ECONOMIC RISK QUANTIFICATION OF TOLL HIGHWAY PROJECTS

BY
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B.Eng., Hokkaido University, Japan, 1983

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We accept this thesis as conforming to the required standard

UNIVERSITY OF BRITISH COLUMBIA
July 1994

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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 $Y=g(X)$, where $Y$ is the derived variable and $X$ 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.

<table>
<thead>
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<td>Net Revenue Stream</td>
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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.
Chapter 1: Introduction

Analyst/Expert Input

* Precedence Relations among Work Packages and Revenue Streams
* Functions for Work Package Duration, Cost and Revenue Streams
* Subjective Estimates for Percentiles of Primary Variables and Correlation Matrices, and Shared Variables in Functions for Work Package Durations, Costs and Revenue Streams

W.P Durations  W.P Start Times  W.P Costs and Revenue Streams

Work Package/Revenue Stream Level

First Four Moments for Work Package and Revenue Stream Start Times, Work Package Durations, Cost and Net Revenue Streams

Project Performance Level

First four Moments for Project Duration, Cost and Revenue

Project Decision Level

First Four Moments for Project Net Present Value and Cumulative Distribution Function for Project Internal Rate of Return

Figure 1.1 Flowchart for the Analytical Approach
(Ranasinghe, 1990)
Chapter 1: Introduction

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 TIBRA 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;
Chapter 2: Analytical Model

(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](image)

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 \( (Q_0) \) in a base year is derived from a traffic forecast, traffic volume \( (Q_i) \) at year \( i \) is:

\[
Q_i = k_i/k_0 \times Q_0
\]  \hspace{1cm} (2.1)

where \( k_0 \) 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.

\[
\text{toll revenue} = \text{(traffic volume)} \times \text{(toll rate)} \hspace{1cm} (2.2)
\]

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 on-
site 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:
\[
\text{Financing} = (1-f) \times \text{current dollar expenditure of each work package.}
\]

(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.
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
Chapter 2: Analytical Model

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.

\[
WPC_i = f \cdot e^{(\theta_i - y)T_{ci}} \int_0^{T_{ci}} C_{oi}(\tau) \cdot e^{(\theta_i - y)\tau} d\tau
+ \int_0^{T_{p} - T_{ci}} e^{\theta_i T_{ci}} e^{r(T_p - T_{ci})} \int_0^{T_{ci}} C_{oi}(\tau) \cdot e^{(\theta_i - y)\tau} d\tau \cdot e^{rT_{ci}} dT
\]

(2.4)

where \(WPC_i\) is the discounted cost for the \(i\)th work package; \(C_{oi}(\tau)\) and \(C_i(\tau)\) are the functions for constant dollar cash flow and current dollar cash flow for the \(i\)th work package respectively (note: \(C_i(\tau) = C_{oi}(\tau) \cdot e^{\theta_{ci}(T_{ci} + \tau)}\)); \(T_{sci}\), \(T_{ci}\) 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; \(\theta_{ci}\), \(r\) and \(y\) are inflation, interest and discount rates, which are invariant with time, respectively. See figure 2.7 for reference.
(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:

$$ NRS_i = e^{-yt} \int_{0}^{T_f} (R_i(\tau) - M_i(\tau)) \cdot e^{-\gamma \tau} d\tau $$  \hspace{1cm} (2.5)

where $NRS_i$ is the discounted $i$th net revenue stream; $R_i(\tau)$ is the function for current dollar cash flow for the $i$th 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: $M_i(t) = M_0(t) \cdot e^{\theta t - (T_{SRi} + t)}$; $T_{SRi}$ and $T_{Rs}$ are revenue stream start time and duration of the revenue stream; $\theta$, $r$, and $y$ are inflation and discount rates respectively. See Figure 2.8 for reference.

![Figure 2.8 Cash Flow Diagram for Net Revenue Stream](image)

Figure 2.9 shows cost and revenue factors at the work package/revenue stream level. They are described in more detail later.
Chapter 2: Analytical Model

Toll Highway Project

- revenue
  - toll revenue streams

- maintenance and operation costs
  - maintenance costs
    - road cleaning
    - road maintenance
    - road lighting
    - bridge maintenance
      - repairing bridge
      - repainting bridge
    - tunnel maintenance
    - snow and ice control
    - overlay
    - others
  - operation costs
    - labor costs
      - operation office overhead
      - operation bureau overhead
      - headquarters overhead
  - consignment costs
    - toll collection
    - machine maintenance
  - others
    - building and repainting
    - relevant expenses of operation
    - cost for machine and equipment
    - others

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:

\[ T_j = \sum_{i=1}^{n} WPD_{ij} \]  \hspace{1cm} (2.6)

where \( T_j \) is the duration of the \( j \)th path and \( WPD_{ij} \) is the duration of the \( i \)th work package on the \( j \)th 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),

\[ \rho_{ij} = \frac{\sum_{k=1}^{m} \sigma_{yk}^2}{\sigma_i \sigma_j} \]  \hspace{1cm} (2.7)

where \( \sigma_{yk}^2 \) is the variance of the \( k \)th common activity on paths \( i \) and \( j \), \( \sigma_i \) and \( \sigma_j \) are the standard deviations for duration of paths \( i \) and \( j \), and \( \rho_{ij} \) is the correlation
coefﬁcient between paths i and j. Those paths with \( \rho > \rho_0 \) are represented by path i (the longest path) from the assumption that \( \rho_0 = 0.5 \) 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

\[
p(t) = P(T_1 \leq t)P(T_2 \leq t)\ldots P(T_r \leq t) \tag{2.8}
\]

where \( P(T_1 \leq t)P(T_2 \leq t)\ldots P(T_r \leq t) \) 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:

\[
\text{Discounted project cost} = \sum_{i=1}^{n} \text{WPC}_i \tag{2.9}
\]

(3) Project Revenue
The discounted project revenue is described as follows:

\[
\text{Discounted project revenue} = \sum_{i=1}^{n} \text{NRS}_i \tag{2.10}
\]
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

\[ \text{NPV} = \text{Discounted Project Revenue} - \text{Discounted Project Cost} \]  

(2.11)

(2) Internal Rate of Return

\[ \text{IRR} = \text{Discount Rate when NPV} = 0 \]  

(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.

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

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.
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.
### Table 2.2 Input Data for Revenue Streams

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

where \(D\) : deterministic variable  
\(P\) : probabilistic variable

In its simplest form, toll revenue is computed as:

\[
R = Q \times r
\]  
(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 1, exit at m, pay fare \(r_{im}\)).

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)

Table 2.3 Interchange Pair Daily Traffic Volume

Table 2.4 Interchange Pair Toll

Table 2.5 Interchange Pair Annual Toll Revenue

\[
R_{i,j} = \sum_{l=1}^{4} \sum_{m=5}^{5} Q(i,l,m,j) \cdot r(i,l,m,j) \text{ } (2.14)
\]
Chapter 2: Analytical Model

where

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

\( Q_{(i,i,m,j)} \) : interchange pair traffic volume between

interchanges \#1 and \#m for vehicle type \#j in

year \( i \)

\( r_{(i,i,m,j)} \) : interchange pair toll between interchanges \#1

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
Chapter 2: Analytical Model

- 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
Chapter 2: Analytical Model

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:

\[
  r = r_p d + r_f
\]

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
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.

<table>
<thead>
<tr>
<th>class</th>
<th>description</th>
<th>toll ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>class 1</td>
<td>Light motor vehicle</td>
<td>a</td>
</tr>
<tr>
<td>Class 2</td>
<td>Ordinary motor vehicle</td>
<td>1.00</td>
</tr>
<tr>
<td>class 3</td>
<td>Medium-sized motor vehicle</td>
<td>b</td>
</tr>
<tr>
<td>class 4</td>
<td>Large-sized motor vehicle</td>
<td>c</td>
</tr>
<tr>
<td>class 5</td>
<td>Special large-sized motor vehicle</td>
<td>d</td>
</tr>
</tbody>
</table>

Table 2.6 Vehicle Type and Toll Ratio
For both cases, the toll rate is described as:

\[ t_{oi} = \alpha_i \cdot t_{oi} \quad (2.16) \]

where \( t_{oi} \) and \( t_{oi} \) are the toll rates in base year and year \( i \) respectively, and \( \alpha_i \) 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. \( \alpha_i \) are sometimes described as \( \alpha_i = (1 + \alpha)^{-1} \), where \( \alpha \) is average annual growth rate.

\( \alpha_i \) for both cases looks like Figures 2.14 and 2.15.
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:
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- 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.

$$P_{TOLL} = \sum_{i=1}^{nrv} \sum_{j=1}^{rvd(i)} \sum_{k=1}^{nic(i)} \sum_{l=1}^{nvt(i)} \sum_{m=1}^{R(i,j,k,l,m)}$$

$$= \sum_{i=1}^{nrv} \sum_{j=1}^{rvd(i)-1} \sum_{k=1}^{nic(i)-1} \sum_{l=1}^{nvt(i)} \sum_{m=1}^{Q(i,k,l,m)} \frac{k_{(i,j)}}{k_{(i,1)}} \cdot r_{(i,k,l,m)} \cdot q_{(i,j)} \times 365$$

(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 jth 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
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\( r(i, k, l, m) \) : 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 |
| \( rvd(i) \) | 2 |
| \( rvd(2) \) | 3 |
| \( nic(i) \) | 2 |
| \( nic(2) \) | 3 |
| \( nvt(i) \) | 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)
According to equation (2.18), toll revenues are shown in Tables (2.16) to (2.26)

Revenue Stream #1:

Table 2.16
Annual Revenue ($ million)
$14.60

Table 2.17
Annual Revenue ($ million)
$30.66
### Chapter 2: Analytical Model

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

<table>
<thead>
<tr>
<th>I.C.#2</th>
<th>I.C.#1</th>
<th>15.45</th>
</tr>
</thead>
</table>

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

<table>
<thead>
<tr>
<th>I.C.#2</th>
<th>I.C.#1</th>
<th>32.45</th>
</tr>
</thead>
</table>

Revenue Stream #2:

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

<table>
<thead>
<tr>
<th>I.C.#2</th>
<th>I.C.#1</th>
<th>5.69</th>
<th>18.98</th>
<th>42.52</th>
</tr>
</thead>
</table>

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

<table>
<thead>
<tr>
<th>I.C.#2</th>
<th>I.C.#1</th>
<th>10.63</th>
<th>37.20</th>
<th>56.94</th>
</tr>
</thead>
</table>

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

<table>
<thead>
<tr>
<th>I.C.#2</th>
<th>I.C.#1</th>
<th>5.95</th>
<th>19.82</th>
<th>44.40</th>
</tr>
</thead>
</table>

#### Table 2.23
Annual Revenue ($ million) \( R_{(2,2,k,1,2)} \)

<table>
<thead>
<tr>
<th>I.C.#2</th>
<th>I.C.#1</th>
<th>11.10</th>
<th>38.85</th>
<th>59.47</th>
</tr>
</thead>
</table>

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

<table>
<thead>
<tr>
<th>I.C.#2</th>
<th>I.C.#1</th>
<th>6.21</th>
<th>20.68</th>
<th>46.33</th>
</tr>
</thead>
</table>

#### Table 2.25
Annual Revenue ($ million) \( R_{(2,3,k,1,2)} \)

<table>
<thead>
<tr>
<th>I.C.#2</th>
<th>I.C.#1</th>
<th>11.58</th>
<th>40.54</th>
<th>62.05</th>
</tr>
</thead>
</table>

Then, total revenues are:

<table>
<thead>
<tr>
<th>Total Revenue of RVS #1</th>
<th>$93.16 million</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Revenue of RVS #2</td>
<td>$538.94 million</td>
</tr>
<tr>
<td>Total</td>
<td>$632.10 million</td>
</tr>
</tbody>
</table>

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            |
| tunnel maintenance  | bridge repainting        |
| snow and ice        |                          |
| overlay             |                          |
| others              |                          |

Table 2.27 Maintenance Costs
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<table>
<thead>
<tr>
<th>labor costs</th>
<th>operation office overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>operation bureau overhead</td>
</tr>
<tr>
<td></td>
<td>headquarters overhead</td>
</tr>
<tr>
<td>consignment costs</td>
<td>toll collection</td>
</tr>
<tr>
<td></td>
<td>toll collection machine</td>
</tr>
<tr>
<td></td>
<td>maintenance</td>
</tr>
<tr>
<td>others</td>
<td>building and repairs</td>
</tr>
<tr>
<td></td>
<td>relevant expenses of operation</td>
</tr>
<tr>
<td></td>
<td>cost of machine and equipment</td>
</tr>
<tr>
<td></td>
<td>others</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th></th>
<th>2 Lanes</th>
<th>4 lanes</th>
<th>6 lanes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge</td>
<td>(l_{B1})</td>
<td>(l_{B4})</td>
<td>(l_{B6})</td>
<td>(l_B = l_{B1} + l_{B4} + l_{B6})</td>
</tr>
<tr>
<td>Tunnel</td>
<td>(l_{T1})</td>
<td>(l_{T4})</td>
<td>(l_{T6})</td>
<td>(l_T = l_{T1} + l_{T4} + l_{T6})</td>
</tr>
<tr>
<td>earthwork</td>
<td>(l_{E1})</td>
<td>(l_{E4})</td>
<td>(l_{E6})</td>
<td>(l_E = l_{E1} + l_{E4} + l_{E6})</td>
</tr>
<tr>
<td>Total</td>
<td>(l_2 = l_{B1} + l_{T1} + l_{E1})</td>
<td>(l_4 = l_{B4} + l_{T4} + l_{E4})</td>
<td>(l_6 = l_{B6} + l_{T6} + l_{E6})</td>
<td>(l = l_2 + l_4 + l_6)</td>
</tr>
</tbody>
</table>

Table 2.29 Road Length
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Table 2.30 Tunnel Length by Ventilation Methods

<table>
<thead>
<tr>
<th>ventilation</th>
<th>jet fan</th>
<th>others</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>$l_{D}$</td>
<td>$l_{f}$</td>
<td>$l_{o}$</td>
<td>$l_{T}$</td>
</tr>
</tbody>
</table>

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)**

Legend:
- : earth work
- : tunnel
- : bridge
- : road direction
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<table>
<thead>
<tr>
<th></th>
<th>2 Lanes</th>
<th>4 lanes</th>
<th>6 lanes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge</td>
<td>0</td>
<td>b1</td>
<td>0</td>
<td>b1</td>
</tr>
<tr>
<td>Tunnel</td>
<td>0</td>
<td>t1+t2</td>
<td>0</td>
<td>t1+t2</td>
</tr>
<tr>
<td>earthwork</td>
<td>0</td>
<td>e2+e3+e4</td>
<td>e1</td>
<td>e1+e2+e3+e4</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>b1+t1+t2+e2+e3+e4</td>
<td>e1</td>
<td>L</td>
</tr>
</tbody>
</table>

Table 2.31 Road Length (Example)

<table>
<thead>
<tr>
<th></th>
<th>jet fan</th>
<th>others</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>no ventilation</td>
<td>t2</td>
<td>0</td>
<td>t1+t2</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>the number of lanes</th>
<th>cost ($/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>$c_{t1}$</td>
</tr>
<tr>
<td>4 or more</td>
<td>$c_{t4}$</td>
</tr>
</tbody>
</table>

Table 2.33 Road cleaning Costs

Road Cleaning Costs = $c_{t1} \times l_2 + c_{t4} \times (l_4 + l_6)$ \hspace{1cm} (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
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include pavement repair, road marking, roadside maintenance, planting, and so on.

Earth work length

\[ \text{earth work length} = \text{road length} - \text{bridge and tunnel length} \quad (2.19) \]

Input data are as follows.

<table>
<thead>
<tr>
<th>the number of lanes</th>
<th>cost ($/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>( C_{m2} )</td>
</tr>
<tr>
<td>4</td>
<td>( C_{m4} )</td>
</tr>
<tr>
<td>6</td>
<td>( C_{m6} )</td>
</tr>
</tbody>
</table>

Table 2.34 Road Maintenance Costs

\[ \text{road maintenance costs} = C_{m2} \times l_{E2} + C_{m4} \times l_{E4} + C_{m6} \times l_{E6} \quad (2.20) \]

(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.

<table>
<thead>
<tr>
<th>the number of lanes</th>
<th>cost ($/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 or 2</td>
<td>( a_1 )</td>
</tr>
<tr>
<td>4 or 6</td>
<td>( a_4 )</td>
</tr>
</tbody>
</table>

Table 2.35 Road Lighting Costs

\[ \text{road lighting costs} = a_1 \times (l_{B2} + l_{E2}) + a_4 \times \{(l_{B4} + l_{B6}) + (l_{E4} + l_{E6})\} \quad (2.21) \]

(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.

<table>
<thead>
<tr>
<th>the number of lanes</th>
<th>cost ($/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>$c_{r2}$</td>
</tr>
<tr>
<td>4</td>
<td>$c_{r4}$</td>
</tr>
<tr>
<td>6</td>
<td>$c_{r6}$</td>
</tr>
</tbody>
</table>

Table 2.36 Bridge Maintenance (Repairing) Costs

bridge repair costs = $c_{r2} \times l_b + c_{r4} \times l_b + c_{r6} \times l_b$  

(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 $n_1$ years (for this thesis, $n_1$ equals 7).

Input data are as follows.

<table>
<thead>
<tr>
<th>the number of lanes</th>
<th>cost ($/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>$c_{p2}$</td>
</tr>
<tr>
<td>4</td>
<td>$c_{p4}$</td>
</tr>
<tr>
<td>6</td>
<td>$c_{p6}$</td>
</tr>
</tbody>
</table>

Table 2.37 Bridge Maintenance (Repainting) Costs

bridge repaint costs = $c_{p2} \times l_b + c_{p4} \times l_b + c_{p6} \times l_b$  

(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.

<table>
<thead>
<tr>
<th>ventilation methods</th>
<th>cost ($/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>no ventilation</td>
<td>$C_n$</td>
</tr>
<tr>
<td>jet fan</td>
<td>$C_v$</td>
</tr>
<tr>
<td>others</td>
<td>$C_o$</td>
</tr>
</tbody>
</table>

Table 2.38 Tunnel Maintenance Costs

\[
tunnel \text{ maintenance} = 2(C_n \times l_{n} + C_v \times l_{v} + C_o \times l_o) \quad (2.24)
\]

(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.
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<table>
<thead>
<tr>
<th>weather condition</th>
<th>cost ($/km/2lanes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>area of heavy snowfall (1)</td>
<td>$C_{sh}$</td>
</tr>
<tr>
<td>area of ordinary snowfall (2)</td>
<td>$C_{so}$</td>
</tr>
</tbody>
</table>

Table 2.39 Snow and Ice Control Costs

\[
\text{snow and ice control} = c_{sh} \times (l_2 + 2l_4 + 3l_6) \quad \text{or,} \\
\quad c_{so} \times (l_2 + 2l_4 + 3l_6)
\]

(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 $n_2$ years (for this thesis, $n_2$ equals 12).

Input data are as follows.

<table>
<thead>
<tr>
<th>the number of lanes</th>
<th>cost ($/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>$C_{o2}$</td>
</tr>
<tr>
<td>4</td>
<td>$C_{o4}$</td>
</tr>
<tr>
<td>6</td>
<td>$C_{o6}$</td>
</tr>
</tbody>
</table>

Table 2.40 Overlay Costs

\[
\text{overlay} : l_2 \times c_{o2} + l_4 \times c_{o4} + l_6 \times c_{o6}
\]

(2.26)
(9) Other Indirect Maintenance Costs

Other Indirect Maintenance Costs

\[ \{\text{total of costs for (1) to (6)}\} \times \beta \quad (2.27) \]

where

\[ \beta \quad : \text{parameter for other indirect maintenance costs} \]

### 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.
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57

traffic volume (vehicles/day) | A | B | C | D | E | sum  
---|---|---|---|---|---|---
0 to t01 | a1 | b1 | c1 | d1 | e1 | S1  
t01 to t02 | a2 | b2 | c2 | d2 | e2 | S2  
t02 to t03 | a3 | b3 | c3 | d3 | e3 | S3  
t03 to t04 | a4 | b4 | c4 | d4 | e4 | S4  
t04 to t05 | a5 | b5 | c5 | d5 | e5 | S5  
t05 or more | a6 | b6 | c6 | d6 | e6 | S6  

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.

<table>
<thead>
<tr>
<th></th>
<th>cost ($/person)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>director</td>
</tr>
<tr>
<td>B</td>
<td>vice-director</td>
</tr>
<tr>
<td>C</td>
<td>chief</td>
</tr>
<tr>
<td>D</td>
<td>clerk or engineer</td>
</tr>
<tr>
<td>E</td>
<td>worker</td>
</tr>
</tbody>
</table>

Table 2.42 Labour Cost for Operation Office

For example, if traffic volume is between t03 and t04, 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.

\[
\text{Operation Bureau Overhead} = R \times \alpha_2
\]

(2.29)

where

\[ \alpha_2 : \text{parameter for labor costs (operation bureau overhead)} \]

(3) Labor Costs (Headquarters Overhead)

These are labor costs for headquarters.

\[
\text{Headquarters Overhead} = R \times \alpha_3
\]

(2.30)

where

\[ \alpha_3 : \text{parameter for labour costs (headquarters overhead)} \]

(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.

\[ \alpha_6 : \text{labour cost ($/person)} \]

\[ \alpha_5 : \text{(closed system) parameter for consignment costs (toll collection)} \]

\[ \alpha_6 : \text{(open system) parameter for consignment costs (toll collection)} \]
### Table 2.43 Manpower Required for Toll Collection

<table>
<thead>
<tr>
<th>closed system</th>
<th>open system</th>
</tr>
</thead>
<tbody>
<tr>
<td>traffic volume (vehicles/day)</td>
<td>clerk</td>
</tr>
<tr>
<td>0 to ( t_{11} )</td>
<td>( x_1 )</td>
</tr>
<tr>
<td>( t_{11} ) to ( t_{12} )</td>
<td>( x_2 )</td>
</tr>
<tr>
<td>( t_{12} ) to ( t_{13} )</td>
<td>( x_3 )</td>
</tr>
<tr>
<td>( t_{13} ) to ( t_{14} )</td>
<td>( x_4 )</td>
</tr>
<tr>
<td>( t_{14} ) to ( t_{15} )</td>
<td>( x_5 )</td>
</tr>
<tr>
<td>( t_{15} ) to ( t_{16} )</td>
<td>( x_6 )</td>
</tr>
<tr>
<td>( t_{16} ) to ( t_{17} )</td>
<td>( x_7 )</td>
</tr>
<tr>
<td>( t_{17} ) to ( t_{18} )</td>
<td>( x_8 )</td>
</tr>
<tr>
<td>( t_{18} ) to ( t_{19} )</td>
<td>( x_9 )</td>
</tr>
<tr>
<td>( t_{19} ) to ( t_{20} )</td>
<td>( x_{10} )</td>
</tr>
<tr>
<td>( t_{20} ) to ( t_{21} )</td>
<td>( x_{11} )</td>
</tr>
<tr>
<td>( t_{21} ) to ( t_{22} )</td>
<td>( x_{12} )</td>
</tr>
<tr>
<td>( t_{22} ) to ( t_{23} )</td>
<td>( x_{13} )</td>
</tr>
<tr>
<td>( t_{23} ) to ( t_{24} )</td>
<td>( x_{14} )</td>
</tr>
<tr>
<td>( t_{24} ) to ( t_{25} )</td>
<td>( x_{15} )</td>
</tr>
<tr>
<td>( t_{25} ) to ( t_{26} )</td>
<td>( x_{16} )</td>
</tr>
<tr>
<td>( t_{26} ) to ( t_{27} )</td>
<td>( x_{17} )</td>
</tr>
<tr>
<td>( t_{27} ) or more</td>
<td>( x_{18} )</td>
</tr>
<tr>
<td>( t_{48} ) or more</td>
<td>( x_{19} )</td>
</tr>
</tbody>
</table>

Table 2.43 Manpower Required for Toll Collection

a. closed system

Consignment Costs (Toll Collection)

\[
= \{\Sigma(\text{the number of clerks}) \times c_o\} \times \alpha_5 \quad (2.31)
\]

b. open system

Consignment Costs (Toll Collection)

\[
= \{\Sigma(\text{the number of clerks}) \times c_o\} \times \alpha_6 \quad (2.32)
\]
(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)

\[ = \text{Consignment Costs (Toll Collection)} \times \alpha_7 \]  
\[ (2.33) \]

(open system)

Consignment Costs (Toll Collection Machine Maintenance)

\[ = \text{Consignment Costs (Toll Collection)} \times \alpha_8 \]  
\[ (2.34) \]

where

\[ \alpha_7 : (\text{closed system}) \]

parameter for consignment costs
(toll collection machine maintenance)

\[ \alpha_8 : (\text{open system}) \]

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.
Chapter 2: Analytical Model

The total of (6) to (9)

\[ \{c_{op} \times (o_s + t_s) + c_{of}\} \]  \hspace{1cm} (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.

\[ P_{M\&O} = \sum_{i=1}^{nrv} \sum_{j=1}^{nm} \sum_{k=1}^{no} (M(i,j) + O(i,k)) \]  \hspace{1cm} (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.

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

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 ($\theta_k$ and $\theta_m$), 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.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>$\sigma$</th>
<th>$\sqrt{\beta_1}$</th>
<th>$\beta_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta_k$</td>
<td>4.311%</td>
<td>1.093%</td>
<td>2.0</td>
<td>9.4</td>
</tr>
<tr>
<td>$\theta_m$</td>
<td>4.311%</td>
<td>1.093%</td>
<td>2.0</td>
<td>9.4</td>
</tr>
<tr>
<td>$r$</td>
<td>6.500%</td>
<td>0.163%</td>
<td>0.1</td>
<td>5.9</td>
</tr>
<tr>
<td>$y$</td>
<td>6.500%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$f$</td>
<td>0.000</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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

$\sqrt{\beta_1}$ and $\beta_2$ 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.
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.
Chapter 3: Application

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.

<table>
<thead>
<tr>
<th>category</th>
<th>2.5%</th>
<th>5.0%</th>
<th>50.0%</th>
<th>95.0%</th>
<th>97.5%</th>
<th>$\sqrt{\beta}$</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>survey &amp; design</td>
<td>0.900</td>
<td>0.910</td>
<td>1.000</td>
<td>1.180</td>
<td>1.200</td>
<td>0.6</td>
<td>2.4</td>
</tr>
<tr>
<td>land acquisition</td>
<td>0.900</td>
<td>0.910</td>
<td>1.000</td>
<td>1.180</td>
<td>1.200</td>
<td>2.0</td>
<td>8.0</td>
</tr>
<tr>
<td>earth work</td>
<td>0.850</td>
<td>0.870</td>
<td>1.000</td>
<td>1.450</td>
<td>1.500</td>
<td>0.9</td>
<td>2.8</td>
</tr>
<tr>
<td>bridge</td>
<td>0.900</td>
<td>0.910</td>
<td>1.000</td>
<td>1.180</td>
<td>1.200</td>
<td>0.6</td>
<td>2.4</td>
</tr>
<tr>
<td>pavement</td>
<td>0.900</td>
<td>0.910</td>
<td>1.000</td>
<td>1.100</td>
<td>1.100</td>
<td>0.0</td>
<td>2.2</td>
</tr>
<tr>
<td>IC</td>
<td>0.850</td>
<td>0.870</td>
<td>1.000</td>
<td>1.450</td>
<td>1.500</td>
<td>0.9</td>
<td>2.8</td>
</tr>
<tr>
<td>ancillary facilities</td>
<td>0.900</td>
<td>0.910</td>
<td>1.000</td>
<td>1.100</td>
<td>1.100</td>
<td>0.0</td>
<td>2.2</td>
</tr>
<tr>
<td>appurtenant work</td>
<td>0.900</td>
<td>0.910</td>
<td>1.000</td>
<td>1.450</td>
<td>1.500</td>
<td>1.1</td>
<td>3.2</td>
</tr>
<tr>
<td>building &amp; repairing</td>
<td>0.900</td>
<td>0.910</td>
<td>1.000</td>
<td>1.100</td>
<td>1.100</td>
<td>0.0</td>
<td>2.2</td>
</tr>
<tr>
<td>overhead</td>
<td>0.900</td>
<td>0.910</td>
<td>1.000</td>
<td>1.180</td>
<td>1.200</td>
<td>0.6</td>
<td>2.4</td>
</tr>
<tr>
<td>revenue</td>
<td>0.900</td>
<td>0.910</td>
<td>1.000</td>
<td>1.100</td>
<td>1.100</td>
<td>0.0</td>
<td>2.2</td>
</tr>
</tbody>
</table>

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

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

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
### Table 3.5 Deterministic Values for Work Package Durations and Costs

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

*Note: WP# refers to Work Package Numbers.*
<table>
<thead>
<tr>
<th>WP#</th>
<th>Duration (year)</th>
<th>Constant Dollar Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E[WPD]</td>
<td>σWP</td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
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Table 3.6 Statistics for Work Package Durations and Costs
### Table 3.7 Discounted Work Package Costs

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<td><strong>Total</strong></td>
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</table>

"Chapter 3: Application"
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.

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<th>5.0%</th>
<th>50.0%</th>
<th>95.0%</th>
<th>97.5%</th>
<th>( \sqrt{\beta} )</th>
<th>( \beta )</th>
</tr>
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<td>1.000</td>
<td>1.350</td>
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<tr>
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<td>0.910</td>
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<td>1.200</td>
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<td>1.060</td>
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<tr>
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<td>0.750</td>
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<td>1.090</td>
<td>1.100</td>
<td>-1.0</td>
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<td>1.000</td>
<td>1.070</td>
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<td></td>
<td></td>
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<tr>
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<td>1.250</td>
<td>1.300</td>
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<td>0.910</td>
<td>1.000</td>
<td>1.250</td>
<td>1.300</td>
<td>1.0</td>
<td>3.4</td>
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<tr>
<td>(operation cost)</td>
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<td>1.300</td>
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<td>1.250</td>
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<td>1.250</td>
<td>1.300</td>
<td>1.0</td>
<td>3.4</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>I.C. #1</th>
<th>I.C. #2</th>
<th>I.C. #3</th>
<th>I.C. #4</th>
<th>I.C. #5</th>
<th>I.C. #6</th>
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Table 3.9 Interchange Distances

(Unit : Dollar)

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<th>I.C. #3</th>
<th>I.C. #4</th>
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<td>2.0</td>
<td>1.0</td>
<td>2.0</td>
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</table>

Table 3.10 Toll for Light Motor Vehicle
Chapter 3: Application

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

<table>
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<th>Daily Traffic Volume (vehicles/day)</th>
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<td>0</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
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<tr>
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<td>11,419</td>
</tr>
<tr>
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This table shows the daily traffic volume at different years and RVS (Right of Way Station) numbers between Interchange #1 and #2.
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Table 3.16 Spot Traffic Volume between Interchange #2 and #3
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Table 3.17 Spot Traffic Volume between Interchange #3 and #4
### Chapter 3: Application

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

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Table 3.18 Spot Traffic Volume between Interchange #4 and #5
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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
Chapter 3: Application

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

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

<table>
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<th>annual operation costs ($)</th>
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Table 3.20 Deterministic Annual Revenues and Annual Maintenance and Operating Costs (Constant Dollar)
### Table 3.21 Discounted Revenues for the Original Feasibility Analysis

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### 3.2.4 Calculation Results

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

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<th>kurtosis</th>
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Table 3.22 Statistics for Discounted Work Package Costs
### Chapter 3: Application

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<th>kurtosis</th>
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<td>8</td>
<td>124,448,704</td>
<td>23,890,288</td>
<td>0.210</td>
<td>2.053</td>
</tr>
<tr>
<td>9</td>
<td>305,117,600</td>
<td>69,715,768</td>
<td>0.246</td>
<td>2.073</td>
</tr>
</tbody>
</table>

Table 3.23 Statistics for Discounted Revenues

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>σWPD</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Duration (month)</td>
<td>135.77</td>
<td>7.21</td>
<td>0.700</td>
<td>3.600</td>
</tr>
<tr>
<td>Project Cost ($)</td>
<td>717,174,144</td>
<td>39,283,612</td>
<td>0.876</td>
<td>4.100</td>
</tr>
<tr>
<td>Project Revenue ($)</td>
<td>705,507,584</td>
<td>77,309,352</td>
<td>0.190</td>
<td>1.411</td>
</tr>
<tr>
<td>NPV($)</td>
<td>-11,666,560</td>
<td>86,717,576</td>
<td>0.053</td>
<td>2.043</td>
</tr>
</tbody>
</table>

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.

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

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.
Table 3.26 Cumulative Probability of Project Cost

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

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.

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

Table 3.27 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.
Chapter 3: Application

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

Table 3.28 Cumulative Probability of Project Net Present Value

Figure 3.13 Cumulative Probability of Project Net Present Value
Chapter 3: Application

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),

$$\frac{\Delta Y}{Y} \approx \sum_i S_i \frac{\Delta X_i}{X_i}$$

(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),

$$S_i = \frac{\partial Y}{\partial X_i} \frac{X_i}{Y}$$

(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.

\[
\frac{\Delta Y}{Y} \approx \sum_i S_i \frac{\Delta Z_i}{Z_i}
\]  

(3.3)

\[
S_i = \frac{\partial Y}{\partial Z_i} \frac{Z_i}{Y}
\]

(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.
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(Deterministic Duration Estimate : 1 year)

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

Table 3.29 Total sensitivity Coefficients for RVS #1

(Deterministic Duration Estimate : 1 year)

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

Table 3.30 Total sensitivity Coefficients for RVS #2
Chapter 3: Application

(Deterministic Duration Estimate : 1 year)

<table>
<thead>
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<th>Ranking</th>
<th>Primary Variable</th>
<th>$S_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>parameter (toll rate growth)</td>
<td>1.28879</td>
</tr>
<tr>
<td>2</td>
<td>RVS early start time</td>
<td>-0.675688</td>
</tr>
<tr>
<td>3</td>
<td>toll (Ic#2-#6, vehicle-2)</td>
<td>0.325839</td>
</tr>
<tr>
<td>3</td>
<td>traffic volume (Ic#2-#6, vehicle-2)</td>
<td>0.325839</td>
</tr>
<tr>
<td>5</td>
<td>labor cost (toll collection)</td>
<td>-0.166774</td>
</tr>
<tr>
<td>5</td>
<td>parameter (consignment cost of toll collection)</td>
<td>-0.166774</td>
</tr>
<tr>
<td>7</td>
<td>toll (Ic#2-#5, vehicle-2)</td>
<td>0.125868</td>
</tr>
<tr>
<td>7</td>
<td>traffic volume (Ic#2-#5, vehicle-2)</td>
<td>0.125868</td>
</tr>
<tr>
<td>9</td>
<td>toll (Ic#3-#6, vehicle-2)</td>
<td>0.123317</td>
</tr>
<tr>
<td>9</td>
<td>traffic volume</td>
<td>0.123317</td>
</tr>
<tr>
<td>9</td>
<td>toll (Ic#3-#6, vehicle-2)</td>
<td>0.123317</td>
</tr>
<tr>
<td>11</td>
<td>inflation rate</td>
<td>-0.120515</td>
</tr>
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</table>

Table 3.31 Total sensitivity Coefficients for RVS #3

(Deterministic Duration Estimate : 1 year)

<table>
<thead>
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<th>Primary Variable</th>
<th>$S_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>parameter (toll rate growth)</td>
<td>1.28737</td>
</tr>
<tr>
<td>2</td>
<td>RVS early start time</td>
<td>-0.755225</td>
</tr>
<tr>
<td>3</td>
<td>toll (Ic#2-#6, vehicle-2)</td>
<td>0.313043</td>
</tr>
<tr>
<td>3</td>
<td>traffic volume (Ic#2-#6, vehicle-2)</td>
<td>0.313043</td>
</tr>
<tr>
<td>5</td>
<td>labor cost (toll collection)</td>
<td>-0.169169</td>
</tr>
<tr>
<td>5</td>
<td>parameter (consignment cost of toll collection)</td>
<td>-0.169169</td>
</tr>
<tr>
<td>7</td>
<td>inflation rate</td>
<td>-0.133920</td>
</tr>
<tr>
<td>8</td>
<td>toll (Ic#2-#5, vehicle-2)</td>
<td>0.125191</td>
</tr>
<tr>
<td>8</td>
<td>traffic volume (Ic#2-#5, vehicle-2)</td>
<td>0.125191</td>
</tr>
<tr>
<td>10</td>
<td>toll (Ic#3-#6, vehicle-2)</td>
<td>0.105923</td>
</tr>
<tr>
<td>10</td>
<td>traffic volume (Ic#3-#6, vehicle-2)</td>
<td>0.105923</td>
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</table>

Table 3.32 Total sensitivity Coefficients for RVS #4
### (Deterministic Duration Estimate: 2 year)

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

**Table 3.33 Total sensitivity Coefficients for RVS #5**
(Deterministic Duration Estimate : 2 year)

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

Table 3.34 Total sensitivity Coefficients for RVS #6
## Chapter 3: Application

(Deterministic Duration Estimate: 4 year)

<table>
<thead>
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<th>Ranking</th>
<th>Primary Variable</th>
<th>$S_i$</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>RVS early start time</td>
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</tr>
<tr>
<td>2</td>
<td>parameter (traffic growth)</td>
<td>-0.992122</td>
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<tr>
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</tr>
<tr>
<td>3</td>
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</tr>
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<td>4</td>
<td>parameter (toll rate growth)</td>
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</tr>
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</tr>
<tr>
<td>5</td>
<td>parameter (toll rate growth)</td>
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</tr>
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<td></td>
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</tr>
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<td>6</td>
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<td>8</td>
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<tr>
<td>8</td>
<td>parameter (toll rate growth)</td>
<td>0.315163</td>
</tr>
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<td></td>
<td>the fourth year</td>
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<tr>
<td>10</td>
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<td>11</td>
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<td>13</td>
<td>parameter (consignment cost of toll collection)</td>
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<td>traffic volume (Ic#1-#6, vehicle-2)</td>
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Table 3.35 Total sensitivity Coefficients for RVS #7
(Deterministic Duration Estimate : 4 year)

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<th>Primary Variable</th>
<th>$S_i$</th>
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<td>1</td>
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</tr>
<tr>
<td>2</td>
<td>parameter (traffic growth) the first year</td>
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<td>4</td>
<td>parameter (traffic growth) the second year</td>
<td>0.323165</td>
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<td>parameter (traffic growth) the third year</td>
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<td>10</td>
<td>inflation rate</td>
<td>-0.295489</td>
</tr>
<tr>
<td>11</td>
<td>traffic volume (Ic#1-#6, vehicle-2)</td>
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<td>toll (Ic#1-#6, vehicle-2)</td>
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<td>13</td>
<td>labor cost (toll collection)</td>
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<td>parameter (consignment cost of toll collection)</td>
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<td>traffic volume (Ic#2-#6, vehicle-2)</td>
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<td>toll (Ic#1-#6, vehicle-4)</td>
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<td>traffic volume (Ic#1-#6, vehicle-4)</td>
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Table 3.36 Total sensitivity Coefficients for RVS #8
### Table 3.37 Total sensitivity Coefficients for RVS #9

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<td>2</td>
<td>parameter (traffic growth) the first year</td>
<td>-1.21835</td>
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<tr>
<td>3</td>
<td>inflation rate</td>
<td>-0.520859</td>
</tr>
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<td>4</td>
<td>parameter (consignment cost of toll collection)</td>
<td>-0.210106</td>
</tr>
<tr>
<td>6</td>
<td>traffic volume (Ic#1-#6, vehicle-2)</td>
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<tr>
<td>6</td>
<td>toll (Ic#1-#6, vehicle-2)</td>
<td>0.181898</td>
</tr>
<tr>
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<td>toll (Ic#2-#6, vehicle-2)</td>
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<td>8</td>
<td>traffic volume (Ic#2-#6, vehicle-2)</td>
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<tr>
<td>10</td>
<td>toll (Ic#1-#6, vehicle-4)</td>
<td>0.122000</td>
</tr>
<tr>
<td>10</td>
<td>traffic (Ic#1-#6, vehicle-4)</td>
<td>0.122000</td>
</tr>
<tr>
<td>12</td>
<td>parameter (toll rate growth) the first year</td>
<td>0.118742</td>
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<td>13</td>
<td>parameter (toll rate growth) the second year</td>
<td>0.112559</td>
</tr>
<tr>
<td>13</td>
<td>parameter (traffic growth) the second year</td>
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</tr>
<tr>
<td>15</td>
<td>parameter (toll rate growth) the third year</td>
<td>0.113193</td>
</tr>
<tr>
<td>15</td>
<td>parameter (traffic growth) the third year</td>
<td>0.113193</td>
</tr>
<tr>
<td>17</td>
<td>parameter (toll rate growth) the fourth year</td>
<td>0.107248</td>
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<tr>
<td>17</td>
<td>parameter (traffic growth) the fourth year</td>
<td>0.107248</td>
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<td>toll (Ic#1-#5, vehicle-4)</td>
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<td>19</td>
<td>traffic volume (Ic#1-#5, vehicle-4)</td>
<td>0.102694</td>
</tr>
<tr>
<td>21</td>
<td>parameter (toll rate growth) the fifth year</td>
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</tr>
<tr>
<td>21</td>
<td>parameter (traffic growth) the fifth year</td>
<td>0.101456</td>
</tr>
<tr>
<td>23</td>
<td>parameter (toll rate growth) the sixth year</td>
<td>0.101953</td>
</tr>
<tr>
<td>23</td>
<td>parameter (traffic growth) the sixth year</td>
<td>0.101953</td>
</tr>
</tbody>
</table>
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;
Chapter 4: Risk Management

(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.

<table>
<thead>
<tr>
<th>category</th>
<th>2.5%</th>
<th>5.0%</th>
<th>50.0%</th>
<th>95.0%</th>
<th>97.5%</th>
<th>$\beta$</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>survey &amp; design</td>
<td>0.900</td>
<td>0.910</td>
<td>1.000</td>
<td>1.180</td>
<td>1.200</td>
<td>0.6</td>
<td>2.4</td>
</tr>
<tr>
<td>land acquisition</td>
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<td>0.910</td>
<td>1.000</td>
<td>1.500</td>
<td>1.650</td>
<td>2.0</td>
<td>8.0</td>
</tr>
<tr>
<td>earth work</td>
<td>0.850</td>
<td>0.870</td>
<td>1.000</td>
<td>1.450</td>
<td>1.500</td>
<td>0.9</td>
<td>2.8</td>
</tr>
<tr>
<td>bridge</td>
<td>0.900</td>
<td>0.910</td>
<td>1.000</td>
<td>1.180</td>
<td>1.200</td>
<td>0.6</td>
<td>2.4</td>
</tr>
<tr>
<td>pavement</td>
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<td>0.910</td>
<td>1.000</td>
<td>1.090</td>
<td>1.100</td>
<td>0.0</td>
<td>2.2</td>
</tr>
<tr>
<td>IC</td>
<td>0.850</td>
<td>0.870</td>
<td>1.000</td>
<td>1.450</td>
<td>1.500</td>
<td>0.9</td>
<td>2.8</td>
</tr>
<tr>
<td>ancillary facilities</td>
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<td>0.910</td>
<td>1.000</td>
<td>1.090</td>
<td>1.100</td>
<td>0.0</td>
<td>2.2</td>
</tr>
<tr>
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<td>0.910</td>
<td>1.000</td>
<td>1.450</td>
<td>1.500</td>
<td>1.1</td>
<td>3.2</td>
</tr>
<tr>
<td>building &amp; repairing</td>
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<td>0.910</td>
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<td>1.090</td>
<td>1.100</td>
<td>0.0</td>
<td>2.2</td>
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<tr>
<td>overhead</td>
<td>0.900</td>
<td>0.910</td>
<td>1.000</td>
<td>1.180</td>
<td>1.200</td>
<td>0.6</td>
<td>2.4</td>
</tr>
<tr>
<td>revenue phase duration</td>
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<td>0.910</td>
<td>1.000</td>
<td>1.090</td>
<td>1.100</td>
<td>0.0</td>
<td>2.2</td>
</tr>
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</table>

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

<table>
<thead>
<tr>
<th>category</th>
<th>2.5%</th>
<th>5.0%</th>
<th>50.0%</th>
<th>95.0%</th>
<th>97.5%</th>
<th>$\beta$</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>survey &amp; design</td>
<td>0.950</td>
<td>0.955</td>
<td>1.000</td>
<td>1.090</td>
<td>1.100</td>
<td>0.6</td>
<td>2.4</td>
</tr>
<tr>
<td>land acquisition</td>
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<td>0.955</td>
<td>1.000</td>
<td>1.280</td>
<td>1.325</td>
<td>1.5</td>
<td>4.8</td>
</tr>
<tr>
<td>earth work</td>
<td>0.925</td>
<td>0.930</td>
<td>1.000</td>
<td>1.200</td>
<td>1.250</td>
<td>1.4</td>
<td>5.3</td>
</tr>
<tr>
<td>bridge</td>
<td>0.950</td>
<td>0.955</td>
<td>1.000</td>
<td>1.090</td>
<td>1.100</td>
<td>0.6</td>
<td>2.4</td>
</tr>
<tr>
<td>pavement</td>
<td>0.950</td>
<td>0.955</td>
<td>1.000</td>
<td>1.045</td>
<td>1.050</td>
<td>0.0</td>
<td>2.2</td>
</tr>
<tr>
<td>IC</td>
<td>0.925</td>
<td>0.930</td>
<td>1.000</td>
<td>1.200</td>
<td>1.250</td>
<td>1.4</td>
<td>5.3</td>
</tr>
<tr>
<td>ancillary facilities</td>
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<td>0.955</td>
<td>1.000</td>
<td>1.045</td>
<td>1.050</td>
<td>0.0</td>
<td>2.2</td>
</tr>
<tr>
<td>appurtenant work</td>
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<td>0.960</td>
<td>1.000</td>
<td>1.200</td>
<td>1.250</td>
<td>1.7</td>
<td>6.3</td>
</tr>
<tr>
<td>building &amp; repairing</td>
<td>0.950</td>
<td>0.955</td>
<td>1.000</td>
<td>1.045</td>
<td>1.050</td>
<td>0.0</td>
<td>2.2</td>
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<tr>
<td>overhead</td>
<td>0.950</td>
<td>0.955</td>
<td>1.000</td>
<td>1.090</td>
<td>1.100</td>
<td>0.6</td>
<td>2.4</td>
</tr>
<tr>
<td>revenue phase duration</td>
<td>0.950</td>
<td>0.955</td>
<td>1.000</td>
<td>1.045</td>
<td>1.050</td>
<td>0.0</td>
<td>2.2</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Case</th>
<th>mean</th>
<th>$\sigma$</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
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<tr>
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<td>77,309,352</td>
<td>0.190</td>
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<td>729,199,360</td>
<td>74,547,520</td>
<td>0.241</td>
<td>1.495</td>
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</table>

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

<table>
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<tr>
<th>Cumulative probability (%)</th>
<th>Case 1 ($,000,000)</th>
<th>Case 2 ($,000,000)</th>
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</thead>
<tbody>
<tr>
<td>0.25</td>
<td>488.5</td>
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<td>0.50</td>
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<td>1.00</td>
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<td>2.50</td>
<td>554.0</td>
<td>583.1</td>
</tr>
<tr>
<td>5.00</td>
<td>578.3</td>
<td>606.6</td>
</tr>
<tr>
<td>10.00</td>
<td>606.4</td>
<td>633.7</td>
</tr>
<tr>
<td>25.00</td>
<td>653.4</td>
<td>678.9</td>
</tr>
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<td>729.2</td>
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<tr>
<td>99.75</td>
<td>922.5</td>
<td>938.5</td>
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</table>

Table 4.4 Cumulative Probability of the Project Revenue (case-1 and case-2)
Chapter 4: Risk Management

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

<table>
<thead>
<tr>
<th>case</th>
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<th>σ</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
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<td>-11,666,560</td>
<td>86,717,576</td>
<td>0.053</td>
<td>2.043</td>
</tr>
<tr>
<td>2</td>
<td>9,563,840</td>
<td>84,254,624</td>
<td>0.078</td>
<td>2.131</td>
</tr>
</tbody>
</table>

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

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

Table 4.6 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 $\sigma$, 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 $\alpha$ 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

<table>
<thead>
<tr>
<th></th>
<th>2.5%</th>
<th>5.0%</th>
<th>50.0%</th>
<th>95.0%</th>
<th>97.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>case-1</td>
<td>0.800</td>
<td>0.850</td>
<td>1.000</td>
<td>1.050</td>
<td>1.060</td>
</tr>
<tr>
<td>case-3</td>
<td>0.900</td>
<td>0.910</td>
<td>1.000</td>
<td>1.028</td>
<td>1.030</td>
</tr>
</tbody>
</table>

Table 4.7 Five Percentile Estimate Parameters for Toll Rate Growth Parameters

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>$\sqrt{\beta_1}$</th>
<th>$\beta_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>case-1</td>
<td>0.9815</td>
<td>0.0703</td>
<td>-2.0</td>
<td>10.2</td>
</tr>
<tr>
<td>case-3</td>
<td>0.9885</td>
<td>0.0383</td>
<td>-0.9</td>
<td>2.8</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>case</th>
<th>mean</th>
<th>$\sigma$</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>705,507,584</td>
<td>77,309,352</td>
<td>0.190</td>
<td>1.411</td>
</tr>
<tr>
<td>3</td>
<td>715,485,760</td>
<td>77,054,544</td>
<td>0.200</td>
<td>1.396</td>
</tr>
</tbody>
</table>

Table 4.9 Comparison of the Project Revenue (case-1 and case-3)
Chapter 4: Risk Management

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

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

![Cumulative Probability of the Project Revenue (case-1 and case-3)](image)

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

<table>
<thead>
<tr>
<th>case</th>
<th>mean</th>
<th>$\sigma$</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-11,666,560</td>
<td>86,717,576</td>
<td>0.053</td>
<td>2.043</td>
</tr>
<tr>
<td>3</td>
<td>-1,688,384</td>
<td>86,490,488</td>
<td>0.060</td>
<td>2.036</td>
</tr>
</tbody>
</table>

Table 4.11 Comparison 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.

<table>
<thead>
<tr>
<th></th>
<th>2.5%</th>
<th>5.0%</th>
<th>50.0%</th>
<th>95.0%</th>
<th>97.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>case-1</td>
<td>0.700</td>
<td>0.750</td>
<td>1.000</td>
<td>1.090</td>
<td>1.100</td>
</tr>
<tr>
<td>case-4</td>
<td>0.850</td>
<td>0.870</td>
<td>1.000</td>
<td>1.045</td>
<td>1.050</td>
</tr>
</tbody>
</table>

Table 4.13 Five Percentile Estimate Parameters for traffic volume growth parameters

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>( \sqrt{\beta_1} )</th>
<th>( \beta_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>case-1</td>
<td>0.9704</td>
<td>0.1104</td>
<td>-1.0</td>
<td>3.4</td>
</tr>
<tr>
<td>case-4</td>
<td>0.9843</td>
<td>0.0568</td>
<td>-0.9</td>
<td>2.9</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>case</th>
<th>mean</th>
<th>( \sigma )</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>705,507,584</td>
<td>77,309,352</td>
<td>0.190</td>
<td>1.411</td>
</tr>
<tr>
<td>4</td>
<td>702,523,968</td>
<td>61,274,760</td>
<td>-0.170</td>
<td>1.383</td>
</tr>
</tbody>
</table>

Table 4.15 Comparison of the Project Revenue (case-1 and case-4)
### Table 4.16 Cumulative Probability of the Project Revenue (case-1 and case-4)

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

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

<table>
<thead>
<tr>
<th>case</th>
<th>mean</th>
<th>$\sigma$</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-11,666,560</td>
<td>86,717,576</td>
<td>0.053</td>
<td>2.043</td>
</tr>
<tr>
<td>4</td>
<td>-14,650,176</td>
<td>72,785,976</td>
<td>-0.239</td>
<td>2.281</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Case</th>
<th>2.5%</th>
<th>5.0%</th>
<th>50.0%</th>
<th>95.0%</th>
<th>97.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case-1</td>
<td>0.900</td>
<td>0.910</td>
<td>1.000</td>
<td>1.180</td>
<td>1.200</td>
</tr>
<tr>
<td>Case-5</td>
<td>0.950</td>
<td>0.955</td>
<td>1.000</td>
<td>1.09</td>
<td>1.100</td>
</tr>
</tbody>
</table>

Table 4.19 Five Percentile Estimate Parameters for Tolls

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>$\sqrt{\beta}$</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case-1</td>
<td>1.0167</td>
<td>0.0850</td>
<td>0.6</td>
<td>2.4</td>
</tr>
<tr>
<td>Case-5</td>
<td>1.0083</td>
<td>0.0425</td>
<td>0.6</td>
<td>2.4</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>case</th>
<th>mean</th>
<th>$\sigma$</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>705,507,584</td>
<td>77,309,352</td>
<td>0.190</td>
<td>1.411</td>
</tr>
<tr>
<td>5</td>
<td>699,348,992</td>
<td>76,269,088</td>
<td>0.192</td>
<td>1.419</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>cumulative probability(%)</th>
<th>Case 1 ($,000,000)</th>
<th>Case 5 ($,000,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>488.5</td>
<td>485.3</td>
</tr>
<tr>
<td>0.50</td>
<td>506.4</td>
<td>502.9</td>
</tr>
<tr>
<td>1.00</td>
<td>525.7</td>
<td>521.9</td>
</tr>
<tr>
<td>2.50</td>
<td>554.0</td>
<td>549.9</td>
</tr>
<tr>
<td>5.00</td>
<td>578.3</td>
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<tr>
<td>10.00</td>
<td>606.4</td>
<td>601.6</td>
</tr>
<tr>
<td>25.00</td>
<td>653.4</td>
<td>647.9</td>
</tr>
<tr>
<td>50.00</td>
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<td>699.3</td>
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<td>75.00</td>
<td>757.7</td>
<td>750.8</td>
</tr>
<tr>
<td>90.00</td>
<td>804.9</td>
<td>797.1</td>
</tr>
<tr>
<td>95.00</td>
<td>832.7</td>
<td>824.8</td>
</tr>
<tr>
<td>97.50</td>
<td>857.0</td>
<td>848.8</td>
</tr>
<tr>
<td>99.00</td>
<td>885.4</td>
<td>876.8</td>
</tr>
<tr>
<td>99.50</td>
<td>904.6</td>
<td>895.8</td>
</tr>
<tr>
<td>99.75</td>
<td>922.5</td>
<td>913.4</td>
</tr>
</tbody>
</table>
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1•3 20-

E 3 0

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

<table>
<thead>
<tr>
<th>case</th>
<th>mean</th>
<th>$\sigma$</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-11,666,560</td>
<td>86,717,576</td>
<td>0.053</td>
<td>2.043</td>
</tr>
<tr>
<td>5</td>
<td>-17,825,152</td>
<td>85,791,464</td>
<td>0.051</td>
<td>2.061</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Cumulative Probability (%)</th>
<th>Case 1 ($,000,000)</th>
<th>Case 5 ($,000,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>-255.1</td>
<td>-258.6</td>
</tr>
<tr>
<td>0.50</td>
<td>-235.0</td>
<td>-238.7</td>
</tr>
<tr>
<td>1.00</td>
<td>-213.4</td>
<td>-217.4</td>
</tr>
<tr>
<td>2.50</td>
<td>-181.6</td>
<td>-186.0</td>
</tr>
<tr>
<td>5.00</td>
<td>-154.3</td>
<td>-158.9</td>
</tr>
<tr>
<td>10.00</td>
<td>-122.8</td>
<td>-127.8</td>
</tr>
<tr>
<td>25.00</td>
<td>-70.2</td>
<td>-75.7</td>
</tr>
<tr>
<td>50.00</td>
<td>-11.7</td>
<td>-17.8</td>
</tr>
<tr>
<td>75.00</td>
<td>46.8</td>
<td>40.0</td>
</tr>
<tr>
<td>90.00</td>
<td>99.5</td>
<td>92.1</td>
</tr>
<tr>
<td>95.00</td>
<td>131.0</td>
<td>123.3</td>
</tr>
<tr>
<td>97.50</td>
<td>158.3</td>
<td>150.3</td>
</tr>
<tr>
<td>99.00</td>
<td>190.1</td>
<td>181.8</td>
</tr>
<tr>
<td>99.50</td>
<td>211.7</td>
<td>203.2</td>
</tr>
<tr>
<td>99.75</td>
<td>231.7</td>
<td>223.0</td>
</tr>
</tbody>
</table>

Table 4.24 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.
### Table 4.25 Five Percentile Estimate Parameters for Traffic Volume

<table>
<thead>
<tr>
<th></th>
<th>2.5%</th>
<th>5.0%</th>
<th>50.0%</th>
<th>95.0%</th>
<th>97.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>case-1</td>
<td>0.350</td>
<td>0.500</td>
<td>1.000</td>
<td>1.350</td>
<td>1.400</td>
</tr>
<tr>
<td>case-6</td>
<td>0.675</td>
<td>0.700</td>
<td>1.000</td>
<td>1.180</td>
<td>1.200</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>$\sqrt{\beta_1}$</th>
<th>$\beta_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>case-1</td>
<td>0.9723</td>
<td>0.2667</td>
<td>-1.0</td>
<td>5.9</td>
</tr>
<tr>
<td>case-6</td>
<td>0.9778</td>
<td>0.1488</td>
<td>-0.4</td>
<td>2.2</td>
</tr>
</tbody>
</table>

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.

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

<table>
<thead>
<tr>
<th>case</th>
<th>mean</th>
<th>$\sigma$</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>705,507,584</td>
<td>77,309,352</td>
<td>0.190</td>
<td>1.411</td>
</tr>
<tr>
<td>6</td>
<td>712,278,592</td>
<td>73,196,800</td>
<td>0.249</td>
<td>1.472</td>
</tr>
<tr>
<td>cumulative probability(%)</td>
<td>Case 1 ($,000,000)</td>
<td>Case 6 ($,000,000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------</td>
<td>---------------------</td>
<td>---------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>488.5</td>
<td>506.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.50</td>
<td>506.4</td>
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<td></td>
<td></td>
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<td>542.0</td>
<td></td>
<td></td>
</tr>
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<td>2.50</td>
<td>554.0</td>
<td>568.8</td>
<td></td>
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</tr>
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<td>5.00</td>
<td>578.3</td>
<td>591.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td>606.4</td>
<td>618.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25.00</td>
<td>653.4</td>
<td>662.9</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>705.5</td>
<td>712.3</td>
<td></td>
<td></td>
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<td>757.7</td>
<td>761.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90.00</td>
<td>804.9</td>
<td>806.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>95.00</td>
<td>832.7</td>
<td>832.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>97.50</td>
<td>857.0</td>
<td>855.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>99.00</td>
<td>885.4</td>
<td>882.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>99.50</td>
<td>904.6</td>
<td>900.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>99.75</td>
<td>922.5</td>
<td>917.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

![Cumulative Probability of the Project Revenue](image)

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

<table>
<thead>
<tr>
<th>case</th>
<th>mean</th>
<th>σ</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-11,666,560</td>
<td>8,6717,576</td>
<td>0.053</td>
<td>2.043</td>
</tr>
<tr>
<td>6</td>
<td>-4,895,552</td>
<td>7,3196,800</td>
<td>0.249</td>
<td>1.472</td>
</tr>
</tbody>
</table>

Table 4.29 Comparison of the Project NPV (case-1 and case-6)
Chapter 4: Risk Management

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

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.

<table>
<thead>
<tr>
<th></th>
<th>2.5%</th>
<th>5.0%</th>
<th>50.0%</th>
<th>95.0%</th>
<th>97.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>case-1</td>
<td>0.800</td>
<td>0.820</td>
<td>1.000</td>
<td>1.300</td>
<td>1.400</td>
</tr>
<tr>
<td>case-7</td>
<td>0.900</td>
<td>0.910</td>
<td>1.000</td>
<td>1.180</td>
<td>1.200</td>
</tr>
</tbody>
</table>

Table 4.31 Five Percentile Estimate Parameters for Inflation Rate

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>(\sqrt{\beta_1})</th>
<th>(\beta_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>case-1</td>
<td>1.0222</td>
<td>0.1540</td>
<td>1.4</td>
<td>7.7</td>
</tr>
<tr>
<td>case-7</td>
<td>1.0167</td>
<td>0.0850</td>
<td>0.6</td>
<td>2.4</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>case</th>
<th>mean</th>
<th>(\sigma)</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>705,507,584</td>
<td>77,309,352</td>
<td>0.190</td>
<td>1.411</td>
</tr>
<tr>
<td>7</td>
<td>709,877,120</td>
<td>73,241,816</td>
<td>0.334</td>
<td>1.491</td>
</tr>
</tbody>
</table>

Table 4.33 Comparison of the Project Revenue (case-1 and case-7)
Chapter 4: Risk Management

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

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)

<table>
<thead>
<tr>
<th>case</th>
<th>mean</th>
<th>$\sigma$</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-11,666,560</td>
<td>86,717,576</td>
<td>0.053</td>
<td>2.043</td>
</tr>
<tr>
<td>7</td>
<td>-6,317,120</td>
<td>82,959,512</td>
<td>0.137</td>
<td>2.139</td>
</tr>
</tbody>
</table>

Table 4.35 Comparison of the Project NPV (case-1 and case-7)
Table 4.36 Cumulative Probability of the Project NPV (case-1 and case-7)

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

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.

<table>
<thead>
<tr>
<th></th>
<th>2.5%</th>
<th>5.0%</th>
<th>50.0%</th>
<th>95.0%</th>
<th>97.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>case-1</td>
<td>0.900</td>
<td>0.910</td>
<td>1.000</td>
<td>1.250</td>
<td>1.300</td>
</tr>
<tr>
<td>case-8</td>
<td>0.950</td>
<td>0.955</td>
<td>1.000</td>
<td>1.120</td>
<td>1.150</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>$\sqrt{\beta_1}$</th>
<th>$\beta_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>case-1</td>
<td>1.0296</td>
<td>0.1104</td>
<td>1.0</td>
<td>3.4</td>
</tr>
<tr>
<td>case-7</td>
<td>1.0139</td>
<td>0.0539</td>
<td>1.4</td>
<td>5.6</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>case</th>
<th>mean</th>
<th>$\sigma$</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>705,507,584</td>
<td>77,309,352</td>
<td>0.190</td>
<td>1.411</td>
</tr>
<tr>
<td>8</td>
<td>708,981,504</td>
<td>76,916,008</td>
<td>0.197</td>
<td>1.420</td>
</tr>
</tbody>
</table>

Table (4.39) Comparison of the Project Revenue (case-1 and case-8)
Table 4.40 Cumulative Probability of the Project Revenue (case-1 and case-8)

<table>
<thead>
<tr>
<th>cumulative probability(%)</th>
<th>Case 1 ($,000,000)</th>
<th>Case 8 ($,000,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>488.5</td>
<td>493.1</td>
</tr>
<tr>
<td>0.50</td>
<td>506.4</td>
<td>510.9</td>
</tr>
<tr>
<td>1.00</td>
<td>525.7</td>
<td>530.1</td>
</tr>
<tr>
<td>2.50</td>
<td>554.0</td>
<td>558.2</td>
</tr>
<tr>
<td>5.00</td>
<td>578.3</td>
<td>582.5</td>
</tr>
<tr>
<td>10.00</td>
<td>606.4</td>
<td>610.4</td>
</tr>
<tr>
<td>25.00</td>
<td>653.4</td>
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</tr>
<tr>
<td>50.00</td>
<td>705.5</td>
<td>709.0</td>
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<tr>
<td>75.00</td>
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<td>807.6</td>
</tr>
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<td>835.5</td>
</tr>
<tr>
<td>97.50</td>
<td>857.0</td>
<td>859.7</td>
</tr>
<tr>
<td>99.00</td>
<td>885.4</td>
<td>887.9</td>
</tr>
<tr>
<td>99.50</td>
<td>904.6</td>
<td>907.1</td>
</tr>
<tr>
<td>99.75</td>
<td>922.5</td>
<td>924.9</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>case</th>
<th>mean</th>
<th>$\sigma$</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-11,666,560</td>
<td>86,717,576</td>
<td>0.053</td>
<td>2.043</td>
</tr>
<tr>
<td>8</td>
<td>-8,192,640</td>
<td>86,367,096</td>
<td>0.056</td>
<td>2.053</td>
</tr>
</tbody>
</table>

Figure 4.13 Cumulative Probability of the Project Revenue (case-1 and case-8)
Chapter 4: Risk Management

<table>
<thead>
<tr>
<th>Cumulative Probability (%)</th>
<th>Case 1 ($,000,000)</th>
<th>Case 8 ($,000,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>-255.1</td>
<td>-250.6</td>
</tr>
<tr>
<td>0.50</td>
<td>-235.0</td>
<td>-230.7</td>
</tr>
<tr>
<td>1.00</td>
<td>-213.4</td>
<td>-209.1</td>
</tr>
<tr>
<td>2.50</td>
<td>-181.6</td>
<td>-177.5</td>
</tr>
<tr>
<td>5.00</td>
<td>-154.3</td>
<td>-150.3</td>
</tr>
<tr>
<td>10.00</td>
<td>-122.8</td>
<td>-118.9</td>
</tr>
<tr>
<td>25.00</td>
<td>-70.2</td>
<td>-66.4</td>
</tr>
<tr>
<td>50.00</td>
<td>-11.7</td>
<td>-8.2</td>
</tr>
<tr>
<td>75.00</td>
<td>46.8</td>
<td>50.1</td>
</tr>
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<td>90.00</td>
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<td>102.5</td>
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<td>95.00</td>
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<td>161.1</td>
</tr>
<tr>
<td>99.00</td>
<td>190.1</td>
<td>192.7</td>
</tr>
<tr>
<td>99.50</td>
<td>211.7</td>
<td>214.3</td>
</tr>
<tr>
<td>99.75</td>
<td>231.7</td>
<td>234.2</td>
</tr>
</tbody>
</table>

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

![Cumulative Probability of the Project NPV](image)

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.
Chapter 4: Risk Management

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.

<table>
<thead>
<tr>
<th>case</th>
<th>mean</th>
<th>σ</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>705,507,584</td>
<td>77,309,352</td>
<td>0.190</td>
<td>1.411</td>
</tr>
<tr>
<td>8</td>
<td>733,059,648</td>
<td>40,677,744</td>
<td>0.161</td>
<td>1.355</td>
</tr>
</tbody>
</table>

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

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

Table 4.44 Cumulative Probability of the Project Revenue (case-1 and case-9)
Chapter 4: Risk Management

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

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-11,666,560</td>
<td>0.053</td>
<td>2.043</td>
</tr>
<tr>
<td>9</td>
<td>13,424,128</td>
<td>-0.236</td>
<td>2.819</td>
</tr>
</tbody>
</table>

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

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

Table 4.46 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.
Table 4.47 Five Percentile Estimate Parameters for Traffic Volume

<table>
<thead>
<tr>
<th></th>
<th>2.5%</th>
<th>5.0%</th>
<th>50.0%</th>
<th>95.0%</th>
<th>97.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>case-1</td>
<td>0.350</td>
<td>0.500</td>
<td>1.000</td>
<td>1.350</td>
<td>1.400</td>
</tr>
<tr>
<td>case-10</td>
<td>0.9996</td>
<td>0.9997</td>
<td>1.000</td>
<td>1.0003</td>
<td>1.0004</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>$\sqrt{\beta}$</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>case-1</td>
<td>0.9723</td>
<td>0.2667</td>
<td>-1.0</td>
<td>5.9</td>
</tr>
<tr>
<td>case-10</td>
<td>1.0000</td>
<td>0.0002</td>
<td>0.0</td>
<td>9.0</td>
</tr>
</tbody>
</table>

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.

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

<table>
<thead>
<tr>
<th>case</th>
<th>mean</th>
<th>$\sigma$</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>705,507,584</td>
<td>77,309,352</td>
<td>0.190</td>
<td>1.411</td>
<td></td>
</tr>
<tr>
<td>729,600,320</td>
<td>72,625,800</td>
<td>0.276</td>
<td>1.518</td>
<td></td>
</tr>
</tbody>
</table>
Table 4.50 Cumulative Probability of the Project Revenue (case-1 and case-10)

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

Figure 4.17 Cumulative Probability of the Project Revenue (case-1 and case-10)
Chapter 4: Risk Management

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

<table>
<thead>
<tr>
<th>case</th>
<th>mean</th>
<th>σ</th>
<th>skewness</th>
<th>kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-11,666,560</td>
<td>86,717,576</td>
<td>0.053</td>
<td>2.043</td>
</tr>
<tr>
<td>8</td>
<td>12,426,176</td>
<td>82,569,424</td>
<td>0.094</td>
<td>2.169</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Cumulative Probability (%)</th>
<th>Case 1 ($,000,000)</th>
<th>Case 2 ($,000,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>-255.1</td>
<td>-219.3</td>
</tr>
<tr>
<td>0.50</td>
<td>-235.0</td>
<td>-200.3</td>
</tr>
<tr>
<td>1.00</td>
<td>-213.4</td>
<td>-179.7</td>
</tr>
<tr>
<td>2.50</td>
<td>-181.6</td>
<td>-149.4</td>
</tr>
<tr>
<td>5.00</td>
<td>-154.3</td>
<td>-123.4</td>
</tr>
<tr>
<td>10.00</td>
<td>-122.8</td>
<td>-93.4</td>
</tr>
<tr>
<td>25.00</td>
<td>-70.2</td>
<td>-43.3</td>
</tr>
<tr>
<td>50.00</td>
<td>-11.7</td>
<td>12.4</td>
</tr>
<tr>
<td>75.00</td>
<td>46.8</td>
<td>68.1</td>
</tr>
<tr>
<td>90.00</td>
<td>99.5</td>
<td>118.2</td>
</tr>
<tr>
<td>95.00</td>
<td>131.0</td>
<td>148.2</td>
</tr>
<tr>
<td>97.50</td>
<td>158.3</td>
<td>174.3</td>
</tr>
<tr>
<td>99.00</td>
<td>190.1</td>
<td>204.5</td>
</tr>
<tr>
<td>99.50</td>
<td>211.7</td>
<td>225.1</td>
</tr>
<tr>
<td>99.75</td>
<td>231.7</td>
<td>244.2</td>
</tr>
</tbody>
</table>

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;
Chapter 5: Conclusions and Recommendations

(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.
Bibliography


[28] Thomas, Roy, "Traffic Assignment Techniques", Centre for Transport Studies, Department of Civil Engineering, University of Salford, 1991


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 ith work package cost

\[ Co_i(t) \] is the function for constant dollar cash flow for the ith 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)

\[ T_{TR} \] is operation phase duration

\[ f \] is the equity fraction,
\( \theta_c, r \) and \( y \) are inflation, interest and discount rates respectively which are invaried with time.

First, figure out the amount of annual repayment for ith work package, \( P_i \).

FW at end of WP#i is:

\[
(1-f) \cdot \int_0^{T_a} e^{\theta_c \cdot \tau} \cdot C_o(\tau) \cdot e^{r(\tau)} \cdot e^{(T_a-\tau)r} d\tau
\]

\[
= (1-f) \cdot e^{\theta_c \cdot T_a} \cdot e^{rT_a} \cdot \int_0^{T_a} C_o(\tau) \cdot e^{(\theta_c-r)\tau} d\tau
\]

FW at \( T_p \) is:

\[
(1-f) \cdot e^{\theta_c \cdot T_a} \cdot e^{rT_a} \cdot \int_0^{T_a} C_o(\tau) \cdot e^{(\theta_c-r)\tau} d\tau \cdot e^{r(T_p-T_{sec}-T_{el})}
\]

\[
= (1-f) \cdot e^{\theta_c \cdot T_a} \cdot e^{r(T_p-T_{sec})} \cdot \int_0^{T_a} C_o(\tau) \cdot e^{(\theta_c-r)\tau} d\tau
\]

FW at \( T_p \) is also described as:

\[
\int_0^{T_p-T_{sec}} P_i \cdot e^{-r\tau} d\tau
\]

Therefore,

\[
P_i = (1-f) \cdot e^{\theta_c \cdot T_a} e^{r(T_p-T_{sec})} \cdot \int_0^{T_a} C_o(\tau) \cdot e^{(\theta_c-r)\tau} d\tau / \int_0^{T_p-T_{sec}} e^{-r\tau} d\tau
\]

Then, discounted ith work package cost is,
Appendix A: Discounted Work Package Cost

\[ WPC_i = f \cdot e^{(\bar{a}_i - y)T_a} \int_0^{T_a} C_a(\tau) \cdot e^{(\bar{a}_i - y)\tau} d\tau + \int_0^{T - T_f} P_i \cdot e^{-y\tau} dt \cdot e^{-yT_f} \]

\[ = f \cdot e^{(\bar{a}_i - y)T_a} \int_0^{T_a} C_a(\tau) \cdot e^{(\bar{a}_i - y)\tau} d\tau \]

\[ + \int_0^{T - T_f} e^{-y\tau} dt \cdot e^{-yT_f} \cdot (1 - f) \cdot e^{(\bar{a}_i T_a) e^{(T_f - T_a)\tau}} \int_0^{T_a} C_a(\tau) \cdot e^{(\bar{a}_i - y)\tau} d\tau / \int_0^{T - T_f} e^{-y\tau} dt \]
Appendix B

Input Data for Revenue Stream

The following tables show input data for revenue streams.

### B.1 Closed System (Fixed Toll Rate)

<table>
<thead>
<tr>
<th>Input Data</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>nAL</td>
<td>the number of interchanges (IC)</td>
</tr>
<tr>
<td>nP</td>
<td>the number of vehicle types</td>
</tr>
<tr>
<td>nWC</td>
<td>weather classification</td>
</tr>
<tr>
<td>nOL</td>
<td>periodic overlay</td>
</tr>
<tr>
<td>nBR</td>
<td>periodic bridge repainting</td>
</tr>
<tr>
<td>iby</td>
<td>start time of the revenue stream</td>
</tr>
<tr>
<td>ird</td>
<td>revenue stream duration</td>
</tr>
<tr>
<td>fee(I,J,K,L)</td>
<td>toll rate of vehicle type L between IC #J and #K at the first year</td>
</tr>
<tr>
<td>ptr(I)</td>
<td>toll growth rate parameter at year I</td>
</tr>
<tr>
<td>ptv(I)</td>
<td>traffic volume growth rate parameter at year I</td>
</tr>
<tr>
<td>traf(I,J,K,L)</td>
<td>traffic volume of vehicle type L between IC #J and #K at the first year</td>
</tr>
</tbody>
</table>
Appendix B: Input Data for Revenue Stream

<table>
<thead>
<tr>
<th></th>
<th>(Maintenance Cost)</th>
</tr>
</thead>
<tbody>
<tr>
<td>lb2</td>
<td>2 lane bridge length</td>
</tr>
<tr>
<td>lb4</td>
<td>4 lane bridge length</td>
</tr>
<tr>
<td>lb6</td>
<td>6 lane bridge length</td>
</tr>
<tr>
<td>lt2</td>
<td>2 lane tunnel length</td>
</tr>
<tr>
<td>lt4</td>
<td>4 lane tunnel length</td>
</tr>
<tr>
<td>lt6</td>
<td>6 lane tunnel length</td>
</tr>
<tr>
<td>le2</td>
<td>2 lane earthwork section length</td>
</tr>
<tr>
<td>le4</td>
<td>4 lane earthwork section length</td>
</tr>
<tr>
<td>le6</td>
<td>6 lane earthwork section length</td>
</tr>
<tr>
<td>ltn</td>
<td>length of tunnel with no ventilation</td>
</tr>
<tr>
<td>ltj</td>
<td>length of tunnel with jet fan</td>
</tr>
<tr>
<td>lto</td>
<td>length of tunnel with other ventilation</td>
</tr>
<tr>
<td>ec2</td>
<td>road cleaning cost (2 lanes)</td>
</tr>
<tr>
<td>ec4</td>
<td>road cleaning cost (4 lanes or more)</td>
</tr>
<tr>
<td>cm2</td>
<td>road maintenance cost (2 lanes)</td>
</tr>
<tr>
<td>cm4</td>
<td>road maintenance cost (4 lanes)</td>
</tr>
<tr>
<td>cm6</td>
<td>road maintenance cost (6 lanes)</td>
</tr>
<tr>
<td>cl1</td>
<td>lighting cost (1 or 2 lanes)</td>
</tr>
<tr>
<td>cl4</td>
<td>lighting cost (4 or 6 lanes)</td>
</tr>
<tr>
<td>cr2</td>
<td>bridge repair cost (2 lanes)</td>
</tr>
<tr>
<td>cr4</td>
<td>bridge repair cost (4 lanes)</td>
</tr>
<tr>
<td>cr6</td>
<td>bridge repair cost (6 lanes)</td>
</tr>
<tr>
<td>cp2</td>
<td>bridge paint cost (2 lanes)</td>
</tr>
<tr>
<td>cp4</td>
<td>bridge paint cost (4 lanes)</td>
</tr>
<tr>
<td>cp6</td>
<td>bridge paint cost (6 lanes)</td>
</tr>
<tr>
<td>ctn</td>
<td>tunnel maintenance cost (no ventilation)</td>
</tr>
<tr>
<td>ctj</td>
<td>tunnel maintenance cost (jet fan)</td>
</tr>
<tr>
<td>cto</td>
<td>tunnel maintenance cost (others)</td>
</tr>
<tr>
<td>csh</td>
<td>snow and ice control cost (heavy snow area)</td>
</tr>
<tr>
<td>cso</td>
<td>snow and ice control cost (ordinary snow area)</td>
</tr>
<tr>
<td>co2</td>
<td>overlay cost (2 lanes)</td>
</tr>
<tr>
<td>co4</td>
<td>overlay cost (4 lanes)</td>
</tr>
<tr>
<td>co6</td>
<td>overlay cost (6 lanes)</td>
</tr>
<tr>
<td>pcot</td>
<td>other maintenance cost parameter</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>(Operation Cost)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ldir</td>
<td>labor cost of operation office (director)</td>
</tr>
<tr>
<td>lvdir</td>
<td>labor cost of operation office (vice director)</td>
</tr>
<tr>
<td>lchi</td>
<td>(chief)</td>
</tr>
<tr>
<td>------</td>
<td>---------</td>
</tr>
<tr>
<td>leng</td>
<td>(clerk or engineer)</td>
</tr>
<tr>
<td>lwor</td>
<td>(worker)</td>
</tr>
<tr>
<td>t1</td>
<td>traffic volume(boundary-1)</td>
</tr>
<tr>
<td>ita1</td>
<td>the number of directors needed for less traffic volume than t1</td>
</tr>
<tr>
<td>itb1</td>
<td>the number of vice directors needed</td>
</tr>
<tr>
<td>itc1</td>
<td>the number of chiefs needed</td>
</tr>
<tr>
<td>itd1</td>
<td>the number of clerks and engineers needed</td>
</tr>
<tr>
<td>ite1</td>
<td>the number of workers needed</td>
</tr>
<tr>
<td>t2</td>
<td>traffic volume(boundary-2)</td>
</tr>
<tr>
<td>ita2</td>
<td>the number of directors needed for less traffic volume than t2</td>
</tr>
<tr>
<td>itb2</td>
<td>the number of vice directors needed</td>
</tr>
<tr>
<td>itc2</td>
<td>the number of chiefs needed</td>
</tr>
<tr>
<td>itd2</td>
<td>the number of clerks and engineers needed</td>
</tr>
<tr>
<td>ite2</td>
<td>the number of workers needed</td>
</tr>
<tr>
<td>t3</td>
<td>traffic volume(boundary-3)</td>
</tr>
<tr>
<td>ita3</td>
<td>the number of directors needed for less traffic volume than t3</td>
</tr>
<tr>
<td>itb3</td>
<td>the number of vice directors needed</td>
</tr>
<tr>
<td>itc3</td>
<td>the number of chiefs needed</td>
</tr>
<tr>
<td>itd3</td>
<td>the number of clerks and engineers needed</td>
</tr>
<tr>
<td>ite3</td>
<td>the number of workers needed</td>
</tr>
<tr>
<td>t4</td>
<td>traffic volume(boundary-4)</td>
</tr>
<tr>
<td>ita4</td>
<td>the number of directors needed for less traffic volume than t4</td>
</tr>
<tr>
<td>itb4</td>
<td>the number of vice directors needed</td>
</tr>
<tr>
<td>itc4</td>
<td>the number of chiefs needed</td>
</tr>
<tr>
<td>itd4</td>
<td>the number of clerks and engineers needed</td>
</tr>
<tr>
<td>ite4</td>
<td>the number of workers needed</td>
</tr>
<tr>
<td>t5</td>
<td>traffic volume(boundary-5)</td>
</tr>
<tr>
<td>ita5</td>
<td>the number of directors needed for less traffic volume than t5</td>
</tr>
<tr>
<td>itb5</td>
<td>the number of vice directors needed</td>
</tr>
<tr>
<td>itc5</td>
<td>the number of chiefs needed</td>
</tr>
<tr>
<td>itd5</td>
<td>the number of clerks and engineers needed</td>
</tr>
<tr>
<td>ite5</td>
<td>the number of workers needed</td>
</tr>
<tr>
<td>ita6</td>
<td>the number of directors needed for more traffic volume than t5</td>
</tr>
<tr>
<td>itb6</td>
<td>the number of vice directors needed</td>
</tr>
</tbody>
</table>
### Appendix B: Input Data for Revenue Stream

<table>
<thead>
<tr>
<th>i tc</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>itc6</td>
<td>the number of chiefs needed</td>
</tr>
<tr>
<td>itc6</td>
<td>the number of clerks and engineers needed</td>
</tr>
<tr>
<td>itc6</td>
<td>the number of workers needed</td>
</tr>
<tr>
<td>lt c</td>
<td>labor cost of toll collection (clerk)</td>
</tr>
<tr>
<td>tc1</td>
<td>traffic volume (boundary-1)</td>
</tr>
<tr>
<td>itc1</td>
<td>the number of clerks needed for less traffic volume than t1</td>
</tr>
<tr>
<td>tc2</td>
<td>traffic volume (boundary-2)</td>
</tr>
<tr>
<td>itc2</td>
<td>the number of toll collection clerks needed for less traffic volume than t2</td>
</tr>
<tr>
<td>tc3</td>
<td>traffic volume (boundary-3)</td>
</tr>
<tr>
<td>itc3</td>
<td>the number of toll collection clerks needed for less traffic volume than t3</td>
</tr>
<tr>
<td>tc4</td>
<td>traffic volume (boundary-4)</td>
</tr>
<tr>
<td>itc4</td>
<td>the number of toll collection clerks needed for less traffic volume than t4</td>
</tr>
<tr>
<td>tc5</td>
<td>traffic volume (boundary-5)</td>
</tr>
<tr>
<td>itc5</td>
<td>the number of toll collection clerks needed for less traffic volume than t5</td>
</tr>
<tr>
<td>tc6</td>
<td>traffic volume (boundary-6)</td>
</tr>
<tr>
<td>itc6</td>
<td>the number of toll collection clerks needed for less traffic volume than t6</td>
</tr>
<tr>
<td>tc7</td>
<td>traffic volume (boundary-7)</td>
</tr>
<tr>
<td>itc7</td>
<td>the number of toll collection clerks needed for less traffic volume than t7</td>
</tr>
<tr>
<td>tc8</td>
<td>traffic volume (boundary-8)</td>
</tr>
<tr>
<td>itc8</td>
<td>the number of toll collection clerks needed for less traffic volume than t8</td>
</tr>
<tr>
<td>tc9</td>
<td>traffic volume (boundary-9)</td>
</tr>
<tr>
<td>itc9</td>
<td>the number of toll collection clerks needed for less traffic volume than t9</td>
</tr>
<tr>
<td>tc10</td>
<td>traffic volume (boundary-10)</td>
</tr>
<tr>
<td>itc10</td>
<td>the number of toll collection clerks needed for less traffic volume than t10</td>
</tr>
<tr>
<td>tc11</td>
<td>traffic volume (boundary-11)</td>
</tr>
<tr>
<td>itc11</td>
<td>the number of toll collection clerks needed for less traffic volume than t11</td>
</tr>
<tr>
<td>tc12</td>
<td>traffic volume (boundary-12)</td>
</tr>
<tr>
<td>itc12</td>
<td>the number of toll collection clerks needed for less traffic volume than t12</td>
</tr>
<tr>
<td>tc13</td>
<td>traffic volume (boundary-13)</td>
</tr>
</tbody>
</table>
### Table B.1 Closed System (Fixed Toll Rate)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>itctl3</td>
<td>the number of toll collection clerks needed for less traffic volume than t13</td>
</tr>
<tr>
<td>tc14</td>
<td>traffic volume (boundary-14)</td>
</tr>
<tr>
<td>itctl4</td>
<td>the number of toll collection clerks needed for less traffic volume than t14</td>
</tr>
<tr>
<td>tc15</td>
<td>traffic volume (boundary-15)</td>
</tr>
<tr>
<td>itctl5</td>
<td>the number of toll collection clerks needed for less traffic volume than t15</td>
</tr>
<tr>
<td>tc16</td>
<td>traffic volume (boundary-16)</td>
</tr>
<tr>
<td>itctl6</td>
<td>the number of toll collection clerks needed for less traffic volume than t16</td>
</tr>
<tr>
<td>tc17</td>
<td>traffic volume (boundary-17)</td>
</tr>
<tr>
<td>itctl7</td>
<td>the number of toll collection clerks needed for less traffic volume than t17</td>
</tr>
<tr>
<td>itctl18</td>
<td>the number of toll collection clerks needed for more traffic volume than t17</td>
</tr>
<tr>
<td>ptct</td>
<td>(consignment costs of toll collection) are (toll collection labor costs) * ptct (parameter)</td>
</tr>
<tr>
<td>ptcm</td>
<td>toll collection machine maintenance costs) are (consignment costs of toll collection) * ptcm (parameter)</td>
</tr>
<tr>
<td>ibrco1</td>
<td>cost parameter of building and repainting expenses etc.</td>
</tr>
<tr>
<td>ibrco2</td>
<td>cost parameter of building and repainting expenses etc.</td>
</tr>
<tr>
<td>pobo</td>
<td>operation bureau overhead parameter</td>
</tr>
<tr>
<td>pho</td>
<td>headquarters overhead</td>
</tr>
<tr>
<td>flr</td>
<td>inflation rate (maintenance and operation costs)</td>
</tr>
</tbody>
</table>
## B.2 Closed System (Distance Proportional Toll Rate)

<table>
<thead>
<tr>
<th>Input Data</th>
<th>Deterministic Type</th>
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<tbody>
<tr>
<td>nAL the number of interchanges (IC)</td>
<td></td>
</tr>
<tr>
<td>nP the number of vehicle types</td>
<td></td>
</tr>
<tr>
<td>nWC weather classification</td>
<td></td>
</tr>
<tr>
<td>nOL periodic overlay</td>
<td></td>
</tr>
<tr>
<td>nBR periodic bridge repainting</td>
<td></td>
</tr>
<tr>
<td>ilby start time of the revenue stream</td>
<td>automatically calculated</td>
</tr>
<tr>
<td>ird revenue stream duration</td>
<td></td>
</tr>
<tr>
<td>(General Data)</td>
<td></td>
</tr>
<tr>
<td>disc1 toll discount boundary-1 (distance)</td>
<td></td>
</tr>
<tr>
<td>rate1 toll discount rate-1</td>
<td></td>
</tr>
<tr>
<td>disc2 toll discount boundary-2 (distance)</td>
<td></td>
</tr>
<tr>
<td>rate2 toll discount rate-2</td>
<td></td>
</tr>
<tr>
<td>perKm toll rate (distance proportional part) of ordinary motor vehicle</td>
<td></td>
</tr>
<tr>
<td>entFee toll rate (fixed part) of ordinary motor vehicle</td>
<td></td>
</tr>
<tr>
<td>a(I) distance between IC #I-1 and #I</td>
<td></td>
</tr>
<tr>
<td>p(I) toll ratios compared between ordinary motor vehicle and vehicle type K</td>
<td></td>
</tr>
<tr>
<td>ptr(I) toll growth rate parameter at year I</td>
<td></td>
</tr>
<tr>
<td>(Data related to Traffic Volume)</td>
<td></td>
</tr>
<tr>
<td>ptv(I) traffic volume growth rate parameter at year I</td>
<td></td>
</tr>
<tr>
<td>traf(1, J, K, L) traffic volume of vehicle type L between IC #J and #K at the first year</td>
<td></td>
</tr>
<tr>
<td>(Maintenance Cost)</td>
<td></td>
</tr>
<tr>
<td>lb2 2 lane bridge length</td>
<td></td>
</tr>
<tr>
<td>lb4 4 lane bridge length</td>
<td></td>
</tr>
<tr>
<td>lb6 6 lane bridge length</td>
<td></td>
</tr>
<tr>
<td>lt2 2 lane tunnel length</td>
<td></td>
</tr>
<tr>
<td>lt4 4 lane tunnel length</td>
<td></td>
</tr>
<tr>
<td>lt6 6 lane tunnel length</td>
<td></td>
</tr>
<tr>
<td>le2 2 lane earthwork section length</td>
<td></td>
</tr>
<tr>
<td>le4 4 lane earthwork section length</td>
<td></td>
</tr>
</tbody>
</table>
### Appendix B: Input Data for Revenue Stream

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>le6</td>
<td>6 lane earthwork section length</td>
</tr>
<tr>
<td>ltn</td>
<td>length of tunnel with no ventilation</td>
</tr>
<tr>
<td>ltf</td>
<td>length of tunnel with jet fan</td>
</tr>
<tr>
<td>lto</td>
<td>length of tunnel with other ventilation</td>
</tr>
<tr>
<td>cc2</td>
<td>road cleaning cost (2 lanes)</td>
</tr>
<tr>
<td>cc4</td>
<td>road cleaning cost (4 lanes or more)</td>
</tr>
<tr>
<td>cm2</td>
<td>road maintenance cost (2 lanes)</td>
</tr>
<tr>
<td>cm4</td>
<td>road maintenance cost (4 lanes)</td>
</tr>
<tr>
<td>cm6</td>
<td>road maintenance cost (6 lanes)</td>
</tr>
<tr>
<td>cl1</td>
<td>lighting cost (1 or 2 lanes)</td>
</tr>
<tr>
<td>cl4</td>
<td>lighting cost (4 or 6 lanes)</td>
</tr>
<tr>
<td>cr2</td>
<td>bridge repair cost (2 lanes)</td>
</tr>
<tr>
<td>cr4</td>
<td>bridge repair cost (4 lanes)</td>
</tr>
<tr>
<td>cr6</td>
<td>bridge repair cost (6 lanes)</td>
</tr>
<tr>
<td>cp2</td>
<td>bridge paint cost (2 lanes)</td>
</tr>
<tr>
<td>cp4</td>
<td>bridge paint cost (4 lanes)</td>
</tr>
<tr>
<td>cp6</td>
<td>bridge paint cost (6 lanes)</td>
</tr>
<tr>
<td>ctn</td>
<td>tunnel maintenance cost (no ventilation)</td>
</tr>
<tr>
<td>ctt</td>
<td>tunnel maintenance cost (jet fan)</td>
</tr>
<tr>
<td>cto</td>
<td>tunnel maintenance cost (others)</td>
</tr>
<tr>
<td>csh</td>
<td>snow and ice control cost (heavy snow area)</td>
</tr>
<tr>
<td>cso</td>
<td>snow and ice control cost (ordinary snow area)</td>
</tr>
<tr>
<td>co2</td>
<td>overlay cost (2 lanes)</td>
</tr>
<tr>
<td>co4</td>
<td>overlay cost (4 lanes)</td>
</tr>
<tr>
<td>co6</td>
<td>overlay cost (6 lanes)</td>
</tr>
<tr>
<td>pcot</td>
<td>other maintenance cost parameter</td>
</tr>
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</table>

#### (Operation Cost)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ldir</td>
<td>labor cost of operation office (director)</td>
</tr>
<tr>
<td>lvdir</td>
<td>labor cost of operation office (vice director)</td>
</tr>
<tr>
<td>lchi</td>
<td>labor cost of operation office (chief)</td>
</tr>
<tr>
<td>lengl</td>
<td>labor cost of operation office (clerk or engineer)</td>
</tr>
<tr>
<td>lwor</td>
<td>labor cost of operation office (worker)</td>
</tr>
<tr>
<td>t1</td>
<td>traffic volume (boundary-1)</td>
</tr>
<tr>
<td>ita1</td>
<td>the number of directors needed for less traffic volume than t1</td>
</tr>
<tr>
<td>itb1</td>
<td>the number of vice directors needed</td>
</tr>
<tr>
<td>itc1</td>
<td>the number of chiefs needed</td>
</tr>
<tr>
<td>itd1</td>
<td>the number of clerks and engineers needed</td>
</tr>
<tr>
<td>ite1</td>
<td>the number of workers needed</td>
</tr>
<tr>
<td>t2</td>
<td>traffic volume(boundary-2)</td>
</tr>
<tr>
<td>-----</td>
<td>----------------------------</td>
</tr>
<tr>
<td>ita2</td>
<td>the number of directors needed for less traffic volume than t2</td>
</tr>
<tr>
<td>itb2</td>
<td>the number of vice directors needed</td>
</tr>
<tr>
<td>itc2</td>
<td>the number of chiefs needed</td>
</tr>
<tr>
<td>itd2</td>
<td>the number of clerks and engineers needed</td>
</tr>
<tr>
<td>ite2</td>
<td>the number of workers needed</td>
</tr>
<tr>
<td>t3</td>
<td>traffic volume(boundary-3)</td>
</tr>
<tr>
<td>ita3</td>
<td>the number of directors needed for less traffic volume than t3</td>
</tr>
<tr>
<td>itb3</td>
<td>the number of vice directors needed</td>
</tr>
<tr>
<td>itc3</td>
<td>the number of chiefs needed</td>
</tr>
<tr>
<td>itd3</td>
<td>the number of clerks and engineers needed</td>
</tr>
<tr>
<td>ite3</td>
<td>the number of workers needed</td>
</tr>
<tr>
<td>t4</td>
<td>traffic volume(boundary-4)</td>
</tr>
<tr>
<td>ita4</td>
<td>the number of directors needed for less traffic volume than t4</td>
</tr>
<tr>
<td>itb4</td>
<td>the number of vice directors needed</td>
</tr>
<tr>
<td>itc4</td>
<td>the number of chiefs needed</td>
</tr>
<tr>
<td>itd4</td>
<td>the number of clerks and engineers needed</td>
</tr>
<tr>
<td>ite4</td>
<td>the number of workers needed</td>
</tr>
<tr>
<td>t5</td>
<td>traffic volume(boundary-5)</td>
</tr>
<tr>
<td>ita5</td>
<td>the number of directors needed for less traffic volume than t5</td>
</tr>
<tr>
<td>itb5</td>
<td>the number of vice directors needed</td>
</tr>
<tr>
<td>itc5</td>
<td>the number of chiefs needed</td>
</tr>
<tr>
<td>itd5</td>
<td>the number of clerks and engineers needed</td>
</tr>
<tr>
<td>ite5</td>
<td>the number of workers needed</td>
</tr>
<tr>
<td>ita6</td>
<td>the number of directors needed for more traffic volume than t5</td>
</tr>
<tr>
<td>itb6</td>
<td>the number of vice directors needed</td>
</tr>
<tr>
<td>itc6</td>
<td>the number of chiefs needed</td>
</tr>
<tr>
<td>itd6</td>
<td>the number of clerks and engineers needed</td>
</tr>
<tr>
<td>ite6</td>
<td>the number of workers needed</td>
</tr>
<tr>
<td>ltc</td>
<td>labor cost of toll collection (clerk)</td>
</tr>
<tr>
<td>tc1</td>
<td>traffic volume(boundary-1)</td>
</tr>
<tr>
<td>itct1</td>
<td>the number of clerks needed for less traffic volume than t1</td>
</tr>
<tr>
<td>tc2</td>
<td>traffic volume(boundary-2)</td>
</tr>
<tr>
<td>itct2</td>
<td>the number of toll collection clerks needed for less traffic volume than t2</td>
</tr>
<tr>
<td>tc3</td>
<td>traffic volume (boundary-3)</td>
</tr>
<tr>
<td>-----</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>itct3</td>
<td>the number of toll collection clerks needed for less traffic volume than t3</td>
</tr>
<tr>
<td>tc4</td>
<td>traffic volume (boundary-4)</td>
</tr>
<tr>
<td>itct4</td>
<td>the number of toll collection clerks needed for less traffic volume than t4</td>
</tr>
<tr>
<td>tc5</td>
<td>traffic volume (boundary-5)</td>
</tr>
<tr>
<td>itct5</td>
<td>the number of toll collection clerks needed for less traffic volume than t5</td>
</tr>
<tr>
<td>tc6</td>
<td>traffic volume (boundary-6)</td>
</tr>
<tr>
<td>itct6</td>
<td>the number of toll collection clerks needed for less traffic volume than t6</td>
</tr>
<tr>
<td>tc7</td>
<td>traffic volume (boundary-7)</td>
</tr>
<tr>
<td>itct7</td>
<td>the number of toll collection clerks needed for less traffic volume than t7</td>
</tr>
<tr>
<td>tc8</td>
<td>traffic volume (boundary-8)</td>
</tr>
<tr>
<td>itct8</td>
<td>the number of toll collection clerks needed for less traffic volume than t8</td>
</tr>
<tr>
<td>tc9</td>
<td>traffic volume (boundary-9)</td>
</tr>
<tr>
<td>itct9</td>
<td>the number of toll collection clerks needed for less traffic volume than t9</td>
</tr>
<tr>
<td>tc10</td>
<td>traffic volume (boundary-10)</td>
</tr>
<tr>
<td>itct10</td>
<td>the number of toll collection clerks needed for less traffic volume than t10</td>
</tr>
<tr>
<td>tc11</td>
<td>traffic volume (boundary-11)</td>
</tr>
<tr>
<td>itct11</td>
<td>the number of toll collection clerks needed for less traffic volume than t11</td>
</tr>
<tr>
<td>tc12</td>
<td>traffic volume (boundary-12)</td>
</tr>
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<td>itct12</td>
<td>the number of toll collection clerks needed for less traffic volume than t12</td>
</tr>
<tr>
<td>tc13</td>
<td>traffic volume (boundary-13)</td>
</tr>
<tr>
<td>itct13</td>
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</tr>
<tr>
<td>tc14</td>
<td>traffic volume (boundary-14)</td>
</tr>
<tr>
<td>itct14</td>
<td>the number of toll collection clerks needed for less traffic volume than t14</td>
</tr>
<tr>
<td>tc15</td>
<td>traffic volume (boundary-15)</td>
</tr>
<tr>
<td>itct15</td>
<td>the number of toll collection clerks needed for less traffic volume than t15</td>
</tr>
<tr>
<td>tc16</td>
<td>traffic volume (boundary-16)</td>
</tr>
</tbody>
</table>
### Appendix B: Input Data for Revenue Stream

<table>
<thead>
<tr>
<th>Itctl16</th>
<th>the number of toll collection clerks needed for less traffic volume than t16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tc17</td>
<td>traffic volume(boundary-17)</td>
</tr>
<tr>
<td>Itctl17</td>
<td>the number of toll collection clerks needed for less traffic volume than t17</td>
</tr>
<tr>
<td>Itctl18</td>
<td>the number of toll collection clerks needed for more traffic volume than t17</td>
</tr>
<tr>
<td>Ptct</td>
<td>(consignment costs of toll collection) are (toll collection labor costs) * ptct(parameter)</td>
</tr>
<tr>
<td>Ptcm</td>
<td>toll collection machine maintenance costs) are (consignment costs of toll collection) * ptcm(parameter)</td>
</tr>
<tr>
<td>Ibrcol</td>
<td>cost parameter of building and repainting expenses etc.</td>
</tr>
<tr>
<td>Ibrc02</td>
<td>cost parameter of building and repainting expenses etc.</td>
</tr>
<tr>
<td>Pobo</td>
<td>operation bureau overhead parameter</td>
</tr>
<tr>
<td>Pho</td>
<td>headquarters overhead</td>
</tr>
<tr>
<td>Flr</td>
<td>inflation rate (maintenance and operation costs)</td>
</tr>
</tbody>
</table>

Table D.2 Closed System (Distance Proportional Toll Rate)
### Appendix B: Input Data for Revenue Stream

#### B.3 Open System (Fixed Toll Rate)

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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>cc2</td>
<td>road cleaning cost (2 lanes)</td>
<td></td>
</tr>
<tr>
<td>cc4</td>
<td>(4 lanes or more)</td>
<td></td>
</tr>
<tr>
<td>cm2</td>
<td>road maintenance cost (2 lanes)</td>
<td></td>
</tr>
<tr>
<td>cm4</td>
<td>(4 lanes)</td>
<td></td>
</tr>
<tr>
<td>cm6</td>
<td>(6 lanes)</td>
<td></td>
</tr>
<tr>
<td>cl1</td>
<td>lighting cost (1 or 2 lanes)</td>
<td></td>
</tr>
<tr>
<td>cl4</td>
<td>(4 or 6 lanes)</td>
<td></td>
</tr>
<tr>
<td>cr2</td>
<td>bridge repair cost (2 lanes)</td>
<td></td>
</tr>
<tr>
<td>cr4</td>
<td>(4 lanes)</td>
<td></td>
</tr>
<tr>
<td>cr6</td>
<td>(6 lanes)</td>
<td></td>
</tr>
<tr>
<td>cp2</td>
<td>bridge paint cost (2 lanes)</td>
<td></td>
</tr>
<tr>
<td>cp4</td>
<td>(4 lanes)</td>
<td></td>
</tr>
<tr>
<td>cp6</td>
<td>(6 lanes)</td>
<td></td>
</tr>
<tr>
<td>ctn</td>
<td>tunnel maintenance cost (no ventilation)</td>
<td></td>
</tr>
<tr>
<td>ctj</td>
<td>tunnel maintenance cost (jet fan)</td>
<td></td>
</tr>
<tr>
<td>cto</td>
<td>tunnel maintenance cost (others)</td>
<td></td>
</tr>
<tr>
<td>csh</td>
<td>snow and ice control cost (heavy snow area)</td>
<td></td>
</tr>
<tr>
<td>cso</td>
<td>(ordinary snow area)</td>
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</tr>
<tr>
<td>co2</td>
<td>overlay cost (2 lanes)</td>
<td></td>
</tr>
<tr>
<td>co4</td>
<td>(4 lanes)</td>
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</tr>
<tr>
<td>co6</td>
<td>(6 lanes)</td>
<td></td>
</tr>
<tr>
<td>pcot</td>
<td>other maintenance cost parameter</td>
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**Operation Cost**

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<td>ldir</td>
<td>labor cost of operation office (director)</td>
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</tr>
<tr>
<td>lvdir</td>
<td>(vice director)</td>
<td></td>
</tr>
<tr>
<td>lchi</td>
<td>(chief)</td>
<td></td>
</tr>
<tr>
<td>leng</td>
<td>(clerk or engineer)</td>
<td></td>
</tr>
<tr>
<td>lwor</td>
<td>(worker)</td>
<td></td>
</tr>
<tr>
<td>t1</td>
<td>traffic volume (boundary-1)</td>
<td></td>
</tr>
<tr>
<td>ita1</td>
<td>the number of directors needed for less traffic volume than t1</td>
<td></td>
</tr>
<tr>
<td>itb1</td>
<td>the number of vice directors needed</td>
<td></td>
</tr>
<tr>
<td>itc1</td>
<td>the number of chiefs needed</td>
<td></td>
</tr>
<tr>
<td>itd1</td>
<td>the number of clerks and engineers needed</td>
<td></td>
</tr>
<tr>
<td>ite1</td>
<td>the number of workers needed</td>
<td></td>
</tr>
<tr>
<td>t2</td>
<td>traffic volume (boundary-2)</td>
<td></td>
</tr>
<tr>
<td>ita2</td>
<td>the number of directors needed for less traffic volume than t2</td>
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<tr>
<td>itb2</td>
<td>the number of vice directors needed</td>
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<td>Variable</td>
<td>Description</td>
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<td>------------------------------------------------------------------------------</td>
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<td>itc2</td>
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<td>itd2</td>
<td>the number of clerks and engineers needed</td>
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<td>the number of workers needed</td>
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<tr>
<td>t3</td>
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</tr>
<tr>
<td>ita3</td>
<td>the number of directors needed for less traffic volume than t3</td>
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</tr>
<tr>
<td>itb3</td>
<td>the number of vice directors needed</td>
<td></td>
</tr>
<tr>
<td>itc3</td>
<td>the number of chiefs needed</td>
<td></td>
</tr>
<tr>
<td>itd3</td>
<td>the number of clerks and engineers needed</td>
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<tr>
<td>ite3</td>
<td>the number of workers needed</td>
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<tr>
<td>t4</td>
<td>traffic volume (boundary-4)</td>
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</tr>
<tr>
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</tr>
<tr>
<td>itb4</td>
<td>the number of vice directors needed</td>
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<td>the number of clerks and engineers needed</td>
<td></td>
</tr>
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<td>ite4</td>
<td>the number of workers needed</td>
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<td>traffic volume (boundary-5)</td>
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</tr>
<tr>
<td>itb5</td>
<td>the number of vice directors needed</td>
<td></td>
</tr>
<tr>
<td>itc5</td>
<td>the number of chiefs needed</td>
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<tr>
<td>itd5</td>
<td>the number of clerks and engineers needed</td>
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</tr>
<tr>
<td>ite5</td>
<td>the number of workers needed</td>
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</tr>
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<td>ita6</td>
<td>the number of directors needed for more traffic volume than t5</td>
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<tr>
<td>itb6</td>
<td>the number of vice directors needed</td>
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</tr>
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<td>itc6</td>
<td>the number of chiefs needed</td>
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<td>itd6</td>
<td>the number of clerks and engineers needed</td>
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<td>ite6</td>
<td>the number of workers needed</td>
<td></td>
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<td>ltc</td>
<td>labor cost of toll collection (clerk)</td>
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<td>tc2</td>
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</tr>
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<td>the number of toll collection clerks needed for less traffic volume than t2</td>
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<td>tc3</td>
<td>traffic volume (boundary-3)</td>
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<td>itct3</td>
<td>the number of toll collection clerks needed for less traffic volume than t3</td>
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<td>tc4</td>
<td>traffic volume (boundary-4)</td>
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<tr>
<td>Attachment Code</td>
<td>Description</td>
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<td>tc5</td>
<td>traffic volume (boundary-5)</td>
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<tr>
<td>itct5</td>
<td>the number of toll collection clerks needed for less traffic volume than t5</td>
<td></td>
</tr>
<tr>
<td>tc6</td>
<td>traffic volume (boundary-6)</td>
<td></td>
</tr>
<tr>
<td>itct6</td>
<td>the number of toll collection clerks needed for less traffic volume than t6</td>
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<td>tc7</td>
<td>traffic volume (boundary-7)</td>
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</tr>
<tr>
<td>itct7</td>
<td>the number of toll collection clerks needed for less traffic volume than t7</td>
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<td>tc8</td>
<td>traffic volume (boundary-8)</td>
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<td>tc9</td>
<td>traffic volume (boundary-9)</td>
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<td>the number of toll collection clerks needed for less traffic volume than t9</td>
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<td>traffic volume (boundary-10)</td>
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<td>the number of toll collection clerks needed for less traffic volume than t10</td>
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<td>tc11</td>
<td>traffic volume (boundary-11)</td>
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</tr>
<tr>
<td>itct11</td>
<td>the number of toll collection clerks needed for less traffic volume than t11</td>
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<tr>
<td>tc12</td>
<td>traffic volume (boundary-12)</td>
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<td>itct12</td>
<td>the number of toll collection clerks needed for less traffic volume than t12</td>
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<tr>
<td>tc13</td>
<td>traffic volume (boundary-13)</td>
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</tr>
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<td>itct13</td>
<td>the number of toll collection clerks needed for less traffic volume than t13</td>
<td></td>
</tr>
<tr>
<td>tc14</td>
<td>traffic volume (boundary-14)</td>
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</tr>
<tr>
<td>itct14</td>
<td>the number of toll collection clerks needed for less traffic volume than t14</td>
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</tr>
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<td>tc15</td>
<td>traffic volume (boundary-15)</td>
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<td>the number of toll collection clerks needed for less traffic volume than t15</td>
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<td>tc16</td>
<td>traffic volume (boundary-16)</td>
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<td>itct16</td>
<td>the number of toll collection clerks needed for less traffic volume than t16</td>
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</tr>
<tr>
<td>tc17</td>
<td>traffic volume (boundary-17)</td>
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</tr>
<tr>
<td>itct17</td>
<td>the number of toll collection clerks needed for less traffic volume than t17</td>
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### Table D.3 Open System (Fixed Toll Rate)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>tc18</td>
<td>traffic volume (boundary-18)</td>
</tr>
<tr>
<td>itct18</td>
<td>the number of toll collection clerks needed for less traffic volume than t18</td>
</tr>
<tr>
<td>itct19</td>
<td>the number of toll collection clerks needed for more traffic volume than t18</td>
</tr>
<tr>
<td>ptct</td>
<td>(consignment costs of toll collection) are (toll collection labor costs) * ptct (parameter)</td>
</tr>
<tr>
<td>ptcem</td>
<td>toll collection machine maintenance costs are (consignment costs of toll collection) * ptcem (parameter)</td>
</tr>
<tr>
<td>ibrcol</td>
<td>cost parameter of building and repainting expenses etc.</td>
</tr>
<tr>
<td>ibrc02</td>
<td>cost parameter of building and repainting expenses etc.</td>
</tr>
<tr>
<td>pob0</td>
<td>operation bureau overhead parameter</td>
</tr>
<tr>
<td>pho</td>
<td>headquarters overhead</td>
</tr>
<tr>
<td>flr</td>
<td>inflation rate (maintenance and operation costs)</td>
</tr>
</tbody>
</table>
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.
### Appendix C: Traffic Volume and Growth Rates

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

<table>
<thead>
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<th>Vehicle Type</th>
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<th>I.C.</th>
<th>I.C.</th>
<th>I.C.</th>
<th>I.C.</th>
<th>I.C.</th>
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<td>#2</td>
<td>#3</td>
<td>#4</td>
<td>#5</td>
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<td></td>
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</tr>
<tr>
<td><strong>Medium-sized Motor Vehicle</strong></td>
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<td><strong>Large-sized Motor Vehicle</strong></td>
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<td><strong>Special Large-sized Motor Vehicle</strong></td>
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<td>(vehicle type-5)</td>
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| 1,636   | 853     | 2,275   | 449     | 1,400   | 6,785   |
| 4,585   | 2,660   | 6,785   | 1,846   | 2,892   | 7,493   |
| 723     | 448     | 1,099   | 278     | 1,400   | 4,344   |
| 505     | 346     | 862     | 183     | 1,177   | 11,106  |
| 44      | 39      | 85      | 12      | 15      | 0       |
| 7,493   | 4,344   | 11,106  | 2,389   | 3,967   | 0       |

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Appendix C: Traffic Volume and Growth Rates

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Table C.2: Interchange Pair Traffic Volume at Base Year for RVS #2.
### Appendix C: Traffic Volume and Growth Rates

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Table C.3: Interchange Pair Traffic Volume at Base Year for RVS #3.
### Appendix C: Traffic Volume and Growth Rates

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<th>I.C. #6</th>
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**Table C.4: Interchange Pair Traffic Volume at Base Year for RVS #4.**
### Appendix C: Traffic Volume and Growth Rates

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

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</tr>
<tr>
<td>I.C. #5</td>
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<tr>
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<td></td>
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<tr>
<td><strong>Total</strong></td>
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<td>1,399</td>
<td>3,318</td>
<td>4,530</td>
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<td>2,454</td>
<td>9,347</td>
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<td></td>
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<tr>
<td>I.C. #2</td>
<td>2,690</td>
<td>3,976</td>
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<td>I.C. #3</td>
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<td></td>
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</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I.C. #6</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
- I.C. stands for interchange control number.
- The data represents traffic volume at base year for RVS #5.
### Appendix C: Traffic Volume and Growth Rates

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

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>I.C. #1</th>
<th>I.C. #2</th>
<th>I.C. #3</th>
<th>I.C. #4</th>
<th>I.C. #5</th>
<th>I.C. #6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle #1</strong> (light motor vehicle)</td>
<td>80</td>
<td>302</td>
<td>318</td>
<td>688</td>
<td>1,164</td>
<td></td>
</tr>
<tr>
<td><strong>Vehicle #2</strong> (ordinary motor vehicle)</td>
<td>312</td>
<td>1,134</td>
<td>832</td>
<td>2,745</td>
<td>2,699</td>
<td></td>
</tr>
<tr>
<td><strong>Vehicle #3</strong> (medium-sized motor vehicle)</td>
<td>42</td>
<td>151</td>
<td>173</td>
<td>134</td>
<td>474</td>
<td></td>
</tr>
<tr>
<td><strong>Vehicle #4</strong> (large-sized motor vehicle)</td>
<td>31</td>
<td>96</td>
<td>142</td>
<td>111</td>
<td>393</td>
<td></td>
</tr>
<tr>
<td><strong>Vehicle #5</strong> (special large-sized motor vehicle)</td>
<td>4</td>
<td>13</td>
<td>12</td>
<td>7</td>
<td>28</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(total)</th>
<th>I.C. #1</th>
<th>I.C. #2</th>
<th>I.C. #3</th>
<th>I.C. #4</th>
<th>I.C. #5</th>
<th>I.C. #6</th>
</tr>
</thead>
<tbody>
<tr>
<td>469</td>
<td>1,696</td>
<td>1,477</td>
<td>3,685</td>
<td>4,758</td>
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</tr>
</tbody>
</table>
### Appendix C: Traffic Volume and Growth Rates

Vehicle type-1  
(light motor vehicle)  

<table>
<thead>
<tr>
<th>I.C.</th>
<th>C.1</th>
<th>C.2</th>
<th>C.3</th>
<th>C.4</th>
<th>C.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.C. #1</td>
<td>110</td>
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<td>371</td>
<td>770</td>
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<td>586</td>
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<td>493</td>
<td>1,624</td>
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</tr>
<tr>
<td>I.C. #3</td>
<td>437</td>
<td>482</td>
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<td></td>
</tr>
<tr>
<td>I.C. #4</td>
<td>558</td>
<td>960</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I.C. #5</td>
<td>3,528</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I.C. #6</td>
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</tbody>
</table>

Vehicle type-2  
(ordinary motor vehicle)  

<table>
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<tr>
<th>I.C.</th>
<th>C.1</th>
<th>C.2</th>
<th>C.3</th>
<th>C.4</th>
<th>C.5</th>
<th>C.6</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1,706</td>
<td>960</td>
<td>3,081</td>
<td>3,583</td>
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<td>1,241</td>
<td>1,915</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td></td>
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</tbody>
</table>

Vehicle type-3  
(medium-sized motor vehicle)  

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<th>I.C.</th>
<th>C.1</th>
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<th>C.3</th>
<th>C.4</th>
<th>C.5</th>
<th>C.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.C. #1</td>
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<td>91</td>
<td>189</td>
<td>83</td>
<td>953</td>
<td>722</td>
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<tr>
<td>I.C. #2</td>
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<td>91</td>
<td>130</td>
<td>83</td>
<td>83</td>
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<tr>
<td>I.C. #3</td>
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<td>217</td>
<td>354</td>
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<td></td>
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</tr>
<tr>
<td>I.C. #4</td>
<td>309</td>
<td>774</td>
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</tr>
<tr>
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Vehicle type-4  
(large-sized motor vehicle)  

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<th>C.1</th>
<th>C.2</th>
<th>C.3</th>
<th>C.4</th>
<th>C.5</th>
<th>C.6</th>
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<td>289</td>
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Vehicle type-5  
(special large-sized motor vehicle)  

<table>
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<th>C.1</th>
<th>C.2</th>
<th>C.3</th>
<th>C.4</th>
<th>C.5</th>
<th>C.6</th>
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</table>

(total)  

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<th>C.2</th>
<th>C.3</th>
<th>C.4</th>
<th>C.5</th>
<th>C.6</th>
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</tbody>
</table>

Table C.7: Interchange Pair Traffic Volume at Base Year for RVS #7.
### Table C.8: Interchange Pair Traffic Volume at Base Year for RVS #8.

#### Vehicle Type-1
(light motor vehicle)

<table>
<thead>
<tr>
<th>I.C. #1</th>
<th>I.C. #2</th>
<th>I.C. #3</th>
<th>I.C. #4</th>
<th>I.C. #5</th>
<th>I.C. #6</th>
</tr>
</thead>
<tbody>
<tr>
<td>195</td>
<td>617</td>
<td>497</td>
<td>402</td>
<td>1,114</td>
<td>2,177</td>
</tr>
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</table>

#### Vehicle Type-2
(ordinary motor vehicle)

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<thead>
<tr>
<th>I.C. #1</th>
<th>I.C. #2</th>
<th>I.C. #3</th>
<th>I.C. #4</th>
<th>I.C. #5</th>
<th>I.C. #6</th>
</tr>
</thead>
<tbody>
<tr>
<td>908</td>
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</table>

#### Vehicle Type-3
(medium-sized motor vehicle)

<table>
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<tr>
<th>I.C. #1</th>
<th>I.C. #2</th>
<th>I.C. #3</th>
<th>I.C. #4</th>
<th>I.C. #5</th>
<th>I.C. #6</th>
</tr>
</thead>
<tbody>
<tr>
<td>119</td>
<td>346</td>
<td>196</td>
<td>387</td>
<td>3,667</td>
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</table>

#### Vehicle Type-4
(large-sized motor vehicle)

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<tr>
<th>I.C. #1</th>
<th>I.C. #2</th>
<th>I.C. #3</th>
<th>I.C. #4</th>
<th>I.C. #5</th>
<th>I.C. #6</th>
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</thead>
<tbody>
<tr>
<td>88</td>
<td>267</td>
<td>169</td>
<td>309</td>
<td>3,194</td>
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</tr>
</tbody>
</table>

#### Vehicle Type-5
(special large-sized motor vehicle)

<table>
<thead>
<tr>
<th>I.C. #1</th>
<th>I.C. #2</th>
<th>I.C. #3</th>
<th>I.C. #4</th>
<th>I.C. #5</th>
<th>I.C. #6</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>35</td>
<td>17</td>
<td>39</td>
<td>371</td>
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</tbody>
</table>

### Total

<table>
<thead>
<tr>
<th>I.C. #1</th>
<th>I.C. #2</th>
<th>I.C. #3</th>
<th>I.C. #4</th>
<th>I.C. #5</th>
<th>I.C. #6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,320</td>
<td>4,792</td>
<td>1,877</td>
<td>6,793</td>
<td>16,555</td>
<td></td>
</tr>
</tbody>
</table>

Appendix C: Traffic Volume and Growth Rates
### Appendix C: Traffic Volume and Growth Rates

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

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>IC #1</th>
<th>IC #2</th>
<th>IC #3</th>
<th>IC #4</th>
<th>IC #5</th>
<th>IC #6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle type-1</strong>&lt;br&gt; (Light motor vehicle)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4,443</td>
<td></td>
</tr>
<tr>
<td>IC #1</td>
<td>219</td>
<td>967</td>
<td>441</td>
<td>1,193</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC #2</td>
<td>705</td>
<td>679</td>
<td>601</td>
<td></td>
<td>1,732</td>
<td></td>
</tr>
<tr>
<td>IC #3</td>
<td>709</td>
<td>1,075</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC #4</td>
<td>560</td>
<td>572</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Vehicle type-2</strong>&lt;br&gt; (Ordinary motor vehicle)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12,614</td>
<td></td>
</tr>
<tr>
<td>IC #1</td>
<td>1,035</td>
<td>3,846</td>
<td>1,200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC #2</td>
<td>1,888</td>
<td>1,559</td>
<td>2,339</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC #3</td>
<td>1,183</td>
<td>2,657</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC #4</td>
<td>1,138</td>
<td>3,811</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Vehicle type-3</strong>&lt;br&gt; (Medium-sized motor vehicle)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2,319</td>
<td></td>
</tr>
<tr>
<td>IC #1</td>
<td>146</td>
<td>460</td>
<td>215</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC #2</td>
<td>177</td>
<td>176</td>
<td>105</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC #3</td>
<td>44</td>
<td>214</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC #4</td>
<td>176</td>
<td>826</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Vehicle type-4</strong>&lt;br&gt; (Large-sized motor vehicle)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,684</td>
<td></td>
</tr>
<tr>
<td>IC #1</td>
<td>106</td>
<td>357</td>
<td>188</td>
<td>264</td>
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<td></td>
</tr>
<tr>
<td>IC #2</td>
<td>104</td>
<td>1,208</td>
<td>58</td>
<td>664</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC #3</td>
<td>32</td>
<td>125</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Vehicle type-5</strong>&lt;br&gt; (Special large-sized motor vehicle)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>276</td>
<td></td>
</tr>
<tr>
<td>IC #1</td>
<td>15</td>
<td>46</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC #2</td>
<td>17</td>
<td>15</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC #3</td>
<td>6</td>
<td>31</td>
<td>62</td>
<td></td>
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</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>21,336</td>
<td></td>
</tr>
<tr>
<td>IC #1</td>
<td>1,521</td>
<td>5,676</td>
<td>2,064</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC #2</td>
<td>2,891</td>
<td>3,637</td>
<td>3,120</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>IC #3</td>
<td>1,825</td>
<td>3,599</td>
<td>5,811</td>
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<td></td>
<td></td>
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<tr>
<td>IC #4</td>
<td>4,181</td>
<td>6,868</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: IC stands for Interchange Pair.
C.2 Traffic Volume Growth Parameters

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

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

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.

<table>
<thead>
<tr>
<th>RVS #</th>
<th>Year in RVS</th>
<th>Parameter</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>1</td>
<td>1.0000</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1.0000</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1.0000</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1.0404</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1.0404</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1.1041</td>
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<td>1</td>
<td>1.1041</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.1717</td>
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<td>8</td>
<td>1</td>
<td>1.2434</td>
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<tr>
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<td>1.2434</td>
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<td>3</td>
<td>1.2434</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.3195</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>1.3195</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.3195</td>
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<tr>
<td></td>
<td>3</td>
<td>1.4002</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.4002</td>
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<td>12</td>
<td>1.6734</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>1.6734</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>1.6734</td>
</tr>
</tbody>
</table>

Table C.11 Toll Rate Growth Parameters
Appendix D

Source Code of the Model

Appendix D shows source code of the model.
Appendix D: Source Code of the Model

Main Program
  WPDURA
    VARBLE
      TRANS
        WPDFF
        MMTWPL
        COVAR
    COVAR
  EAST
    NETWRK
      EARLY
        TANSP
          INV
          DECOMP
          DGMULT
        INPOL
          CDFUNC
          ESTMMT
  WPCOST
    VARBLE
      TRANS
        WPCMMT
        WPCFF
        COVAR
    WPCFF
    MMTWPL
  REVSTR
    VARBLE
      TRANS
        RVSSMT
        RVSSF
        COVAR
    RVSSF
    MMTWPL
    RVSSF
    MMTWPL
    RVSSF
    MMTWPL
    RVSSF
    MMTWPL
    RVSSF
    MMTWPL
    INTPOL

Figure D.1 Program Structure
<table>
<thead>
<tr>
<th>main program</th>
<th>AMMA</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>sub-routine</td>
<td>WPDURA</td>
<td>evaluate the first four moments of the work package duration.</td>
</tr>
<tr>
<td></td>
<td>EAST</td>
<td>evaluate the first four moments of the early start time of work packages. obtain the calendar month of the early start time.</td>
</tr>
<tr>
<td></td>
<td>WPCOST</td>
<td>evaluate the first four moments of the work package cost.</td>
</tr>
<tr>
<td></td>
<td>REVSTR</td>
<td>evaluate the first four moments of the net revenue stream.</td>
</tr>
<tr>
<td></td>
<td>PRJCST</td>
<td>approximate the first four moments of the project cost at the MARR.</td>
</tr>
<tr>
<td></td>
<td>PRJREV</td>
<td>approximate the first four moments of the project revenue at the MARR.</td>
</tr>
<tr>
<td></td>
<td>PRJNPV</td>
<td>approximate the first four moments of the project NPV at the MARR.</td>
</tr>
<tr>
<td></td>
<td>PRJIRR</td>
<td>approximate the cumulative distribution function and the first four moments of the project IRR.</td>
</tr>
<tr>
<td></td>
<td>CDFUNC</td>
<td>obtain values of cumulative distribution function of a dependent variable approximated by a pearson typed distribution.</td>
</tr>
<tr>
<td></td>
<td>INTPOL</td>
<td>interpolate the beta1 and beta2 values of the pearson table by a method of linear interpolation.</td>
</tr>
<tr>
<td></td>
<td>VARBLE</td>
<td>approximate a variable to a pearson type distribution by using five percentile estimates.</td>
</tr>
<tr>
<td></td>
<td>TRANS</td>
<td>transform a set of correlated variables to a set of uncorrelated variables.</td>
</tr>
<tr>
<td></td>
<td>TANSP</td>
<td>transform correlated work package costs/revenue streams to uncorrelated work package costs/revenue.</td>
</tr>
<tr>
<td></td>
<td>WPDDFF</td>
<td>check the type of functional form for work package duration. estimate the function at the mean values of the transformed variables.</td>
</tr>
<tr>
<td></td>
<td>WPCMMT</td>
<td>evaluate the first four moments of the work package cost for different discount rates.</td>
</tr>
<tr>
<td>Program</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>RVSMMT</td>
<td>Evaluate the first four moments of the revenue streams for different discount rates.</td>
<td></td>
</tr>
<tr>
<td>WPCFF</td>
<td>Check the type of functional form for work package cost. Estimate the function at the mean values of the transformed variables.</td>
<td></td>
</tr>
<tr>
<td>RVSFF</td>
<td>Check the type of functional form for revenue streams. Estimate the function at the mean values of the transformed variables.</td>
<td></td>
</tr>
<tr>
<td>MMTWPL</td>
<td>Approximate the first four moments of a dependent variables at work package/revenue stream level (by Taylor series).</td>
<td></td>
</tr>
<tr>
<td>COVAR</td>
<td>Approximate the correlation between two dependent variables by using information between the primary variables and their partial derivatives.</td>
<td></td>
</tr>
<tr>
<td>NETWRK</td>
<td>Evaluate the first four moments of work package early start time (by PNET).</td>
<td></td>
</tr>
<tr>
<td>EARLY</td>
<td>Evaluate the first four moments of a path early start time by uncorrelating the work package durations.</td>
<td></td>
</tr>
<tr>
<td>ESTMMT</td>
<td>Approximate the first four moments for early start time (if PNET is used).</td>
<td></td>
</tr>
<tr>
<td>INV</td>
<td>Invert a matrix</td>
<td></td>
</tr>
<tr>
<td>DECOMP</td>
<td>Decompose $A = L \cdot L^{\text{transpose}}$ (by Choleski method).</td>
<td></td>
</tr>
<tr>
<td>DGMULT</td>
<td>Calculate matrix $\times$ matrix e.g. transformation matrix $(L^{-1} \times D^{-1})$</td>
<td></td>
</tr>
<tr>
<td>RVSF11 -13</td>
<td>The functional forms for revenue streams for toll highway projects</td>
<td></td>
</tr>
<tr>
<td>SPARSE</td>
<td>Save huge arrays that contain mainly zero.</td>
<td></td>
</tr>
<tr>
<td>FOO1</td>
<td>Called by &quot;RVSF12&quot;</td>
<td></td>
</tr>
<tr>
<td>TRACE</td>
<td>Trace the procedure</td>
<td></td>
</tr>
</tbody>
</table>

Table D.1 Program List
Appendix D: Source Code of the Model

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
Appendix D: Source Code of the Model

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

 REAL*4 WPTIME (:,:), CORRD (:,:), ESTART (:,:) 
 INTEGER IWPC (:), NWFCF (:), NDVR (:)
 INTEGER NRVSF (:), NDRV (:)

 REAL*4 XUCOST (:,:,), TRIWPC (:,:), COST (:,:), CORRC (:,:)
 REAL*4 BOTTLE (:,:), XUREV (:,:,), REV (:,:), CORRC (:,:) 

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

 REAL*4 PCOST (4), PREV (4) 
 ALLOCATABLE WPTIME, CORRD, ESTART 
 ALLOCATABLE IWPC, NWFCF, NDVR, NRVSF, NDRV, BOTTLE 
 ALLOCATABLE XUCOST, TRIWPC, COST, CORRC 
 ALLOCATABLE XUREV, TRIRVS, REV, CORRC 

 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
Appendix D: Source Code of the Model

```
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
Appendix D: Source Code of the Model

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', 'minimum 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 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(:,:), 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
Appendix D: Source Code of the Model

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
Appendix D: Source Code of the Model

```plaintext
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)
170 FORMAT(20F6.2)
       DO 80 K=JPV1,NNVR
           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 VARIABLE (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
      ENDIF
160 CORRD (J,INWP) = 0.0D0
170 CONTINUE
```
Appendix D: Source Code of the Model

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)
            FORMAT(F6.2)
            CORRD(J,INWP) = CORRD(INWP,J)
         ENDIF
      190 CONTINUE
   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 DERAVATIVES WITH RESPECT TO THE TRANSFORMED VARIABLES.

    DO 210 JPV=1,NNVR
      Z(JPV) = ZWPD(1,INWP,JPV)
  210
    DO 220 JPV=1,NNVR
      X(JPV) = 0.0D0
      DO 220 KSV=1,NNVR
      X(JPV) = X(JPV) + TRIWPD(JPV,KSV) * Z(KSV)
  220

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
Appendix D: Source Code of the Model

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
   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
Appendix D: Source Code of the Model

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

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

C THE FIRST PARTIAL DERIVATIVE 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
   340 CONTINUE

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 DERIVATIVE 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)
               370 CONTINUE
         ENDIF
      380 CONTINUE

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
Appendix D: Source Code of the Model

CORRD (JWP, INWP) = 0.0D0

ELSE

CALL COVAR(JU, NDCV, INWP, JWP, NI, NJ,
  + PWPDX,
  + XWPD,
  + WPDCO,
  + STFO(INWP), STFO(JWP),
  + CORRD)

ENDIF

ENDIF

CONTINUE

CONTINUE

END
Appendix D: Source Code of the Model

C East.FOR

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=======================================================================
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 meant 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)


Appendix D: Source Code of the Model

GO TO 1000
ENDIF

IF (IYS == 0) THEN
  SDATE = 0.0D0
  GO TO 400
ENDIF

IWW = NW - 4

IYB = 1988
ICH = IYS - IYB
ND = ICH * DAYS (13, IWW)
NDS = ND + IDS + DAYS (IMS, IWW)

IF (0 < ICH) GO TO 180
IF (IMS < 3) GO TO 200

180 NDS = NDS + 1
JS = IFIX (ICH / 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 NETWK (PEARSN, WPTIME, CORRD, ESTART, TRCOR)
IF (0 < IERR) GO TO 1000

C the work package durations in the specified time unit
Appendix D: Source Code of the Model

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
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 time from absolute time.
SELECT CASE (NWW + NUNT - 1)
C 7 day WW, daily
CASE (7)
   AMST = ESTART (1, I) + SDATE
   AMET (I) = ESTART (1, I) / 30.4167D0
   SDET (I) = SDET (I) / 30.4167D0
Appendix D: Source Code of the Model

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)
Appendix D: Source Code of the Model

\[
\text{AMP} = \text{ESTART (1, NWP)}
\]

\[
\text{CASE (3)}
\]

\[
\text{AMP} = \text{ESTART (1, NWP)} \times 12.0D0
\]

END SELECT

\[
\text{SDP} = \text{SDET (NWP)}
\]

\[
\text{SKP} = \text{SKET (NWP)}
\]

\[
\text{AKP} = \text{AKET (NWP)}
\]

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, F15.2)
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, 3A3, '/ ', 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', + /}'
Appendix D: Source Code of the Model

```plaintext
+ /
+ /
+ /
+ /
END
```
Appendix D: Source Code of the Model

C WpCost.FOR

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
Appendix D: Source Code of the Model

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 wrong

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

    DO 35
Appendix D: Source Code of the Model

```
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, CI, C2, C3, C4)
      IF (IERR == 1) GO TO 9001
      XCOST(1, I, J) = CI
      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   CONTINUE
   ELSE
      CONTINUE
   ENDIF

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 VARPBE (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
 CONTINUE

C CORRELATION COEFFICIENTS BETWEEN THE PRIMARY VARIABLES IN
C THE WORK PACKAGE. CORRELATION MATRIX IS POSITIVE DEFINITE.

DO 140 J = 4, NNVR
J = J+1
IF (J <= 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.

J = 1
READ (12, 8010) A, B, C, D, E
CALL VARPBE (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

GO TO 300

C MOMENTS OF THE WORK PACKAGE DURATIONS ARE ENTERED DIRECTLY

READ (12, 210) (COST (K, I), K = 1, 4)
FORMAT (4F25.6)

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
   ENDIF
400 CONTINUE

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 WPCMNT (I, DR, FRA,
+ NWPCF, NDVR,
+ XUCOST, TRIWPC,
+ COST,
+ STPO (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 DERIVATIVE WITH RESPECT TO THE CORRELATED VARIABLES.

NN = NWP-1
DO 450 I=2,NN
   IF (I < 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 DERIVATIVE 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)
   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)
   CALL WPCFF(NWPCF(I),DR,FRA,X,GZL(J))
C THE FIRST PARTIAL DERIVATIVE 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.
Appendix D: Source Code of the Model

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
         ENDIF
      ENDIF
   ENDIF
470 CONTINUE
500 CONTINUE
1000 DEALLOCATE(XCOST, WPCCO, STFO, TRI)
   CALL TRACE(2, 'WPCOST', 'exiting.')
RETURN

8010 FORMAT(5F20.4)
8020 FORMAT(I2)
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
Appendix D: Source Code of the Model

C RevStr.FOR

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, RVSMNT

C=================================================================================

SUBROUTINE REVSTR (PEARSN,
                     + DR, 
                     + WPTIME, 
                     + ESTART, 
                     + NRVSF, NDRV, 
                     + XUREV, 
                     + TRIRVS, 
                     + REV, CORRR, 
                     + BOTTLE)
C=================================================================================

C if you have 16M Ram, choose "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
Appendix D: Source Code of the Model

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)
  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
  CONTINUE
  RVSCO (INRS, J, J) = 1.0D0
60 CONTINUE
65 CONTINUE

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),
Appendix D: Source Code of the Model

```fortran
+ 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)
```

Appendix D: Source Code of the Model

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 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 /= 0.00D0) THEN
WRITE (7, 9901) DR
ELSE
WRITE (7, 9902)
ENDIF
WRITE (7, 9903)

DO 100 I = 1, NWP

IF (COST (2, I) == 0.00D0) THEN
SDWPC = 0.00D0
SKWPC = 0.00D0
AKWPC = 0.00D0
ELSE
SDWPC = COST (2, I) ** 0.50D0
SKWPC = COST (3, I) / (COST (2, I) ** 1.50D0)
ASKP = 1.20D0* (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) = 0.00D0
PCOST (2) = 0.00D0
PCOST (3) = 0.00D0
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
      ENDIF
   COR (L, K) = TEMP
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 derivatives of the transformed W.P costs, second
C partial derivative 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) * PD (I) * Z (2, I - 1)
   PCOST (3) = PCOST (3) + PD (I) * PD (I) * PD (I) * Z (3, I - 1)
   FC = 0.0D0
   IF (I < (NWP - 1)) THEN
      DO 180 J = (I + 1), (NWP - 1)
         FC = FC + 6.0D0 *
         + (PD (I) * PD (J)) * PD (I) * PD (J) * Z (2, I - 1) * Z (3, I - 1)
      ENDIF
200   PCOST (4) = PCOST (4) + FC + PD (I) * PD (I) * PD (I) * 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)
Appendix D: Source Code of the Model

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 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).

SUBROUTINE PRJREV (DR,
                    + REV,
                    + CORRR,
                    + PREV)

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
Appendix D: Source Code of the Model

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=====''
+ 'Organizational Revenue')
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=====''
+ 'Organizational Revenue')
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
Appendix D: Source Code of the Model

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,F15.3)
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',
Appendix D: Source Code of the Model

```
+    ',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
```
Appendix D: Source Code of the Model

C PrjIrr.FOR
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, choose "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

$ENDIF

REAL*4 XUREV (4, NRS, *), REV (4, *)
REAL*4 BOTTLE (NRS, *)
REAL*4 STPO
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)
c these are almost personality arrays, except for A and Z...

sfo = 0.0d0
km = 0

allocate (4, nmp)
allocate (4, nmp)
call trace (2, 'printer', starting')
Appendix D: Source Code of the Model

```
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
    COR (L, K) = TEMP
  CONTINUE
ENDIF
50 CONTINUE
C transform the correlated W.P costs to uncorrelated W.P costs.
ALLOCATE (TRI (NNVR, NNVR))
CALL TANSF (NNVR, X, Z, COR, TRI)
IF (0 < IERR) GO TO 1200
DEALLOCATE (COR)
C first partial derivatives of the transformed W.P costs.
DO 80 M = 2, NN
  PDC (M) = 0.0D0
  DO 80 J = 2, NN
    PDC (M) = PDC (M) + TRI (J - 1, M - 1)
  CONTINUE
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
      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
  CALL RVSMRM (J, DR, BOTTLE, 
                NRVSF, NDRV, 
                XUREV, TIRVS, 
                REV, STFO)
Appendix D: Source Code of the Model

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)
Appendix D: Source Code of the Model

\[ \text{AKNPV} = \frac{\text{FNPV}}{(\text{SNPV}^2)} \]

C values of the cumulative distribution function approximated
C for the net present value of the project

\[
\text{CALL CDFUNC (PEARSN,} \\
+ \quad \text{ANPV,SDNPV,SKNPV,AKNPV,} \\
+ \quad \text{VA,VB,VC,VD,VE,VF,VG,} \\
+ \quad \text{VM,} \\
+ \quad \text{VT,VU,VV,VW,VX,VY,VZ)}
\]

C probability of NPV = 0 at this discount rate

\[
\text{IF (I == 1) THEN} \\
\quad \text{VA1 = VA} \\
\text{ENDIF}
\]

\[
\text{IF (0.0D0 <= VA1) GO TO 205} \\
\text{IF (0 < KM) GO TO 205} \\
\quad \text{KM = 1}
\]

205 \text{ IF (0.0D0 < VA) GO TO 490}

\[
\text{IF (VA < 0.0D0 .AND. 0.0D0 <= VB) GO TO 210} \\
\text{IF (VB < 0.0D0 .AND. 0.0D0 <= VC) GO TO 230} \\
\text{IF (VC < 0.0D0 .AND. 0.0D0 <= VD) GO TO 250} \\
\text{IF (VD < 0.0D0 .AND. 0.0D0 <= VE) GO TO 270} \\
\text{IF (VE < 0.0D0 .AND. 0.0D0 <= VF) GO TO 290} \\
\text{IF (VF < 0.0D0 .AND. 0.0D0 <= VG) GO TO 310} \\
\text{IF (VG < 0.0D0 .AND. 0.0D0 <= VM) GO TO 330} \\
\text{IF (VM < 0.0D0 .AND. 0.0D0 <= VT) GO TO 350}
\]

\[
\text{IF (VT < 0.0D0 .AND. 0.0D0 <= VU) GO TO 370} \\
\text{IF (VU < 0.0D0 .AND. 0.0D0 <= VV) GO TO 390} \\
\text{IF (VV < 0.0D0 .AND. 0.0D0 <= VW) GO TO 410} \\
\text{IF (VW < 0.0D0 .AND. 0.0D0 <= VX) GO TO 430} \\
\text{IF (VX < 0.0D0 .AND. 0.0D0 <= VY) GO TO 450} \\
\text{IF (VY < 0.0D0 .AND. 0.0D0 <= VZ) GO TO 470}
\]

\[
\text{IF (VZ < 0.0D0) GO TO 500}
\]

210 \text{ KM = I}

\[
\text{PIRR (I) = 0.0025D0 + ((0.0D0-VA)*0.0025D0/(VB-VA))} \\
\text{PRB1 = PIRR(I)} \\
\text{DRB1 = FLOAT(I) / 100.0D0} \\
\text{GO TO 490}
\]

230 \text{ PIRR(I) = 0.0050D0 + ((0.0D0-VB)*0.0050D0/(VC-VB))} \\
\text{IF (PRB2.GT.0.0D0) GO TO 240} \\
\text{PRB2 = PIRR(I)} \\
\text{DRB2 = FLOAT(I) / 100.0D0}
Appendix D: Source Code of the Model

240  
PRC1 = PIRR(I)  
DRC1 = FLOAT(I) / 100.0DO  
IF (PRB2.LE.PIRR(I)) GO TO 490  
PRB2 = PIRR(I)  
DRB2 = FLOAT(I) / 100.0DO  
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) / 100.0DO

260  
PRD1 = PIRR(I)  
DRD1 = FLOAT(I) / 100.0DO  
IF (PRC2.LE.PIRD(I)) GO TO 490  
PRC2 = PIRR(I)  
DRC2 = FLOAT(I) / 100.0DO  
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) / 100.0DO

280  
PRE1 = PIRR(I)  
DRE1 = FLOAT(I) / 100.0DO  
IF (PRD2.LE.PRE(I)) GO TO 490  
PRD2 = PIRR(I)  
DRD2 = FLOAT(I) / 100.0DO  
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) / 100.0DO

300  
PRF1 = PIRR(I)  
DRF1 = FLOAT(I) / 100.0DO  
IF (PRE2.LE.PRF(I)) GO TO 490  
PRE2 = PIRR(I)  
DRE2 = FLOAT(I) / 100.0DO  
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) / 100.0DO

320  
PRG1 = PIRR(I)  
DRG1 = FLOAT(I) / 100.0DO  
IF (PRF2.LE.PRG(I)) GO TO 490  
PRF2 = PIRR(I)  
DRF2 = FLOAT(I) / 100.0DO  
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) / 100.0DO

340  
PRM1 = PIRR(I)  
DRM1 = FLOAT(I) / 100.0DO
Appendix D: Source Code of the Model

\[
\text{IF } (\text{PRG2} \leq \text{PIRR}(I)) \text{ GO TO 490}
\]
\[
\text{PRG2} = \text{PIRR}(I)
\]
\[
\text{DRG2} = \text{FLOAT}(I) / 100.0D0
\]
\[
\text{GO TO 490}
\]

\begin{align*}
350 & \quad \text{PIRR}(I) = 0.5000D0 + ((0.0D0-VM) \ast 0.2500D0/(VT-VM)) \\
& \quad \text{IF } (\text{PRM2} \gt 0.0D0) \text{ GO TO 360}
\end{align*}
\[
\text{PRM2} = \text{PIRR}(I)
\]
\[
\text{DRM2} = \text{FLOAT}(I) / 100.0D0
\]

\begin{align*}
360 & \quad \text{PRT1} = \text{PIRR}(I) \\
& \quad \text{DRT1} = \text{FLOAT}(I) / 100.0D0
\end{align*}
\[
\text{IF } (\text{PRM2} \leq \text{PIRR}(I)) \text{ GO TO 490}
\]
\[
\text{PRM2} = \text{PIRR}(I)
\]
\[
\text{DRM2} = \text{FLOAT}(I) / 100.0D0
\]
\[
\text{GO TO 490}
\]

\begin{align*}
370 & \quad \text{PIRR}(I) = 0.7500D0 + ((0.0D0-VT) \ast 0.1500D0/(VU-VT)) \\
& \quad \text{IF } (\text{PRN2} \gt 0.0D0) \text{ GO TO 380}
\end{align*}
\[
\text{PRN2} = \text{PIRR}(I)
\]
\[
\text{DRN2} = \text{FLOAT}(I) / 100.0D0
\]

\begin{align*}
380 & \quad \text{PRU1} = \text{PIRR}(I) \\
& \quad \text{DRU1} = \text{FLOAT}(I) / 100.0D0
\end{align*}
\[
\text{IF } (\text{PRN2} \leq \text{PIRR}(I)) \text{ GO TO 490}
\]
\[
\text{PRN2} = \text{PIRR}(I)
\]
\[
\text{DRN2} = \text{FLOAT}(I) / 100.0D0
\]
\[
\text{GO TO 490}
\]

\begin{align*}
390 & \quad \text{PIRR}(I) = 0.9000D0 + ((0.0D0-VU) \ast 0.0500D0/(VV-VU)) \\
& \quad \text{IF } (\text{PRU2} \gt 0.0D0) \text{ GO TO 400}
\end{align*}
\[
\text{PRU2} = \text{PIRR}(I)
\]
\[
\text{DRU2} = \text{FLOAT}(I) / 100.0D0
\]

\begin{align*}
400 & \quad \text{PRV1} = \text{PIRR}(I) \\
& \quad \text{DRV1} = \text{FLOAT}(I) / 100.0D0
\end{align*}
\[
\text{IF } (\text{PRU2} \leq \text{PIRR}(I)) \text{ GO TO 490}
\]
\[
\text{PRU2} = \text{PIRR}(I)
\]
\[
\text{DRU2} = \text{FLOAT}(I) / 100.0D0
\]
\[
\text{GO TO 490}
\]

\begin{align*}
410 & \quad \text{PIRR}(I) = 0.9500D0 + ((0.0D0-VV) \ast 0.0250D0/(VW-VV)) \\
& \quad \text{IF } (\text{PRV2} \gt 0.0D0) \text{ GO TO 420}
\end{align*}
\[
\text{PRV2} = \text{PIRR}(I)
\]
\[
\text{DRV2} = \text{FLOAT}(I) / 100.0D0
\]

\begin{align*}
420 & \quad \text{PRW1} = \text{PIRR}(I) \\
& \quad \text{DRW1} = \text{FLOAT}(I) / 100.0D0
\end{align*}
\[
\text{IF } (\text{PRV2} \leq \text{PIRR}(I)) \text{ GO TO 490}
\]
\[
\text{PRV2} = \text{PIRR}(I)
\]
\[
\text{DRV2} = \text{FLOAT}(I) / 100.0D0
\]
\[
\text{GO TO 490}
\]

\begin{align*}
430 & \quad \text{PIRR}(I) = 0.9750D0 + ((0.0D0-VW) \ast 0.0150D0/(VX-VW)) \\
& \quad \text{IF } (\text{PRW2} \gt 0.0D0) \text{ GO TO 440}
\end{align*}
\[
\text{PRW2} = \text{PIRR}(I)
\]
\[
\text{DRW2} = \text{FLOAT}(I) / 100.0D0
\]

\begin{align*}
440 & \quad \text{PRX1} = \text{PIRR}(I) \\
& \quad \text{DRX1} = \text{FLOAT}(I) / 100.0D0
\end{align*}
\[
\text{IF } (\text{PRW2} \leq \text{PIRR}(I)) \text{ GO TO 490}
\]
\[
\text{PRW2} = \text{PIRR}(I)
\]
Appendix D: Source Code of the Model

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
   GO TO 490

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, 0.75, 0.90, 0.95, 0.975 & 0.99) to approximate the expected 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 + ((0.0050D0-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))
Appendix D: Source Code of the Model

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
Appendix D: Source Code of the Model

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*, 'checkin point A'
Appendix D: Source Code of the Model

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'

Appendix D: Source Code of the Model

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')
Appendix D: Source Code of the Model

1200 DEALLOCATE (x, Z)
CALL TRACE (2, 'PRJIRR', 'exiting.'
RETURN
END
C Varble.FOR

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,0-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 < SI) THEN
    SIGM1(K) = (EST75 - EST25) / SI
ELSE
    SIGM1(K) = (EST75 - EST25) / 3.08D0
END IF

GOTO 50
70 CONTINUE

C approximated standard deviation from 5% and 95% estimates

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
Appendix D: Source Code of the Model

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 previously, 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 ROUTINE TO TRANSFORM A SET OF CORRELATED VARIABLES TO A SET OF
C UNCORRELATED VARIABLES USING THE CORRELATION MATRIX. THE
C APPROACH IS REFERRED 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

SUBROUTINE TRANS (I, NM, NSIZE1, NSIZE2, CALC1, CALC2, COR, +
   TRI)

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
   END DO
END DO

Appendix D: Source Code of the Model
C correlation matrix as a 1-D array for Cholesky decomposition

```fortran
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

```fortran
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 triangular matrix from the Cholesky decomposition

```fortran
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

```fortran
CALL INV (NM, NM, CORRL, IPERM, NM, CORLI, DDET, JEXP, DCOND)
IF (DDET == 0) THEN
   WRITE (7, 9903) I
   GO TO 9999
ENDIF
```
Appendix D: Source Code of the Model

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) = O.ODO
  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) = O.ODO
  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) = O.ODO
  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(',15,',') , MTX INV. FAILED.' , /, /)
9902 FORMAT(/,'WP(',15,',') , CHOLESKY DECOMP. FAILED.' , /, /)
9903 FORMAT(/,'WP(',15,',') , LOWER TRI MTX INV. FAILED.' , /, /)
9904 FORMAT(/,'WP(',15,',') , TRNSF MTX INV. FAILED.' , /, /)
END
Appendix D: Source Code of the Model

C WpDFP.FOR

C Routine to check the type of functional form for work package
duration and to estimate the function at the mean values of
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
Appendix D: Source Code of the Model

C MmTwPl.FOR
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.

SUBROUTINE MMTWPL (I,NN,NDIM,CALCl,GZ,PD1,PD2,CALC2,STFO)

IMPLICIT REAL*4(A-H,0-Z)
INCLUDE 'DEBUG.CMN'
REAL*4 CALC1 (4, NDIM, *), CALC2 (4, *)
REAL*4 PDl (*), PD2 (*)

DOUBLE PRECISION TROUBL

CALL TRACE (3, 'MMTWPL', 'starting.')

CALC2 (1,1) = GZ ! the expected value of the dependent variable
CALC2 (2,1) = 0.0D0
CALC2 (3,1) = 0.0D0
CALC2 (4,1) = 0.0D0

STFO = 0.0D0

DO 10 J=1,NN
   CALC2 (1,1) = CALC2 (1,1) + 0.5D0 * PD2 (J) * CALC1 (2,I,J)
   STFO = STFO + PD1 (J)**2 * CALC1(2,I,J)
   CALC2(2,I) = CALC2(2,I) + PD1 (J)**2 * CALC1 (3,I,J) + 1.5D0 * PD1(J)**2 * PD2 (J)* (CALC1(4,I,J) - CALC1(2,I,J)**2)
   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)
   CALC2(4,I) = CALC2(4,I) + PD1 (J)**4 * CALC1(4,I,J) + 2.0D0 * PD1(J)**3 * PD2 (J)* (CALC1(3,I,J) - CALC1(2,I,J)**3)

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 *

C the third central moment of the dependent variable

CALC2(3,I) = CALC2(3,I) + PD1(J)**3 *

C the fourth central moment of the dependent variable
Appendix D: Source Code of the Model

TROUBL = PD1(J) ** 4 * CALC1(4, I, J)
10 CALC2(4,I) = CALC2(4,I) + TROUBL

CALL TRACE (3, 'MMTWPL', 'exiting.')
RETURN
END
Appendix D: Source Code of the Model

C CoVar.FOR

C ROUTINE TO APPROXIMATE THE CORRELATION BETWEEN TWO DEPENDENT
C VARIABLES USING CORRELATION INFORMATION BETWEEN THE PRIMARY
C VARIABLES AND THEIR PARTIAL DERIVATIVES.

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 derivative
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)
Appendix D: Source Code of the Model

\[
\text{CORR}(I,L,K) = \text{COR}(I,LLI,MMI) \\
\text{CORR}(J,K,L) = \text{COR}(J,MMJ,LLJ) \\
\text{CORR}(J,L,K) = \text{COR}(J,LLJ,MMJ)
\]

40 CONTINUE
50 CONTINUE

C renumber the second central moment and the partial derivative
C of the other variables in the functional forms

\[
\text{LL} = \text{NDCV} \\
\text{DO 80} \ K = 1,NI \\
\quad \text{DO 70} \ L=1,NDCV \\
\quad \quad \text{MMI} = \text{MI}(L) \\
\quad \quad \text{IF (K.EQ.MMI) GO TO 80} \\
70 \text{CONTINUE}
\]

\[
\text{LL} = \text{LL}+1 \\
\text{MI}(\text{LL}) = K \\
\text{PD}(I,\text{LL}) = PX(I,K) \\
\text{SD}(I,\text{LL}) = SX(2,I,K)
\]
80 CONTINUE

\[
\text{LL} = \text{NDCV} \\
\text{DO 100} \ K = 1,NJ \\
\quad \text{DO 90} \ L=1,NDCV \\
\quad \quad \text{MMJ} = \text{MJ}(L) \\
\quad \quad \text{IF (K.EQ.MMJ) GO TO 100} \\
90 \text{CONTINUE}
\]

\[
\text{LL} = \text{LL}+1 \\
\text{MJ}(\text{LL}) = K \\
\text{PD}(J,\text{LL}) = PX(J,K) \\
\text{SD}(J,\text{LL}) = SX(2,J,K)
\]
100 CONTINUE

C the correlation between the common variables and the others.

\[
\text{LL} = \text{NDCV}+1 \\
\text{DO 120} \ K=LL,NI \\
\quad \text{MMK} = \text{MI}(K) \\
\quad \text{DO 110} \ L=1,NI \\
\quad \quad \text{MMI} = \text{MI}(L) \\
\quad \quad \text{IF (MMI.EQ.MMK) GO TO 110} \\
\quad \text{CORR}(I,K,L) = \text{COR}(I,MMK,MMI) \\
\quad \text{CORR}(I,L,K) = \text{COR}(I,MMI,MMK)
\]
110 CONTINUE
120 CONTINUE

\[
\text{LL} = \text{NDCV}+1 \\
\text{DO 150} \ K=LL,NJ \\
\quad \text{MMK} = \text{MJ}(K) \\
\quad \text{DO 140} \ L=1,NJ \\
\quad \quad \text{MMJ} = \text{MJ}(L) \\
\quad \quad \text{IF (MMJ.EQ.MMK) GO TO 140} \\
\quad \text{CORR}(J,K,L) = \text{COR}(J,MMK,MMJ) \\
\quad \text{CORR}(J,L,K) = \text{COR}(J,MMJ,MMK)
\]
140 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)
```

CONTINUE

```
CALL TRACE (2, 'COVAR', 'exiting."
RETURN
END
```
Appendix D: Source Code of the Model

C NetWrk.FOR

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 PNRT ALGORITHM

C calls EARLY, CDFUNC, ESTMMT

===---------------------------------------------------------------------
SUBROUTINE NETWRK (PEARSN, WPTIME, CORRD, ESTART, TRCOR)
==---------------------------------------------------------------------

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), LPFS (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
Appendix D: Source Code of the Model

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
    STACK (J) = 0
12 DO 13 J = 0, 20
    LIS (J) = 0
13 DO 14 J = 0, 100
    NTEMP (J) = 0
14

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)
990

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
Appendix D: Source Code of the Model

```fortran
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)
            SCOR(K) = SCOR(K) + CORRD(J1, J2)
            * (WPTIME(2, J1) * WPTIME(2, J2))**0.5D0
         END IF
      210   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
```
Appendix D: Source Code of the Model

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
      LISTS(MR, K) = LIST(MO, K)
   280  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
      LISTR(MR,K) = LISTS(MO,K)
   330  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
         385  RVAL(MO) = 0.0D0
      ENDIF
      RVAL(MO) = 0.0D0
   390  GO TO 300

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
   CONTINUE
C no common work packages in the two paths
IF (MNO /= 0) THEN
   DO 380 L=1,MNO
      J1 = LCOM(L)
   C0RTR(J,K) = CORTR(J,K) +
   + (WPTIME (2, J1) / ((RSIGM(J) * RSIGM(K))**0.5D0))
   ENDIF
   CONTINUE
ENDIF
CONTINUE
C select the representative paths
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
         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
         CONTINUE
      ENDIF
   ENDIF
CONTINUE
ENDIF
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
Appendix D: Source Code of the Model

ETEMP (4, J) = 0.0D0

LN = J
LP = LREP(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), VE(J), VF(J), VG(J),
   + VM(J),
   + VT(J), VU(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
Appendix D: Source Code of the Model

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
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. VN(K) >= TM(J)) THEN
        PTE(J,K) = 0.5000D0
Appendix D: Source Code of the Model

```plaintext
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. VW(K) >= TM(J)) THEN
    PTE(J,K) = 0.9000D0 +
    + ((TM(J) - VU(K)) * 0.0500D0 / (VW(K) - VU(K)))
ELSE IF (VW(K) < TM(J) .AND. VX(K) >= TM(J)) THEN
    PTE(J,K) = 0.9500D0 +
    + ((TM(J) - VW(K)) * 0.0250D0 / (VX(K) - VW(K)))
ELSE IF (VX(K) < TM(J) .AND. VY(K) >= TM(J)) THEN
    PTE(J,K) = 0.9750D0 +
    + ((TM(J) - VX(K)) * 0.0150D0 / (VY(K) - VX(K)))
ELSE IF (VY(K) < TM(J) .AND. VZ(K) >= TM(J)) THEN
    PTE(J,K) = 0.9900D0 +
    + ((TM(J) - VY(K)) * 0.0050D0 / (VZ(K) - VY(K)))
ELSE IF (VZ(K) < TM(J)) THEN
    PTE(J,K) = 1.00D0
ENDIF

700 CONTINUE

C cumulative probability of the duration being EST

```

```plaintext
PT(J) = 1.00D0
DO 710 K = 1,MREP
    PT(J) = PT(J)*PTE(J,K)
710
IF (PT(J) < 0.025D0) 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

```

```plaintext
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
        INWP = TM(K)+(0.0250D0-PT(K))*(TM(J)-TM(K))/(PT(J)-PT(K))
    ELSEIF (TM(J) >= 0.050D0) THEN
        INWP = TM(K)+(0.050D0-PT(K))*(TM(J)-TM(K))/(PT(J)-PT(K))
    ELSEIF (VZ(K) < TM(J)) THEN
        INWP = TM(K)+(0.0025D0-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
Appendix D: Source Code of the Model

900 \[ LN = MREP \]
\[ LPP(LN) = LPREP(LN) + 1 \]
\[ LP = LPREP(LN) \]

DO 920 K = 1, LP

\[ \text{LIST}(LN,K) = \text{LISREP}(LN,K) \]

C first four moments when only one PATH to the work package

950 \[ \text{ESTART}(1, \text{INWP}) = 0.0D0 \]
\[ \text{ESTART}(2, \text{INWP}) = 0.0D0 \]
\[ \text{ESTART}(3, \text{INWP}) = 0.0D0 \]
\[ \text{ESTART}(4, \text{INWP}) = 0.0D0 \]

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)
        \[ \text{ESTART}(1, \text{INWP}) = \text{ESTART}(1, \text{INWP}) + \text{WPTIME}(1, J1) \]
        \[ \text{ESTART}(2, \text{INWP}) = \text{ESTART}(2, \text{INWP}) + \text{WPTIME}(2, J1) \]
        \[ \text{ESTART}(3, \text{INWP}) = \text{ESTART}(3, \text{INWP}) + \text{WPTIME}(3, J1) \]
        \[ \text{ESTART}(4, \text{INWP}) = \text{ESTART}(4, \text{INWP}) + \text{WPTIME}(4, J1) \]
    ENDDO
ENDIF

990 CONTINUE

1000 CALL TRACE (1, 'NETWRK', 'exiting."
RETURN

9901 FORMAT(F6.3)
9902 FORMAT(2I3,3A10)
9903 FORMAT(30I3)

END
Appendix D: Source Code of the Model

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 derivatives 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 derivative with respect to Z(J)  
    PWPC1(J) = (GZL(J) - GZS(J)) / (2.0D0 * SZ(J))  
    C the second partial derivative 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
Appendix D: Source Code of the Model

C WpCff.FOR

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)
Appendix D: Source Code of the Model

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))) / (X(13) - X(12)) + X(10) * X(4) * X(5) * (DEXP((X(14)-X(12))*X(2))) / (X(14) - X(12)) + X(11) * X(6) * (DEXP((X(15)-X(12))*X(2))) / (X(15) - X(12)) + (X(7)/X(1)) * (DEXP((X(16)-X(12))*X(2))) / (X(16) - X(12)) + X(8) * (DEXP((X(17)-X(12))*X(2))) / (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))

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)

+ (X(7)/X(4)) * (DEXP(-X(6)*X(4))-1)

GO TO 1140
Appendix D: Source Code of the Model

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
Appendix D: Source Code of the Model

C RvsMMT.FOR

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))
Appendix D: Source Code of the Model

$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 derivatives 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
Appendix D: Source Code of the Model

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 derivative 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
Appendix D: Source Code of the Model

C Rvsff.for

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
Appendix D: Source Code of the Model

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'
Appendix D: Source Code of the Model

C TanSp.FOR

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
Appendix D: Source Code of the Model

C correlation matrix as a 1-D array for Cholesky decomposition

40 LL = NM * NM

   DO 50 J = 1, LL
   50  CORR (J) = 0.D0

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

       IF (J < K) GO TO 90
       L = (LLN * K) + J - LLN
       CORR (L) = 1.D0
   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.D0) 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.D0) THEN
      DO 160 J = 1, NM
          KK = J + 1
          IF (KK <= NM) THEN
              DO 150 K = KK, NM
                  COR (J, K) = 0.D0
                  COR (K, J) = 0.D0
              ENDIF
          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.D0
           ELSE
               L = (LLN * K) + J - LLN
               CORRL (J, K) = CORR (L)
           ENDIF
   200  CONTINUE

C
Appendix D: Source Code of the Model

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)
Appendix D: Source Code of the Model

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
      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
      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.

=============================================================================
SUBROUTINE CDPUNC (PEARSN,
                    +  AM,SD,SK,AK,
                    +  VA,VB,VC,VD,VE,VF,VG,
                    +  VM,
                    +  VT,VU,VV,VW,VX,VY,VZ)
=============================================================================

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

CALL TRACE (3, 'CDFUNC', 'starting.')</n
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 betal

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 betal fits a pearson type distribution

50  RSKW = YS
     RKRT = YK

C is the lower bound of betal 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 betal

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

C lower bound of betal fits a pearson type distribution

GO TO 200
Appendix D: Source Code of the Model

C upper bound of beta! fits a Pearson type distribution
C redo with arrays, then this becomes a simple loop

C is the upper bound of beta! 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)
Appendix D: Source Code of the Model

300 CALL TRACE (3, 'CDFUNC', 'exiting.')
RETURN
END

INCLUDE 'INTPOL.INC'
Appendix D: Source Code of the Model

C Inv.MJW

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, Tl, IP, NDIMA, A, DET, IEXP, COND)
C=================================================================

IMPLICIT REAL*4 (A-H,0-Z)
REAL*4 A (NDIMA, NDIMA), Tl (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) = Tl (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
    ENDFI
  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
Appendix D: Source Code of the Model

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.DO) 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
Appendix D: Source Code of the Model

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 (IH0, '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
K=1
AMAX=0.0D0
GO TO 300

C the INV of a DIAGONAL matrix is trivial... I think...

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
Appendix V: Source Code of the Model

C Decomp.FOR

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

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

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
Appendix D: Source Code of the Model

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
Appendix D: Source Code of the Model

```
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 (0.0D0 < 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
    GO TO 1000
60
PRINT *, "System is NOT POSITIVE DEFINITE in row", NROW
    GO TO 1000
53
RATIO=SML/BIGL
1000 CALL TRACE (3, 'DECOMP', 'exiting."
RETURN
END
```
C DgMMJW.FOR

SUBROUTINE DGMULT (A, B, C, IAROWS, IBROWS, IBCOLS)

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 {(IBO * 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
               C (I, J) = C (I, J) + (TEMP * B (K, J) )
            4 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

   ENDIF

DO 8 I = 1, IAROWS
   DO 8 K = 1, IBROWS
      TEMP = A (I, K)
      IF (TEMP .NE. 0.0D0) THEN

   8 ENDIF

DO 9 J = 1, IBCOLS
   DO 9 K = 1, IBROWS
      TEMP = B (K, J)
      IF (TEMP .NE. 0.0D0) THEN

   9 ENDIF

END
Appendix D: Source Code of the Model

DO 6 I = 1, IAROWS
   C (I, J) = C (I, J) + (A (I, K) * TEMP )
ENDIF
7 CONTINUE
ENDIF
RETURN
END
C Early.FOR

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 (LP), Z (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
Appendix D: Source Code of the Model

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 < lERR) GOTO 500

C first partial derivatives of the transformed W.P. durations.

DO 150 K = 1, LP
   PD (K) = 0.0D0
   DO 150 M = 1, LP
      PD (K) = PD (K) + TRI (M, K)
   150 CONTINUE

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
         FC = FC + 6.0D0 * (PD (K) * PD (M)) ** 2 * Z (2, K) * Z (2, M)
      180 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
Appendix D: Source Code of the Model

C EstMMT.FOR

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 (NPPEARS, *)
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
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
Appendix D: Source Code of the Model

\[
\begin{align*}
\text{ESTART}(3, \text{JPV}) &= \text{BETAT} \times (\text{ESTART}(2, \text{JPV}) ^ 1.5) \\
\text{ESTART}(4, \text{JPV}) &= \text{BETAT} \times (\text{ESTART}(2, \text{JPV}) ^ 2)
\end{align*}
\]

250 CONTINUE
CALL TRACE (3, 'ESTMMT', 'exiting."
RETURN

C default to a normal distribution

9999 \text{ESTART}(3, \text{JPV}) = 0.0D0
\text{ESTART}(4, \text{JPV}) = 3.0D0 \times (\text{ESTART}(2, \text{JPV}) ^ 2)
GO TO 250

END
Appendix D: Source Code of the Model

C RvSfll.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 RVSFL (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 mcbpl(50),mcol(50),ots(50)
REAL*4 ooo(50),oom(50),reve(50)
REAL*4 tcm(50),tcc(50),tccm(50),brco(50),obo(50),ho(50)
REAL*4 maint(50),oper(50),aoper(50)
REAL*4 X(200),X2(200)
REAL*4 cost (:,:,:,:), traf (:,:,,:,:)
REAL*4 tcc (:,:), tcm (:,:), cts (:,:)
ALLOCATABLE cost, traf, tcc, tcm, cts

C -----------------------------------
--
C CALL TRACE (2, 'RVSFL', 'starting.')

nAL = BOTTLE (I, 1)
nP = BOTTLE (I, 2)
WNC = BOTTLE (I, 3)
OVL = BOTTLE (I, 4)
BR = BOTTLE (I, 5)

IBY = 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
Appendix D: Source Code of the Model

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

   cost(II,J,K,L) = ((travld + (break1 * RATE1) + (break2 * RATE2))
   perKM * X(7+nAL+L) + entFee) * X(7+nAL+nP+II)

CALL TRACE (3, 'RVSFll', '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, 'RVSFll', '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 (II) +
            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, 'RVSFll', '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)))
Appendix D: Source Code of the Model

```
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)
    mcs =
       + 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)
    msc =
       + 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
    mcs = 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) * (mrc + mc + mcl + mcb + mctm + mcs)

DO 2295 I=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
      mcbp(I) = mcbp
   ELSE
      mcbp(I) = 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
      mcol(I) = mcol
   ELSE
      mcol(I) = 0.00
   END IF

2295 CONTINUE

C OPERATION COSTS

CALL TRACE (3, 'RVSFll', 'operation costs...')
```

C-----------------------------
C Operation office overhead

```
Appendix D: Source Code of the Model

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
            XI(M) = X(X0)
            IF (KP == X0) THEN
                IF (KT == 1) THEN
                    XI(M) = X(X0)/0.99
                ELSE IF (KT == 3) THEN
                    XI(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
        END DO
    END DO
    M=M+1
    X0 = 7+nAL+nP+2*IRD+M
    XI(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
END DO

2500 tref (II,J,K,L)= XI(M) * X2(II) / X2(II)

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)+tref(II,J,K,L)
        END DO
    END DO
    CONTINUE
    CONTINUE
    CONTINUE
    CONTINUE
END DO

DO 3485 II=1,IRD
    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)*X(L1+37)+X(L1+44)*X(L1+38)+X(L1+45)*X(L1+39)
1  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)*X(L1+50)+X(L1+51)*X(L1+52)
1  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)*X(L1+56)+X(L1+57)*X(L1+58)
1  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)*X(L1+52)+X(L1+53)*X(L1+54)
      oom(II)=X(L1+59)+X(L1+60)+X(L1+61)+X(L1+52)+X(L1+53)
ELSE IF (ots(II) .LE.X7) THEN
  ooo(II)=X(L1+65)*X(L1+35)+X(L1+66)*X(L1+36)+X(L1+67)*X(L1+52)+X(L1+53)*X(L1+54)
      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)*X(L1+52)+X(L1+53)*X(L1+54)
      oom(II)=X(L1+70)+X(L1+71)+X(L1+72)+X(L1+52)+X(L1+53)
END IF

3485 CONTINUE

C---------------------------------
C CONSIGNMENT COSTS OF TOLL COLLECTION
Appendix D: Source Code of the Model

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
    tec(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
Appendix D: Source Code of the Model

```
tcc(II,M) = \times(L1+93) * \times(L1+75) * \times(L1+111)
tcm(II,M) = \times(L1+93)
ELSE IF (cts(II,M) \leq X17) THEN
  tcc(II,M) = \times(L1+95) * \times(L1+75) * \times(L1+111)
tcm(II,M) = \times(L1+95)
ELSE IF (cts(II,M) \leq X18) THEN
  tcc(II,M) = \times(L1+97) * \times(L1+75) * \times(L1+111)
tcm(II,M) = \times(L1+97)
ELSE IF (cts(II,M) \leq X19) THEN
  tcc(II,M) = \times(L1+99) * \times(L1+75) * \times(L1+111)
tcm(II,M) = \times(L1+99)
ELSE IF (cts(II,M) \leq X20) THEN
  tcc(II,M) = \times(L1+101) * \times(L1+75) * \times(L1+111)
tcm(II,M) = \times(L1+101)
ELSE IF (cts(II,M) \leq X21) THEN
  tcc(II,M) = \times(L1+103) * \times(L1+75) * \times(L1+111)
tcm(II,M) = \times(L1+103)
ELSE IF (cts(II,M) \leq X22) THEN
  tcc(II,M) = \times(L1+105) * \times(L1+75) * \times(L1+111)
tcm(II,M) = \times(L1+105)
ELSE IF (cts(II,M) \leq X23) THEN
  tcc(II,M) = \times(L1+107) * \times(L1+75) * \times(L1+111)
tcm(II,M) = \times(L1+107)
ELSE IF (cts(II,M) \leq X24) THEN
  tcc(II,M) = \times(L1+109) * \times(L1+75) * \times(L1+111)
tcm(II,M) = \times(L1+109)
ELSE
  tcc(II,M) = \times(L1+110) * \times(L1+75) * \times(L1+111)
tcm(II,M) = \times(L1+110)
END IF
3780 CONTINUE
3790 CONTINUE

DO 3797 II=1,IRD
tcmt(II) = 0
DO 3794 M=1,nAL
  tcm(II) = tcm(II) + tcm(II,M)
3794 CONTINUE
3797 CONTINUE

C TOLL COLLECTION MACHINE MAINTENANCE COSTS

DO 3820 II=1,IRD
tccc(II) = 0
DO 3812 J=1,nAL
  tccc(II) = tccc(II) + tcc(II,J)
3812 CONTINUE
3820 CONTINUE

C BUILDING AND REPAINTING EXPENSES
```
Appendix D: Source Code of the Model

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, 'RVSFII', 'total costs calculation.')
C---------------------------------------------------------------

C Calculate annual maintenance costs
C---------------------------------------------------------------

      CALL TRACE (3, 'RVSFII', 'annual maintenance costs.')

      DO 4200 II=1,IRD
         maint (II) = mcrc + mcrm + mcl + mcbr + mcbpl (II) + mctm
         + mcsc + mcoll (II) + mcot
      4200 CONTINUE
C---------------------------------------------------------------

C Calculate annual operation costs.
C---------------------------------------------------------------

      CALL TRACE (3, 'RVSFII', '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
Appendix D: Source Code of the Model

C--------------------------------------------------------
C Calculate discounted net revenue.
C--------------------------------------------------------

C--------------------------------------------------------
C  DO 4500  I = 1, 177
C 4500   PRINT *, 'Y(',I,') = ',Y(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+II)= ',X(L1+II)
C  PRINT *, 'DR= ',DR
C  PRINT *, 'Z= ',Z
C--------------------------------------------------------

Z=X(L1+II)-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 mcbpl(50),mcoll(50),ots(50)  
REAL*4 ooo(50),oom(50),reve(50)  
REAL*4 tcm(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)
Appendix D: Source Code of the Model

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
            traf (II,J,K,L) =
            + X (2 + nTG + nP + 2 * IRD + M)
            + * X (2 + nTG + nP + IRD + II)
            + / X (3 + nTG + nP + IRD)
   1150
   DO 1500 11=1,IRD
      DO 1500 J=1,nTG
         DO 1500 K=1,nP
            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 11=1,IRD
      reve(II)=0.00
      DO 1510 J=1,nTG
         DO 1510 K=1,nP
            reve(II)=reve(II)+ttraf(II,J,K)*cost(II,J,K)*365
      1510
   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...
Appendix D: Source Code of the Model

\[ + X (L_1 + 13) * \\
+ X (L_1 + 2) + X (L_1 + 5) + X (L_1 + 8) + \\
+ X (L_1 + 3) + X (L_1 + 6) + X (L_1 + 9) \]

\[ \text{mcrm} = ! \text{road maintenance} \]
\[ + X (L_1 + 15) * X (L_1 + 7) + \\
+ X (L_1 + 16) * X (L_1 + 8) + \\
+ X (L_1 + 17) * X (L_1 + 9) \]

\[ \text{mcl} = ! \text{lighting} \]
\[ + X (L_1 + 18) * (X (L_1 + 1) + X (L_1 + 7)) + \\
+ X (L_1 + 19) * \\
+ (X (L_1 + 2) + X (L_1 + 3)) + (X (L_1 + 8) + X (L_1 + 9)) \]

\[ \text{mcbr} = ! \text{bridge repair} \]
\[ + X (L_1 + 20) * X (L_1 + 1) + \\
+ X (L_1 + 21) * X (L_1 + 2) + \\
+ X (L_1 + 22) * X (L_1 + 3) \]

\[ \text{mcbp} = ! \text{bridge painting} \]
\[ + X (L_1 + 23) * X (L_1 + 1) + \\
+ X (L_1 + 24) * X (L_1 + 2) + \\
+ X (L_1 + 25) * X (L_1 + 3) \]

\[ \text{mctm} = ! \text{tunnel maintenance} \]
\[ + X (L_1 + 10) * X (L_1 + 26) + \\
+ X (L_1 + 11) * X (L_1 + 27) + \\
+ X (L_1 + 12) * X (L_1 + 28) \]

SELECT CASE (nWC) ! snow and ice control?
CASE (1)
mcsc = 
+ X (L_1 + 29) * (X (L_1 + 1) + X (L_1 + 4) + X (L_1 + 7)) 
+ +2*(X (L_1 + 2) + X (L_1 + 5) + X (L_1 + 8)) 
+ +3*(X (L_1 + 3) + X (L_1 + 6) + X (L_1 + 9)) 
CASE (2)
mcsc = 
+ X (L_1 + 30) * (X (L_1 + 1) + X (L_1 + 4) + X (L_1 + 7)) 
+ +2*(X (L_1 + 2) + X (L_1 + 5) + X (L_1 + 8)) 
+ +3*(X (L_1 + 3) + X (L_1 + 6) + X (L_1 + 9))
CASE DEFAULT
mcsc = 0.0D0
END SELECT

\[ \text{mcol} = ! \text{overlay} \]
\[ + X (L_1 + 31) * (X (L_1 + 1) + X (L_1 + 4) + X (L_1 + 7)) + \\
+ X (L_1 + 32) * (X (L_1 + 2) + X (L_1 + 5) + X (L_1 + 8)) + \\
+ X (L_1 + 33) * (X (L_1 + 3) + X (L_1 + 6) + X (L_1 + 9)) \]
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
Appendix D: Source Code of the Model

```
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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) = XI(M) * X2(II) / X2(I)

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  J=1,nTG
      Ots(II)=0.00
      DO 3450  K=1,nP
        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
```

```
Appendix D: Source Code of the Model

\[
X_4 = \frac{X(L_l + 46)}{1.01}
\]

END IF
ELSE IF (KP == L_l + 52) THEN
  IF (KT == 1) THEN
    X_5 = \frac{X(L_l + 52)}{0.99}
  ELSE IF (KT == 3) THEN
    X_5 = \frac{X(L_l + 52)}{1.01}
  END IF
ELSE IF (KP == L_l + 58) THEN
  IF (KT == 1) THEN
    X_6 = \frac{X(L_l + 58)}{0.99}
  ELSE IF (KT == 3) THEN
    X_6 = \frac{X(L_l + 58)}{1.01}
  END IF
ELSE IF (KP == L_l + 64) THEN
  IF (KT == 1) THEN
    X_7 = \frac{X(L_l + 64)}{0.99}
  ELSE IF (KT == 3) THEN
    X_7 = \frac{X(L_l + 64)}{1.01}
  END IF
END IF
END IF

DO 3485 11=1,IRD
  IF (ots (II) <= X_3) THEN
    CALL FOOl (X, 41, 35, ooo (II), oom (II))
  ELSE IF (ots (II) <= X_4) THEN
    CALL FOOl (X, 47, 35, ooo (II), oom (II))
  ELSE IF (ots (II) <= X_5) THEN
    CALL FOOl (X, 53, 35, ooo (II), oom (II))
  ELSE IF (ots (II) <= X_6) THEN
    CALL FOOl (X, 59, 35, ooo (II), oom (II))
  ELSE IF (ots (II) <= X_7) THEN
    CALL FOOl (X, 65, 35, ooo (II), oom (II))
  ELSE
    CALL FOOl (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)
  END DO
35550 CONTINUE

X_8 = X (L_l + 75) \times X (L_l + 113)

DO 3790 II=1,ntG
  DO 3780 M=1,nAL
    X_9 = 0.0D0
    X_10 = 0.0D0
  END DO
Appendix D: Source Code of the Model

\begin{verbatim}
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

\end{verbatim}
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
Appendix D: Source Code of the Model

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)
Appendix D: Source Code of the Model

\[
\text{tc\text{m} (II, M) = X(L1+103)}
\]

\[
\text{ELSE IF (cts (II, M) <= X25) THEN}
\text{tc\text{c} (II, M) = X(L1+105) \times X(L1+75) \times X(L1+113)}
\]

\[
\text{ELSE IF (cts (II, M) <= X26) THEN}
\text{tc\text{c} (II, M) = X(L1+107) \times X(L1+75) \times X(L1+113)}
\]

\[
\text{ELSE IF (cts (II, M) <= X27) THEN}
\text{tc\text{c} (II, M) = X(L1+109) \times X(L1+75) \times X(L1+113)}
\]

\[
\text{ELSE IF (cts (II, M) <= X28) THEN}
\text{tc\text{c} (II, M) = X(L1+111) \times X(L1+75) \times X(L1+113)}
\]

\[
\text{ELSE}
\text{tc\text{c} (II, M) = X(L1+112) \times X(L1+75) \times X(L1+113)}
\]

\[
\text{tc\text{m} (II, M) = X(L1+112)}
\]

\[
\text{END IF}
\]

\[
\text{CONTINUE}
\]

\[
\text{DO 3794 II=1,IRD}
\text{tc\text{m} (II) = 0.0D0}
\]

\[
\text{DO 3794 M=1,nTG}
\text{tc\text{m} (II) = tc\text{m} (II) + tc\text{m} (II, M)}
\]

\[
\text{C-----------------------------------------------}
\text{C TOLL COLLECTION MACHINE MAINTENANCE COSTS}
\text{C-----------------------------------------------}
\]

\[
\text{DO 3820 II=1,IRD}
\text{t\text{c\text{c}} (II) = 0}
\]

\[
\text{DO 3812 J=1,nTG}
\text{t\text{c\text{c}} (II) = t\text{c\text{c}} (II) + t\text{c\text{c}} (II, J)}
\]

\[
\text{t\text{c\text{m}} (II) = t\text{c\text{c}} (II) \times X (L1 + 114)}
\]

\[
\text{C-----------------------------------------------}
\text{C BUILDING AND REPAINTING EXPENSES}
\text{C RELEVANT EXPENSES TO OPERATION}
\text{C COST FOR MACHINE AND EQUIPMENT}
\text{C OTHERS}
\text{C-----------------------------------------------}
\]

\[
\text{DO 3860 II=1,IRD}
\text{br\text{c\text{o}} (II) = X(L1+115) \times (oom(II)+tc\text{m}(II)) + X(L1+116)}
\]

\[
\text{C-----------------------------------------------}
\text{C OPERATION BUREAU OVERHEAD}
\text{C-----------------------------------------------}
\]

\[
\text{DO 3890 II=1,IRD}
\text{C}
\text{PRINT *, II, reve (II), L1+117, X(L1+117)}
\]

\[
\text{obo (II) = reve (II) \times X(L1+117)}
\]
Appendix D: Source Code of the Model

C HEADQUARTERS OVERHEAD

C DO 3930 II=1,IRD
    3930   ho(II)=reve(II)*X(L1+II)

C REVENUE

C This calculate annual revenue
C and
C maintenance and operation costs.

C PRINT *, 'total costs calculation starting.'

C Calculate annual maintenance costs

C DO 4200 II=1,IRD
    4200 maint (II) = mcrc + mcrc + mcl + mcbr + mcbpl (II) +
                      + mctm + mscc + mcoll (II) + mcot

C Calculate annual operation costs.

C DO 4300 II=1,IRD
    4300 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 Calculate discounted net revenue.

C PRINT *, 'NPV calculation starting.'

Y = 0.0D0

C DO 5100 II=1,IRD
    5100   AZ = (DEXP (-DR * (X (1) + II ) ) -
                      + DEXP (-DR * (X (1) + II - 1) ) ) / (- DR)
Appendix D: Source Code of the Model

\[ Z(1) = X(L1 + 119) - DR \]

\[
\text{IF } (\text{DABS}(Z(1)) \leq 0.001D0) \text{ THEN} \\
\quad BZ = 1.0D0 \\
\quad \text{GO TO 4400} \\
\text{ELSE} \\
\quad BZ = \frac{\left(\exp(Z(1) \cdot (X(1) + II)) - \exp(Z(1) \cdot (X(1) + II - 1))\right)}{Z(1)} \\
\text{END IF}
\]

\[ 4400 \quad AY = (\text{reve}(II) \cdot AZ) - (\text{aoper}(II) \cdot BZ) \]

C \[
\text{PRINT } *, 'II = ', II \\
\text{PRINT } *, ' AZ = ', AZ \\
\text{PRINT } *, ' Z(1) = ', Z(1) \\
\text{PRINT } *, ' X(1) = ', X(1) \\
\text{PRINT } *, ' BZ = ', BZ \\
\text{PRINT } *, ' \text{reve}(II) = ', \text{reve}(II) \\
\text{PRINT } *, ' \text{aoper}(II) = ', \text{aoper}(II) \\
\text{PRINT } *, ' AY = ', AY \\
\text{PRINT } *
\]

\[ 5100 \quad Y = Y + AY \]

\text{DEALLOCATE TGL, cost, traf, ttraf, tcc, tcm, cts} \\
\text{RETURN} \\
\text{END}

C remove some redundant stuff to make the code nicer.

\text{SUBROUTINE FOO1 (X, OFF1, OFF2, ooo, oom)} \\
\text{REAL*4 X (*)} \\
\text{ooc = 0.0D0} \\
\text{oom = 0.0D0} \\
\text{DO 10 I = 0, 4} \\
\quad \text{ooc = ooc + (X(OFF1 + I) \cdot X(OFF2 + I))} \\
\text{10 oom = oom + (X(OFF1))} \\
\text{RETURN} \\
\text{END}
Appendix D: Source Code of the Model

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 mcbpl(0:50),mcoll(0:50),ots(0:50)
REAL*4 ooo(0:50),oom(0:50),reve(0:50)
REAL*4 tccc(0:50),tccm(0:50),tccc(0:50),brco(0:50),obo(0:50)
REAL*4 ho(0:50),maint(0:50),oper(0:50),aoper(0:50)
REAL*4 Xl(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)
WC = BOTTLE (I, 3)
OL = BOTTLE (I, 4)
BR = 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.')
Appendix D: Source Code of the Model

C {
traf (1, is undefined, but accessed in the next loop....

DO 1150 II=1,IRD

M=0
XCO = 2 + nAL * (nAL - 1) / 2 * nP + 2 * IRD
XCI = 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 (XCO + M) * XCI

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 +
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 = 1 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
      mcoll(II) = mcol
   ELSE
      mcoll(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 == XO) THEN
  IF (KT == 1) THEN
    X1(M) = X(XO) / 0.99
  ELSE IF (KT == 3) THEN
    X1(M) = X(XO) / 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
APPENDIX D: SOURCE CODE OF THE MODEL

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\[
X_4 = \frac{X(L_1+46)}{1.01}
\]

END IF

ELSE IF (KP == L_1+52) THEN

IF (KT == 1) THEN

\[
X_5 = \frac{X(L_1+52)}{0.99}
\]

ELSE IF (KT == 3) THEN

\[
X_5 = \frac{X(L_1+52)}{1.01}
\]

END IF

ELSE IF (KP == L_1+58) THEN

IF (KT == 1) THEN

\[
X_6 = \frac{X(L_1+58)}{0.99}
\]

ELSE IF (KT == 3) THEN

\[
X_6 = \frac{X(L_1+58)}{1.01}
\]

END IF

ELSE IF (KP == L_1+64) THEN

IF (KT == 1) THEN

\[
X_7 = \frac{X(L_1+64)}{0.99}
\]

ELSE IF (KT == 3) THEN

\[
X_7 = \frac{X(L_1+64)}{1.01}
\]

END IF

IF (ots(II).LE.X3) THEN

\[
ooo_3(II) = X(L_1+41)*X(L_1+35)+X(L_1+42)*X(L_1+36)+X(L_1+43)*X(L_1+37)+X(L_1+44)*X(L_1+38)+X(L_1+45)*X(L_1+39)
\]

1

\[
oom(II) = X(L_1+41)+X(L_1+42)+X(L_1+43)+X(L_1+44)+X(L_1+45)
\]

ELSE IF (ots(II).LE.X4) THEN

\[
ooo_3(II) = X(L_1+47)*X(L_1+35)+X(L_1+48)*X(L_1+36)+X(L_1+49)*X(L_1+37)+X(L_1+50)*X(L_1+38)+X(L_1+51)*X(L_1+39)
\]

1

\[
oom(II) = X(L_1+47)+X(L_1+48)+X(L_1+49)+X(L_1+50)+X(L_1+51)
\]

ELSE IF (ots(II).LE.X5) THEN

\[
ooo_3(II) = X(L_1+53)*X(L_1+35)+X(L_1+54)*X(L_1+36)+X(L_1+55)*X(L_1+37)+X(L_1+56)*X(L_1+38)+X(L_1+57)*X(L_1+39)
\]

1

\[
oom(II) = X(L_1+53)+X(L_1+54)+X(L_1+55)+X(L_1+56)+X(L_1+57)
\]

ELSE IF (ots(II).LE.X6) THEN

\[
ooo_3(II) = X(L_1+59)*X(L_1+35)+X(L_1+60)*X(L_1+36)+X(L_1+61)*X(L_1+37)+X(L_1+62)*X(L_1+38)+X(L_1+63)*X(L_1+39)
\]

1

\[
oom(II) = X(L_1+59)+X(L_1+60)+X(L_1+61)+X(L_1+62)+X(L_1+63)
\]

ELSE IF (ots(II).LE.X7) THEN

\[
ooo_3(II) = X(L_1+65)*X(L_1+35)+X(L_1+66)*X(L_1+36)+X(L_1+67)*X(L_1+37)+X(L_1+68)*X(L_1+38)+X(L_1+69)*X(L_1+39)
\]

1

\[
oom(II) = X(L_1+65)+X(L_1+66)+X(L_1+67)+X(L_1+68)+X(L_1+69)
\]

ELSE

\[
ooo_3(II) = X(L_1+70)*X(L_1+35)+X(L_1+71)*X(L_1+36)+X(L_1+72)*X(L_1+37)+X(L_1+73)*X(L_1+38)+X(L_1+74)*X(L_1+39)
\]

1

\[
oom(II) = X(L_1+70)+X(L_1+71)+X(L_1+72)+X(L_1+73)+X(L_1+74)
\]

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

C...
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)
         CONTINUE
      3520 CONTINUE
   ELSE
      DO 3525 L=1,nP
         temp = temp + traf (II,J,M,L)
      3525 CONTINUE
   END IF
3 53 0 CONTINUE
3 54 0 CONTINUE
3 55 0 CONTINUE
DO 3790 11=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
      END IF
   3780 CONTINUE
3 7 9 0 CONTINUE
ct{(II,M) = temp
3 5 4 0 CONTINUE
3 5 5 0 CONTINUE

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
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
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
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
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

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

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\[ tcc(II, M) = X(L1 + 91) \cdot X(L1 + 75) \cdot X(L1 + 111) \]
\[ tcm(II, M) = X(L1 + 91) \]
ELSE IF (cts(II, M) \leq X16) THEN
\[ tcc(II, M) = X(L1 + 93) \cdot X(L1 + 75) \cdot X(L1 + 111) \]
\[ tcm(II, M) = X(L1 + 93) \]
ELSE IF (cts(II, M) \leq X17) THEN
\[ tcc(II, M) = X(L1 + 95) \cdot X(L1 + 75) \cdot X(L1 + 111) \]
\[ tcm(II, M) = X(L1 + 95) \]
ELSE IF (cts(II, M) \leq X18) THEN
\[ tcc(II, M) = X(L1 + 97) \cdot X(L1 + 75) \cdot X(L1 + 111) \]
\[ tcm(II, M) = X(L1 + 97) \]
ELSE IF (cts(II, M) \leq X19) THEN
\[ tcc(II, M) = X(L1 + 99) \cdot X(L1 + 75) \cdot X(L1 + 111) \]
\[ tcm(II, M) = X(L1 + 99) \]
ELSE IF (cts(II, M) \leq X20) THEN
\[ tcc(II, M) = X(L1 + 101) \cdot X(L1 + 75) \cdot X(L1 + 111) \]
\[ tcm(II, M) = X(L1 + 101) \]
ELSE IF (cts(II, M) \leq X21) THEN
\[ tcc(II, M) = X(L1 + 103) \cdot X(L1 + 75) \cdot X(L1 + 111) \]
\[ tcm(II, M) = X(L1 + 103) \]
ELSE IF (cts(II, M) \leq X22) THEN
\[ tcc(II, M) = X(L1 + 105) \cdot X(L1 + 75) \cdot X(L1 + 111) \]
\[ tcm(II, M) = X(L1 + 105) \]
ELSE IF (cts(II, M) \leq X23) THEN
\[ tcc(II, M) = X(L1 + 107) \cdot X(L1 + 75) \cdot X(L1 + 111) \]
\[ tcm(II, M) = X(L1 + 107) \]
ELSE IF (cts(II, M) \leq X24) THEN
\[ tcc(II, M) = X(L1 + 109) \cdot X(L1 + 75) \cdot X(L1 + 111) \]
\[ tcm(II, M) = X(L1 + 109) \]
ELSE
\[ tcc(II, M) = X(L1 + 110) \cdot X(L1 + 75) \cdot X(L1 + 111) \]
\[ tcm(II, M) = X(L1 + 110) \]
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
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\[ \text{tccm} (II) = \text{temp} \times X(L1+112) \]

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) \times X(L1+115)
3890 CONTINUE

C---------------------------------------------------------------
C HEADQUARTERS OVERHEAD
C---------------------------------------------------------------

DO 3930 II=1,IRD
    ho(II) = reve(II) \times X(L1+116)
3930 CONTINUE

C---------------------------------------------------------------
C REVENUE
C---------------------------------------------------------------
C This calculate annual revenue and 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
    maint (II) = mcrc + mcrm + mcl + mcbr + mcbrpl (II) + mctm
    + mesc + mcoll (II) + mcot
4200 CONTINUE

C---------------------------------------------------------------
C Calculate annual operation costs.
C---------------------------------------------------------------

CALL TRACE (3, 'RVSF13', 'annual operation costs.')
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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
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 (LI + II7) - 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 called only by CdFunc.FOR  
C THIS ROUTINE INTERPOLATES THE BETA1 AND BETA2 VALUES OF THE 
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 (NPearns, *)  

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) )
+ (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
ENDIF
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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 SPASUM (THEARY, NSIZE)
REAL*4 THEARY (*)

SPASUM = 0.0D0
IF (THEARY (1) == NSIZE) THEN
    DO 100 I = 1, NSIZE
        SPASUM = (SPASUM + THEARY (I)) * 2
        IF (1.0D15 < SPASUM) THEN
            SPASUM = SPASUM / 1.0D14
        ENDIF
    CONTINUE
    ELSE
        PRINT *, 'Array size is different than defined!' ENDIF

RETURN
END
Appendix D: Source Code of the Model

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, MAXDV, MAXDVR, NPEARS, IDEBUG, IERR