XUCOST (4, NWP, *), COST (4, *), CORRR (NRS, *)

$IF enough .EQ. 1
      REAL*4 TRIRVS (NRS, MAXDVR, *)
$ELSE
      REAL*4 TRIRVS (*)
$ENDIF

      REAL*4 XUREV (4, NRS, *), REV (4, *)
      REAL*4 BOTTLE (NRS, *)
      REAL*4 STFO
      REAL*4 X (:,:), Z (:,:), COR (:,:), TRI (:,:)

      ALLOCATABLE X, Z, COR, TRI

C correlation arrays, etc

      REAL*4 PDC(JSZ)
      REAL*4 PDR(300)
      REAL*4 PIRR(300)
```

```
      CALL TRACE (2, 'PRJIRR', 'starting.')

      ALLOCATE (X (4, NWP))
      ALLOCATE (Z (4, NWP))

      KM = 0
      STFO = 0.0D0

C these are almost pearson arrays, except for A and Z....

      PRB1 = 0.0D0
      PRC1 = 0.0D0
      PRD1 = 0.0D0
      PRE1 = 0.0D0
      PRF1 = 0.0D0
      PRG1 = 0.0D0
       PRM1 = 0.0D0
        PRT1 = 0.0D0
        PRU1 = 0.0D0
        PRV1 = 0.0D0
        PRW1 = 0.0D0
        PRX1 = 0.0D0
        PRY1 = 0.0D0
C
      DRB1 = 0.0D0
      DRC1 = 0.0D0
      DRD1 = 0.0D0
      DRE1 = 0.0D0
      DRF1 = 0.0D0
      DRG1 = 0.0D0
       DRM1 = 0.0D0
        DRT1 = 0.0D0
        DRU1 = 0.0D0
        DRV1 = 0.0D0
        DRW1 = 0.0D0
        DRX1 = 0.0D0
        DRY1 = 0.0D0
C
      PRB2 = 0.0D0
      PRC2 = 0.0D0
      PRD2 = 0.0D0
      PRE2 = 0.0D0
      PRF2 = 0.0D0
      PRG2 = 0.0D0
       PRM2 = 0.0D0
        PRT2 = 0.0D0
        PRU2 = 0.0D0
        PRV2 = 0.0D0
        PRW2 = 0.0D0
        PRX2 = 0.0D0
        PRY2 = 0.0D0
C
      DRB2 = 0.0D0
      DRC2 = 0.0D0
      DRD2 = 0.0D0
      DRE2 = 0.0D0
```

```
      DRF2 = 0.0D0
      DRG2 = 0.0D0
       DRM2 = 0.0D0
        DRT2 = 0.0D0
        DRU2 = 0.0D0
        DRV2 = 0.0D0
        DRW2 = 0.0D0
        DRX2 = 0.0D0
        DRY2 = 0.0D0

C the cycle to obtain the cumulative distribution function for
C project internal rate of return at various Discount Rates
C between 1% and 300%

      I = 1

  10  DR = FLOAT (I) / 100.0D0
      IF (300 < I) GO TO 1200 ! give up.


C call WPCMMT a number of times to generate the first four moments
C of the work package costs

      NN = NWP - 1
      DO 30 J = 2, NN
         IF (1 < IWPC (J)) THEN
            COST (1, J) = 0.0D0
            COST (2, J) = 0.0D0
            COST (3, J) = 0.0D0
            COST (4, J) = 0.0D0
         ELSE
            CALL WPCMMT (J, DR, FRA,
     +                   NWPCF, NDVR,
     +                   XUCOST, TRIWPC,
     +                   COST, STFO)
         ENDIF
  30  CONTINUE

C first four moments of the project cost

      APRC = 0.0D0
      SPRC = 0.0D0
      TPRC = 0.0D0
      FPRC = 0.0D0

      NNVR = NWP-2
      NN   = NWP-1

      ALLOCATE (COR (NNVR, NNVR))

      DO 50 M = 2, NN
         K = M - 1
         X (1, K) = COST (1, M)
         X (2, K) = COST (2, M)
         X (3, K) = COST (3, M)
         X (4, K) = COST (4, M)
         JJ = M + 1
```

```
          IF (JJ <= NN) THEN
             DO 40 J = JJ, NN
                L = J - 1
                TEMP = CORRC (M, J)
                COR (K, L) = TEMP
C                COR (L, K) = TEMP
  40         CONTINUE
          ENDIF
  50   CONTINUE


C transform the correlated W.P costs to uncorrelated W.P costs

       ALLOCATE (TRI (NNVR, NNVR))

       CALL TANSP (NNVR, X, Z, COR, TRI)
       IF (0 < IERR) GO TO 1200

       DEALLOCATE (COR)

C first partial deravatives of the transformed W.P costs.

       DO 80 M = 2, NN
          PDC (M) = 0.0D0
          DO 80 J = 2, NN
  80         PDC (M) = PDC (M) + TRI (J - 1, M - 1)

       DEALLOCATE (TRI)

       DO 110 M = 2, NN
          APRC = APRC + PDC (M)      * Z (1, M - 1)
          SPRC = SPRC + PDC (M) ** 2 * Z (2, M - 1)
          TPRC = TPRC + PDC (M) ** 3 * Z (3, M - 1)
          FC   = 0.0D0

          JJ = M + 1
          IF (NN >= JJ) THEN
             DO 100 J=JJ, NN
 100            FC = FC + 6.0D0 * (PDC (M) * PDC (J)) ** 2 *
     +                   Z (2, M - 1) * Z (2, J - 1)
          ENDIF

          FPRC = FPRC + FC + PDC(M) ** 4 * Z (4, M - 1)
 110   CONTINUE


C first four moments of the net revenue streams
C this is where the major time is being spent...
C do we have to shake all the leaves?
C can we shake the whole tree at once?

       DO 140 J = 1, NRS
          STFO = 0.0D0
 140      CALL RVSMMT (J, DR, BOTTLE,
     +                 NRVSF, NDRV,
     +                 XUREV, TRIRVS,
     +                 REV, STFO)
```

```
C first four moments of the project revenue

      APRR = 0.0D0
      SPRR = 0.0D0
      TPRR = 0.0D0
      FPRR = 0.0D0

C transform the correlated RVS to uncorrelated RVS.

      ALLOCATE (TRI (NRS, NRS))

      CALL TANSP (NRS,
     +            REV,
     +            Z,
     +            CORRR,
     +            TRI)
      IF (0 < IERR) GO TO 1200


      DO 150 M = 1, NRS
         PDR (M) = 0.0D0
         DO 150 J = 1, NRS
 150        PDR (M) = PDR (M) + TRI (J, M)

      DEALLOCATE (TRI)

      DO 200 M = 1, NRS

         APRR = APRR + PDR (M)      * Z (1, M)
         SPRR = SPRR + PDR (M) ** 2 * Z (2, M)
         TPRR = TPRR + PDR (M) ** 3 * Z (3, M)
         FR   = 0.0D0

         JJ = M + 1
         IF (JJ <= NRS) THEN
            DO 180 J=JJ,NRS
 180           FR = FR + 6.0D0 * (PDR (M) * PDR (J)) ** 2 *
     +                 Z (2, M) * Z (2, J)
         ENDIF


 200     FPRR = FPRR + FR + PDR (M) ** 4 * Z (4, M)


C first four moments of project net present value

      ANPV = APRR - APRC
      SNPV = SPRR + SPRC
      TNPV = TPRR - TPRC
      FNPV = FPRR + FPRC + 6.0D0 * SPRR * SPRC

C standard deviation, skewness and kurtosis of project NPV

      SDNPV = SNPV ** 0.5D0
      SKNPV = TNPV / (SNPV ** 1.5D0)
```

```
      AKNPV = FNPV / (SNPV ** 2)


C values of the cumulative distribution function approximated
C for the net present value of the project


      CALL CDFUNC (PEARSN,
     +             ANPV,SDNPV,SKNPV,AKNPV,
     +             VA,VB,VC,VD,VE,VF,VG,
     +             VM,
     +             VT,VU,VV,VW,VX,VY,VZ)


C probability of NPV = 0 at this discount rate


      IF (I == 1) THEN
         VA1 = VA
      ENDIF

      IF (0.0D0 <= VA1) GO TO 205
      IF (0 < KM) GO TO 205
      KM = 1

 205  IF (                 0.0D0 <  VA) GO TO 490

      IF (VA < 0.0D0 .AND. 0.0D0 <= VB) GO TO 210
      IF (VB < 0.0D0 .AND. 0.0D0 <= VC) GO TO 230
      IF (VC < 0.0D0 .AND. 0.0D0 <= VD) GO TO 250
      IF (VD < 0.0D0 .AND. 0.0D0 <= VE) GO TO 270
      IF (VE < 0.0D0 .AND. 0.0D0 <= VF) GO TO 290
      IF (VF < 0.0D0 .AND. 0.0D0 <= VG) GO TO 310

      IF (VG < 0.0D0 .AND. 0.0D0 <= VM) GO TO 330
      IF (VM < 0.0D0 .AND. 0.0D0 <= VT) GO TO 350

      IF (VT < 0.0D0 .AND. 0.0D0 <= VU) GO TO 370
      IF (VU < 0.0D0 .AND. 0.0D0 <= VV) GO TO 390
      IF (VV < 0.0D0 .AND. 0.0D0 <= VW) GO TO 410
      IF (VW < 0.0D0 .AND. 0.0D0 <= VX) GO TO 430
      IF (VX < 0.0D0 .AND. 0.0D0 <= VY) GO TO 450
      IF (VY < 0.0D0 .AND. 0.0D0 <= VZ) GO TO 470

      IF (VZ < 0.0D0)                   GO TO 500

 210  KM = I

      PIRR (I) = 0.0025D0 + ((0.0D0-VA)*0.0025D0/(VB-VA))
      PRB1 = PIRR(I)
      DRB1 = FLOAT(I) / 100.0D0
      GO TO 490

 230    PIRR(I) = 0.0050D0 + ((0.0D0-VB)*0.0050D0/(VC-VB))
        IF (PRB2.GT.0.0D0) GO TO 240
        PRB2 = PIRR(I)
        DRB2 = FLOAT(I) / 100.0D0
```

```
 240    PRC1 = PIRR(I)
        DRC1 = FLOAT(I) / 100.0D0
        IF (PRB2.LE.PIRR(I)) GO TO 490
        PRB2 = PIRR(I)
        DRB2 = FLOAT(I) / 100.0D0
        GO TO 490

 250    PIRR(I) = 0.0100D0 + ((0.0D0-VC)*0.0150D0/(VD-VC))
        IF (PRC2.GT.0.0D0) GO TO 260
        PRC2 = PIRR(I)
        DRC2 = FLOAT(I) / 100.0D0
 260    PRD1 = PIRR(I)
        DRD1 = FLOAT(I) / 100.0D0
        IF (PRC2.LE.PIRR(I)) GO TO 490
        PRC2 = PIRR(I)
        DRC2 = FLOAT(I) / 100.0D0
        GO TO 490

 270    PIRR(I) = 0.0250D0 + ((0.0D0-VD)*0.0250D0/(VE-VD))
        IF (PRD2.GT.0.0D0) GO TO 280
        PRD2 = PIRR(I)
        DRD2 = FLOAT(I) / 100.0D0
 280    PRE1 = PIRR(I)
        DRE1 = FLOAT(I) / 100.0D0
        IF (PRD2.LE.PIRR(I)) GO TO 490
        PRD2 = PIRR(I)
        DRD2 = FLOAT(I) / 100.0D0
        GO TO 490

 290    PIRR(I) = 0.0500D0 + ((0.0D0-VE)*0.0500D0/(VF-VE))
        IF (PRE2.GT.0.0D0) GO TO 300
        PRE2 = PIRR(I)
        DRE2 = FLOAT(I) / 100.0D0
 300    PRF1 = PIRR(I)
        DRF1 = FLOAT(I) / 100.0D0
        IF (PRE2.LE.PIRR(I)) GO TO 490
        PRE2 = PIRR(I)
        DRE2 = FLOAT(I) / 100.0D0
        GO TO 490

 310    PIRR(I) = 0.1000D0 + ((0.0D0-VF)*0.1500D0/(VG-VF))
        IF (PRF2.GT.0.0D0) GO TO 320
        PRF2 = PIRR(I)
        DRF2 = FLOAT(I) / 100.0D0
 320    PRG1 = PIRR(I)
        DRG1 = FLOAT(I) / 100.0D0
        IF (PRF2.LE.PIRR(I)) GO TO 490
        PRF2 = PIRR(I)
        DRF2 = FLOAT(I) / 100.0D0
        GO TO 490

 330    PIRR(I) = 0.2500D0 + ((0.0D0-VG)*0.2500D0/(VM-VG))
        IF (PRG2.GT.0.0D0) GO TO 340
        PRG2 = PIRR(I)
        DRG2 = FLOAT(I) / 100.0D0
 340    PRM1 = PIRR(I)
        DRM1 = FLOAT(I) / 100.0D0
```

```
      IF (PRG2.LE.PIRR(I)) GO TO 490
      PRG2 = PIRR(I)
      DRG2 = FLOAT(I) / 100.0D0
      GO TO 490

350   PIRR(I) = 0.5000D0 + ((0.0D0-VM)*0.2500D0/(VT-VM))
      IF (PRM2.GT.0.0D0) GO TO 360
      PRM2 = PIRR(I)
      DRM2 = FLOAT(I) / 100.0D0
360   PRT1 = PIRR(I)
      DRT1 = FLOAT(I) / 100.0D0
      IF (PRM2.LE.PIRR(I)) GO TO 490
      PRM2 = PIRR(I)
      DRM2 = FLOAT(I) / 100.0D0
      GO TO 490

370   PIRR(I) = 0.7500D0 + ((0.0D0-VT)*0.1500D0/(VU-VT))
      IF (PRT2.GT.0.0D0) GO TO 380
      PRT2 = PIRR(I)
      DRT2 = FLOAT(I) / 100.0D0
380   PRU1 = PIRR(I)
      DRU1 = FLOAT(I) / 100.0D0
      IF (PRT2.LE.PIRR(I)) GO TO 490
      PRT2 = PIRR(I)
      DRT2 = FLOAT(I) / 100.0D0
      GO TO 490

390   PIRR(I) = 0.9000D0 + ((0.0D0-VU)*0.0500D0/(VV-VU))
      IF (PRU2.GT.0.0D0) GO TO 400
      PRU2 = PIRR(I)
      DRU2 = FLOAT(I) / 100.0D0
400   PRV1 = PIRR(I)
      DRV1 = FLOAT(I) / 100.0D0
      IF (PRU2.LE.PIRR(I)) GO TO 490
      PRU2 = PIRR(I)
      DRU2 = FLOAT(I) / 100.0D0
      GO TO 490

410   PIRR(I) = 0.9500D0 + ((0.0D0-VV)*0.0250D0/(VW-VV))
      IF (PRV2.GT.0.0D0) GO TO 420
      PRV2 = PIRR(I)
      DRV2 = FLOAT(I) / 100.0D0
420   PRW1 = PIRR(I)
      DRW1 = FLOAT(I) / 100.0D0
      IF (PRV2.LE.PIRR(I)) GO TO 490
      PRV2 = PIRR(I)
      DRV2 = FLOAT(I) / 100.0D0
      GO TO 490

430   PIRR(I) = 0.9750D0 + ((0.0D0-VW)*0.0150D0/(VX-VW))
      IF (PRW2.GT.0.0D0) GO TO 440
      PRW2 = PIRR(I)
      DRW2 = FLOAT(I) / 100.0D0
440   PRX1 = PIRR(I)
      DRX1 = FLOAT(I) / 100.0D0
      IF (PRW2.LE.PIRR(I)) GO TO 490
      PRW2 = PIRR(I)
```

```
      DRW2 = FLOAT(I) / 100.0D0
      GO TO 490

 450  PIRR(I) = 0.9900D0 + ((0.0D0-VX)*0.0050D0/(VY-VX))
      IF (PRX2.GT.0.0D0) GO TO 460
      PRX2 = PIRR(I)
      DRX2 = FLOAT(I) / 100.0D0
 460  PRY1 = PIRR(I)
      DRY1 = FLOAT(I) / 100.0D0
      IF (PRX2.LE.PIRR(I)) GO TO 490
      PRX2 = PIRR(I)
      DRX2 = FLOAT(I) / 100.0D0
      GO TO 490

 470  PIRR(I) = 0.9950D0 + ((0.0D0-VY)*0.0025D0/(VZ-VY))
      IF (PRY2.GT.0.0D0) GO TO 480
      PRY2 = PIRR(I)
      DRY2 = FLOAT(I) / 100.0D0
 480  IF (PRY2.LE.PIRR(I)) GO TO 490
      PRY2 = PIRR(I)
      DRY2 = FLOAT(I) / 100.0D0


 490  I = I+1
      GO TO 10


C we're done, and we have the desired value of IRR...

 500  CONTINUE

      PRINT*,'after line 500'


C the fractile estimates (0.01, 0.025, 0.05, 0.10, 0.25, 0.5,
C 0.75, 0.90, 0.95, 0.975 & 0.99) to approximate the expected
C value and standard deviation of the internal rate of return
C using the approximations given by E.S.PEARSON AND J.W.TUKEY
C and to plot the cumulative distribution function.

C the 0.005 fractile estimate for internal rate of return

      IF (PRB1.EQ.0.0D0.AND.PRB2.EQ.0.0D0) GO TO 510
      IF (DRB1.GT.0.0D0) GO TO 505
      DIRB = DRB2
      GO TO 515
 505  DIRB = DRB1 + ((0.005D0-PRB1) * (DRB2-DRB1) / (PRB2-PRB1))
      GO TO 515
 510  DIRB = 0.0D0

C the 0.01 fractile estimate for internal rate of return

 515  IF (PRC1.EQ.0.0D0.AND.PRC2.EQ.0.0D0) GO TO 525
      IF (DRC1.GT.0.0D0) GO TO 520
      DIRC = DRC2
      GO TO 530
 520  DIRC = DRC1 + ((0.01D0-PRC1) * (DRC2-DRC1) / (PRC2-PRC1))
```

```
      GO TO 530
 525  DIRC = 0.0D0

C the 0.025 fractile estimate for internal rate of return

 530  IF (PRD1.EQ.0.0D0.AND.PRD2.EQ.0.0D0) GO TO 550
      IF (DRD1.GT.0.0D0) GO TO 540
      DIRD = DRD2
      GO TO 560
 540  DIRD = DRD1 + ((0.025D0-PRD1) * (DRD2-DRD1) / (PRD2-PRD1))
      GO TO 560
 550  DIRD = 0.0D0

C the 0.05 fractile estimate for internal rate of return

 560  IF (PRE1.EQ.0.0D0.AND.PRE2.EQ.0.0D0) GO TO 580
      IF (DRE1.GT.0.0D0) GO TO 570
      DIRE = DRE2
      GO TO 590
 570  DIRE = DRE1 + ((0.05D0-PRE1) * (DRE2-DRE1) / (PRE2-PRE1))
      GO TO 590
 580  DIRE = 0.0D0

C the 0.10 fractile estimate for internal rate of return

 590  IF (PRF1.EQ.0.0D0.AND.PRF2.EQ.0.0D0) GO TO 610
      IF (DRF1.GT.0.0D0) GO TO 600
      DIRF = DRF2
      GO TO 620
 600  DIRF = DRF1 + ((0.10D0-PRF1) * (DRF2-DRF1) / (PRF2-PRF1))
      GO TO 620
 610  DIRF = 0.0D0

C the 0.25 fractile estimate for internal rate of return

 620  IF (PRG1.EQ.0.0D0.AND.PRG2.EQ.0.0D0) GO TO 640
      IF (DRG1.GT.0.0D0) GO TO 630
      DIRG = DRG2
      GO TO 650
 630  DIRG = DRG1 + ((0.25D0-PRG1) * (DRG2-DRG1) / (PRG2-PRG1))
      GO TO 650
 640  DIRG = 0.0D0

C the 0.50 fractile estimate for internal rate of return

 650  IF (PRM1.EQ.0.0D0.AND.PRM2.EQ.0.0D0) GO TO 670
      IF (DRM1.GT.0.0D0) GO TO 660
      DIRM = DRM2
      GO TO 680
 660  DIRM = DRM1 + ((0.50D0-PRM1) * (DRM2-DRM1) / (PRM2-PRM1))
      GO TO 680
 670  DIRM = 0.0D0

C the 0.75 fractile estimate for internal rate of return

 680  IF (PRT1.EQ.0.0D0.AND.PRT2.EQ.0.0D0) GO TO 700
      IF (DRT1.GT.0.0D0) GO TO 690
```

```
      DIRT = DRT2
      GO TO 710
690   DIRT = DRT1 + ((0.75D0-PRT1) * (DRT2-DRT1) / (PRT2-PRT1))
      GO TO 710
700   DIRT = 0.0D0

C the 0.90 fractile estimate for internal rate of return

710   IF (PRU1.EQ.0.0D0.AND.PRU2.EQ.0.0D0) GO TO 730
      IF (DRU1.GT.0.0D0) GO TO 720
      DIRU = DRU2
      GO TO 740
720   DIRU = DRU1 + ((0.90D0-PRU1) * (DRU2-DRU1) / (PRU2-PRU1))
      GO TO 740
730   DIRU = 0.0D0

C the 0.95 fractile estimate for internal rate of return

740   IF (PRV1.EQ.0.0D0.AND.PRV2.EQ.0.0D0) GO TO 760
      IF (DRV1.GT.0.0D0) GO TO 750
      DIRV = DRV2
      GO TO 770
750   DIRV = DRV1 + ((0.95D0-PRV1) * (DRV2-DRV1) / (PRV2-PRV1))
      GO TO 770
760   DIRV = 0.0D0

C the 0.975 fractile estimate for internal rate of return

770   IF (PRW1.EQ.0.0D0.AND.PRW2.EQ.0.0D0) GO TO 790
      IF (DRW1.GT.0.0D0) GO TO 780
      DIRW = DRW2
      GO TO 800
780   DIRW = DRW1 + ((0.975D0-PRW1) * (DRW2-DRW1) / (PRW2-PRW1))
      GO TO 800
790   DIRW = 0.0D0

C the 0.99 fractile estimate for internal rate of return

800   IF (PRX1.EQ.0.0D0.AND.PRX2.EQ.0.0D0) GO TO 810
      IF (DRX1.GT.0.0D0) GO TO 805
      DIRX = DRX2
      GO TO 815
805   DIRX = DRX1 + ((0.99D0-PRX1) * (DRX2-DRX1) / (PRX2-PRX1))
      GO TO 815
810   DIRX = 0.0D0

815   IF (PRY1.EQ.0.0D0.AND.PRY2.EQ.0.0D0) GO TO 825
      IF (DRY1.GT.0.0D0) GO TO 820
      DIRY = DRY2
      GO TO 830
820   DIRY = DRY1 + ((0.995D0-PRY1) * (DRY2-DRY1) / (PRY2-PRY1))
      GO TO 830
825   DIRY = 0.0D0


      PRINT*,'cheking point A'
```

```
C check the fractile estimates

 830    IF (DIRB.LT.DIRC.AND.DIRC.LT.DIRD) GO TO 835
        IF (DIRB.GT.DIRD) GO TO 835
        DIRC = DIRB + ((0.01D0-0.005D0)*(DIRD-DIRB)/(0.025D0-
0.005D0))

 835    IF (DIRC.LT.DIRD.AND.DIRD.LT.DIRE) GO TO 840
        IF (DIRC.GT.DIRE) GO TO 840
        DIRD = DIRC + ((0.025D0-0.01D0)*(DIRE-DIRC)/(0.05D0-0.01D0))

 840    IF (DIRD.LT.DIRE.AND.DIRE.LT.DIRF) GO TO 845
        IF (DIRD.GT.DIRF) GO TO 845
        DIRE = DIRD + ((0.05D0-0.025D0)*(DIRF-DIRD)/(0.1D0-0.025D0))

 845    IF (DIRE.LT.DIRF.AND.DIRF.LT.DIRG) GO TO 850
        IF (DIRE.GT.DIRG) GO TO 850
        DIRF = DIRE + ((0.1D0-0.05D0)*(DIRG-DIRE)/(0.25D0-0.05D0))

 850    IF (DIRF.LT.DIRG.AND.DIRG.LT.DIRM) GO TO 855
        IF (DIRF.GT.DIRM) GO TO 855
        DIRG = DIRF + ((0.25D0-0.1D0)*(DIRM-DIRF)/(0.5D0-0.1D0))

 855    IF (DIRG.LT.DIRM.AND.DIRM.LT.DIRT) GO TO 860
        IF (DIRG.GT.DIRT) GO TO 860
        DIRM = DIRG + ((0.5D0-0.25D0)*(DIRT-DIRG)/(0.75D0-0.25D0))

 860    IF (DIRM.LT.DIRT.AND.DIRT.LT.DIRU) GO TO 865
        IF (DIRM.GT.DIRU) GO TO 865
        DIRT = DIRM + ((0.75D0-0.5D0)*(DIRU-DIRM)/(0.9D0-0.5D0))

 865    IF (DIRT.LT.DIRU.AND.DIRU.LT.DIRV) GO TO 870
        IF (DIRT.GT.DIRV) GO TO 870
        DIRU = DIRT + ((0.9D0-0.75D0)*(DIRV-DIRT)/(0.95D0-0.75D0))

 870    IF (DIRU.LT.DIRV.AND.DIRV.LT.DIRW) GO TO 875
        IF (DIRU.GT.DIRW) GO TO 875
        DIRV = DIRU + ((0.95D0-0.9D0)*(DIRW-DIRU)/(0.975D0-0.9D0))

 875    IF (DIRV.LT.DIRW.AND.DIRW.LT.DIRX) GO TO 880
        IF (DIRV.GT.DIRX) GO TO 880
        DIRW = DIRV + ((0.975D0-0.95D0)*(DIRX-DIRV)/(0.99D0-0.95D0))

 880    IF (DIRW.LT.DIRX.AND.DIRX.LT.DIRY) GO TO 900
        IF (DIRW.GT.DIRY) GO TO 900
        DIRX = DIRW + ((0.99D0-0.975D0)*(DIRY-DIRW)/(0.995D0-
0.975D0))

C the expected value of internal rate of return

 900    DELT = DIRV + DIRE - (2.0D0 * DIRM)
        AIRT = DIRM + (0.185D0 * DELT)
        AIRR = AIRT * 100.0D0

        PRINT*,'just after line 900'
```

```
C the standard deviation of internal rate of return

        IF (DIRV <= DIRE) GO TO 950
        SIG1 = (DIRV - DIRE) / 3.25D0
        SIR1 = 3.29D0 - (0.100D0 * (DELT/SIG1)**2)
        IF (SIR1 <= 3.08D0) GO TO 910
        SIGM1 = (DIRV - DIRE) / SIR1
        GO TO 920

 910    SIGM1 = (DIRV - DIRE) / 3.08D0

 920    SIRR = SIGM1 * 100.0D0
        GO TO 960

 950    SIRR = 0.0D0

 960    WRITE (7,970)
 970    FORMAT (/,'The Internal Rate of Return for the Project (%)')
        WRITE (7,980)
 980    FORMAT ('           Exp.Value===== S.Dev=========')
        WRITE (7,990) AIRR,SIRR
 990    FORMAT (10X,2F15.3)

        DIRD = DIRD * 100.0D0
        DIRE = DIRE * 100.0D0
        DIRF = DIRF * 100.0D0
        DIRG = DIRG * 100.0D0
        DIRM = DIRM * 100.0D0
        DIRT = DIRT * 100.0D0
        DIRU = DIRU * 100.0D0
        DIRV = DIRV * 100.0D0
        DIRW = DIRW * 100.0D0

      WRITE (7, 1100)
 1100 FORMAT (/,'Probable IRRs')

      WRITE (7, 1101) ' 2.5', DIRD
      WRITE (7, 1101) ' 5.0', DIRE
      WRITE (7, 1101) '10.0', DIRF
      WRITE (7, 1101) '25.0', DIRG
      WRITE (7, 1101) '50.0', DIRM
      WRITE (7, 1101) '75.0', DIRT
      WRITE (7, 1101) '90.0', DIRU
      WRITE (7, 1101) '95.0', DIRV
      WRITE (7, 1101) '97.5', DIRW
 1101 FORMAT (A4,'% =    ', F15.2)

      WRITE (20, 9910)
     +     DIRD,DIRE,DIRF,DIRG,DIRM,DIRT,DIRU,DIRV,DIRW


      PRINT*,'DIRD,DIRE,DIRF,DIRG,DIRM,DIRT,DIRU,DIRV,DIRW',
     +        DIRD,DIRE,DIRF,DIRG,DIRM,DIRT,DIRU,DIRV,DIRW

 9910 FORMAT (' Project IRR export for EXCEL',
     +        /,' ',F20.2,', 2.50',
     +        /,' ',F20.2,', 5.00',
```

```
     +         /,'  ',F20.2,',10.00',
     +         /,'  ',F20.2,',25.00',
     +         /,'  ',F20.2,',50.00',
     +         /,'  ',F20.2,',75.00',
     +         /,'  ',F20.2,',90.00',
     +         /,'  ',F20.2,',95.00',
     +         /,'  ',F20.2,',97.50')

 1200 DEALLOCATE (x, Z)
      CALL TRACE (2, 'PRJIRR', 'exiting.')
      RETURN
      END
```

```
C Varble.FOR
C modified by Toshiaki Hatakama in July, 1994.

C ROUTINE TO APPROXIMATE A VARIABLE TO A PEARSON TYPE
C DISTRIBUTION USING FIVE PERCENTILE ESTIMATES.

C PEARSN is the pearson table
C EST 1 thru 5 are the 5%ile estimates
C CALC 1 thru 4 are the result calculus entries

C this requires 2.5, 5.0, 50.0, 95.0, and 97.5 percentiles.


C=====================================================================
      SUBROUTINE VARBLE (PEARSN,
     +                   EST05, EST25, EST50, EST75, EST95,
     +                   CALC1, CALC2, CALC3, CALC4)
C=====================================================================

      IMPLICIT REAL*4(A-H,O-Z)
      INCLUDE 'DEBUG.CMN'
      REAL*4 PEARSN (NPEARS, *)
      REAL*4 SIGM1(600), SIGM2(600)

      DEL   = EST75 + EST25 - 2.0D0 * EST50
      CALC1 = EST50 + 0.185D0 * DEL

      SIG1  = (EST75 - EST25) / 3.25D0
      SIG2  = (EST95 - EST05) / 3.92D0
      IF (SIG1 .EQ. 0.0D0 .AND. SIG2 .EQ. 0.0D0) THEN

         CALC1 = EST50
         CALC2 = 0.0D0
         CALC3 = 0.0D0
         CALC4 = 0.0D0
         GOTO 9999
      ENDIF

      SIGM1(1) = 0.0D0
      SIGM2(1) = 0.0D0
      K = 2
      SIGM1(K) = SIG1

 50   IF (590 < K) GO TO 700

      XSIGM1 = SIGM1(K) - SIGM1(K-1)

      XCHEK1 = SIGM1(K-1) * 0.0001D0
      IF (DABS (XSIGM1) < DABS (XCHEK1)) GO TO 70

      K = K + 1


      S1 = 3.29D0 - 0.100D0 * (DEL/SIGM1(K-1))**2
```

```
      IF (3.08D0 < S1) THEN
         SIGM1(K) = (EST75 - EST25) / S1
      ELSE
         SIGM1(K) = (EST75 - EST25) / 3.08D0
      END IF

      GOTO 50
 70   CONTINUE

C -----------------------------------------------------------
C approximated standard deviation from 5% and 95% estimates
C -----------------------------------------------------------

      ASIGM1 = SIGM1(K)

      K = 2
      SIGM2(K) = SIG2

 80   IF (590 < K) GO TO 700
      XSIGM2 = SIGM2(K) - SIGM2(K-1)
      XCHEK2 = SIGM2(K-1) * 0.0001D0
      IF (DABS (XSIGM2) < DABS (XCHEK2)) GO TO 100

      K = K + 1
      S2 = 3.98D0 - 0.138D0 * (DEL/SIGM2(K-1))**2
      IF (3.66D0 < S2) THEN
         SIGM2(K) = (EST95 - EST05) / S2
      ELSE
         SIGM2(K) = (EST95 - EST05) / 3.66D0
      END IF
      GOTO 80

 100  CONTINUE
      ASIGM2 = SIGM2(K)

      IF (ASIGM1 < ASIGM2) GO TO 110
      SIGMAD = ASIGM1
      GO TO 120

 110  SIGMAD = ASIGM2

 120  CALC2 = SIGMAD ** 2

      XA     = (EST05 - CALC1) / SIGMAD
      XB     = (EST25 - CALC1) / SIGMAD
      XC     = (EST50 - CALC1) / SIGMAD
      XD     = (EST75 - CALC1) / SIGMAD
      XE     = (EST95 - CALC1) / SIGMAD

C Select best fit distribution

C compare standardised values to those of the pearson table
C to obtain the skewness and the kurtosis from an approximated
C pearson type distribution

      XX = 10.0
```

```
C       NP = 0

      DO 150 K = 1,2655

         SUMSQ =   (PEARSN (K, 4)  - XA ) ** 2 +
     +             (PEARSN (K, 5)  - XB ) ** 2 +
     +             (PEARSN (K, 8)  - XC ) ** 2 +
     +             (PEARSN (K,11)  - XD ) ** 2 +
     +             (PEARSN (K,12)  - XE ) ** 2

C if the square root of the sum of squared deviations is bigger than
10,
C or what we've seen previousely, don't save 'em.

         IF (SUMSQ < XX) THEN
            XX      = SUMSQ
C            NP      = K

            BET1    = PEARSN (K, 16)
            BET2    = PEARSN (K, 17)
         ENDIF

 150  CONTINUE

C       IF (0.01D0 < XX) GO TO 700

C 2.5% and 97.5% estimates

      CALC3 = BET1 * CALC2 ** 1.5
      CALC4 = BET2 * CALC2 ** 2


9999  RETURN

700   IERR = 1
      GOTO 9999

      END
```

```
C Trans.FOR
C modified by Toshiaki Hatakama in July, 1994.

C ROUTINE TO TRANSFORM A SET OF CORRELATED VARIABLES TO A SET OF
C UNCORRELATED VARIABLES USING THE CORRELATION MATRIX. THE
C APPROACH IS REFFERED TO AS THE VARIABLE TRANSFORMATION METHOD.
C THE FIRST FOUR MOMENTS OF THE TRANSFORMED VARIABLES ARE
C EVALUATED FROM THE FIRST FOUR MOMENTS OF THE PRIMARY VARIABLES

C calls INV, DECOMP, DGMULT

C=====================================================================
      SUBROUTINE TRANS (I, NM, NSIZE1, NSIZE2, CALC1, CALC2, COR,
     +                  TRI)
C=====================================================================

      IMPLICIT REAL*4 (A-H,O-Z)
      INCLUDE 'DEBUG.CMN'

      REAL*4 CALC1 (4, NSIZE1, *)
      REAL*4 CALC2 (4, NSIZE1, *)
      REAL*4 COR (NSIZE1, NSIZE2, *)
      REAL*4 TRI (NSIZE2, *)

      INTEGER IPERM (:)
      ALLOCATABLE IPERM

      REAL*4 SCOR (:)
      REAL*4 ADIG (:,:), ADIGI (:,:), TR (:,:), CORR (:)
      REAL*4 CORRL (:,:), CORLI (:,:)
      ALLOCATABLE SCOR, ADIG, ADIGI, TR, CORR, CORRL, CORLI

      CALL TRACE (3, 'TRANS', 'starting.')

      ALLOCATE (IPERM (NM))
      ALLOCATE (SCOR  (NM))
      ALLOCATE (ADIG  (NM, NM))
      ALLOCATE (ADIGI (NM, NM))
      ALLOCATE (TR    (NM, NM))
      ALLOCATE (CORR  (NM * NM))
      ALLOCATE (CORRL (NM, NM))
      ALLOCATE (CORLI (NM, NM))


      DRATIO = 1.0D-7

C diagonal matrix of the standard deviations

      DO 20 J=1,NM
         DO 20 K=1,NM
            IF (J == K) THEN
               ADIG(J,K) = CALC1(2,I,J)**0.5D0
            ELSE
               ADIG(J,K) = 0.0D0
            ENDIF
```

```
  20      CONTINUE

C correlation matrix as a 1-D array for Cholesky decomposition

      LLN = NM - 1
      DO 100 J=1,NM
         DO 90 K=1,NM
            L = (LLN * K) + J - LLN
                 IF (J <  K) THEN
                    CORR (L) = COR(I,K,J)
            ELSE IF (J == K) THEN
                    CORR (L) = 1.0D0
            ELSE
                    CORR (L) = 0.0D0
            ENDIF
  90     CONTINUE
 100  CONTINUE


C the inverse of the diagonal matrix of standard deviations

      CALL INV (NM, NM, ADIG, IPERM, NM, ADIGI, DDET, JEXP, DCOND)
      IF (DDET == 0) THEN
         WRITE (7, 9901) I
         GO TO 9999
      ENDIF

      CALL DECOMP (CORR, NM, NM, DRATIO)
      IF (DRATIO <= 0.0D0) THEN
         WRITE (7, 9902) I
         GO TO 9999
      ENDIF


C the lower traingular matrix from the Cholesky decomposition

      DO 200 J=1,NM
         DO 190 K=1,NM
            IF (J < K) GO TO 180
            L = (LLN*K) + J - LLN
            CORRL(J,K) = CORR(L)
            GO TO 190

 180        CORRL(J,K) = 0.0D0
 190     CONTINUE
 200  CONTINUE


C the inverse of the lower triangular matrix from C.D

      CALL INV (NM, NM, CORRL, IPERM, NM, CORLI, DDET,JEXP,DCOND)
      IF (DDET == 0) THEN
         WRITE(7,9903)I
         GO TO 9999
      ENDIF
```

```
C the transformation matrix

      CALL DGMULT (CORLI, ADIGI, TR, NM, NM, NM)


C the inverse of the transformation matrix
C NSIZE2 had better darn well be larger than NM

      CALL INV (NM, NM, TR, IPERM, NSIZE2, TRI, DDET, JEXP, DCOND)
      IF (DDET == 0) THEN
         WRITE (7, 9904) I
         GO TO 9999
      ENDIF


C MOMENTS OF THE TRANSFORMED UNCORRELATED VARIABLES
C Z = CALC1(1,
C Z : TRANSFORMED VARIABLES
C X : CORRELATED VARIABLES
C A : THE TRANSFORMATION MATRIX
C CALC2(1 : EXPECTED VALUE OF THE TRANSFORMED VARIABLES

      DO 340 J=1,NM
         CALC2(1,I,J) = 0.0D0
         DO 340 K=1,NM
 340        CALC2(1,I,J) = CALC2(1,I,J) + TR(J,K) * CALC1(1,I,K)


C CALC2(2, : SECOND CENTRAL MOMENT OF THE TRANSFORMED VARIABLES

      DO 401 J=1,NM
         SCOR (J) = 0.0D0
         DO 401 K=1,NM-1
            TEMP = TR (J, K)
            IF (TEMP .NE. 0.0D0) THEN
               DO 400 L=K+1,NM
 400              SCOR (J) = SCOR (J) + TEMP * TR (J, L) *
     +              COR (I, K, L) *
     +             (CALC1 (2, I, K) *
     +              CALC1 (2, I, L) ) ** 0.5D0
            ENDIF
 401  CONTINUE

      DO 450 J=1,NM
         CALC2(2,I,J) = 2.0D0 * SCOR(J)
         DO 450 K=1,NM
 450        CALC2(2,I,J) = CALC2(2,I,J) + TR(J,K)**2 * CALC1(2,I,K)


C CALC2(3, : THIRD CENTRAL MOMENT OF THE TRANSFORMED VARIABLES

      DO 500 J=1,NM
         CALC2(3,I,J) = 0.0D0
         DO 500 K=1,NM
 500        CALC2(3,I,J) = CALC2(3,I,J) + TR(J,K)**3 * CALC1(3,I,K)
```

```
C CALC2(4, : FOURTH CENTRAL MOMENT OF THE TRANSFORMED VARIABLES

      DO 600 J=1,NM
         CALC2(4,I,J) = 0.0D0
         DO 600 K=1,NM
 600        CALC2(4,I,J) = CALC2(4,I,J) + TR(J,K)**4 * CALC1(4,I,K)

 1000 CALL TRACE (3, 'TRANS', 'exiting.')
      DEALLOCATE (SCOR, ADIG, ADIGI, TR, CORR, CORRL, CORLI)
      RETURN

 9999 IERR = 1
      GOTO 1000

9901  FORMAT(/,'WP(',I5,'), MTX INV. FAILED.',/,/)
9902  FORMAT(/,'WP(',I5,'), CHOLESKY DECOMP. FAILED.',/,/)
9903  FORMAT(/,'WP(',I5,'), LOWER TRI MTX INV. FAILED.',/,/)
9904  FORMAT(/,'WP(',I5,'), TRNSF MTX INV. FAILED.',/,/)
      END
```

```
C WpDFF.FOR
C modified by Toshiaki Hatakama in July, 1994.

C Routine to check the type of functional form for work package
C duration and to estimate the function at the mean values of
C the transformed variables.

C==============================================================
      SUBROUTINE WPDFF(IFF,X,EVY)
C==============================================================

      IMPLICIT REAL*4(A-H,O-Z)
      INTEGER IFF
      REAL*4 EVY, X(*)

      GO TO (10,10,30,10,10),IFF

   10 EVY = X(1) / (X(2) * X(3))
      GO TO 100

   30 EVY = X(1) + (3000.0D0 / (X(2) * X(3)))
      GO TO 100

  100 RETURN
      END
```

```
C MmTwPl.FOR
C modified by Toshiaki Hatakama in July, 1994.
C 07mar94 MJW

C ROUTINE TO APPROXIMATE THE FIRST FOUR MOMENTS OF A DEPENDENT
C VARIABLE AT WORK PACKAGE/REVENUE STREAM LEVEL. IT USES THE
C MOMENTS OF THE TRANSFORMED VARIABLES WITH THE TRUNCATED
C SECOND ORDER TAYLOR SERIES EXPANSION OF THE FUNCTION.

C==================================================================
      SUBROUTINE MMTWPL (I,NN,NDIM,CALC1,GZ,PD1,PD2,CALC2,STFO)
C==================================================================

      IMPLICIT REAL*4(A-H,O-Z)
      INCLUDE 'DEBUG.CMN'

      REAL*4 CALC1 (4, NDIM, *), CALC2 (4, *)
      REAL*4 PD1 (*), PD2 (*)

      DOUBLE PRECISION TROUBL

      CALL TRACE (3, 'MMTWPL', 'starting.')


      CALC2 (1,I) = GZ      ! the expected value of the dependent
                            ! variable
      CALC2 (2,I) = 0.0D0
      CALC2 (3,I) = 0.0D0
      CALC2 (4,I) = 0.0D0

      STFO = 0.0D0

      DO 10 J=1,NN
         CALC2 (1,I) = CALC2 (1,I) + 0.5D0 * PD2 (J) * CALC1 (2,I,J)

C the second central moment of the dependent variable
C from the first order approximation

         STFO = STFO + PD1(J)**2 * CALC1(2,I,J)

C from the second order approximation

         CALC2(2,I) = CALC2(2,I) + PD1(J)**2 *
     +                  CALC1(2,I,J) + PD1(J) * PD2(J) *
     +                  CALC1(3,I,J) + 0.25D0 * PD2(J)**2 *
     +                 (CALC1(4,I,J) - CALC1(2,I,J)**2)

C the third central moment of the dependent variable

         CALC2(3,I) = CALC2(3,I) + PD1(J)**3 *
     +                  CALC1(3,I,J) + 1.5D0 * PD1(J)**2 * PD2(J) *
     +                 (CALC1(4,I,J) - CALC1(2,I,J)**2)

C the fourth central moment of the dependent variable
```

```
        TROUBL = PD1(J) ** 4 * CALC1 (4, I, J)
 10     CALC2(4,I) = CALC2(4,I) + TROUBL

      CALL TRACE (3, 'MMTWPL', 'exiting.')
      RETURN
      END
```

```
C CoVar.FOR
C modified by Toshiaki Hatakama in July 1994.

C ROUTINE TO APPROXIMATE THE CORRELATION BETWEEN TWO DEPENDENT
C VARIABLES USING CORRELATION INFORMATION BETWEEN THE PRIMARY
C VARIABLES AND THEIR PARTIAL DERAVATIVES.

C SX is a (4,NWP,*) array, we only access SX(2,I,*) & SX(2,J,*).

C======================================================================
      SUBROUTINE COVAR(JU,NDCV, I,J,NI,NJ,PX,SX,COR,STFOI,STFOJ,COC)
C======================================================================

      IMPLICIT REAL*4(A-H,O-Z)
      INCLUDE 'DEBUG.CMN'
      PARAMETER (JSZ=50,KSZ=25)

      REAL*4 PX (NWP, *),
     +        SX (4, NWP, *),
     +         COR (NWP, MAXDVC, *),
     +          COC (NWP, *)

      REAL*4 COV(JSZ,JSZ),CORR(JSZ,KSZ,KSZ)
      REAL*4 PD(JSZ,KSZ),SD(JSZ,KSZ)
      INTEGER MI(KSZ),MJ(KSZ)

C read the number of common variables in the functional forms
C for the dependent variables

      CALL TRACE (2, 'COVAR', 'starting.')

C read the combinations of common variables

      READ (JU, 30) (MI (K), MJ (K), K=1, NDCV)
  30  FORMAT(26(I2,I2))

C renumber the second central moment and the partial deravative
C of common variables in given order

      DO 50 K=1,NDCV
         MMI = MI(K)
         MMJ = MJ(K)
         PD(I,K)  = PX(I,MMI)
         SD(I,K)  = SX(2,I,MMI)
         PD(J,K)  = PX(J,MMJ)
         SD(J,K)  = SX(2,J,MMJ)

C the correlation coefficients between the common variables

         LL = K+1
         IF(LL.GT.NDCV) GO TO 50
         DO 40 L=LL,NDCV
            LLI = MI(L)
            LLJ = MJ(L)
            CORR(I,K,L)  = COR(I,MMI,LLI)
```

```
            CORR(I,L,K) = COR(I,LLI,MMI)
            CORR(J,K,L) = COR(J,MMJ,LLJ)
            CORR(J,L,K) = COR(J,LLJ,MMJ)
 40      CONTINUE
 50   CONTINUE

C renumber the second central moment and the partial deravative
C of the other variables in the functional forms

      LL = NDCV
      DO 80 K = 1,NI
         DO 70 L=1,NDCV
            MMI = MI(L)
            IF (K.EQ.MMI) GO TO 80
 70      CONTINUE

         LL = LL+1
         MI(LL) = K
         PD(I,LL) = PX(I,K)
         SD(I,LL) = SX(2,I,K)
 80   CONTINUE

      LL = NDCV
      DO 100 K = 1,NJ
         DO 90 L=1,NDCV
            MMJ = MJ(L)
            IF (K.EQ.MMJ) GO TO 100
 90      CONTINUE

         LL = LL+1
         MJ(LL) = K
         PD(J,LL) = PX(J,K)
         SD(J,LL) = SX(2,J,K)
100   CONTINUE

C the correlation between the common variables and the others.

      LL = NDCV+1
      DO 120 K=LL,NI
         MMK = MI(K)
         DO 110 L=1,NI
            MMI = MI(L)
            IF (MMI.EQ.MMK) GO TO 110
            CORR(I,K,L) = COR(I,MMK,MMI)
            CORR(I,L,K) = COR(I,MMI,MMK)
110      CONTINUE
120   CONTINUE

      LL = NDCV+1
      DO 150 K=LL,NJ
         MMK = MJ(K)
         DO 140 L=1,NJ
            MMJ = MJ(L)
            IF (MMJ.EQ.MMK) GO TO 140
            CORR(J,K,L) = COR(J,MMK,MMJ)
            CORR(J,L,K) = COR(J,MMJ,MMK)
140      CONTINUE
```

```
 150  CONTINUE

C covariance between two dependent variables I and J
C from the common variables in I and J

      COV(I,J) = 0.0D0
      DO 200 K=1,NDCV
         DO 200 L=1,NDCV
            IF (K.EQ.L) THEN
               CORR(I,K,L) = 1.0D0
               CORR(J,K,L) = 1.0D0
            ENDIF

 200        COV(I,J) = COV(I,J) + PD(I,K) * PD(J,L)
     +                 * (SD(I,K) * SD(J,L))**0.5D0 * CORR(I,K,L)

C from the common variables in I and others in J

      NNV = NDCV+1
      DO 240 K=1,NDCV
         DO 240 L=NNV,NJ
 240        COV(I,J) = COV(I,J) + PD(I,K) * PD(J,L)
     +                 * (SD(I,K) * SD(J,L))**0.5D0 * CORR(J,K,L)

C from the common variables in J and others in I

      NNV = NDCV+1
      DO 300 K=1,NDCV
         DO 300 L=NNV,NI
 300        COV(I,J) = COV(I,J) + PD(J,K) * PD(I,L)
     +                 * (SD(J,K) * SD(I,L))**0.5D0 * CORR(I,K,L)

C the correlation coefficient between two dependent variables

      COC(I,J) = COV(I,J) / ((STFOI * STFOJ)**0.5D0)
      COC(J,I) = COC(I,J)

  500 CONTINUE
      CALL TRACE (2, 'COVAR', 'exiting.')
      RETURN
      END
```

```
C NetWrk.FOR
C Toshiaki Hatakama in July. 1994.

C NOTHING preventing this from being called BEFORE EAST...
C ...directly from MAIN (AMMA).

C ROUTINE TO EVALUATE THE FIRST FOUR MOMENTS OF WORK PACKAGE.
C EARLY START TIME USING THE PNET ALGORITHM

C calls EARLY, CDFUNC, ESTMMT

C=====================================================================
      SUBROUTINE NETWRK (PEARSN, WPTIME, CORRD, ESTART, TRCOR)
C=====================================================================

      IMPLICIT REAL*4(A-H,O-Z)
      PARAMETER (JSZ=50)

      INCLUDE 'DEBUG.CMN'

      REAL*4 PEARSN (NPEARS, 17)
      REAL*4 WPTIME (4, NWP), CORRD (NWP, NWP)
      REAL*4 ESTART (4, NWP)
      INTEGER LIST (200, 40), LISREP (101, 40)
      CHARACTER*10 DESC (JSZ, 3)
      INTEGER WPNO (JSZ), NDEP (JSZ), PREWP (JSZ, 30)
      INTEGER SP, STACK (0:200), LIS (0:40), NTEMP (0:200)
      INTEGER LPP (200), LPPR (200), LISTR (200, 40)
      INTEGER LCOM (40), LPPS (200), LISTS (200, 40)
      INTEGER LPREP (200)

      REAL*4 CORTR (200, 200), SCOR (40)

      REAL*4 EVAL (200), SIGM (200), RVAL (200), RSIG (200)
      REAL*4 REVAL (200), RSIGM (200)
      REAL*4 SDTME (300), SKTME (300), AKTME (300)
      REAL*4 PTE (101,101)

      REAL*4 VA (300), VB (300), VC (300), VD (300), VE (300)
      REAL*4 VF (300)
      REAL*4 VG (300), VM (300), VT (300), VU (300), VV (300)
      REAL*4 VW (300)
      REAL*4 VX (300), VY (300), VZ (300)

      REAL*4 TM (101), PT (101)
      REAL*4 ED (JSZ), EE (JSZ), EG (JSZ),
     +       EM (JSZ),
     +       ET (JSZ), EV (JSZ), EW (JSZ)

      REAL*4 ETEMP (4, 101)

      CALL TRACE (1, 'NETWRK', 'starting.')

      ESTART (1, 1) = 0.0D0
      ESTART (2, 1) = 0.0D0
```

```
      ESTART (3, 1) = 0.0D0
      ESTART (4, 1) = 0.0D0

C read the input data from file at unit 10

      NDEP(1) = 0

C all the data about to be read in (except TRCOR) goes into temp
C vars.
C it never leaves this routine, at least not without being processed.
C WPNO & DESC are read in, then discarded like so much trash....
C TRCOR is returned to the calling routine.

      READ (10, 9901) TRCOR
      DO 11 INWP = 2, NWP
         READ (10, 9902) WPNO (INWP), NDEP (INWP),
     +                    (DESC (INWP, J), J = 1, 3)
   11    READ (10, 9903) (PREWP (INWP, J), J = 1, NDEP (INWP))

      J = WPNO(2) + ICHAR(DESC(2,1)(1:1))

C initialize the arrays (stack machine)

      DO 12 J = 0, 200
  12     STACK (J) = 0

      DO 13 J = 0, 20
  13     LIS   (J) = 0

      DO 14 J = 0, 100
  14     NTEMP (J) = 0

C the first four moments of Estart time from PNET
C set up the stack machine

      DO 990 INWP = 2, NWP
         SP = 0
         LP = 0
         LN = 0
         STACK (SP) = INWP
         LIS (LP) = INWP
         NTEMP (INWP) = NDEP (INWP)

C develop the stack with current W.P. and its predecessors

            DO 90 J = 1, NDEP (INWP)
               PRED = PREWP (INWP, J)
               SP = SP + 1
               STACK (SP) = PRED
  90           NTEMP (PRED) = NDEP (PRED)

C develop the lists of all the paths to the work packages

 100     IF (SP == 0) GO TO 200
         PRED = STACK (SP)
         IF (PRED == 1) GO TO 150
         IF (NTEMP (PRED) == 0) GO TO 180
```

```
        LP = LP + 1
        LIS (LP) = PRED

C predecessors of the predecessors are added to the stack

        DO 110 J = 1, NDEP (PRED)
           SP = SP + 1
           STACK (SP) = PREWP (PRED, J)
           PPRED = PREWP (PRED, J)
 110       NTEMP (PPRED) = NDEP (PPRED)

        GO TO 100

 150    LP = LP+1
        LN = LN+1
        LPP(LN) = LP
        LIS(LP) = PRED
        DO 160 J=1,LP
 160       LIST(LN,J) = LIS(J)

C remove the work package from the stack and list

 180    STACK(SP) = 0
        LIS(LP) = 0
        SP = SP - 1
        LP = LP - 1
        PRED = LIS (LP)
        NTEMP (PRED) = NTEMP (PRED) - 1
        GO TO 100

C check the number of paths to the work package

 200    IF (LN == 1) GO TO 950

C expected value and standard deviation for all paths

        DO 230 J=1,LN
           EVAL(J) = 0.0D0
           SIGM(J) = 0.0D0
           LP = LPP(J)-1
           DO 230 K=1,LP
              SCOR(K) = 0.0D0
              J1 = LIST(J,K)
              EVAL(J) = EVAL(J) + WPTIME (1, J1)
              MM = K+1
              IF (MM <= LP) THEN
                 DO 210 M=MM,LP
                    J2 = LIST(J,M)
 210                SCOR(K) = SCOR(K) + CORRD(J1,J2)
     +                 * (WPTIME (2, J1) * WPTIME (2, J2))**0.5D0
              ENDIF
 220          SIGM(J) = SIGM(J) + WPTIME (2, J1) + 2.0D0*SCOR(K)
 230    CONTINUE

C rearrange lists according to decreasing order of S.D

        MR = 0
```

```
 250      SMAX = 0.0D0
          MR = MR+1
          DO 260 J=1,LN
             IF (SMAX < SIGM (J)) THEN
                SMAX = SIGM (J)
                MO = J
             ENDIF
 260      CONTINUE

          IF (0.0D0 < SMAX) THEN
             RVAL (MR) = EVAL (MO)
             RSIG (MR) = SIGM (MO)
             LPPS (MR) = LPP  (MO) - 1
             LP = LPPS (MR)

             DO 280 K = 1, LP
 280            LISTS (MR, K) = LIST (MO, K)

             SIGM (MO) = 0.0D0
             GO TO 250
          ENDIF

C rearrange lists according to decreasing order of E.V.
C Son of BOGOSORT...

          MR = 0

 300      AMAX = 0.0D0
          MR = MR+1
          DO 310 J=1,LN
             IF (AMAX < RVAL(J)) THEN
                AMAX = RVAL(J)
                MO = J
             ENDIF
 310      CONTINUE

          IF (AMAX /= 0.0D0) THEN
             REVAL(MR) = RVAL(MO)
             RSIGM(MR) = RSIG(MO)
             LPPR(MR)  = LPPS(MO)
             LP = LPPR(MR)

             DO 330 K=1,LP
 330            LISTR(MR,K) = LISTS(MO,K)

             RVAL(MO) = 0.0D0
             GO TO 300
          ENDIF

C transition correlation coefficient between paths

          DO 390 J=1,LN
             LP = LPPR(J)
             KK = J+1
             IF (KK <= LN) THEN
                DO 385 K=KK,LN
```

```
                  MNO = 0
                  MP = LPPR(K)
                  DO 360 L=1,LP
                     J1 = LISTR(J,L)
                     DO 360 M=1,MP
                        J2 = LISTR(K,M)
                        IF (J1 == J2) THEN
                           MNO = MNO+1
                           LCOM(MNO) = J1
                        ENDIF
 360              CONTINUE
                  CORTR(J,K) = 0.0D0

C no common work packages in the two paths

                  IF (MNO /= 0) THEN
                     DO 380 L=1,MNO
                        J1 = LCOM(L)
 380                    CORTR(J,K) = CORTR(J,K) +
     + (WPTIME (2, J1) / ((RSIGM(J) * RSIGM(K))**0.5D0))
                  ENDIF
 385            CONTINUE
             ENDIF
 390      CONTINUE

C select the representative paths

 400      MREP = 0
          DO 450 J=1,LN
             IF (REVAL(J) /= 0.0D0) THEN
                MREP         = MREP+1
                LPREP(MREP)  = LPPR(J)
                LP           = LPREP(MREP)

                DO 420 K=1,LP
 420               LISREP(MREP,K) = LISTR(J,K)

                KK = J+1
                IF (KK <= LN) THEN
                   DO 430 K=KK,LN
                      IF (TRCOR <= CORTR(J,K)) REVAL(K) = 0.0D0
 430               CONTINUE
                ENDIF
             ENDIF
 450      CONTINUE

C if there is only one representative path, skip to line 900

          IF (MREP == 1) GO TO 900

C first four moments of a representative path

          SMAX = 0.0D0
          DO 500 J=1, MREP
             ETEMP (1, J) = 0.0D0
             ETEMP (2, J) = 0.0D0
             ETEMP (3, J) = 0.0D0
```

```
           ETEMP (4, J) = 0.0D0

           LN = J
           LP = LPREP(J)
           IF (LP <= 1) THEN

C only one work package on the path

              DO 470 K=1,LP
                 J1 = LISREP(LN,K)

                 ETEMP (1, J) = ETEMP (1, J) + WPTIME (1, J1)
                 ETEMP (2, J) = ETEMP (2, J) + WPTIME (2, J1)
                 ETEMP (3, J) = ETEMP (3, J) + WPTIME (3, J1)
 470             ETEMP (4, J) = ETEMP (4, J) + WPTIME (4, J1)
           ELSE

C multiple work packages on the path


              CALL EARLY (J, LN, LP, 2,
     +         WPTIME, CORRD,
     +         ETEMP,
     +         LIST, LISREP)
              IF (0 < IERR) GO TO 1000
           ENDIF

C standard deviation, skewness and kurtosis for the path

           SDTME (J) = ETEMP (2, J) ** 0.5D0
           SKTME (J) = ETEMP (3, J) / (ETEMP (2, J) ** 1.5D0)
           AKTME (J) = ETEMP (4, J) / (ETEMP (2, J) ** 2)

C values of the approximated pearson distribution


           CALL CDFUNC (PEARSN,
     +                    ETEMP (1, J), SDTME (J), SKTME (J), AKTME
(J),
     +                    VA(J),VB(J),VC(J),VD(J),VE(J),VF(J),VG(J),
     +                    VM(J),
     +                    VT(J),VU(J),VV(J),VW(J),VX(J),VY(J),VZ(J))

C maximum standard deviation for representative paths

           IF (SMAX < SDTME(J)) THEN
              SMAX = SDTME(J)
           ENDIF
 500    CONTINUE

C starting duration and incremental step for CDF of EST
C this is the only reference to an unindexed value of AETME.
C this means that AETME, SETME, TETME & FETME can probably be
C scrapped.

        TSTART = ETEMP (1, 1) - (3.0D0 * SMAX)
        TSTEP  = SMAX / 10.0D0
```

```
          DO WHILE (VA (1) < TSTART)
             TSTART = TSTART - TSTEP
          END DO

C duration cycle to develop the CDF for EST

          J=1

 530      JNUM = J
          JJ = J-1
          TM(J) = TSTART + (FLOAT(JJ)*TSTEP)

C probability of achieving the duration for each path
C FORTRAN doesn't know how to deal with a REAL*4 valued CASE
C statement
C so this is the closest that we can come. this could be re-written
C to use a table to pull out these two values....
C 0.0D0
C 0.0025D0, 0.0025D0
C 0.0050D0, 0.0050D0
C 0.0100D0, 0.0150D0
C 0.0250D0, 0.0250D0
C 0.0500D0, 0.0500D0
C 0.1000D0, 0.1500D0
C 0.2500D0, 0.2500D0
C 0.5000D0, 0.2500D0
C 0.7500D0, 0.1500D0
C 0.9000D0, 0.0500D0
C 0.9500D0, 0.0250D0
C 0.9750D0, 0.0150D0
C 0.9900D0, 0.0050D0
C 0.9950D0, 0.0025D0
C 1.0D0

          DO 700 K=1,MREP
             IF (TM(J) <= VA(K)) THEN
                PTE(J,K) = 0.0D0
       ELSE IF (VA(K) < TM(J) .AND. VB(K) >= TM(J)) THEN
                PTE(J,K) = 0.0025D0 +
     +                  ((TM(J) - VA(K)) * 0.0025D0 / (VB(K) - VA(K)))
       ELSE IF (VB(K) < TM(J) .AND. VC(K) >= TM(J)) THEN
                PTE(J,K) = 0.0050D0 +
     +                  ((TM(J) - VB(K)) * 0.0050D0 / (VC(K) - VB(K)))
       ELSE IF (VC(K) < TM(J) .AND. VD(K) >= TM(J)) THEN
                PTE(J,K) = 0.0100D0 +
     +                  ((TM(J) - VC(K)) * 0.0150D0 / (VD(K) - VC(K)))
       ELSE IF (VD(K) < TM(J) .AND. VE(K) >= TM(J)) THEN
                PTE(J,K) = 0.0250D0 +
     +                  ((TM(J) - VD(K)) * 0.0250D0 / (VE(K) - VD(K)))
       ELSE IF (VE(K) < TM(J) .AND. VF(K) >= TM(J)) THEN
                PTE(J,K) = 0.0500D0 +
     +                  ((TM(J) - VE(K)) * 0.0500D0 / (VF(K) - VE(K)))
       ELSE IF (VF(K) < TM(J) .AND. VG(K) >= TM(J)) THEN
                PTE(J,K) = 0.1000D0 +
     +                  ((TM(J) - VF(K)) * 0.1500D0 / (VG(K) - VF(K)))
       ELSE IF (VG(K) < TM(J) .AND. VM(K) >= TM(J)) THEN
```

```
               PTE(J,K) = 0.2500D0 +
     +                  ((TM(J) - VG(K)) * 0.2500D0 / (VM(K) - VG(K)))
          ELSE IF (VM(K) < TM(J) .AND. VT(K) >= TM(J)) THEN
               PTE(J,K) = 0.5000D0 +
     +                  ((TM(J) - VM(K)) * 0.2500D0 / (VT(K) - VM(K)))
          ELSE IF (VT(K) < TM(J) .AND. VU(K) >= TM(J)) THEN
               PTE(J,K) = 0.7500D0 +
     +                  ((TM(J) - VT(K)) * 0.1500D0 / (VU(K) - VT(K)))
          ELSE IF (VU(K) < TM(J) .AND. VV(K) >= TM(J)) THEN
               PTE(J,K) = 0.9000D0 +
     +                  ((TM(J) - VU(K)) * 0.0500D0 / (VV(K) - VU(K)))
          ELSE IF (VV(K) < TM(J) .AND. VW(K) >= TM(J)) THEN
               PTE(J,K) = 0.9500D0 +
     +                  ((TM(J) - VV(K)) * 0.0250D0 / (VW(K) - VV(K)))
          ELSE IF (VW(K) < TM(J) .AND. VX(K) >= TM(J)) THEN
               PTE(J,K) = 0.9750D0 +
     +                  ((TM(J) - VW(K)) * 0.0150D0 / (VX(K) - VW(K)))
          ELSE IF (VX(K) < TM(J) .AND. VY(K) >= TM(J)) THEN
               PTE(J,K) = 0.9900D0 +
     +                  ((TM(J) - VX(K)) * 0.0050D0 / (VY(K) - VX(K)))
          ELSE IF (VY(K) < TM(J) .AND. VZ(K) >= TM(J)) THEN
               PTE(J,K) = 0.9950D0 +
     +                  ((TM(J) - VY(K)) * 0.0025D0 / (VZ(K) - VY(K)))
          ELSE IF (VZ(K) < TM(J)) THEN
               PTE(J,K) = 1.0D0
             ENDIF
 700      CONTINUE

C cumulative probability of the duration being EST

          PT(J) = 1.0D0
          DO 710 K = 1,MREP
 710         PT(J) = PT(J)*PTE(J,K)

          IF (PT(J) < 1.0D0) THEN
             J=J+1
             GO TO 530
          ENDIF

C re-check this CAREFULLY with the original source to make sure that
C all the tests come out correctly.
C this is very messy. but I gather that it has a point.
C notice the interchanging of K & J throughout.
C fractile values of the CDF for work package EST

          DO 800 J = 2, JNUM
             K=J-1

             IF (PT(J) < 0.025D0) GOTO 800
             IF (PT(K) < 0.025D0 .AND. PT(J) >= 0.025D0) THEN
                ED (INWP) =
     +             TM(K)+(0.025D0-PT(K))*(TM(J)-TM(K))/(PT(J)-PT(K))
                IF (TM(J) >= 0.050D0) EE (INWP) =
     +             TM(K)+(0.050D0-PT(K))*(TM(J)-TM(K))/(PT(J)-PT(K))
             ENDIF

             IF (PT(J) < 0.050D0) GOTO 800
```

```
            IF (PT(K) < 0.050D0 .AND. PT(J) >= 0.050D0) THEN
               EE (INWP) =
     +            TM(K)+(0.050D0-PT(K))*(TM(J)-TM(K))/(PT(J)-PT(K))
               IF (TM(J) >= 0.250D0) EG (INWP) =
     +            TM(K)+(0.250D0-PT(K))*(TM(J)-TM(K))/(PT(J)-PT(K))
            ENDIF

            IF (PT(J) < 0.250D0) GOTO 800
            IF (PT(K) < 0.250D0 .AND. PT(J) >= 0.250D0) THEN
               EG (INWP) =
     +            TM(K)+(0.250D0-PT(K))*(TM(J)-TM(K))/(PT(J)-PT(K))
               IF (TM(J) >= 0.500D0) EM (INWP) =
     +            TM(K)+(0.500D0-PT(K))*(TM(J)-TM(K))/(PT(J)-PT(K))
            ENDIF

            IF (PT(J) < 0.500D0) GOTO 800
            IF (PT(K) < 0.500D0 .AND. PT(J) >= 0.500D0) THEN
               EM (INWP) =
     +            TM(K)+(0.500D0-PT(K))*(TM(J)-TM(K))/(PT(J)-PT(K))
               IF (TM(J) >= 0.750D0) ET (INWP) =
     +            TM(K)+(0.750D0-PT(K))*(TM(J)-TM(K))/(PT(J)-PT(K))
            ENDIF

            IF (PT(J) < 0.750D0) GOTO 800
            IF (PT(K) < 0.750D0 .AND. PT(J) >= 0.750D0) THEN
               ET (INWP) =
     +            TM(K)+(0.750D0-PT(K))*(TM(J)-TM(K))/(PT(J)-PT(K))
               IF (TM(J) >= 0.950D0) EV (INWP) =
     +            TM(K)+(0.950D0-PT(K))*(TM(J)-TM(K))/(PT(J)-PT(K))
            ENDIF

            IF (PT(J) < 0.950D0) GOTO 800
            IF (PT(K) < 0.950D0 .AND. PT(J) >= 0.950D0) THEN
               EV (INWP) =
     +            TM(K)+(0.950D0-PT(K))*(TM(J)-TM(K))/(PT(J)-PT(K))
               IF (TM(J) >= 0.975D0) EW (INWP) =
     +            TM(K)+(0.975D0-PT(K))*(TM(J)-TM(K))/(PT(J)-PT(K))
            ENDIF

            IF (PT(J) < 0.975D0) GOTO 800
            IF (PT(K) < 0.975D0 .AND. PT(J) >= 0.975D0) THEN
               EW (INWP) =
     +            TM(K)+(0.975D0-PT(K))*(TM(J)-TM(K))/(PT(J)-PT(K))
            ENDIF

 800     CONTINUE

C first four moments of work package Estart time

         CALL ESTMMT (INWP, PEARSN,
     +                ED,EE,EG,EM,ET,EV,EW,
     +                ESTART)

         GO TO 990

C when there is only one representative path
```

```
 900      LN = MREP
          LPP(LN) = LPREP(LN)+1
          LP = LPREP(LN)

          DO 920 K = 1, LP
 920         LIST(LN,K) = LISREP(LN,K)

C first four moments when only one PATH to the work package

 950      ESTART (1, INWP) = 0.0D0
          ESTART (2, INWP) = 0.0D0
          ESTART (3, INWP) = 0.0D0
          ESTART (4, INWP) = 0.0D0

          LP = LPP(LN)-1

C deal with the special case of only one WORK PACKAGE.

          IF (1 < LP) THEN
             CALL EARLY (INWP, 1, LP, 1,
     +                   WPTIME, CORRD,
     +                   ESTART,
     +                   LIST, LISREP)
             IF (0 < IERR) GO TO 1000
          ELSE
             DO 970 K=1,LP
                J1 = LIST(LN,K)
                ESTART (1, INWP) = ESTART (1, INWP) + WPTIME (1, J1)
                ESTART (2, INWP) = ESTART (2, INWP) + WPTIME (2, J1)
                ESTART (3, INWP) = ESTART (3, INWP) + WPTIME (3, J1)
 970            ESTART (4, INWP) = ESTART (4, INWP) + WPTIME (4, J1)
          ENDIF

 990  CONTINUE

1000  CALL TRACE (1, 'NETWRK', 'exiting.')
      RETURN

9901  FORMAT(F6.3)
9902  FORMAT(2I3,3A10)
9903  FORMAT(30I3)

      END
```

```
C WpCmmt.FOR
C modified by Toshiaki Hatakama in July, 1994

C ROUTINE TO EVALUATE THE FIRST FOUR MOMENTS OF THE WORK
C PACKAGE COST FOR DIFFERENT DISCOUNT RATES.

C=====================================================
      SUBROUTINE WPCMMT (I,DR,FRA,
     +                   NWPCF, NDVR,
     +                   XUCOST, TRIWPC,
     +                   COST, STFO)
C=====================================================

      IMPLICIT REAL*4(A-H,O-Z)
      INCLUDE 'DEBUG.CMN'

      INTEGER NWPCF (*), NDVR (*)
      REAL*4 XUCOST (4, NWP, *), TRIWPC (NWP, NWP, *)
      REAL*4 COST (4, *)

      REAL*4 X (:), Z (:), SZ (:), GZS (:), GZL (:)
      REAL*4 PWPC1 (:),PWPC2(:)
      ALLOCATABLE X, Z, SZ, GZS, GZL, PWPC1, PWPC2

      CALL TRACE (3, 'WPCMMT', 'starting.')

      NNVR = NDVR(I)

      ALLOCATE (X (NNVR))
      ALLOCATE (Z (NNVR))
      ALLOCATE (SZ (NNVR))
      ALLOCATE (GZS (NNVR))
      ALLOCATE (GZL (NNVR))
      ALLOCATE (PWPC1 (NNVR))
      ALLOCATE (PWPC2 (NNVR))

C estimate G(Z) from the g(X) given by the user at the mean
C values of Z (the transformed variables) and the partial
C deratives with respect to the transformed variables.

      DO 10 J=1,NNVR
  10     Z(J) = XUCOST (1, I, J)

      DO 20 J=1,NNVR
         X(J) = 0.0D0
         DO 20 K=1,NNVR
  20        X(J) = X(J) + TRIWPC(I,J,K) * Z(K)

C the value of G(Z) at the mean values of Z

      CALL WPCFF (NWPCF (I), DR, FRA, X, GZ)


C the partial deravatives of the transformed variables
```

```
      DO 100 J=1,NNVR
         Z(J)  = XUCOST (1, I, J) * 0.99D0
         SZ(J) = XUCOST (1, I, J) * 0.01D0
         DO 50 K=1,NNVR
            X(K) = 0.0D0
            DO 50 L=1,NNVR
  50           X(K) = X(K) + TRIWPC(I,K,L) * Z(L)

C the value for G(Z) when Z(J) is less than the mean value
C (negative increment)


         CALL WPCFF (NWPCF (I), DR, FRA, X, GZS (J))

         Z(J)  = XUCOST (1, I, J) * 1.01D0
         DO 60 K=1,NNVR
            X(K) = 0.0D0
            DO 60 L=1,NNVR
  60           X(K) = X(K) + TRIWPC(I,K,L) * Z(L)

C the value for G(Z) when Z(J) is more than the mean value
C (positive increment)



         CALL WPCFF (NWPCF (I), DR, FRA, X, GZL (J))

C the first partial deravative with respect to Z(J)

         PWPC1(J) = (GZL(J) - GZS(J)) / (2.0D0 * SZ(J))

C the second partial deravative with respect to Z(J)

         PWPC2(J) = (GZL(J)+GZS(J)-2.0D0*GZ) / (SZ(J)**2)
         Z(J) = XUCOST (1, I, J)


C         PRINT*,'I,J,PWPC2,XUCOST (2, I, J)=',I,J,PWPC2(J),
C     +                                         XUCOST (2, I, J)


  100 CONTINUE

C the first four moments for the work package cost


      CALL MMTWPL (I,NNVR,
     +             NWP, XUCOST,
     +             GZ,PWPC1,PWPC2,
     +             COST, STFO)


      DEALLOCATE (X, Z, SZ, GZS, GZL, PWPC1, PWPC2)
      CALL TRACE (3, 'WPCMMT', 'exiting.')
      RETURN
      END
```

```
C WpCff.FOR
C modified by Toshiaki Hatakama in July, 1994.

C Routine to check the type of functional form for work package
C cost and to estimate the function at the mean values of the
C transformed variables.

C==============================================================
      SUBROUTINE WPCFF (IFF, DR, FRA, X, EVY)
C==============================================================

      IMPLICIT REAL*4(A-H,O-Z)
      INTEGER IFF
      REAL*4 EVY, X (*)
      REAL*4 Z (5), AZ (5)

      EVY = 0.0D0
      GO TO (100,200,200,200,200,200,200,200,900,1000,1100),IFF

C Type 1 functional form
  100 Z(1) = X(13)-DR
      IF (DABS(Z(1)).GT.0.001D0) GO TO 110
      AZ(1) = X(1)
      GO TO 120

  110 AZ(1) = (DEXP(Z(1)*X(2)) - DEXP(Z(1)*(X(2)-X(1)))) / Z(1)

  120 Z(2) = X(14)-DR
      IF (DABS(Z(2)).GT.0.001D0) GO TO 130
      AZ(2) = X(1)
      GO TO 140

  130 AZ(2) = (DEXP(Z(2)*X(2)) - DEXP(Z(2)*(X(2)-X(1)))) / Z(2)

  140 Z(3) = X(15)-DR
      IF (DABS(Z(3)).GT.0.001D0) GO TO 150
      AZ(3) = X(1)
      GO TO 160

  150 AZ(3) = (DEXP(Z(3)*X(2)) - DEXP(Z(3)*(X(2)-X(1)))) / Z(3)

  160 Z(4) = X(16)-DR
      IF (DABS(Z(4)).GT.0.001D0) GO TO 170
      AZ(4) = X(1)
      GO TO 180

  170 AZ(4) = (DEXP(Z(4)*X(2)) - DEXP(Z(4)*(X(2)-X(1)))) / Z(4)

  180 Z(5) = X(17)-DR
      IF (DABS(Z(5)).GT.0.001D0) GO TO 190
      AZ(5) = X(1)
      GO TO 191

  190 AZ(5) = (DEXP(Z(5)*X(2)) - DEXP(Z(5)*(X(2)-X(1)))) / Z(5)
```

```
  191 Y1 =   X(9) * X(5) * AZ(1)  + X(10) * X(4) * X(5) * AZ(2)
     +       + X(11) * X(6) * AZ(3) + (X(7)/X(1)) * AZ(4)
     +       + X(8) * AZ(5)

      Y2 =   X(9) * X(5) * (DEXP((X(13)-X(12))*X(2))
     +      - DEXP((X(13)-X(12))*(X(2)-X(1)))) / (X(13) - X(12))
     +       + X(10) * X(4) * X(5) * (DEXP((X(14)-X(12))*X(2))
     +      - DEXP((X(14)-X(12))*(X(2)-X(1)))) / (X(14) - X(12))
     +       + X(11) * X(6) * (DEXP((X(15)-X(12))*X(2))
     +      - DEXP((X(15)-X(12))*(X(2)-X(1)))) / (X(15) - X(12))
     +       + (X(7)/X(1)) * (DEXP((X(16)-X(12))*X(2))
     +      - DEXP((X(16)-X(12))*(X(2)-X(1)))) / (X(16) - X(12))
     +       + X(8) * (DEXP((X(17)-X(12))*X(2))
     +      - DEXP((X(17)-X(12))*(X(2)-X(1)))) / (X(17) - X(12))

      EVY = FRA * Y1 + (1-FRA) * DEXP((X(12)-DR)*X(3)) * Y2
      GO TO 9999

C Type 2, 3, 4, 5, 6, 7, and 8 functional forms.
  200 EVY = X(1) / (X(2) * X(3))
      GO TO 9999

C Type 9 functional form, just constant dollar cost
  900 EVY = X(4)
      GO TO 9999

C Type 10 functional form.
 1000 Z(1) = X(6)-DR
      IF (0.001D0 < DABS (Z (1))) GO TO 1010
      AZ(1) = X(1)
      GO TO 1020

 1010 AZ(1) = (DEXP(Z(1)*X(2)) - DEXP(Z(1)*(X(2)-X(1)))) / Z(1)

 1020 Y1 =   (X(4)/X(1)) * AZ(1)
      Y2 =   (X(4)/X(1)) * (DEXP(X(6)*(X(2)-X(1))+(X(6)-X(5))*X(1))
     C       - DEXP(X(6)*(X(2)-X(1)))) / (X(6) - X(5))

      EVY = FRA * Y1 + (1-FRA) * DEXP((X(5)-DR)*X(3)) * Y2
      GO TO 9999


C Type 11 functional form (toll highway).

 1100 Z(1) = X(7)-DR
      IF (DABS(Z(1)).GT.0.001D0) GO TO 1110
      AZ(1) = X(1)
      GO TO 1120

 1110 AZ(1) = (DEXP(Z(1)*X(2)) - DEXP(Z(1)*(X(2)-X(1)))) / Z(1)

 1120 Z(2) = X(7)-X(6)
      IF (DABS(Z(2)).GT.0.001D0) GO TO 1130

      AZ(2) = (DEXP(X(7)*(X(2)-X(1))+X(6)*X(3)))*X(1)
     +          /(DEXP(-X(6)*X(4))-1)
      GO TO 1140
```

```
1130 AZ(2) = (DEXP(X(7)*(X(2)-X(1))+X(6)*(X(3)-(X(2)-X(1)))))
    +         *(DEXP((X(7)-X(6))*X(1))-1)
    +         /(DEXP(-X(6)*X(4))-1)/(X(7)-X(6))

1140 IF (DABS(DR).GT.0.001D0) GO TO 1150
     AZ(3) = X(4)
     GO TO 1160

1150 AZ(3) = (DEXP(-DR*(X(3)+X(4)))-DEXP(-DR*X(3)))/DR

1160 Y1 =   (X(5)/X(1)) * AZ(1)
     Y2 =   X(6)*(X(5)/X(1)) * AZ(2) * AZ(3)
     EVY = FRA * Y1 + (1-FRA) *  Y2

9999 RETURN
     END
```

```
C RvsMMT.FOR
C modified by Toshiaki Hatakama in July, 1994.

C ROUTINE TO EVALUATE THE FIRST FOUR MOMENTS OF THE REVENUE
C STREAMS FOR DIFFERENT DISCOUNT RATES.

C DR is passed unchanged thru to RVSFF.
C pass X, our beloved carrier variable, to RVSMMT as well.
C let RVSF11 & 12 take their parameters from there.
C everyone else is doing it.... EXCEPT PRJIRR!
C all values in X beyond NNVR are not modified by this routine.
C NNVR is NDRV(I), the maximum value of which is MAXDV...

C calls RVSFF, MMTWPL
C called by REVSTR, PRJIRR

C==================================================================
      SUBROUTINE RVSMMT (I, DR, BOTTLE,
     +                   NRVSF, NDRV,
     +                   XUREV, TRIRVS,
     +                   REV,
     +                   STFO)
C==================================================================

C if you have 16M Ram   enough =  1
C if not                       =\ 1

$DEFINE enough = 0

      INCLUDE 'DEBUG.CMN'
      IMPLICIT REAL*4(A-H,O-Z)

      INTEGER NRVSF (*), NDRV (*)
      REAL*4 XUREV (4, NRS, *)

$IF enough .EQ. 1
      REAL*4 TRIRVS (NRS, MAXDVR, *)
$ELSE
      REAL*4 TRIRVS (*), TEMPRVS (:,:)
      ALLOCATABLE TEMPRVS
$ENDIF

      REAL*4 REV (4, *), BOTTLE (NRS, *)
      REAL*4 X (:), Z (:), PRVS1 (:), PRVS2 (:)
      ALLOCATABLE X, Z, PRVS1, PRVS2

      CALL TRACE (3, 'RVSMMT', 'starting.')

      NNVR = NDRV (I)

      ALLOCATE (X (NNVR))
      ALLOCATE (Z (NNVR))
      ALLOCATE (PRVS1 (NNVR))
      ALLOCATE (PRVS2 (NNVR))
```

```
$IF enough .NE. 1
      ALLOCATE (TEMPRVS (NNVR, NNVR))
$ENDIF

C estimate G(Z) from the g(X) given by the user at the mean
C values of Z (the transformed variables) and the partial
C deratives with respect to the transformed variables.

      DO 10 J = 1, NNVR
         Z (J) = XUREV (1, I, J)
  10  CONTINUE


      DO 20 J = 1, NNVR
         X (J) = 0.0D0
         DO 20 K = 1, NNVR

$IF enough .EQ. 1
            X (J) = X (J) + TRIRVS (I, J, K) * Z (K)
$ELSE
            TEMPRVS (J, K) = SPA_GET3 (TRIRVS, I, J, K)
            X (J) = X (J) + TEMPRVS (J, K) * Z (K)
$ENDIF

  20  CONTINUE


      PRINT *, 'shakin tree #', I
      CALL RVSFF (NRVSF (I), 0, 2, DR, BOTTLE, I, X, GZ)  ! G(Z) at
meanVal of Z(J)

      PRINT*,'mean value finished'

      DO 100 J = 1, NNVR
         SZ = XUREV (1, I, J) * 0.01D0



         Z (J)  = XUREV (1, I, J) * 0.99D0  ! G(Z) when Z(J) <
                                            ! meanVal
         DO 50 K = 1, NNVR
            X (K) = 0.0D0
            DO 50 L = 1, NNVR

$IF enough .EQ. 1
               X (K) = X (K) + TRIRVS (I, K, L) * Z (L)
$ELSE
               X (K) = X (K) + TEMPRVS (K, L) * Z (L)
$ENDIF

  50     CONTINUE
         CALL RVSFF (NRVSF (I), J, 1, DR, BOTTLE, I, X, GZS)



         Z (J)  = XUREV (1, I, J) * 1.01D0  ! G(Z) when Z(J) >
                                            ! meanVal
```

```
          DO 70 K = 1, NNVR
             X (K) = 0.0D0
             DO 70 L = 1, NNVR

$IF enough .EQ. 1
                X (K) = X (K) + TRIRVS (I, K, L) * Z (L)
$ELSE
                X (K) = X (K) + TEMPRVS (K, L) * Z (L)
$ENDIF

  70      CONTINUE
          CALL RVSFF (NRVSF (I), J, 3, DR, BOTTLE, I, X, GZL)

C the first and second partial deravative with respect to Z(J)


          PRVS1 (J) = (GZL - GZS) / (2.0D0 * SZ)
          PRVS2 (J) = (GZL + GZS - 2.0D0 * GZ) / (SZ ** 2)
          Z     (J) = XUREV (1, I, J)

        SENSITIVE = PRVS1 (J) * Z (J) / GZ
        WRITE (121, *) 'Sensitivity coefficient1 for',J,'=',SENSITIVE
        DY = sensitive * 0.02
        WRITE (122, *) 'Sensitivity coefficient2 for',J,'=',DY

 100  CONTINUE

C the first four moments for the revenue stream

      CALL MMTWPL (I, NNVR, NRS, XUREV, GZ, PRVS1, PRVS2, REV, STFO)

      DEALLOCATE (X, Z, PRVS1, PRVS2)

$IF enough .NE. 1
      DEALLOCATE (TEMPRVS)
$ENDIF

      CALL TRACE (3, 'RVSMMT', 'exiting.')
      RETURN
      END
```

```
C RvSff.for
C modified by Toshiaki Hatakama in July, 1994.

C Routine to check the type of functional form for revenue
C streams and to estimate the function at the mean values of
C the transformed variables.

C includes calls to RVSF11, RVSF12
C called by RVSMMT

C==================================================================
      SUBROUTINE RVSFF (IFF, KP, KT, DR, BOTTLE, I, X, EVY)
C==================================================================

      IMPLICIT REAL*4(A-H,O-Z)
      INCLUDE 'DEBUG.CMN'

      REAL*4 X (*), BOTTLE (NRS, *)
      REAL*4 Z (5), AZ (5)

      GO TO
     + (100,200,200,200,200,200,200,200,200,1000,1100,1200,1300),
     +      IFF

C Type 1 functional form.

  100 Z (1) = X (5) - DR
      IF (0.001D0 < DABS (Z (1))) THEN
         AZ (1) =
     +         ( DEXP (Z (1) * X (4) - DR * X (1))
     +         - DEXP (               - DR * X (1)) ) / Z(1)
      ELSE
         AZ (1) = X (4)
      ENDIF

      Z (2) = X (6) - DR
      IF (0.001D0 < DABS (Z (2))) THEN
         AZ (2) =
     +         ( DEXP (Z (2) * (X (1) + X (4)))
     +         - DEXP (Z (2) *  X (1)          ) ) / Z(2)
      ELSE
         AZ (2) = X(4)
      ENDIF

      EVY = (X (2) * AZ (1)) - (X (3) * AZ (2))
      GO TO 9999


C Type 2, 3, 4, 5, 6, 7, 8, and 9 functional forms

  200 EVY = X(1) / (X(2) * X(3))
      GO TO 9999


C Type 10 functional form
```

```
 1000 Z(1) = X(5)-DR
      IF (DABS(Z(1)).GT.0.001D0) GO TO 1010
      AZ(1) = X(4)
      GO TO 1020

 1010 AZ(1) = (DEXP(Z(1)*(X(1)+X(4))) - DEXP(Z(1)*X(1))) / Z(1)

 1020 Z(2) = X(6)-DR
      IF (DABS(Z(2)).GT.0.001D0) GO TO 1030
      AZ(2) = X(4)
      GO TO 1040

 1030 AZ(2) = (DEXP(Z(2)*(X(1)+X(4))) - DEXP(Z(2)*X(1))) / Z(2)

 1040 EVY = (X(2) * AZ(1)) - (X(3) * AZ(2))
      GO TO 9999


C Type 11 functional form (Closed Toll Highway)

 1100 CALL RVSF11 (KP, KT, DR, BOTTLE, I, X, EVY)
      GOTO 9999

C Type 12 functional form ('Open' Toll Highway)

 1200 CALL RVSF12 (KP, KT, DR, BOTTLE, I, X, EVY)
      GOTO 9999

C Type 13 functional form ('Closed' Toll Highway: fixed toll)

 1300 CALL RVSF13 (KP, KT, DR, BOTTLE, I, X, EVY)
      GOTO 9999

 9999 RETURN
      END

      INCLUDE 'RVSF11.INC'
      INCLUDE 'RVSF12.INC'
      INCLUDE 'RVSF13.INC'
```

```
C TanSp.FOR
C modified by Toshiaki Hatakama in July, 1994.

C ROUTINE TO TRANSFORM CORRELATED WORK PACKAGE COSTS OR REVENUE
C STREAMS TO UNCORRELATED WORK PACKAGE COSTS / REVENUE STREAMS.

C this should take some sort of an offset into X to reduce the work
C of copying arrays that are slightly non-standard into tempVars...

C=====================================================================
      SUBROUTINE TANSP (NM,
     +                  X,
     +                  Z,
     +                  COR,
     +                  TRI)
C=====================================================================

      IMPLICIT REAL*4(A-H,O-Z)
      INCLUDE 'DEBUG.CMN'

      REAL*4 X (4, *)
      REAL*4 Z (4, *)
      REAL*4 COR (NM, NM)
      REAL*4 TRI (NM, NM)
      INTEGER IPERM (300) ! just in case this is used on MAXDVR vars.
      REAL*4 SCOR (:), CORR (:)
      REAL*4 ADIG (:,:), ADIGI (:,:)
      REAL*4 TR (:,:)
      REAL*4 CORRL (:,:), CORLI (:,:)

      ALLOCATABLE SCOR, CORR, ADIG, ADIGI, TR, CORRL, CORLI

      CALL TRACE (3, 'TANSP', 'starting.')

      ALLOCATE (SCOR  (NM))
      ALLOCATE (CORR  (NM * NM))
      ALLOCATE (ADIG  (NM, NM))
      ALLOCATE (ADIGI (NM, NM))
      ALLOCATE (TR    (NM, NM))
      ALLOCATE (CORRL (NM, NM))
      ALLOCATE (CORLI (NM, NM))

      DRATIO = 1.0D-7

C diagonal matrix of the standard deviations

      DO 10 J=1, NM
         DO 10 K=1, NM
            IF (J == K) THEN
               ADIG (J, K) = X (2, J) ** 0.5D0
            ELSE
               ADIG (J, K) = 0.0D0
            ENDIF
   10 CONTINUE
```

```
C correlation matrix as a 1-D array for Cholesky decomposition

   40 LL = NM * NM

      DO 50 J = 1, LL
   50    CORR (J) = 0.0D0

      LLN = NM - 1
      DO 100 J = 1, NM
         DO 90 K = 1, NM
            IF (J <= K) GO TO 60

            L = (LLN * K) + J - LLN
            CORR (L) = COR (K, J)
            GO TO 90

   60       IF (J < K) GO TO 90
            L = (LLN * K) + J - LLN
            CORR(L) = 1.0D0
   90    CONTINUE
  100 CONTINUE

C the inverse of the diagonal matrix of standard deviations


      CALL INV (NM, NM, ADIG, IPERM, NM, ADIGI, DDET, JEXP, DCOND)
      IF (DDET == 0.0D0) THEN
         WRITE (7, 9901)
         IERR = 1
         GO TO 1000
      ENDIF

C Cholesky decomposition of the correlation matrix


      CALL DECOMP (CORR, NM, NM, DRATIO)
      IF (DRATIO <= 0.0D0) THEN
         DO 160 J = 1, NM
            KK = J + 1
            IF (KK <= NM) THEN
            DO 150 K = KK, NM
               COR (J, K) = 0.0D0
  150          COR (K, J) = 0.0D0
            ENDIF
  160    CONTINUE
         GO TO 40
      ENDIF

C the lower triangular matrix from the Cholesky decomposition

      DO 200 J = 1, NM
         DO 200 K = 1, NM
            IF (J < K) THEN
               CORRL (J, K) = 0.0D0
            ELSE
               L = (LLN * K) + J - LLN
               CORRL (J, K) = CORR (L)
```

```
            ENDIF
  200 CONTINUE

C the inverse of the lower triangular matrix from the decomposition


      CALL INV (NM, NM, CORRL, IPERM, NM, CORLI, DDET,JEXP,DCOND)
      IF (DDET == 0.0D0) THEN
         WRITE (7, 9902)
         IERR = 1
         GO TO 1000
      ENDIF

C the transformation matrix


      CALL DGMULT (CORLI, ADIGI, TR, NM, NM, NM)

C the inverse of the transformation matrix


      CALL INV (NM, NM, TR, IPERM, NM, TRI, DDET,JEXP,DCOND)
      IF (DDET == 0.0D0) THEN
         WRITE (7, 9903)
         IERR = 1
         GO TO 1000
      ENDIF

C moments of the transformed W.P costs / revenue st : Z = X (1, K)
C Z : transformed W.P.C/R.S
C X : correlated W.P.C/R.S
C A : the transformation matrix
C Z : expected value of the transformed W.P.cost or rev. str.

      DO 300 J = 1, NM
         Z (1, J) = 0.0D0
         DO 300 K = 1, NM
  300       Z (1, J) = Z (1, J) + TR (J, K) * X (1, K)

C Z (2, : second central moment of the transformed W.P.C or R.S

      DO 400 J = 1, NM
         SCOR (J) = 0.0D0
         DO 400 K = 1, NM
            KK = K + 1
            IF (KK <= NM) THEN
               DO 390 L = KK, NM
  390             SCOR (J) = SCOR (J) + TR (J, K) * TR (J, L) *
     +                          COR (K, L) *
     +                          (X (2, K) * X (2, L)) ** 0.5D0
            ENDIF
  400 CONTINUE

      DO 410 J=1,NM
         Z (2, J) = 2.0D0 * SCOR (J)
         DO 410 K=1,NM
  410       Z (2, J) = Z (2, J) + TR (J, K) ** 2 * X (2, K)
```

```
C Z (3, : third central moment of the transformed W.P.C or R.S

      DO 500 J=1,NM
         Z (3, J) = 0.0D0
         DO 500 K=1,NM
  500       Z (3, J) = Z (3, J) + TR (J, K) ** 3 * X (3, K)

C Z (4, : fourth central moment of the transformed W.P.C or R.S

      DO 600 J=1,NM
         Z (4, J) = 0.0D0
         DO 600 K=1,NM
  600       Z (4, J) = Z (4, J) + TR (J, K) ** 4 * X (4, K)

 1000 DEALLOCATE (SCOR, CORR, ADIG, ADIGI, TR, CORRL, CORLI)
      CALL TRACE (3, 'TANSP', 'exiting.')
      RETURN

 9901 FORMAT(/,'INVERSION OF DIAG. MTX OF STD. DEV. FAILED.',//)
 9902 FORMAT(/,'INVERSION OF LOWER TRIANGULAR MTX FAILED.',//)
 9903 FORMAT(/,'INVERSION OF THE TRANSFORMATION MTX FAILED.',//)
      END
```

```
C CdFunc.FOR
C modified by Toshiaki Hatakama in July 1994


C ROUTINE TO OBTAIN VALUES OF THE CUMULATIVE DISTRIBUTION
C FUNCTION OF A DEPENDENT VARIABLE APPROXIMATED BY A PEARSON
C TYPE DISTRIBUTION.

C=================================================================
      SUBROUTINE CDFUNC (PEARSN,
     +                   AM,SD,SK,AK,
     +                   VA,VB,VC,VD,VE,VF,VG,
     +                   VM,
     +                   VT,VU,VV,VW,VX,VY,VZ)
C=================================================================

      IMPLICIT REAL*4(A-H,O-Z)
      INCLUDE 'DEBUG.CMN'
      REAL*4 PEARSN (NPEARS,*)

      CALL TRACE (3, 'CDFUNC', 'starting.')

C select the pearson distribution that best approximates the
C shape characteristics of the dependent variable.
C the beta2 values for the lower bound of beta1

      DO 40 PINDEX = 1,NPEARS
         YS = SK - PEARSN (PINDEX, 16)
         YK = AK - PEARSN (PINDEX, 17)
         IF (0.0D0 <= YS .AND. YS < 0.1D0) THEN
            IF (0.0D0 <= YK .AND. YK < 0.1D0) GO TO 50
         ENDIF
  40  CONTINUE
      GO TO 200

C lower bound of beta1 fits a pearson type distribution

  50  RSKW = YS
      RKRT = YK

C is the lower bound of beta1 the last value

      YCHK = PEARSN (PINDEX + 1, 16) - PEARSN (PINDEX, 16)
      IF (0.0001D0 < YCHK) GO TO 200
      IY1 = PINDEX
      IY2 = PINDEX + 1

C the beta2 values for the upper bound of the beta1

      DO 90 PINDEX = 1,NPEARS
         ZS = PEARSN (PINDEX,16) - SK
         ZK = AK - PEARSN (PINDEX,17)
         IF (0.0D0 <= ZS .AND. ZS < 0.1D0) THEN
            IF (0.0D0 <= ZK .AND. ZK < 0.1D0) GO TO 100
```

```
         ENDIF
   90   CONTINUE
        GO TO 200

C upper bound of beta1 fits a pearson type distribution
C redo with arrays, then this becomes a simple loop

C is the upper bound of beta1 the last value

100     ZCHK = PEARSN (PINDEX+1, 16) - PEARSN (PINDEX, 16)
        IF (0.0001D0 < ZCHK) GO TO 200
        IZ1 = PINDEX
        IZ2 = PINDEX + 1

C interpolate the percentage points and evaluate values of the
C cumulative distribution function of the dependent variable.

C redo with arrays, then this becomes a simple loop.

Call IntPol (Pearsn,RSKW,RKRT,IY1,IY2,IZ1,IZ2,<n>,SD,AM,V<n>)

        CALL INTPOL (PEARSN,RSKW,RKRT,IY1,IY2,IZ1,IZ2, 1,SD,AM,VA)
        CALL INTPOL (PEARSN,RSKW,RKRT,IY1,IY2,IZ1,IZ2, 2,SD,AM,VB)
        CALL INTPOL (PEARSN,RSKW,RKRT,IY1,IY2,IZ1,IZ2, 3,SD,AM,VC)
        CALL INTPOL (PEARSN,RSKW,RKRT,IY1,IY2,IZ1,IZ2, 4,SD,AM,VD)
        CALL INTPOL (PEARSN,RSKW,RKRT,IY1,IY2,IZ1,IZ2, 5,SD,AM,VE)
        CALL INTPOL (PEARSN,RSKW,RKRT,IY1,IY2,IZ1,IZ2, 6,SD,AM,VF)
        CALL INTPOL (PEARSN,RSKW,RKRT,IY1,IY2,IZ1,IZ2, 7,SD,AM,VG)
        CALL INTPOL (PEARSN,RSKW,RKRT,IY1,IY2,IZ1,IZ2, 8,SD,AM,VM)
        CALL INTPOL (PEARSN,RSKW,RKRT,IY1,IY2,IZ1,IZ2, 9,SD,AM,VT)
        CALL INTPOL (PEARSN,RSKW,RKRT,IY1,IY2,IZ1,IZ2,10,SD,AM,VU)
        CALL INTPOL (PEARSN,RSKW,RKRT,IY1,IY2,IZ1,IZ2,11,SD,AM,VV)
        CALL INTPOL (PEARSN,RSKW,RKRT,IY1,IY2,IZ1,IZ2,12,SD,AM,VW)
        CALL INTPOL (PEARSN,RSKW,RKRT,IY1,IY2,IZ1,IZ2,13,SD,AM,VX)
        CALL INTPOL (PEARSN,RSKW,RKRT,IY1,IY2,IZ1,IZ2,14,SD,AM,VY)
        CALL INTPOL (PEARSN,RSKW,RKRT,IY1,IY2,IZ1,IZ2,15,SD,AM,VZ)

        GO TO 300

C the normal distribution is used as the default distribution

 200    VA  =  AM - (2.8070D0 * SD)
        VB  =  AM - (2.5758D0 * SD)
        VC  =  AM - (2.3263D0 * SD)
        VD  =  AM - (1.9600D0 * SD)
        VE  =  AM - (1.6449D0 * SD)
        VF  =  AM - (1.2816D0 * SD)
        VG  =  AM - (0.6745D0 * SD)
        VM  =  AM
        VT  =  AM + (0.6745D0 * SD)
        VU  =  AM + (1.2816D0 * SD)
        VV  =  AM + (1.6449D0 * SD)
        VW  =  AM + (1.9600D0 * SD)
        VX  =  AM + (2.3263D0 * SD)
        VY  =  AM + (2.5758D0 * SD)
        VZ  =  AM + (2.8070D0 * SD)
```

```
300   CALL TRACE (3, 'CDFUNC', 'exiting.')
      RETURN
      END

      INCLUDE 'INTPOL.INC'
```

```
C Inv.MJW
C modified by Toshiaki Hatakama in July, 1994.

C this optimized version tests for the special case of a diagonal
C matrix.
C A can be as large as it likes, we only access up to [N,N]...

C=================================================================
      SUBROUTINE INV (N, NDIMT, T1, IP, NDIMA, A, DET, IEXP, COND)
C=================================================================

      IMPLICIT REAL*4 (A-H,O-Z)
      REAL*4 A (NDIMA, NDIMA), T1 (NDIMT, NDIMT)
      INTEGER IP (*)

C copy T1[N,N] into A

      DET = 1.D0
      IEXP = 0
      COND = 0.0D0

      ISDIAG = 1
      DO 30 J=1,N
       DO 30 I=1,N
         A (I, J) = T1 (I, J)

         IF (I == J .AND. A (I, J) == 0.0D0) THEN
            ISDIAG = 0
         ELSE
            IF (I .NE. J .AND. A (I, J) .NE. 0.0D0) THEN
             ISDIAG = 0
            ENDIF
         ENDIF

   30 CONTINUE

      IF (N == 1) GO TO 1991
      IF (ISDIAG == 1) GOTO 1993


C first part of Cond

      CSUMA=0.D0
      DO 45 J=1,N
       DO 45 I=1,N
   45       CSUMA = CSUMA + A(I,J) ** 2

C inversion starts

      DO 199 K=1,N

C find maximum element in K*th column
      AMAX=DABS(A(K,K))
      IMAX=K
```

```
      IF(K.EQ.N) GO TO 65
   50    KP=K+1
      DO 60 I=KP,N
         AIK=DABS(A(I,K))
         IF (AIK.LE.AMAX) GO TO 60
   55       AMAX=AIK
         IMAX=I
   60    CONTINUE

C test for singularity

   65    IF (AMAX == 0.D0) GO TO 300

C interchange rows K and IMAX

      IP (K) = IMAX
      IF (K.EQ.IMAX) GO TO 100
      DET=-DET

C compute the determinant, and scale as appropriate.

  100    DET = DET * A (IMAX, K)

      IF (1.0D15 < DABS (DET)) THEN
         DET = DET * 1.0D-15
         IEXP = IEXP + 15
      ENDIF

      IF (DABS (DET) < 1.0D-15) THEN
         DET = DET * 1.0D15
         IEXP = IEXP - 15
      ENDIF

C divide K*th row by A(K,K)

  750    T=1./A(IMAX,K)
      A(IMAX,K)=A(K,K)
      A(K,K)=-1.0D0

      DO 1999 I=1,N
         A(I,K)=-A(I,K)*T
 1999       CONTINUE

      DO 144 J=1,N
         IF (J == K) GO TO 144
C interchange rows K and IMAX
         TEMP=A(IMAX,J)
         IF (K.EQ.IMAX) GO TO 140
         A(IMAX,J)=A(K,J)
   75       A(K,J)=TEMP

C divide K*th row by A(K,K)

  140       A(K,J)=TEMP*T

C subtract A(I,K) times K*th row from other rows
```

```
         DO 109 I = 1, N
            IF (I .NE. K) THEN
            A (I, J) = A (I, J) + TEMP * A (I, K)
            ENDIF
  109       CONTINUE
  144    CONTINUE
  199 CONTINUE

C restore proper column order in the inverse

      NM1=N-1
      DO 250 KK=1,NM1

C column now in K*th position actually column......

      K=N-KK
  210    J=IP(K)

C ... of the inverse. Therefore......

      IF (J == K) GO TO 250

C relocate column K to position J

  220    DO 225 I=1,N
          T=A(I,J)
          A(I,J)=A(I,K)
          A(I,K)=T
  225    CONTINUE
  250 CONTINUE


C calculate COND

  260 CSUMB = 0.0D0
      DO 270 J = 1, N
      DO 270 I = 1, N
  270        CSUMB = CSUMB + A (I, J) ** 2

  275 COND = DSQRT (CSUMA * CSUMB) / FLOAT (N)
      RETURN

C procedure for singular or nearly singular matrix.

  300 WRITE(6,310) K,AMAX
  310 FORMAT (1H0,'STEP',I3,' PIVOT =',D18.8,', is singular?')
      DET=0.0D0
      IEXP=0
      COND=0.0D0
      RETURN

C *** CODE FOR ORDER 1
 1991 IF (A (1, 1) == 0.0D0) GO TO 1992
      DET=A(1,1)
      A(1,1)=1.D0/A(1,1)
      COND=1.0D0
      RETURN
```

```
 1992 K=1
      AMAX=0.0D0
      GO TO 300


C the INV of a DIAGonal matrix is trivial... I think...

 1993 SUMA = 0.0D0
      SUMB = 0.0D0

      DO 1994 J = 1, N
       A (J, J) = 1.0D0 / T1 (J, J)
       DET = DET * T1 (J, J)
       SUMA = SUMA + T1 (J, J) ** 2
       SUMB = SUMB + A  (J, J) ** 2

       IF (1.D15 < DABS (DET)) THEN
          DET = DET * 1.0D-15
          IEXP = IEXP + 15
       ENDIF

       IF (DABS (DET) < 1.0D-15) THEN
          DET = DET * 1.0D15
          IEXP = IEXP - 15
       ENDIF
 1994 CONTINUE

      COND = DSQRT (SUMA * SUMB) / FLOAT (N)
      RETURN
      END
```

```
C Decomp.FOR
C modified by Toshiaki Hatakama in July, 1994.

C THIS ROUTINE DECOMPOSES A TO A=L*LTRANSPOSE VIA CHOLESKI METHOD.

C=================================================================
      SUBROUTINE DECOMP (A, N, M, RATIO)
C=================================================================

      IMPLICIT REAL*4 (A-H,O-Z)
      REAL*4 A(*)

      CALL TRACE (3, 'DECOMP', 'starting.')

      MM=M-1
      NM=N*M
      NM1=NM-MM

 3001 MP=M+1

C transformation of A.
C A is transformed into a lower triangular matrix L such that A=L.LT
C (LT=transpose of L.).
C error return taken if RATIO<1.E-7
C
      KK=2
      NCN=0
      DET=1.D0
      FAC=RATIO
      BIGL=DSQRT(A(1))
      SML=BIGL

      IF (M == 1) GO TO 101
      IF (0.0D0 < A(1)) GO TO 15

      NROW=1
      RATIO=A(1)
      GO TO 60
15    DET=A(1)
      A(1)=SML
      A(2)=A(2)/A(1)
      TEMP=A(MP)-A(2)*A(2)
      IF (TEMP <= 0.0D0) RATIO=TEMP
      IF (0.0D0 < TEMP) GO TO 21

      NROW=2
      GO TO 60

101   DO 102 I=1,N
      TEMP=A(I)
      DET=TEMP*DET

      IF (TEMP <= 0.0D0) GO TO 104
      IF (DET < 1.D15) GO TO 1144
```

```
      DET=DET*1.D-15
      NCN=NCN+15
      GO TO 1145

1144     IF (1.0D-15 < DET) GO TO 1145
      DET=DET*1.D15
      NCN=NCN-15

1145     CONTINUE
      A(I)=DSQRT(TEMP)
      IF (BIGL < A(I)) BIGL=A(I)
      IF (A(I) < SML) SML=A(I)
102   CONTINUE

      GO TO 52

104   RATIO=TEMP
103   NROW=I
      GO TO 60

21    A(MP)=DSQRT(TEMP)
      DET=DET*TEMP
      IF (BIGL < A(MP)) BIGL=A(MP)
      IF (A(MP) < SML) SML=A(MP)
      IF (N == 2) GO TO 52

      MP=MP+M
      DO 62 J=MP,NM1,M
      JP=J-MM
      MZC=0
      IF(M <= KK) GO TO 1

      KK=KK+1
      II=1
      JC=1
      GO TO 2

1     KK=KK+M
      II=KK-MM
      JC=KK-MM

2     DO 65 I=KK,JP,MM
      IF (A(I) == 0.0D0) GO TO 64
      GO TO 66
64       JC=JC+M
65       MZC=MZC+1

      ASUM1=0.D0
      GO TO 61
66    MMZC=MM*MZC
      II=II+MZC
      KM=KK+MMZC
      A(KM)=A(KM)/A(JC)

      IF(JP <= KM) GO TO 6
      KJ=KM+MM
      DO 5 I=KJ,JP,MM
```

```
       ASUM2=0.D0
       IM=I-MM
       II=II+1
       KI=II+MMZC
       DO 7 K=KM,IM,MM
          ASUM2=ASUM2+A(KI)*A(K)
7            KI=KI+MM

5         A(I)=(A(I)-ASUM2)/A(KI)

6      ASUM1=0.D0
       DO 4 K=KM,JP,MM
4         ASUM1=ASUM1+A(K)*A(K)

61     S=A(J)-ASUM1
       IF (S < 0.0D0) RATIO=S
       IF (0.D0 < S) GO TO 63

       NROW=(J+MM)/M
       GO TO 60

   63 A(J)=DSQRT(S)
      DET=DET*S
      IF (1.D-15 < DET) GO TO 144
      DET=DET*1.D+15
      NCN=NCN-15
      GO TO 145

  144 IF (DET < 1.D+15) GO TO 145
      DET=DET*1.D-15
      NCN=NCN+15

  145 CONTINUE

      IF (BIGL < A(J)) BIGL=A(J)
      IF (A(J) < SML) SML=A(J)
   62 CONTINUE

   52 IF (SML <= FAC*BIGL) GO TO 54
      GO TO 53

   54 RATIO=0.D0
      GOTO 1000

   60 PRINT *, "System is NOT POSITIVE DEFINITE in row", NROW
      GOTO 1000

   53 RATIO=SML/BIGL
 1000 CALL TRACE (3, 'DECOMP', 'exiting.')
      RETURN
      END
```

```
C DgMMJW.FOR
C modified by Toshiaki Hatakama in July, 1994.

C==============================================================
      SUBROUTINE DGMULT (A, B, C, IAROWS, IBROWS, IBCOLS)
C==============================================================

      REAL*4 A (IAROWS, IBROWS)
      REAL*4 B (IBROWS, IBCOLS)
      REAL*4 C (IAROWS, IBCOLS)
      INTEGER I, J, K, IA0, IB0

      IA0 = 0 ! this will contain the number of zero entries in A
      DO 2 I = 1, IAROWS
       DO 1 K = 1, IBROWS
          IF (A (I, K) == 0.0D0) IA0 = IA0 + 1
    1    CONTINUE

       DO 2 J = 1, IBCOLS
          C (I, J) = 0.0D0
    2 CONTINUE

      IB0 = 0 ! this will contain the number of zero entries in B
      DO 3 J = 1, IBCOLS
       DO 3 K = 1, IBROWS
          IF (B (K, J) == 0.0D0) IB0 = IB0 + 1
    3 CONTINUE


C we have a decision to make. which order should we do the calcs in?
C it is possible (probable) that it won't make any difference, but it
C could.
C so, which path will result in the most savings...?

      IF ((IB0 * IAROWS) <= (IA0 * IBCOLS)) THEN

C there are more (or just as many) zero-product-reductions in A.

      DO 5 I = 1, IAROWS
         DO 5 K = 1, IBROWS
            TEMP = A (I, K)
            IF (TEMP .NE. 0.0D0) THEN
            DO 4 J = 1, IBCOLS
    4                C (I, J) = C (I, J) + (TEMP * B (K, J) )
            ENDIF
    5    CONTINUE
      ELSE

C there are more zero-product-reductions in B, so use that way in
C stead.

      DO 7 J = 1, IBCOLS
         DO 7 K = 1, IBROWS
            TEMP = B (K, J)
            IF (TEMP .NE. 0.0D0) THEN
```

```
              DO 6 I = 1, IARROWS
6                   C (I, J) = C (I, J) + (A (I, K) * TEMP )
              ENDIF
7         CONTINUE
      ENDIF

      RETURN
      END
```

```
C Early.FOR
C modified by Toshiaki Hatakama in July, 1994.


C ROUTINE TO EVALUATE THE FIRST FOUR MOMENTS OF A PATH EARLY
C START TIME BY UNCORRELATING THE WORK PACKAGE DURATIONS.
C
C 'Suggested' enhancement. redo the defs of LIST & LISREP so that
C they can be passed interchangeably to EARLY, then forget LID,
C cause then it's useless. It's only function is to choose between
C the two.  That's it.  If one is used, the other is ignored.

C==============================================================
      SUBROUTINE EARLY (J,
     +  LN,
     +  LP,
     +  LID,            ! choose between LIST or LISREP
     +  WPTIME, CORRD,
     +  ESTART,
     +  LIST, LISREP)   ! two tables with similar information....
C===============================================================

      IMPLICIT REAL*4(A-H,O-Z)
      INCLUDE 'DEBUG.CMN'

      INTEGER LN, LP, LID
      REAL*4 WPTIME (4, *), CORRD (NWP, *)
      REAL*4 ESTART (4, *)
      INTEGER LIST (200, 40), LISREP (101, 40)

      REAL*4 COR (:,:), TRI (:,:), PD (:), X (:,:), Z (:,:)
      ALLOCATABLE COR, TRI, PD, X, Z

      CALL TRACE (3, 'EARLY', 'starting.')

      ALLOCATE (COR (LP, LP), TRI (LP, LP), PD (LP))
      ALLOCATE (X (4, LP), Z (4, LP))

      DO 32 K = 1, LP
         DO 31 L = 1, 4
 31         Z (L, K) = 0.0D0
         DO 32 L = 1, LP
            IF (K == L) THEN
               COR (K, K) = 1.0D0
            ELSE
               COR (L, K) = 0.0D0
            ENDIF
 32         TRI (L, K) = 0.0D0

      DO 120 K = 1, LP
         IF (LID == 1) THEN
            J1 = LIST   (LN, K)
         ELSE
            J1 = LISREP (LN, K)
         ENDIF
```

```
         X (1, K) = WPTIME (1, J1)
         X (2, K) = WPTIME (2, J1)
         X (3, K) = WPTIME (3, J1)
         X (4, K) = WPTIME (4, J1)

         MM = K + 1
         IF (MM <= LP) THEN
            DO 110 M = MM,LP
               IF (LID == 1) THEN
                  J2 = LIST   (LN, M)
               ELSE
                  J2 = LISREP (LN, M)
               ENDIF

               COR (K, M) = CORRD (J1, J2)
               COR (M, K) = COR (K, M)
 110        CONTINUE
         ENDIF
 120  CONTINUE

C transform correlated W.P. durations to uncorrelated durations

      CALL TANSP (LP, X, Z, COR,TRI)
      IF (0 < IERR) GOTO 500

C first partial deravatives of the transformed W.P durations.

      DO 150 K = 1, LP
         PD (K) = 0.0D0
         DO 150 M = 1, LP
 150        PD (K) = PD (K) + TRI (M, K)

C first four moments of a path early start time

      DO 190 K = 1, LP
         ESTART (1, J) = ESTART (1, J) + PD (K)      * Z (1, K)
         ESTART (2, J) = ESTART (2, J) + PD (K) ** 2 * Z (2, K)
         ESTART (3, J) = ESTART (3, J) + PD (K) ** 3 * Z (3, K)

         FC = 0.0D0
         MM = K + 1

         IF (MM <= LP) THEN
            DO 180 M = MM, LP
 180           FC = FC + 6.0D0 * (PD   (K) * PD   (M)) ** 2 *
     +                           Z (2, K) * Z (2, M)
         ENDIF

 190     ESTART (4, J) = ESTART (4, J) + FC + PD (K) ** 4 * Z (4, K)

 500  DEALLOCATE (TRI, COR, PD, X, Z)
      CALL TRACE (3, 'EARLY', 'exiting.')
      RETURN

      END
```

```
C EstMMT.FOR
C modified by Toshiaki Hatakama in July, 1994.


C ROUTINE TO APPROXIMATE THE FIRST FOUR MOMENTS FOR EARLY START
C TIME WHEN THE MODIFIED PNET ALGORITHM IS USED.

C=====================================================================
      SUBROUTINE ESTMMT(JPV, PEARSN,
     +                  D,E,G,M,T,V,W,
     +                  ESTART)
C=====================================================================

      IMPLICIT REAL*4(A-H,O-Z)
      INCLUDE 'DEBUG.CMN'

      REAL*4 PEARSN (NPEARS, *)
      REAL*4 D(*), E(*), G(*), M(*), T(*), V(*), W(*)
      REAL*4 ESTART (4,*)

C expected value of early start time

      CALL TRACE (3, 'ESTMMT', 'starting')

      DEL             = V (JPV) + E (JPV) - 2.0D0 * M (JPV)
      ESTART (1, JPV) = M (JPV) + 0.185D0 * DEL

C standard deviation of elements V & E
C parameters 3.25D0, 0.0001D0, 3.29D0, 0.100D0, 3.08D0

      K = 2
      SIGML = 0.0D0
      SIGM1 = (V (JPV) - E (JPV)) / 3.25D0

50    IF (590 < K) GO TO 9999

      XSIGM1 = SIGM1 - SIGML
      XCHEK1 = SIGML * 0.0001D0
      IF (DABS(XSIGM1) < DABS(XCHEK1)) GOTO 70

      K = K+1
      SIGML = SIGM1
      SIGM1 = (V (JPV) - E (JPV)) /
     +        DMAX1 (3.29D0 - 0.100D0 * (DEL / SIGML) ** 2, 3.08D0)
      GO TO 50

70    ASIGM1 = SIGM1

C standard deviation of elements W & D
C parameters 3.92D0, 0.0001D0, 3.98D0, 0.138D0, 3.66D0

      K = 2
      SIGML = 0.0D0
      SIGM2 = (W (JPV) - D (JPV)) / 3.92D0
```

```
80    IF (590 < K) GO TO 9999
      XSIGM2 = SIGM2 - SIGML
      XCHEK2 = SIGML * 0.0001D0
      IF (DABS (XSIGM2) < DABS (XCHEK2)) GO TO 100

      K = K+1
      SIGML = SIGM2
      SIGM2 = (W (JPV) - D (JPV)) /
     +         DMAX1 (3.98D0 - 0.138D0 * (DEL / SIGML) ** 2, 3.66D0)
      GO TO 80

100   ASIGM2 = SIGM2


C OK, which SD is greater???

      SIGMAD = DMAX1 (ASIGM1, ASIGM2)

C use that one to scale the vector for the pearson comparison

      ESTART (2, JPV)   = SIGMAD ** 2

      X4     = (D (JPV) - ESTART (1, JPV)) / SIGMAD
      X5     = (E (JPV) - ESTART (1, JPV)) / SIGMAD

      X7     = (G (JPV) - ESTART (1, JPV)) / SIGMAD
      X8     = (M (JPV) - ESTART (1, JPV)) / SIGMAD
      X9     = (T (JPV) - ESTART (1, JPV)) / SIGMAD

      X11    = (V (JPV) - ESTART (1, JPV)) / SIGMAD
      X12    = (W (JPV) - ESTART (1, JPV)) / SIGMAD


C compare standardized values to those from the pearson table

      RLOW = 10.0
      DO 150 K = 1, NPEARS
         SUMSQR = ( (PEARSN (K, 4) - X4 ) ** 2
     +            + (PEARSN (K, 5) - X5 ) ** 2
     +            + (PEARSN (K, 7) - X7 ) ** 2
     +            + (PEARSN (K, 8) - X8 ) ** 2
     +            + (PEARSN (K, 9) - X9 ) ** 2
     +            + (PEARSN (K,11) - X11) ** 2
     +            + (PEARSN (K,12) - X12) ** 2) ! ** 0.5

         IF (SUMSQR < RLOW) THEN
            RLOW  = SUMSQR
            BETA1  = PEARSN (K, 16)
            BETA2  = PEARSN (K, 17)
         ENDIF
150   CONTINUE

      IF (0.0225D0 < RLOW) GO TO 9999

C third and fourth moments for work package EST
```

```
      ESTART (3, JPV) = BETA1 * (ESTART (2, JPV) ** 1.5)
      ESTART (4, JPV) = BETA2 * (ESTART (2, JPV) ** 2)

  250 CONTINUE
      CALL TRACE (3, 'ESTMMT', 'exiting.')
      RETURN

C default to a normal distribution

9999  ESTART (3, JPV) = 0.0D0
      ESTART (4, JPV) = 3.0D0 * (ESTART (2, JPV) ** 2)
      GO TO 250

      END
```

```
C RvSf11.INC
C 07mar94 MJW rationalization of the functions
C
C Closed System (Manual Collection)
C we ask nicely for the money from the motorist!
C

      SUBROUTINE RVSF11 (KP, KT, DR, BOTTLE, I, X, Y)
      IMPLICIT REAL*4(A-H,O-Z)
      INCLUDE 'DEBUG.CMN'

      REAL*4 BOTTLE (NRS, *), X (*)

      REAL*4 Y,AY,AZ,BZ,Z
      REAL*4 mcbp1(50),mcoll(50),ots(50)
      REAL*4 ooo(50),oom(50),reve(50)
      REAL*4 tcmt(50),tccc(50),tccm(50),brco(50),obo(50),ho(50)
      REAL*4 maint(50),oper(50),aoper(50)
      REAL*4 X1(200),X2(200)
      REAL*4 cost (:,:,:,:), traf (:,:,:,:)
      REAL*4 tcc (:,:), tcm (:,:), cts (:,:)
      ALLOCATABLE cost, traf, tcc, tcm, cts

C ------------------------------------------------------------------
--

C      CALL TRACE (2, 'RVSF11', 'starting.')

      nAL = BOTTLE (I, 1)
      nP  = BOTTLE (I, 2)
      nWC = BOTTLE (I, 3)
      nOL = BOTTLE (I, 4)
      nBR = BOTTLE (I, 5)

      rIBY    = X (1)
      IRD     = NINT (X (2))

      ALLOCATE (cost (IRD, nAL, nAL, nP))
      ALLOCATE (traf (IRD, nAL, nAL, nP))
      ALLOCATE (tcc  (IRD, nAL))
      ALLOCATE (tcm  (IRD, nAL))
      ALLOCATE (cts  (IRD, nAL))

      DISC1   = X (3)
      RATE1   = X (4)

      DISC2   = X (5)
      RATE2   = X (6)

      perKM   = X (7)
      entFee  = X (8)

      DO 90 II=1,IRD
         DO 90 J=1,nAL-1
            travld = 0
```

```
            DO 90 K=J+1,nAL
               travld = travld + X(7+K)
               break1 = 0
               break2 = 0
               IF (DISC1 < travld) THEN
                  break1 = travld - DISC1
                  travld = DISC1
               ENDIF
               IF (DISC2 < (travld + break1)) THEN
                  break2 = (travld + break1) - DISC2
                  break1 = (DISC2 - DISC1)
               ENDIF

               DO 90 L=1,nP
 90               cost(II,J,K,L)
     +            = ((travld + (break1 * RATE1) + (break2 * RATE2))
     +            * perKM * X(7+nAL+L) + entFee) * X(7+nAL+nP+II)


      CALL TRACE (3, 'RVSF11', 'traffic volume calculation.')

      DO 1150 II=1,IRD
         M=0
         DO 1150 J=1,nAL-1
            DO 1150 K=J+1,nAL
               DO 1150 L=1,nP
                  M=M+1
1150              traf (II,J,K,L)=
     +                X(7+nAL+nP+ 2 * IRD+M ) *
     +                X(7+nAL+nP+     IRD+II) /
     +                X(8+nAL+nP+     IRD   )

      CALL TRACE (3, 'RVSF11', 'annual toll revenue...')

      DO 1470 II=1,IRD
         reve (II) = 0.00
         DO 1470 J=1,nAL
            DO 1470 K=J+1,nAL
               DO 1470 L=1,nP
1470              reve (II) = reve (I) +
     +             traf (II,J,K,L)*cost (II,J,K,L)*365


      L1 = 7 + nAL + nP + 2*IRD + nAL*(nAL-1)/2*nP

      CALL TRACE (3, 'RVSF11', 'fixed costs...')

      mcrc = ! road cleaning costs
     +  X(L1+13)*(X(L1+1) + X(L1+4) + X(L1+7)) + X(L1+14)*(X(L1+2) +
     +  X(L1+5) + X(L1+8) + X(L1+3) + X(L1+6) + X(L1+9))

      mcrm = ! road maintenance
     +  X(L1+15)*X(L1+7) + X(L1+16)*X(L1+8) + X(L1+17)*X(L1+9)

      mcl  = ! lighting
     +  X(L1+18)*(X(L1+1) + X(L1+7)) +
     +  X(L1+19)*( (X(L1+2) + X(L1+3)) + (X(L1+8) + X(L1+9)))
```

```
      mcbr = ! bridge repair
     +  X(L1+20)*X(L1+1) + X(L1+21)*X(L1+2) + X(L1+22)*X(L1+3)

      mcbp = ! bridge painting
     +  X(L1+23)*X(L1+1) + X(L1+24)*X(L1+2) + X(L1+25)*X(L1+3)

      mctm = ! tunnel maintenance
     +  X(L1+10)*X(L1+26) + X(L1+11)*X(L1+27) + X(L1+12)*X(L1+28)


      SELECT CASE (nWC) ! snow and ice control based on nWC
      CASE (1)
      mcsc =
     +  X(L1+29)*( (X(L1+1) + X(L1+4) + X(L1+7))
     +          +2*(X(L1+2) + X(L1+5) + X(L1+8))
     +          +3*(X(L1+3) + X(L1+6) + X(L1+9)) )
      CASE (2)
      mcsc =
     +  X(L1+30)*( (X(L1+1) + X(L1+4) + X(L1+7))
     +          +2*(X(L1+2) + X(L1+5) + X(L1+8))
     +          +3*(X(L1+3) + X(L1+6) + X(L1+9)) )
      CASE DEFAULT
      mcsc = 0.00
      END SELECT


      mcol = ! overlay
     +  X(L1+31)*( X(L1+1) + X(L1+4) + X(L1+7) ) +
     +  X(L1+32)*( X(L1+2) + X(L1+5) + X(L1+8) ) +
     +  X(L1+33)*( X(L1+3) + X(L1+6) + X(L1+9) )

      mcot = X (L1 + 34) * (mcrc + mcrm + mcl + mcbr + mctm + mcsc)

      DO 2295 II=1,IRD
         IF (II.EQ.nBR .OR. II.EQ.(nBR+7) .OR. II.EQ.(nBR+14)
     +       .OR. II.EQ.(nBR+21) .OR. II.EQ.(nBR+28) .OR.
     +       II.EQ.(nBR+35) .OR. II.EQ.(nBR+42) .OR.
     +       II.EQ.(nBR+49)) THEN
            mcbp1(II) = mcbp
         ELSE
            mcbp1(II) = 0.00
         END IF
         IF (II.EQ.nOL .OR. II.EQ.(nOL+12) .OR. II.EQ.(nOL+24)
     +       .OR. II.EQ.(nOL+36) .OR. II.EQ.(nOL+48)) THEN
            mcol1(II) = mcol
         ELSE
            mcol1(II) = 0.00
         END IF
 2295 CONTINUE

C OPERATION COSTS

      CALL TRACE (3, 'RVSF11', 'operation costs...')

C-------------------------------
C Operation office overhead
```

```
C------------------------------

      DO 2500 II=1,IRD
         M=0
         X2(II) = X(7+nAL+nP+IRD+II)
         X00 = 7+nAL+nP+IRD+II
         DO 2500 J=1,nAL-1
            DO 2500 K=J+1,nAL
               DO 2500 L=1,nP
                  M=M+1
                  X0 = 7+nAL+nP+2*IRD+M
                  X1(M) = X(X0)
                  IF (KP == X0) THEN
                     IF (KT == 1) THEN
                        X1(M) = X(X0)/0.99
                     ELSE IF (KT == 3) THEN
                        X1(M) = X(X0)/1.01
                     END IF
                  ELSE IF (KP == X00) THEN
                     IF (KT == 1) THEN
                        X2(II) = X(X00)/0.99
                     ELSE IF (KT == 3) THEN
                        X2(II) = X(X00)/1.01
                     END IF
                  END IF

 2500             traf (II,J,K,L)= X1(M) * X2(II) / X2(1)


      DO 3450 II=1,IRD
         ots(II)=0.00
         DO 3440 J=1,nAL-1
            DO 3430 K=J+1,nAL
               DO 3420 L=1,nP
                  ots(II)=ots(II)+traf(II,J,K,L)
 3420          CONTINUE
 3430       CONTINUE
 3440    CONTINUE
 3450 CONTINUE

      DO 3485 II=1,IRD
         ooo(II)=0
C treated traffic is half of through traffic
         ots(II)=ots(II)*0.5

         X3 = X(L1 + 40)
         X4 = X(L1 + 46)
         X5 = X(L1 + 52)
         X6 = X(L1 + 58)
         X7 = X(L1 + 64)

         IF (KP == L1+40) THEN
            IF (KT == 1) THEN
               X3 = X(L1+40)/0.99
            ELSE IF (KT == 3) THEN
               X3 = X(L1+40)/1.01
            END IF
```

```
        ELSE IF (KP == L1+46) THEN
           IF (KT == 1) THEN
              X4 = X(L1+46)/0.99
           ELSE IF (KT == 3) THEN
              X4 = X(L1+46)/1.01
           END IF
        ELSE IF (KP == L1+52) THEN
           IF (KT == 1) THEN
              X5 = X(L1+52)/0.99
           ELSE IF (KT == 3) THEN
              X5 = X(L1+52)/1.01
           END IF
        ELSE IF (KP == L1+58) THEN
           IF (KT == 1) THEN
              X6 = X(L1+58)/0.99
           ELSE IF (KT == 3) THEN
              X6 = X(L1+58)/1.01
           END IF
        ELSE IF (KP == L1+64) THEN
           IF (KT == 1) THEN
              X7 = X(L1+64)/0.99
           ELSE IF (KT == 3) THEN
              X7 = X(L1+64)/1.01
           END IF
        END IF


        IF(ots(II).LE.X3) THEN
          ooo(II)=X(L1+41)*X(L1+35)+X(L1+42)*X(L1+36)+X(L1+43)
    1              *X(L1+37)+X(L1+44)*X(L1+38)+X(L1+45)*X(L1+39)
          oom(II)=X(L1+41)+X(L1+42)+X(L1+43)+X(L1+44)+X(L1+45)
        ELSE IF(ots(II).LE.X4) THEN
          ooo(II)=X(L1+47)*X(L1+35)+X(L1+48)*X(L1+36)+X(L1+49)
    1              *X(L1+37)+X(L1+50)*X(L1+38)+X(L1+51)*X(L1+39)
          oom(II)=X(L1+47)+X(L1+48)+X(L1+49)+X(L1+50)+X(L1+51)
        ELSE IF(ots(II).LE.X5) THEN
          ooo(II)=X(L1+53)*X(L1+35)+X(L1+54)*X(L1+36)+X(L1+55)
    1              *X(L1+37)+X(L1+56)*X(L1+38)+X(L1+57)*X(L1+39)
          oom(II)=X(L1+53)+X(L1+54)+X(L1+55)+X(L1+56)+X(L1+57)
        ELSE IF(ots(II).LE.X6) THEN
          ooo(II)=X(L1+59)*X(L1+35)+X(L1+60)*X(L1+36)+X(L1+61)
    1              *X(L1+37)+X(L1+62)*X(L1+38)+X(L1+63)*X(L1+39)
          oom(II)=X(L1+59)+X(L1+60)+X(L1+61)+X(L1+62)+X(L1+63)
        ELSE IF(ots(II).LE.X7) THEN
          ooo(II)=X(L1+65)*X(L1+35)+X(L1+66)*X(L1+36)+X(L1+67)
    1              *X(L1+37)+X(L1+68)*X(L1+38)+X(L1+69)*X(L1+39)
          oom(II)=X(L1+65)+X(L1+66)+X(L1+67)+X(L1+68)+X(L1+69)
        ELSE
          ooo(II)=X(L1+70)*X(L1+35)+X(L1+71)*X(L1+36)+X(L1+72)
    1              *X(L1+37)+X(L1+73)*X(L1+38)+X(L1+74)*X(L1+39)
          oom(II)=X(L1+70)+X(L1+71)+X(L1+72)+X(L1+73)+X(L1+74)
        END IF

 3485   CONTINUE

C-----------------------------------------------
C CONSIGNMENT COSTS OF TOLL COLLECTION
```

```
C-----------------------------------------

      DO 3550 II=1,IRD
         DO 3540 M=1,nAL
            cts(II,M)=0.00
            DO 3530 J=1,nAL-1
               DO 3520 K=J+1,nAL
                  DO 3510 L=1,nP
                     IF(J.EQ.M .OR. K.EQ.M) THEN
                     cts(II,M)=cts(II,M)+traf(II,J,K,L)
                     ELSE
                     cts(II,M)=cts(II,M)
                     END IF
 3510             CONTINUE
 3520          CONTINUE
 3530       CONTINUE
 3540     CONTINUE
 3550  CONTINUE

       DO 3790 II=1,IRD
         DO 3780 M=1,nAL
            tcc(II,M)=0

            X8  = X(L1 + 76)
            X9  = X(L1 + 78)
            X10 = X(L1 + 80)
            X11 = X(L1 + 82)
            X12 = X(L1 + 84)
            X13 = X(L1 + 86)
            X14 = X(L1 + 88)
            X15 = X(L1 + 90)
            X16 = X(L1 + 92)
            X17 = X(L1 + 94)
            X18 = X(L1 + 96)
            X19 = X(L1 + 98)
            X20 = X(L1 + 100)
            X21 = X(L1 + 102)
            X21 = X(L1 + 104)
            X21 = X(L1 + 106)
            X21 = X(L1 + 108)

            IF (KP == L1+76) THEN
               IF (KT == 1) THEN
                  X8 = X(L1+76)/0.99
               ELSE IF (KT == 3) THEN
                  X8 = X(L1+76)/1.01
               END IF
            ELSE IF (KP == L1+78) THEN
               IF (KT == 1) THEN
                  X9 = X(L1+78)/0.99
               ELSE IF (KT == 3) THEN
                  X9 = X(L1+78)/1.01
               END IF
            ELSE IF (KP == L1+80) THEN
               IF (KT == 1) THEN
                  X10 = X(L1+80)/0.99
               ELSE IF (KT == 3) THEN
```

```
            X10 = X(L1+80)/1.01
         END IF
      ELSE IF (KP == L1+82) THEN
         IF (KT == 1) THEN
            X11 = X(L1+82)/0.99
         ELSE IF (KT == 3) THEN
            X11 = X(L1+82)/1.01
         END IF
      ELSE IF (KP == L1+84) THEN
         IF (KT == 1) THEN
            X12 = X(L1+84)/0.99
         ELSE IF (KT == 3) THEN
            X12 = X(L1+84)/1.01
         END IF
      ELSE IF (KP == L1+86) THEN
         IF (KT == 1) THEN
            X13 = X(L1+86)/0.99
         ELSE IF (KT == 3) THEN
            X13 = X(L1+86)/1.01
         END IF
      ELSE IF (KP == L1+88) THEN
         IF (KT == 1) THEN
            X14 = X(L1+88)/0.99
         ELSE IF (KT == 3) THEN
            X14 = X(L1+88)/1.01
         END IF
      ELSE IF (KP == L1+90) THEN
         IF (KT == 1) THEN
            X15 = X(L1+90)/0.99
         ELSE IF (KT == 3) THEN
            X15 = X(L1+90)/1.01
         END IF
      ELSE IF (KP == L1+92) THEN
         IF (KT == 1) THEN
            X16 = X(L1+92)/0.99
         ELSE IF (KT == 3) THEN
            X16 = X(L1+92)/1.01
         END IF
      ELSE IF (KP == L1+94) THEN
         IF (KT == 1) THEN
            X17 = X(L1+94)/0.99
         ELSE IF (KT == 3) THEN
            X17 = X(L1+94)/1.01
         END IF
      ELSE IF (KP == L1+96) THEN
         IF (KT == 1) THEN
            X18 = X(L1+96)/0.99
         ELSE IF (KT == 3) THEN
            X18 = X(L1+96)/1.01
         END IF
      ELSE IF (KP == L1+98) THEN
         IF (KT == 1) THEN
            X19 = X(L1+98)/0.99
         ELSE IF (KT == 3) THEN
            X19 = X(L1+98)/1.01
         END IF
      ELSE IF (KP == L1+100) THEN
```

```
        IF (KT == 1) THEN
           X20 = X(L1+100)/0.99
        ELSE IF (KT == 3) THEN
           X20 = X(L1+100)/1.01
        END IF
     ELSE IF (KP == L1+102) THEN
        IF (KT == 1) THEN
           X21 = X(L1+102)/0.99
        ELSE IF (KT == 3) THEN
           X21 = X(L1+102)/1.01
        END IF
     ELSE IF (KP == L1+104) THEN
        IF (KT == 1) THEN
           X22 = X(L1+104)/0.99
        ELSE IF (KT == 3) THEN
           X22 = X(L1+104)/1.01
        END IF
     ELSE IF (KP == L1+106) THEN
        IF (KT == 1) THEN
           X23 = X(L1+106)/0.99
        ELSE IF (KT == 3) THEN
           X23 = X(L1+106)/1.01
        END IF
     ELSE IF (KP == L1+108) THEN
        IF (KT == 1) THEN
           X24 = X(L1+108)/0.99
        ELSE IF (KT == 3) THEN
           X24 = X(L1+108)/1.01
        END IF
     END IF


     IF(cts(II,M).LE.X8) THEN
       tcc(II,M)=X(L1+77)*X(L1+75)*X(L1+111)
       tcm(II,M)=X(L1+77)
     ELSE IF(cts(II,M).LE.X9) THEN
       tcc(II,M)=X(L1+79)*X(L1+75)*X(L1+111)
       tcm(II,M)=X(L1+79)
     ELSE IF(cts(II,M).LE.X10) THEN
       tcc(II,M)=X(L1+81)*X(L1+75)*X(L1+111)
       tcm(II,M)=X(L1+81)
     ELSE IF(cts(II,M).LE.X11) THEN
       tcc(II,M)=X(L1+83)*X(L1+75)*X(L1+111)
       tcm(II,M)=X(L1+83)
     ELSE IF(cts(II,M).LE.X12) THEN
       tcc(II,M)=X(L1+85)*X(L1+75)*X(L1+111)
       tcm(II,M)=X(L1+85)
     ELSE IF(cts(II,M).LE.X13) THEN
       tcc(II,M)=X(L1+87)*X(L1+75)*X(L1+111)
       tcm(II,M)=X(L1+87)
     ELSE IF(cts(II,M).LE.X14) THEN
       tcc(II,M)=X(L1+89)*X(L1+75)*X(L1+111)
       tcm(II,M)=X(L1+89)
     ELSE IF(cts(II,M).LE.X15) THEN
       tcc(II,M)=X(L1+91)*X(L1+75)*X(L1+111)
       tcm(II,M)=X(L1+91)
     ELSE IF(cts(II,M).LE.X16) THEN
```

```
          tcc(II,M)=X(L1+93)*X(L1+75)*X(L1+111)
          tcm(II,M)=X(L1+93)
        ELSE IF(cts(II,M).LE.X17) THEN
          tcc(II,M)=X(L1+95)*X(L1+75)*X(L1+111)
          tcm(II,M)=X(L1+95)
        ELSE IF(cts(II,M).LE.X18) THEN
          tcc(II,M)=X(L1+97)*X(L1+75)*X(L1+111)
          tcm(II,M)=X(L1+97)
        ELSE IF(cts(II,M).LE.X19) THEN
          tcc(II,M)=X(L1+99)*X(L1+75)*X(L1+111)
          tcm(II,M)=X(L1+99)
        ELSE IF(cts(II,M).LE.X20) THEN
          tcc(II,M)=X(L1+101)*X(L1+75)*X(L1+111)
          tcm(II,M)=X(L1+101)
        ELSE IF(cts(II,M).LE.X21) THEN
          tcc(II,M)=X(L1+103)*X(L1+75)*X(L1+111)
          tcm(II,M)=X(L1+103)
        ELSE IF(cts(II,M).LE.X22) THEN
          tcc(II,M)=X(L1+105)*X(L1+75)*X(L1+111)
          tcm(II,M)=X(L1+105)
        ELSE IF(cts(II,M).LE.X23) THEN
          tcc(II,M)=X(L1+107)*X(L1+75)*X(L1+111)
          tcm(II,M)=X(L1+107)
        ELSE IF(cts(II,M).LE.X24) THEN
          tcc(II,M)=X(L1+109)*X(L1+75)*X(L1+111)
          tcm(II,M)=X(L1+109)
        ELSE
          tcc(II,M)=X(L1+110)*X(L1+75)*X(L1+111)
          tcm(II,M)=X(L1+110)
        END IF
 3780    CONTINUE
 3790 CONTINUE

      DO 3797 II=1,IRD
         tcmt(II)=0
         DO 3794 M=1,nAL
            tcmt(II)=tcmt(II)+tcm(II,M)
 3794    CONTINUE
 3797 CONTINUE


C-------------------------------------------------------------
C TOLL COLLECTION MACHINE MAINTENANCE COSTS
C------------------------------------------------------------

      DO 3820 II=1,IRD

         tccc(II)=0
         DO 3812 J=1,nAL
            tccc(II)=tccc(II)+tcc(II,J)
 3812    CONTINUE

         tccm(II)=tccc(II)*X(L1+112)
 3820 CONTINUE

C-----------------------------------------------------
C BUILDING AND REPAINTING EXPENSES
```

```
C RELEVANT EXPENSES TO OPERATION
C COST FOR MACHINE AND EQUIPMENT
C OTHERS
C-----------------------------------------------------

      DO 3860 II=1,IRD
         brco(II)=X(L1+113)*(oom(II)+tcmt(II))+X(L1+114)

 3860 CONTINUE

C-----------------------------------------------------
C OPERATION BUREAU OVERHEAD
C-----------------------------------------------------

      DO 3890 II=1,IRD
         obo(II) = reve(II) *X(L1+115)
 3890 CONTINUE

C-----------------------------------------------------
C HEADQUARTERS OVERHEAD
C-----------------------------------------------------

      DO 3930 II=1,IRD
         ho(II)=reve(II)*X(L1+116)
 3930 CONTINUE

C----------------------------------------------------
C     REVENUE
C
C This calculate annual revenue
C                 and
C                 maintenance and operation costs.
C----------------------------------------------------

      CALL TRACE (3, 'RVSF11', 'total costs calculation.')

C-------------------------------------------
C Calculate annual maintenance costs
C-----------------------------------------

      CALL TRACE (3, 'RVSF11', 'annual maintenance costs.')

      DO 4200 II=1,IRD
 4200    maint (II) = mcrc + mcrm + mcl + mcbr + mcbp1 (II) + mctm
     +                     + mcsc + mcoll (II) + mcot

C---------------------------------------
C Calculate annual operation costs.
C--------------------------------------

      CALL TRACE (3, 'RVSF11', 'annual operation costs.')

      DO 4300 II=1,IRD
         oper(II)=ooo(II)+tccc(II)+tccm(II)+brco(II)+obo(II)+ho(II)
         aoper(II)=maint(II)+oper(II)
 4300    CONTINUE
```

```
C-----------------------------------
C Calculate discounted net revenue.
C------------------------------------

C---------------------------------------------------
C      DO 4500 I = 1, 177
C 4500    PRINT *,'X(',I,') = ',X(I)
C-------------------------------------------------

      CALL TRACE (3, 'RVSF11', 'discount NP.')

      Y=0.00
      DO 5100 II=1,IRD

      CALL TRACE (3, 'RVSF11', 'calculating AZ.')


         AZ=(DEXP(-DR*(rIBY+II))-DEXP(-DR*(rIBY+II-1)))/(-DR)

      CALL TRACE (3, 'RVSF11', 'calculating Z.')

C---------------------------------------------------
C      PRINT *,'X(L1+117)= ',X(L1+117)
C      PRINT *,'DR= ',DR
C      PRINT *,'Z= ',Z
C---------------------------------------------------

         Z=X(L1+117)-DR

         IF(DABS(Z).GT.0.001D0) GO TO 5020

         BZ=1.00
         GO TO 5030

C      CALL TRACE (3, 'RVSF11', 'calculating BZ.')

 5020    BZ=(DEXP(Z*(rIBY+II))-DEXP(Z*(rIBY+II-1)))/Z

      CALL TRACE (3, 'RVSF11', 'calculating AY.')

 5030    AY=(reve(II)*AZ)-(aoper(II)*BZ)

      CALL TRACE (3, 'RVSF11', 'calculating Y.')

         Y=Y+AY

 5100 CONTINUE

C      CALL TRACE (2, 'RVSF11', 'finishing.')
      DEALLOCATE (cost, traf, tcc, tcm, cts)
      RETURN

      END
```

```
C RvSf12.INC
C 16mar94 TH
C
C Open System (Manual Collection)
C we ask nicely for the money from the motorist!
C

      SUBROUTINE RVSF12 (KP, KT, DR, BOTTLE, I, X, Y)
      IMPLICIT REAL*4 (A-H,O-Z)
      INCLUDE 'DEBUG.CMN'

      REAL*4 X (*), BOTTLE (NRS, *)

      REAL*4 Y,AY,AZ,BZ,Z(5)
      REAL*4 mcbp1(50),mcoll(50),ots(50)
      REAL*4 ooo(50),oom(50),reve(50)
      REAL*4 tcmt(50),tccc(50),tccm(50),brco(50),obo(50),ho(50)
      REAL*4 maint(50),aoper(50)
      REAL*4 X1(200),X2(200)
      REAL*4 cost (:,:,:), traf(:,:,:,:), ttraf(:,:,:)
      REAL*4 tcc (:,:), tcm(:,:), cts(:,:)
      REAL*4 tgl (:)
      ALLOCATABLE cost, traf, ttraf, tcc, tcm, cts, TGL


      CALL TRACE (3, 'RVSF12', 'toll rate calculation starting.')

      nAL    = BOTTLE (I, 1)
      nP     = BOTTLE (I, 2)
      nWC    = BOTTLE (I, 3)
      nTG    = BOTTLE (I, 6)
      nOL    = BOTTLE (I, 4)
      nBR    = BOTTLE (I, 5)



      ALLOCATE (tgl (nTG))

      DO 10 J = 1, nTG
   10    tgl (J) = BOTTLE (I, 6 + J)

      IRD = NINT (X (2))

      ALLOCATE (cost  (IRD, nTG, nP))
      ALLOCATE (traf  (IRD, nAL, nAL, nP))
      ALLOCATE (ttraf (IRD, nTG, nP))
      ALLOCATE (tcc   (IRD, nTG))
      ALLOCATE (tcm   (IRD, nTG))
      ALLOCATE (cts   (IRD, nTG))

      DO 100 II=1,IRD
         DO 100 J=1,nTG
            DO 100 K=1,nP
  100          cost(II,J,K)=X(2+J)*X(2+nTG+K)*X(2+nTG+nP+II)
```

```
       DO 1150 II=1,IRD
          M=0
          DO 1150 J=1,nAL-1
             DO 1150 K=J+1,nAL
                DO 1150 L=1,nP
                   M=M+1
 1150              traf (II,J,K,L) =
     +                    X (2 + nTG + nP + 2 * IRD + M)
     +                  * X (2 + nTG + nP +     IRD + II)
     +                  / X (3 + nTG + nP +     IRD)

       DO 1500 II=1,IRD
          DO 1500 J=1,nTG
             DO 1500 K=1,nP
                ttraf(II,J,K)=0.0
                DO 1500 JJ=1,nAL
                   XJJ=FLOAT(JJ)
                   IF (TGL (J) == XJJ) THEN
                      DO 1430 L=1,nAL-1
                         DO 1430 LL=L+1,nAL
                            IF (L == JJ .OR. LL == JJ) THEN

ttraf(II,J,K)=ttraf(II,J,K)+traf(II,L,LL,K)
                            END IF
 1430                 CONTINUE
                   ELSE IF (JJ < TGL(J) .AND. TGL(J) < (JJ + 1)) THEN
                      DO 1450 L=1,nAL-1
                         DO 1450 LL=L+1,nAL
                            IF (L <= JJ .AND. JJ < LL)  THEN

ttraf(II,J,K)=ttraf(II,J,K)+traf(II,L,LL,K)
                            ENDIF
 1450                 CONTINUE
                   ENDIF
 1500 CONTINUE


       DO 1510 II=1,IRD
          reve(II)=0.00
          DO 1510 J=1,nTG
             DO 1510 K=1,nP
 1510           reve(II)=reve(II)+ttraf(II,J,K)*cost(II,J,K)*365

C       PRINT *, 'nTG = ', nTG
C       PRINT *, ' IRD = ', IRD
C       PRINT *, '  nAL = ', nAL
C       PRINT *, '   nP  = ', nP

       L1=2+nTG+nP+2*IRD+nAL*(nAL-1)/2*nP

C       PRINT *, '    L1  = ', L1
C       PRINT *,


       mcrc = ! maintenance (road cleaning) costs...
```

```
     +  X (L1 + 13) *
     +     ( X (L1 + 1) + X (L1 + 4) + X (L1 + 7) ) +
     +  X (L1 + 14) *
     +     ( X (L1 + 2) + X (L1 + 5) + X (L1 + 8) +
     +        X (L1 + 3) + X (L1 + 6) + X (L1 + 9) )


      mcrm = ! road maintenance
     +  X (L1 + 15) * X (L1 + 7) +
     +  X (L1 + 16) * X (L1 + 8) +
     +  X (L1 + 17) * X (L1 + 9)


      mcl = ! lighting
     +  X (L1 + 18) * (X (L1 + 1) + X (L1 + 7)) +
     +  X (L1 + 19) *
     +    ( (X (L1 + 2) + X (L1 + 3)) + (X (L1 + 8) + X (L1 + 9)) )


      mcbr = ! bridge repair
     +  X (L1 + 20) * X (L1 + 1) +
     +  X (L1 + 21) * X (L1 + 2) +
     +  X (L1 + 22) * X (L1 + 3)


      mcbp = ! bridge painting
     +  X (L1 + 23) * X (L1 + 1) +
     +  X (L1 + 24) * X (L1 + 2) +
     +  X (L1 + 25) * X (L1 + 3)


      mctm = ! tunnel maintenance
     +  X (L1 + 10) * X (L1 + 26) +
     +  X (L1 + 11) * X (L1 + 27) +
     +  X (L1 + 12) * X (L1 + 28)


      SELECT CASE (nWC)  ! snow and ice control?
      CASE (1)
      mcsc =
     +  X (L1 + 29) * ( (X (L1 + 1) + X (L1 + 4) + X (L1 + 7))
     +                 +2*(X (L1 + 2) + X (L1 + 5) + X (L1 + 8))
     +                 +3*(X (L1 + 3) + X (L1 + 6) + X (L1 + 9)) )
      CASE (2)
      mcsc =
     +  X (L1 + 30) * ( (X (L1 + 1) + X (L1 + 4) + X (L1 + 7))
     +                 +2*(X (L1 + 2) + X (L1 + 5) + X (L1 + 8))
     +                 +3*(X (L1 + 3) + X (L1 + 6) + X (L1 + 9)))
      CASE DEFAULT
      mcsc = 0.0D0
      END SELECT


      mcol = ! overlay
     +  X (L1 + 31) * (X (L1 + 1) + X (L1 + 4) + X (L1 + 7)) +
     +  X (L1 + 32) * (X (L1 + 2) + X (L1 + 5) + X (L1 + 8)) +
     +  X (L1 + 33) * (X (L1 + 3) + X (L1 + 6) + X (L1 + 9))
```

```
      pcot = X (L1 + 34)
      mcot = ! other neat stuff....
     +  pcot * (mcrc + mcrm + mcl + mcbr + mctm + mcsc)


      DO 2295 II=1,IRD

C bridge painting happens every 7 years.

         IF (II.EQ.nBR .OR. II.EQ.(nBR+7) .OR. II.EQ.(nBR+14)
     +       .OR. II.EQ.(nBR+21) .OR. II.EQ.(nBR+28) .OR.
     +       II.EQ.(nBR+35) .OR. II.EQ.(nBR+42) .OR.
     +       II.EQ.(nBR+49)) THEN

             mcbp1 (II) = mcbp
         ELSE
             mcbp1 (II) = 0.00
         END IF

C overlaying takes place every 12 years

         IF (II.EQ.nOL .OR. II.EQ.(nOL+12) .OR. II.EQ.(nOL+24)
     +       .OR. II.EQ.(nOL+36) .OR. II.EQ.(nOL+48)) THEN

             mcol1 (II) = mcol
         ELSE
             mcol1 (II) = 0.00
         END IF

 2295   CONTINUE


C OPERATION COSTS

C Operation office overhead

      DO 2500 II=1,IRD
         M=0
         X2(II) = X(2+nTG+nP+IRD+II)
         X00 = 2+nTG+nP+IRD+II

         DO 2500 J=1,nAL-1
            DO 2500 K=J+1,nAL
               DO 2500 L=1,nP
                  M=M+1
                  X0 = 2+nTG+nP+2*IRD+M
                  X1(M) = X(X0)

                  IF (KP == X0) THEN
                     IF (KT == 1) THEN
                        X1(M) = X(X0)/0.99
                     ELSE IF (KT == 3) THEN
                        X1(M) = X(X0)/1.01
                     END IF
                  ELSE IF (KP == X00) THEN
```

```
                    IF (KT == 1) THEN
                       X2(II) = X(X00)/0.99
                    ELSE IF (KT == 3) THEN
                       X2(II) = X(X00)/1.01
                    END IF
                 END IF

 2500            traf (II,J,K,L) = X1(M) * X2(II) / X2(1)

      DO 2700 II=1,IRD
         DO 2700 J=1,nTG
            DO 2700 K=1,nP
               ttraf(II,J,K)=0.0
               DO 2700 JJ=1,nAL
                  XJJ=FLOAT(JJ)
                  IF (TGL (J) == XJJ) THEN
                     DO 2600 L=1,nAL-1
                        DO 2600 LL=L+1,nAL
                           IF (L == JJ .OR. LL == JJ) THEN

ttraf(II,J,K)=ttraf(II,J,K)+traf(II,L,LL,K)
                           END IF
 2600                CONTINUE
                  ELSE IF (JJ < TGL(J) .AND. TGL(J) < (JJ + 1)) THEN
                     DO 2650 L=1,nAL-1
                        DO 2650 LL=L+1,nAL
                           IF (L <= JJ .AND. JJ < LL)  THEN

ttraf(II,J,K)=ttraf(II,J,K)+traf(II,L,LL,K)
                           ENDIF
 2650                CONTINUE
                  ENDIF
 2700 CONTINUE


      DO 3450 II=1,IRD
         ots(II)=0.00
         DO 3450 J=1,nTG
            DO 3450 K=1,nP
 3450          ots(II)=ots(II)+ttraf(II,J,K)

         X3 = X(L1+40)
         X4 = X(L1+46)
         X5 = X(L1+52)
         X6 = X(L1+58)
         X7 = X(L1+64)

         IF (KP == L1+40) THEN
            IF (KT == 1) THEN
               X3 = X(L1+40)/0.99
            ELSE IF (KT == 3) THEN
               X3 = X(L1+40)/1.01
            END IF
         ELSE IF (KP == L1+46) THEN
            IF (KT == 1) THEN
               X4 = X(L1+46)/0.99
            ELSE IF (KT == 3) THEN
```

```
               X4 = X(L1+46)/1.01
            END IF
         ELSE IF (KP == L1+52) THEN
            IF (KT == 1) THEN
               X5 = X(L1+52)/0.99
            ELSE IF (KT == 3) THEN
               X5 = X(L1+52)/1.01
            END IF
         ELSE IF (KP == L1+58) THEN
            IF (KT == 1) THEN
               X6 = X(L1+58)/0.99
            ELSE IF (KT == 3) THEN
               X6 = X(L1+58)/1.01
            END IF
         ELSE IF (KP == L1+64) THEN
            IF (KT == 1) THEN
               X7 = X(L1+64)/0.99
            ELSE IF (KT == 3) THEN
               X7 = X(L1+64)/1.01
            END IF
         END IF



      DO 3485 II=1,IRD
              IF (ots (II) <= X3) THEN
                 CALL FOO1 (X, 41, 35, ooo (II), oom (II))
         ELSE IF (ots (II) <= X4) THEN
                 CALL FOO1 (X, 47, 35, ooo (II), oom (II))
         ELSE IF (ots (II) <= X5) THEN
                 CALL FOO1 (X, 53, 35, ooo (II), oom (II))
         ELSE IF (ots (II) <= X6) THEN
                 CALL FOO1 (X, 59, 35, ooo (II), oom (II))
         ELSE IF (ots (II) <= X7) THEN
                 CALL FOO1 (X, 65, 35, ooo (II), oom (II))
         ELSE
                 CALL FOO1 (X, 70, 35, ooo (II), oom (II))
         END IF
 3485    CONTINUE

C CONSIGNMENT COSTS OF TOLL COLLECTION

C Calculate traffic volume.

      DO 3550 II=1,IRD
         DO 3550 M=1,nTG
            cts(II,M)=0.00
            DO 3550 L=1,nP
 3550          cts(II,M)=cts(II,M)+ttraf(II,M,L)


      X8 = X (L1 + 75) * X (L1 + 113)
      DO 3790 II=1,nTG
         DO 3780 M=1,nAL
            X9  = 0.0D0
            X10 = 0.0D0
```

```
X11 = X(L1+76)
X12 = X(L1+78)
X13 = X(L1+80)
X14 = X(L1+82)
X15 = X(L1+84)
X16 = X(L1+86)
X17 = X(L1+88)
X18 = X(L1+90)
X19 = X(L1+92)
X20 = X(L1+94)
X21 = X(L1+96)
X22 = X(L1+98)
X23 = X(L1+100)
X24 = X(L1+102)
X25 = X(L1+104)
X26 = X(L1+106)
X27 = X(L1+108)
X28 = X(L1+110)

   IF (KP == L1 + 76) THEN
      IF (KT == 1) THEN
         X11 = X (L1 + 76)/0.99
      ELSE IF (KT == 3) THEN
         X11 = X (L1 + 76)/1.01
      END IF
   ELSE IF (KP == L1 + 78) THEN
      IF (KT == 1) THEN
         X12 = X (L1 + 78)/0.99
      ELSE IF (KT == 3) THEN
         X12 = X (L1 + 78)/1.01
      END IF
   ELSE IF (KP == L1 + 80) THEN
      IF (KT == 1) THEN
         X13 = X (L1 + 80)/0.99
      ELSE IF (KT == 3) THEN
         X13 = X (L1 + 80)/1.01
      END IF
   ELSE IF (KP == L1 + 82) THEN
      IF (KT == 1) THEN
         X14 = X (L1 + 82)/0.99
      ELSE IF (KT == 3) THEN
         X14 = X (L1 + 82)/1.01
      END IF
   ELSE IF (KP == L1 + 84) THEN
      IF (KT == 1) THEN
         X15 = X (L1 + 84)/0.99
      ELSE IF (KT == 3) THEN
         X15 = X (L1 + 84)/1.01
      END IF
   ELSE IF (KP == L1 + 86) THEN
      IF (KT == 1) THEN
         X16 = X (L1 + 86)/0.99
      ELSE IF (KT == 3) THEN
         X16 = X (L1 + 86)/1.01
      END IF
   ELSE IF (KP == L1 + 88) THEN
      IF (KT == 1) THEN
```

```
            X17 = X (L1 + 88)/0.99
         ELSE IF (KT == 3) THEN
            X17 = X (L1 + 88)/1.01
         END IF
      ELSE IF (KP == L1 + 90) THEN
         IF (KT == 1) THEN
            X18 = X (L1 + 90)/0.99
         ELSE IF (KT == 3) THEN
            X18 = X (L1 + 90)/1.01
         END IF
      ELSE IF (KP == L1 + 92) THEN
         IF (KT == 1) THEN
            X19 = X (L1 + 92)/0.99
         ELSE IF (KT == 3) THEN
            X19 = X (L1 + 92)/1.01
         END IF
      ELSE IF (KP == L1 + 94) THEN
         IF (KT == 1) THEN
            X20 = X (L1 + 94)/0.99
         ELSE IF (KT == 3) THEN
            X20 = X (L1 + 94)/1.01
         END IF
      ELSE IF (KP == L1 + 96) THEN
         IF (KT == 1) THEN
            X21 = X (L1 + 96)/0.99
         ELSE IF (KT == 3) THEN
            X21 = X (L1 + 96)/1.01
         END IF
      ELSE IF (KP == L1 + 98) THEN
         IF (KT == 1) THEN
            X22 = X (L1 + 98)/0.99
         ELSE IF (KT == 3) THEN
            X22 = X (L1 + 98)/1.01
         END IF
      ELSE IF (KP == L1 + 100) THEN
         IF (KT == 1) THEN
            X23 = X (L1 + 100)/0.99
         ELSE IF (KT == 3) THEN
            X23 = X (L1 + 100)/1.01
         END IF
      ELSE IF (KP == L1 + 102) THEN
         IF (KT == 1) THEN
            X24 = X (L1 + 102)/0.99
         ELSE IF (KT == 3) THEN
            X24 = X (L1 + 102)/1.01
         END IF
      ELSE IF (KP == L1 + 104) THEN
         IF (KT == 1) THEN
            X25 = X (L1 + 104)/0.99
         ELSE IF (KT == 3) THEN
            X25 = X (L1 + 104)/1.01
         END IF
      ELSE IF (KP == L1 + 106) THEN
         IF (KT == 1) THEN
            X26 = X (L1 + 106)/0.99
         ELSE IF (KT == 3) THEN
            X26 = X (L1 + 106)/1.01
```

```
    END IF
ELSE IF (KP == L1 + 108) THEN
    IF (KT == 1) THEN
        X27 = X (L1 + 108)/0.99
    ELSE IF (KT == 3) THEN
        X27 = X (L1 + 108)/1.01
    END IF
ELSE IF (KP == L1 + 110) THEN
    IF (KT == 1) THEN
        X28 = X (L1 + 110)/0.99
    ELSE IF (KT == 3) THEN
        X28 = X (L1 + 110)/1.01
    END IF
END IF


IF (cts (II, M) <= X11) THEN
    tcc (II, M) = X(L1+77) * X(L1+75) * X(L1+113)
    tcm (II, M) = X(L1+77)
ELSE IF (cts (II, M) <= X12) THEN
    tcc (II, M) = X(L1+79) * X(L1+75) * X(L1+113)
    tcm (II, M) = X(L1+79)
ELSE IF (cts (II, M) <= X13) THEN
    tcc (II, M) = X(L1+81) * X(L1+75) * X(L1+113)
    tcm (II, M) = X(L1+81)
ELSE IF (cts (II, M) <= X14) THEN
    tcc (II, M) = X(L1+83) * X(L1+75) * X(L1+113)
    tcm (II, M) = X(L1+83)
ELSE IF (cts (II, M) <= X15) THEN
    tcc (II, M) = X(L1+85) * X(L1+75) * X(L1+113)
    tcm (II, M) = X(L1+85)
ELSE IF (cts (II, M) <= X16) THEN
    tcc (II, M) = X(L1+87) * X(L1+75) * X(L1+113)
    tcm (II, M) = X(L1+87)
ELSE IF (cts (II, M) <= X17) THEN
    tcc (II, M) = X(L1+89) * X(L1+75) * X(L1+113)
    tcm (II, M) = X(L1+89)
ELSE IF (cts (II, M) <= X18) THEN
    tcc (II, M) = X(L1+91) * X(L1+75) * X(L1+113)
    tcm (II, M) = X(L1+91)
ELSE IF (cts (II, M) <= X19) THEN
    tcc (II, M) = X(L1+93) * X(L1+75) * X(L1+113)
    tcm (II, M) = X(L1+93)
ELSE IF (cts (II, M) <= X20) THEN
    tcc (II, M) = X(L1+95) * X(L1+75) * X(L1+113)
    tcm (II, M) = X(L1+95)
ELSE IF (cts (II, M) <= X21) THEN
    tcc (II, M) = X(L1+97) * X(L1+75) * X(L1+113)
    tcm (II, M) = X(L1+97)
ELSE IF (cts (II, M) <= X22) THEN
    tcc (II, M) = X(L1+99) * X(L1+75) * X(L1+113)
    tcm (II, M) = X(L1+99)
ELSE IF (cts (II, M) <= X23) THEN
    tcc (II, M) = X(L1+101) * X(L1+75) * X(L1+113)
    tcm (II, M) = X(L1+101)
ELSE IF (cts (II, M) <= X24) THEN
    tcc (II, M) = X(L1+103) * X(L1+75) * X(L1+113)
```

```
                    tcm (II, M) = X(L1+103)
                 ELSE IF (cts (II, M) <= X25) THEN
                    tcc (II, M) = X(L1+105) * X(L1+75) * X(L1+113)
                    tcm (II, M) = X(L1+105)
                 ELSE IF (cts (II, M) <= X26) THEN
                    tcc (II, M) = X(L1+107) * X(L1+75) * X(L1+113)
                    tcm (II, M) = X(L1+107)
                 ELSE IF (cts (II, M) <= X27) THEN
                    tcc (II, M) = X(L1+109) * X(L1+75) * X(L1+113)
                    tcm (II, M) = X(L1+109)
                 ELSE IF (cts (II, M) <= X28) THEN
                    tcc (II, M) = X(L1+111) * X(L1+75) * X(L1+113)
                    tcm (II, M) = X(L1+111)
                 ELSE
                    tcc (II, M) = X(L1+112) * X(L1+75) * X(L1+113)
                    tcm (II, M) = X(L1+112)
                 END IF
 3780       CONTINUE
 3790    CONTINUE

         DO 3794 II=1,IRD
            tcmt (II) = 0.0D0
            DO 3794 M=1,nTG
 3794          tcmt (II) = tcmt (II) + tcm (II, M)


C-------------------------------------------------------------
C TOLL COLLECTION MACHINE MAINTENANCE COSTS
C------------------------------------------------------------

         DO 3820 II=1,IRD
            tccc(II)=0
            DO 3812 J=1,nTG
 3812          tccc(II)=tccc(II)+tcc(II,J)
 3820       tccm (II) = tccc (II) * X (L1 + 114)

C-----------------------------------------------------
C BUILDING AND REPAINTING EXPENSES
C RELEVANT EXPENSES TO OPERATION
C COST FOR MACHINE AND EQUIPMENT
C OTHERS
C-----------------------------------------------------

         DO 3860 II=1,IRD
 3860       brco(II)=X(L1+115)*(oom(II)+tcmt(II))+X(L1+116)


C-----------------------------------------------------
C OPERATION BUREAU OVERHEAD
C-----------------------------------------------------

         DO 3890 II=1,IRD

C             PRINT *, II, reve (II), L1+117, X(L1+117)

 3890       obo(II)=reve(II)*X(L1+117)
```

```
C-----------------------------------------------------
C HEADQUARTERS OVERHEAD
C-----------------------------------------------------

      DO 3930 II=1,IRD
 3930    ho(II)=reve(II)*X(L1+118)

C----------------------------------------------------
C     REVENUE
C
C This calculate annual revenue
C                and
C                maintenance and operation costs.
C----------------------------------------------------

C      PRINT *, 'total costs calculation starting.'

C-----------------------------------------
C Calculate annual maintenance costs
C---------------------------------------

      DO 4200 II=1,IRD
 4200    maint (II) = mcrc + mcrm + mcl + mcbr + mcbp1 (II) +
     +                mctm + mcsc + mcoll (II) + mcot

C--------------------------------------
C Calculate annual operation costs.
C-------------------------------------

      DO 4300 II=1,IRD
         aoper (II) =
     +     maint (II) + ooo (II) + tccc (II) + tccm (II) +
     +     brco (II) + obo (II) + ho (II)

C         PRINT *, 'II = ', II
C         PRINT *, ' maint', maint (II)
C         PRINT *, '  ooo', ooo (II)
C         PRINT *, '   tccc', tccc (II)
C         PRINT *, '    tccm', tccm (II)
C         PRINT *, '     brco', brco (II)
C         PRINT *, '      obo', obo (II)
C         PRINT *, '       ho', ho (II)
C         PRINT *,

 4300    CONTINUE

C------------------------------------
C Calculate discounted net revenue.
C-------------------------------------

C      PRINT *, 'NPV calculation starting.'

      Y = 0.0D0

      DO 5100 II=1,IRD
         AZ = (DEXP (-DR * (X (1) + II    ) ) -
     +         DEXP (-DR * (X (1) + II - 1) ) ) / (- DR)
```

```
         Z (1) = X (L1 + 119) - DR

         IF (DABS(Z (1)) <= 0.001D0) THEN
            BZ = 1.0D0
            GO TO 4400
         ELSE
            BZ = (DEXP (Z (1) * (X (1) + II     )) -
     +              DEXP (Z (1) * (X (1) + II - 1)) ) / Z (1)
         END IF

 4400    AY = (reve (II) * AZ) - (aoper (II) * BZ)

C         PRINT *, 'II      = ', II
C         PRINT *, ' AZ      = ', AZ
C         PRINT *, '   Z (1) = ', Z (1)
C         PRINT *, '   X (1)  = ', X (1)
C         PRINT *, '    BZ     = ', BZ
C         PRINT *, '   reve(II) = ', reve (II)
C         PRINT *, '  aoper (II) = ', aoper (II)
C         PRINT *, 'AY = ', AY
C         PRINT *,

 5100    Y = Y + AY

      DEALLOCATE (TGL, cost, traf, ttraf, tcc, tcm, cts)
      RETURN
      END


C remove some redundant stuff to make the code nicer.

      SUBROUTINE FOO1 (X, OFF1, OFF2, ooo, oom)
      REAL*4 X (*)

      ooo = 0.0D0
      oom = 0.0D0

      DO 10 I = 0, 4
         ooo = ooo + (X (OFF1 + I) * X (OFF2 + I))
  10     oom = oom + (X (OFF1))

      RETURN
      END
```

```
C RvSf13.INC
C
C Closed System (Manual Collection) : fixed rate
C we ask nicely for the money from the motorist!

C=====================================================
      SUBROUTINE RVSF13 (KP, KT, DR, BOTTLE, I, X, Y)
C=====================================================

      IMPLICIT REAL*4(A-H,O-Z)
      INCLUDE 'DEBUG.CMN'

      REAL*4 BOTTLE (NRS, *), X (*)

      REAL*4 Y,AY,AZ,BZ,Z
      REAL*4 mcbp1(0:50),mcoll(0:50),ots(0:50)
      REAL*4 ooo(0:50),oom(0:50),reve(0:50)
      REAL*4 tcmt(0:50),tccc(0:50),tccm(0:50),brco(0:50),obo(0:50)
      REAL*4 ho(0:50),maint(0:50),oper(0:50),aoper(0:50)
      REAL*4 X1(0:200), X2(0:200)

      REAL*4 cost (:,:,:,:), traf (:,:,:,:)
      REAL*4 tcc (:,:), tcm (:,:), cts (:,:)
      ALLOCATABLE cost, traf, tcc, tcm, cts


      CALL TRACE (3, 'RVSF13', 'starting.')

      rIBY   = X (1)
      IRD    = NINT (X (2))

      nAL = BOTTLE (I, 1)
      nP  = BOTTLE (I, 2)
      nWC = BOTTLE (I, 3)
      nOL = BOTTLE (I, 4)
      nBR = BOTTLE (I, 5)

      ALLOCATE (cost (0:IRD, 0:nAL, 0:nAL, 0:nP))
      ALLOCATE (traf (0:IRD, 0:nAL, 0:nAL, 0:nP))
      ALLOCATE (tcc  (0:IRD, 0:nAL))
      ALLOCATE (tcm  (0:IRD, 0:nAL))
      ALLOCATE (cts  (0:IRD, 0:nAL))

      DO 90 II = 1, IRD
         M = 0
         XCONST = X (2 + nAL * (nAL - 1) / 2 * nP + II)

         DO 90 J = 1, nAL - 1
            DO 90 K = J + 1, nAL
               DO 90 L = 1, nP
                  M = M + 1
 90               cost (II, J, K, L) = X (2 + M) * XCONST


      CALL TRACE (3, 'RVSF13', 'traffic volume calculation.')
```

```
C traf (1, is undefined, but accessed in the next loop....

      DO 1150 II=1,IRD

         M=0
         XC0 =     2 + nAL * (nAL - 1) / 2 * nP + 2 * IRD
         XC1 = X (2 + nAL * (nAL - 1) / 2 * nP + IRD + II) /
     +         X (3 + nAL * (nAL - 1) / 2 * nP + IRD)

         DO 1150 J=1,nAL-1
            DO 1150 K=J+1,nAL
               DO 1150 L=1,nP
                  M=M+1
 1150             traf (II,J,K,L)= X (XC0 + M) * XC1

      CALL TRACE (3, 'RVSF13', 'annual toll revenue...')

      DO 1480 II=1,IRD
         temp = 0.00

         DO 1470 J=1,nAL
            DO 1470 K=J+1,nAL
               DO 1470 L=1,nP
                  temp = temp +
     +             traf (II,J,K,L) * cost (II,J,K,L) * 365
 1470    CONTINUE

         reve (II) = temp
 1480 CONTINUE


      L1 = 2 + 2 * (nAL*(nAL-1)/2*nP) + 2 * IRD

      CALL TRACE (3, 'RVSF13', 'fixed costs...')

      mcrc = ! road cleaning costs
     +  X(L1+13)*(X(L1+1) + X(L1+4) + X(L1+7)) + X(L1+14)*(X(L1+2) +
     +  X(L1+5) + X(L1+8) + X(L1+3) + X(L1+6) + X(L1+9))

      mcrm = ! road maintenance
     +  X(L1+15)*X(L1+7) + X(L1+16)*X(L1+8) + X(L1+17)*X(L1+9)

      mcl  = ! lighting
     +  X(L1+18)*(X(L1+1) + X(L1+7)) +
     +  X(L1+19)*( (X(L1+2) + X(L1+3)) + (X(L1+8) + X(L1+9)))

      mcbr = ! bridge repair
     +  X(L1+20)*X(L1+1) + X(L1+21)*X(L1+2) + X(L1+22)*X(L1+3)

      mcbp = ! bridge painting
     +  X(L1+23)*X(L1+1) + X(L1+24)*X(L1+2) + X(L1+25)*X(L1+3)

      mctm = ! tunnel maintenance
     +  X(L1+10)*X(L1+26) + X(L1+11)*X(L1+27) + X(L1+12)*X(L1+28)
```

```
      SELECT CASE (nWC) ! snow and ice control based on nWC
      CASE (1)
      mcsc =
     +  X(L1+29)*( (X(L1+1) + X(L1+4) + X(L1+7))
     +           +2*(X(L1+2) + X(L1+5) + X(L1+8))
     +           +3*(X(L1+3) + X(L1+6) + X(L1+9)) )
      CASE (2)
      mcsc =
     +  X(L1+30)*( (X(L1+1) + X(L1+4) + X(L1+7))
     +           +2*(X(L1+2) + X(L1+5) + X(L1+8))
     +           +3*(X(L1+3) + X(L1+6) + X(L1+9)) )
      CASE DEFAULT
      mcsc = 0.00
      END SELECT


      mcol = ! overlay
     +  X(L1+31)*( X(L1+1) + X(L1+4) + X(L1+7) ) +
     +  X(L1+32)*( X(L1+2) + X(L1+5) + X(L1+8) ) +
     +  X(L1+33)*( X(L1+3) + X(L1+6) + X(L1+9) )

      mcot = X (L1 + 34) * (mcrc + mcrm + mcl + mcbr + mctm + mcsc)

      DO 2295 II=1,IRD
         IF (II.EQ.nBR .OR. II.EQ.(nBR+7) .OR. II.EQ.(nBR+14) .OR.
     +        II.EQ.(nBR+21) .OR. II.EQ.(nBR+28) .OR.
     +        II.EQ.(nBR+35) .OR. II.EQ.(nBR+42) .OR.
     +        II.EQ.(nBR+49)) THEN
            mcbp1(II) = mcbp
         ELSE
            mcbp1(II) = 0.00
         END IF
         IF (II.EQ.nOL .OR. II.EQ.(nOL+12) .OR. II.EQ.(nOL+24) .OR.
     +        II.EQ.(nOL+36) .OR. II.EQ.(nOL+48)) THEN
            mcol1(II) = mcol
         ELSE
            mcol1(II) = 0.00
         END IF
 2295 CONTINUE

C OPERATION COSTS

      CALL TRACE (3, 'RVSF13', 'operation costs...')

C------------------------------
C Operation office overhead
C------------------------------

      DO 2500 II=1,IRD

         M=0
         X2 (II) = X (2 + nAL * (nAL - 1) / 2 * nP + IRD + II)
         X00 = 2 + nAL * (nAL - 1) / 2 * nP + IRD + II

         DO 2500 J=1,nAL-1
            DO 2500 K=J+1,nAL
               DO 2500 L=1,nP
```

```
                  M=M+1
                  X0 = 2 + nAL * (nAL - 1) / 2 * nP + 2 * IRD + M
                  X1 (M) = X (X0)

                  IF (KP == X0) THEN
                     IF (KT == 1) THEN
                        X1(M) = X (X0) / 0.99
                     ELSE IF (KT == 3) THEN
                        X1(M) = X (X0) / 1.01
                     END IF
                  ELSE IF (KP == X00) THEN
                     IF (KT == 1) THEN
                        X2(II) = X (X00) / 0.99
                     ELSE IF (KT == 3) THEN
                        X2(II) = X (X00) / 1.01
                     END IF
                  END IF

                  traf (II,J,K,L) = X1 (M) * X2 (II) / X2 (1)

 2500 CONTINUE


      DO 3450 II=1,IRD
         temp = 0.0D0
         DO 3440 J=1,nAL-1
            DO 3430 K=J+1,nAL
               DO 3420 L=1,nP
                  temp = temp + traf(II,J,K,L)
 3420          CONTINUE
 3430       CONTINUE
 3440    CONTINUE
         ots(II) = temp
 3450 CONTINUE

      DO 3485 II=1,IRD
         ooo(II)=0
C treated traffic is half of through traffic
         ots(II)=ots(II)*0.5

               X3 = X(L1+40)
               X4 = X(L1+46)
               X5 = X(L1+52)
               X6 = X(L1+58)
               X7 = X(L1+64)

         IF (KP == L1+40) THEN
            IF (KT == 1) THEN
               X3 = X(L1+40)/0.99
            ELSE IF (KT == 3) THEN
               X3 = X(L1+40)/1.01
            END IF
         ELSE IF (KP == L1+46) THEN
            IF (KT == 1) THEN
               X4 = X(L1+46)/0.99
            ELSE IF (KT == 3) THEN
```

```
               X4 = X(L1+46)/1.01
            END IF
         ELSE IF (KP == L1+52) THEN
            IF (KT == 1) THEN
               X5 = X(L1+52)/0.99
            ELSE IF (KT == 3) THEN
               X5 = X(L1+52)/1.01
            END IF
         ELSE IF (KP == L1+58) THEN
            IF (KT == 1) THEN
               X6 = X(L1+58)/0.99
            ELSE IF (KT == 3) THEN
               X6 = X(L1+58)/1.01
            END IF
         ELSE IF (KP == L1+64) THEN
            IF (KT == 1) THEN
               X7 = X(L1+64)/0.99
            ELSE IF (KT == 3) THEN
               X7 = X(L1+64)/1.01
            END IF
         END IF

         IF(ots(II).LE.X3) THEN
           ooo(II)=X(L1+41)*X(L1+35)+X(L1+42)*X(L1+36)+X(L1+43)
     1              *X(L1+37)+X(L1+44)*X(L1+38)+X(L1+45)*X(L1+39)
           oom(II)=X(L1+41)+X(L1+42)+X(L1+43)+X(L1+44)+X(L1+45)
         ELSE IF(ots(II).LE.X4) THEN
           ooo(II)=X(L1+47)*X(L1+35)+X(L1+48)*X(L1+36)+X(L1+49)
     1              *X(L1+37)+X(L1+50)*X(L1+38)+X(L1+51)*X(L1+39)
           oom(II)=X(L1+47)+X(L1+48)+X(L1+49)+X(L1+50)+X(L1+51)
         ELSE IF(ots(II).LE.X5) THEN
           ooo(II)=X(L1+53)*X(L1+35)+X(L1+54)*X(L1+36)+X(L1+55)
     1              *X(L1+37)+X(L1+56)*X(L1+38)+X(L1+57)*X(L1+39)
           oom(II)=X(L1+53)+X(L1+54)+X(L1+55)+X(L1+56)+X(L1+57)
         ELSE IF(ots(II).LE.X6) THEN
           ooo(II)=X(L1+59)*X(L1+35)+X(L1+60)*X(L1+36)+X(L1+61)
     1              *X(L1+37)+X(L1+62)*X(L1+38)+X(L1+63)*X(L1+39)
           oom(II)=X(L1+59)+X(L1+60)+X(L1+61)+X(L1+62)+X(L1+63)
         ELSE IF(ots(II).LE.X7) THEN
           ooo(II)=X(L1+65)*X(L1+35)+X(L1+66)*X(L1+36)+X(L1+67)
     1              *X(L1+37)+X(L1+68)*X(L1+38)+X(L1+69)*X(L1+39)
           oom(II)=X(L1+65)+X(L1+66)+X(L1+67)+X(L1+68)+X(L1+69)
         ELSE
           ooo(II)=X(L1+70)*X(L1+35)+X(L1+71)*X(L1+36)+X(L1+72)
     1              *X(L1+37)+X(L1+73)*X(L1+38)+X(L1+74)*X(L1+39)
           oom(II)=X(L1+70)+X(L1+71)+X(L1+72)+X(L1+73)+X(L1+74)
         END IF

 3485    CONTINUE

C----------------------------------------------
C CONSIGNMENT COSTS OF TOLL COLLECTION
C----------------------------------------------

      DO 3550 II=1,IRD
         DO 3540 M=1,nAL
            temp=0.0D0
```

```
            DO 3530 J=1,nAL-1
               IF (J == M) THEN
                  DO 3520 K=J+1,nAL
                     DO 3510 L=1,nP
                        temp = temp + traf (II,J,K,L)
3510                 CONTINUE
3520              CONTINUE
               ELSE
                  DO 3525 L=1,nP
                     temp = temp + traf (II,J,M,L)
3525              CONTINUE
               END IF
3530        CONTINUE
            cts(II,M) = temp
3540     CONTINUE
3550  CONTINUE


      DO 3790 II=1,IRD
         DO 3780 M=1,nAL
            tcc(II,M)=0.0D0


C we could realize about a 5% increase in speed
C by not ROCKing 'N ROLLing these variables at all.

                   X8  = X(L1+76)
                   X9  = X(L1+78)
                  X10  = X(L1+80)
                  X11  = X(L1+82)
                  X12  = X(L1+84)
                  X13  = X(L1+86)
                  X14  = X(L1+88)
                  X15  = X(L1+90)
                  X16  = X(L1+92)
                  X17  = X(L1+94)
                  X18  = X(L1+96)
                  X19  = X(L1+98)
                  X20  = X(L1+100)
                  X21  = X(L1+102)
                  X22  = X(L1+104)
                  X23  = X(L1+106)
                  X24  = X(L1+108)

            IF (KP == L1+76) THEN
               IF (KT == 1) THEN
                  X8 = X(L1+76)/0.99
               ELSE IF (KT == 3) THEN
                  X8 = X(L1+76)/1.01
               END IF
            ELSE IF (KP == L1+78) THEN
               IF (KT == 1) THEN
                  X9 = X(L1+78)/0.99
               ELSE IF (KT == 3) THEN
                  X9 = X(L1+78)/1.01
               END IF
```

```
         ELSE IF (KP == L1+80) THEN
            IF (KT == 1) THEN
               X10 = X(L1+80)/0.99
            ELSE IF (KT == 3) THEN
               X10 = X(L1+80)/1.01
            END IF
         ELSE IF (KP == L1+82) THEN
            IF (KT == 1) THEN
               X11 = X(L1+82)/0.99
            ELSE IF (KT == 3) THEN
               X11 = X(L1+82)/1.01
            END IF
         ELSE IF (KP == L1+84) THEN
            IF (KT == 1) THEN
               X12 = X(L1+84)/0.99
            ELSE IF (KT == 3) THEN
               X12 = X(L1+84)/1.01
            END IF
         ELSE IF (KP == L1+86) THEN
            IF (KT == 1) THEN
               X13 = X(L1+86)/0.99
            ELSE IF (KT == 3) THEN
               X13 = X(L1+86)/1.01
            END IF
         ELSE IF (KP == L1+88) THEN
            IF (KT == 1) THEN
               X14 = X(L1+88)/0.99
            ELSE IF (KT == 3) THEN
               X14 = X(L1+88)/1.01
            END IF
         ELSE IF (KP == L1+90) THEN
            IF (KT == 1) THEN
               X15 = X(L1+90)/0.99
            ELSE IF (KT == 3) THEN
               X15 = X(L1+90)/1.01
            END IF
         ELSE IF (KP == L1+92) THEN
            IF (KT == 1) THEN
               X16 = X(L1+92)/0.99
            ELSE IF (KT == 3) THEN
               X16 = X(L1+92)/1.01
            END IF
         ELSE IF (KP == L1+94) THEN
            IF (KT == 1) THEN
               X17 = X(L1+94)/0.99
            ELSE IF (KT == 3) THEN
               X17 = X(L1+94)/1.01
            END IF
         ELSE IF (KP == L1+96) THEN
            IF (KT == 1) THEN
               X18 = X(L1+96)/0.99
            ELSE IF (KT == 3) THEN
               X18 = X(L1+96)/1.01
            END IF
         ELSE IF (KP == L1+98) THEN
            IF (KT == 1) THEN
               X19 = X(L1+98)/0.99
```

```
      ELSE IF (KT == 3) THEN
         X19 = X(L1+98)/1.01
      END IF
   ELSE IF (KP == L1+100) THEN
      IF (KT == 1) THEN
         X20 = X(L1+100)/0.99
      ELSE IF (KT == 3) THEN
         X20 = X(L1+100)/1.01
      END IF
   ELSE IF (KP == L1+102) THEN
      IF (KT == 1) THEN
         X21 = X(L1+102)/0.99
      ELSE IF (KT == 3) THEN
         X21 = X(L1+102)/1.01
      END IF
   ELSE IF (KP == L1+104) THEN
      IF (KT == 1) THEN
         X22 = X(L1+104)/0.99
      ELSE IF (KT == 3) THEN
         X22 = X(L1+104)/1.01
      END IF
   ELSE IF (KP == L1+106) THEN
      IF (KT == 1) THEN
         X23 = X(L1+106)/0.99
      ELSE IF (KT == 3) THEN
         X23 = X(L1+106)/1.01
      END IF
   ELSE IF (KP == L1+108) THEN
      IF (KT == 1) THEN
         X24 = X(L1+108)/0.99
      ELSE IF (KT == 3) THEN
         X24 = X(L1+108)/1.01
      END IF
   END IF

   IF(cts(II,M).LE.X8) THEN
     tcc(II,M)=X(L1+77)*X(L1+75)*X(L1+111)
     tcm(II,M)=X(L1+77)
   ELSE IF(cts(II,M).LE.X9) THEN
     tcc(II,M)=X(L1+79)*X(L1+75)*X(L1+111)
     tcm(II,M)=X(L1+79)
   ELSE IF(cts(II,M).LE.X10) THEN
     tcc(II,M)=X(L1+81)*X(L1+75)*X(L1+111)
     tcm(II,M)=X(L1+81)
   ELSE IF(cts(II,M).LE.X11) THEN
     tcc(II,M)=X(L1+83)*X(L1+75)*X(L1+111)
     tcm(II,M)=X(L1+83)
   ELSE IF(cts(II,M).LE.X12) THEN
     tcc(II,M)=X(L1+85)*X(L1+75)*X(L1+111)
     tcm(II,M)=X(L1+85)
   ELSE IF(cts(II,M).LE.X13) THEN
     tcc(II,M)=X(L1+87)*X(L1+75)*X(L1+111)
     tcm(II,M)=X(L1+87)
   ELSE IF(cts(II,M).LE.X14) THEN
     tcc(II,M)=X(L1+89)*X(L1+75)*X(L1+111)
     tcm(II,M)=X(L1+89)
   ELSE IF(cts(II,M).LE.X15) THEN
```

```
              tcc(II,M)=X(L1+91)*X(L1+75)*X(L1+111)
              tcm(II,M)=X(L1+91)
            ELSE IF(cts(II,M).LE.X16) THEN
              tcc(II,M)=X(L1+93)*X(L1+75)*X(L1+111)
              tcm(II,M)=X(L1+93)
            ELSE IF(cts(II,M).LE.X17) THEN
              tcc(II,M)=X(L1+95)*X(L1+75)*X(L1+111)
              tcm(II,M)=X(L1+95)
            ELSE IF(cts(II,M).LE.X18) THEN
              tcc(II,M)=X(L1+97)*X(L1+75)*X(L1+111)
              tcm(II,M)=X(L1+97)
            ELSE IF(cts(II,M).LE.X19) THEN
              tcc(II,M)=X(L1+99)*X(L1+75)*X(L1+111)
              tcm(II,M)=X(L1+99)
            ELSE IF(cts(II,M).LE.X20) THEN
              tcc(II,M)=X(L1+101)*X(L1+75)*X(L1+111)
              tcm(II,M)=X(L1+101)
            ELSE IF(cts(II,M).LE.X21) THEN
              tcc(II,M)=X(L1+103)*X(L1+75)*X(L1+111)
              tcm(II,M)=X(L1+103)
            ELSE IF(cts(II,M).LE.X22) THEN
              tcc(II,M)=X(L1+105)*X(L1+75)*X(L1+111)
              tcm(II,M)=X(L1+105)
            ELSE IF(cts(II,M).LE.X23) THEN
              tcc(II,M)=X(L1+107)*X(L1+75)*X(L1+111)
              tcm(II,M)=X(L1+107)
            ELSE IF(cts(II,M).LE.X24) THEN
              tcc(II,M)=X(L1+109)*X(L1+75)*X(L1+111)
              tcm(II,M)=X(L1+109)
            ELSE
              tcc(II,M)=X(L1+110)*X(L1+75)*X(L1+111)
              tcm(II,M)=X(L1+110)
            END IF
 3780    CONTINUE
 3790 CONTINUE

      DO 3797 II=1,IRD
         temp = 0.0D0
         DO 3794 M=1,nAL
            temp = temp + tcm (II, M)
 3794    CONTINUE
         tcmt (II) = temp

 3797 CONTINUE


C-----------------------------------------------------
C TOLL COLLECTION MACHINE MAINTENANCE COSTS
C-----------------------------------------------------

      DO 3820 II=1,IRD
         temp = 0.0D0
         DO 3812 J=1,nAL
            temp = temp + tcc(II,J)
 3812    CONTINUE

         tccc (II) = temp
```

```
         tccm (II) = temp * X(L1+112)
 3820 CONTINUE

C---------------------------------------------------------
C BUILDING AND REPAINTING EXPENSES
C RELEVANT EXPENSES TO OPERATION
C COST FOR MACHINE AND EQUIPMENT
C OTHERS
C---------------------------------------------------------

      DO 3860 II=1,IRD
         brco(II)=X(L1+113)*(oom(II)+tcmt(II))+X(L1+114)

 3860 CONTINUE

C---------------------------------------------------------
C OPERATION BUREAU OVERHEAD
C---------------------------------------------------------

      DO 3890 II=1,IRD
         obo(II) = reve(II) *X(L1+115)
 3890 CONTINUE

C---------------------------------------------------------
C HEADQUARTERS OVERHEAD
C---------------------------------------------------------

      DO 3930 II=1,IRD
         ho(II) = reve(II)*X(L1+116)
 3930 CONTINUE

C--------------------------------------------------------
C     REVENUE
C
C This calculate annual revenue
C                and
C                maintenance and operation costs.
C--------------------------------------------------------

      CALL TRACE (3, 'RVSF13', 'total costs calculation.')

C----------------------------------------------
C Calculate annual maintenance costs
C--------------------------------------------

      CALL TRACE (3, 'RVSF13', 'annual maintenance costs.')

      DO 4200 II=1,IRD
 4200    maint (II) = mcrc + mcrm + mcl + mcbr + mcbp1 (II) + mctm
     +                    + mcsc + mcoll (II) + mcot

C-------------------------------------------
C Calculate annual operation costs.
C------------------------------------------

      CALL TRACE (3, 'RVSF13', 'annual operation costs.')
```

```
      DO 4300 II=1,IRD
         oper(II)=ooo(II)+tccc(II)+tccm(II)+brco(II)+obo(II)+ho(II)
         aoper(II)=maint(II)+oper(II)
 4300    CONTINUE

C ---------------------------------------------------------------------
--
C save the values into the array

C       IF (0 < KP) THEN
C          DO 4900 II = 1, IRD
C             VCACHE (I, KT, KP, (II * 2) - 1) = reve  (II)
C             VCACHE (I, KT, KP, (II * 2)    ) = aoper (II)
C 4900     CONTINUE
C       ENDIF

C------------------------------------
C Calculate discounted net revenue.
C-------------------------------------

 5000 CALL TRACE (3, 'RVSF13', 'discount NP.')

      Y=0.00
      DO 5100 II=1,IRD

         IF (DABS (DR) <= 0.001D0) THEN
            AZ = 1.00
         ELSE
            AZ = ( DEXP (-DR * (rIBY + II    )) -
     +             DEXP (-DR * (rIBY + II - 1)) ) / (-DR)
         END IF
         Z = X (L1 + 117) - DR

         IF (DABS (Z) <= 0.001D0) THEN
            BZ = 1.00
         ELSE
            BZ = ( DEXP (Z * (rIBY + II    )) -
     +             DEXP (Z * (rIBY + II - 1)) ) / Z
         END IF
         AY = (reve (II) * AZ) - (aoper (II) * BZ)

         Y = Y + AY

 5100 CONTINUE

      CALL TRACE (3, 'RVSF13', 'finishing.')
      DEALLOCATE (cost, traf, tcc, tcm, cts)
      RETURN


      END
```

```
C IntPol.FOR
C modified by Toshiaki Hatakama in July, 1994.

C called only by CdFunc.FOR

C THIS ROUTINE INTERPOLATES THE BETA1 AND BETA2 VALUES OF THE
C PEARSON TABLE BY A METHOD OF LINEAR INTERPOLATION

C=================================================================
      SUBROUTINE INTPOL (PEARSN, RSKW, RKRT,
     +                   IY1, IY2,
     +                   IZ1, IZ2,
     +                   IPEARS,
     +                   SD, AM, RES)
C=================================================================

      IMPLICIT REAL*4(A-H,O-Z)
      INCLUDE 'DEBUG.CMN'
      REAL*4 PEARSN (NPEARS, *)

      RYDIF = PEARSN (IY2, IPEARS) - PEARSN (IY1, IPEARS)
      RZDIF = PEARSN (IZ2, IPEARS) - PEARSN (IZ1, IPEARS)

      RES = PEARSN (IY1, IPEARS) + (RKRT / 0.1D0) * RYDIF
      RES = AM + SD *
     + ( RES + (RSKW / 0.1D0) *
     +   (PEARSN (IZ1, IPEARS) + (RKRT / 0.1D0) * RZDIF - RES))

      RETURN
      END
```

```
C SPARSE.FOR
C "Sparse-Array" technology for super-large arrays
C

C initialize the size data (the first cell),
C and the dimension list (cell 2 and the rest),
C and the rest of the cells, just to be safe....
      SUBROUTINE SPA_INIT3 (THEARY, NSIZE, ND1, ND2, ND3)
      REAL*4 THEARY (*)
      INTEGER*4 NSIZE, ND1, ND2, ND3

      THEARY (1) = NSIZE ! how many elements in the array, really.
      THEARY (2) = 3     ! the number of dimensions.
      THEARY (3) = ND1   ! the 1st virtual dimension.
      THEARY (4) = ND2   ! the 2nd virtual dimension.
      THEARY (5) = ND3   ! the 3rd virtual dimension.

      DO 100 X = 6, NSIZE
  100    THEARY (X) = 0.0

      RETURN
      END


C for a given cell, set the value referenced by (x,y,z) to theVal...
C I wish FORTRAN supported Variable # of Parameters...
      SUBROUTINE SPA_SET3 (THEARY, THEVAL, ND1, ND2, ND3)
      REAL*4 THEARY (*), THEVAL
      INTEGER*4 ND1, ND2, ND3, KEY, HASH

      KEY = ( (ND1 - 1) * INT (THEARY (4)) + (ND2 - 1) )
     +                  * INT (THEARY (5)) +  ND3

      HASH = 6 + (MOD (KEY, INT ((THEARY (1) - 5) / 2)) * 2)

  100 IF (THEARY (HASH) == KEY) THEN
         THEARY (HASH + 1) = THEVAL
         RETURN
      ENDIF
      IF (THEARY (HASH) == 0.0) THEN
         IF (THEVAL == 0.0) THEN
C Never store a zero when just leaving it will do!
         ELSE
            THEARY (HASH) = KEY
            THEARY (HASH + 1) = THEVAL
         ENDIF
         RETURN
      ENDIF

      HASH = HASH + 2
      IF (INT (THEARY (1)) <= HASH) THEN
         HASH = 6
      END IF
```

```
      GOTO 100
      END


C get a value from the sparse array....
      REAL*4 FUNCTION SPA_GET3 (THEARY, ND1, ND2, ND3)
      REAL*4 THEARY (*)
      INTEGER*4 ND1, ND2, ND3, KEY, HASH


      KEY = ( (ND1 - 1) * INT (THEARY (4)) + (ND2 - 1) )
     +                  * INT (THEARY (5)) +  ND3

      HASH = 6 + (MOD (KEY, INT ((THEARY (1) - 5) / 2)) * 2)

  100 IF (THEARY (HASH) == KEY) THEN
         SPA_GET3 = THEARY (HASH + 1)
         RETURN
      ENDIF
      IF (THEARY (HASH) == 0.0) THEN
         SPA_GET3 = 0.0
         RETURN
      ENDIF

      HASH = HASH + 2
      IF (INT (THEARY (1)) <= HASH) THEN
         HASH = 6
      END IF

      GOTO 100
      END


C get a check-sum of a sparse array... just to be sure.
      REAL*4 FUNCTION SPA_SUM (THEARY, NSIZE)
      REAL*4 THEARY (*)

      SPA_SUM = 0.0D0
      IF (THEARY (1) == NSIZE) THEN
         DO 100 I = 1, NSIZE
            SPA_SUM = (SPA_SUM + THEARY (I)) * 2
            IF (1.0D15 < SPA_SUM) THEN
               SPA_SUM = SPA_SUM / 1.0D14
            ENDIF
  100    CONTINUE
      ELSE
         PRINT *, 'Array size is different than defined!'
      ENDIF

      RETURN
      END
```

```
C Trace.MJW
C 23mar94 MJW
C
C TRACE checks whether or not this particular call contains data
C which is desirable at this debug level, which is set in AMMA.INI
C If it is, then it displays the data on the console

      SUBROUTINE TRACE (NDEBUG, CPROC, MSG)
      CHARACTER CPROC*(*), MSG*(*)
      CHARACTER*8  THEDATE
      CHARACTER*11 THETIME

      INCLUDE 'DEBUG.CMN'

      CALL DATE (THEDATE)
      CALL TIME (THETIME)

      IF (IDEBUG .GE. NDEBUG) THEN
         WRITE (6, *) THEDATE, ' ', THETIME(1:5), ' ', CPROC, ': ',
     +                MSG
C        WRITE (7, *) THEDATE, ' ', THETIME(1:5), ' ', CPROC, ': ',
     +                MSG
      ENDIF
      RETURN
      END
```

```
C DEBUG.CMN
C 25mar94 MJW
C this is a blank common for keeping crucial info regarding the
program

C NWP is Number of Work Packages
C NRS is Number of Revenue Streams
C MAXDV is the MAXimum number of Discrete Variables for certain
arrays
C NPEARS is how many types of Pearson Distributions we know about
C IDEBUG is what level of debug output we want generated
C IERR is the system state, 0=ok, 1+=error->exit

      COMMON NWP, NRS, MAXDVC, MAXDVR, NPEARS, IDEBUG, IERR
```