ARIZONA DEPARTMENT OF TRANSPORTATION

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COST/ BENEFIT AND RISK ASSESSMENT PROCEDURE FOR THE PRODUCT EVALUATION PROGRAM

Volume II
Product Evaluation Model
Reference Manual and User's Guide

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16. Abstract

The Product Evaluation Model (PEM) is designed to enable the Product Resource Investment Deployment and Evaluation program (PRIDE) of the Arizona Department of Transportation (ADOT) to determine the likelihood that a new product is a worthwhile investment from an economic point of view, namely that its benefits outweigh its costs. The model defines characteristics, (or "attributes"), associated with products, utilizes their appropriate units of measure (metrics) and translates these product characteristics into the estimated costs and benefits that occur over a user-defined analysis period. The main feature of the model is to measure the relative change in metrics that occurs with the use of a new product and to forecast the net present value (NPV), or the discounted, present day value of all benefits minus all costs, associated with this change. The resulting estimate of economic benefits allows transportation officials rank or choose among alternative products based on economic criteria.

This volume is the second in a series of two. Volume I is the final project report, containing information on the technical background, analytic approach and verification of PEM.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	centimeters	cm
ft	feet	0.3048	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	6.452	centimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0328	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

Note: Volumes greater than 1000 L shall be shown in m^3.

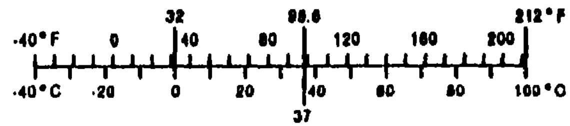
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

These factors conform to the requirement of FHWA Order 5190.1A

*SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
yd	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
yd^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	millimeters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 INTRODUCTION

OVERVIEW

The Arizona Transportation Research Center's Cost-Benefit Product Evaluation Model (hereafter referred to as PEM) is designed to enable the Product Resource Investment Deployment and Evaluation program (PRIDE) to determine the likelihood that a new product is a worthwhile investment from an economic point of view, namely that its benefits outweigh its costs. The model defines characteristics, (or "attributes'), associated with products, utilizes their appropriate units of measure (metrics) and translates these product characteristics into the estimated costs and benefits that occur over a twenty-five year period[1]. The main feature of the model is to measure the relative change in metrics that occurs with the use of a new product and to forecast the net present value (NPV)[2] of the economic effects (benefits-costs) associated with this change. A flow chart describing this process is presented in Figure 1.1.

PEM addresses the uncertainty that often surrounds new product performance with a risk analysis process (RAP). This element of PEM allows the ATRC analyst to assign probability ranges around the product data inputs, based on the availability and the quality of information obtained from company representatives, product vendor sheets, laboratory testing, and ADOT personnel. The RAP element simulates the variability of factors that affect products in the real world and produces a probabilistic estimate of the economic costs and benefits associated with a new product.

The ATRC analyst can use PEM estimates of new product economic benefits for two basic objectives. At the basic level, PEM allows for a screening of a series of new products based on achieving a given threshold of net economic benefits. At a more expanded level, PEM can be used for real-time modelling during a RAP panel session where ADOT personnel, company representatives and industry experts (third-parties with significant professional or academic experience with the product under evaluation) are invited to investigate and deliberate the costs and benefits of a specific product. In either application, PEM provides the ATRC an objective, analytical tool to assess the economic merits of a new product, and to assist decision makers to determine whether the product should be tested or purchased and put into use by the Arizona Department of Transportation (ADOT).

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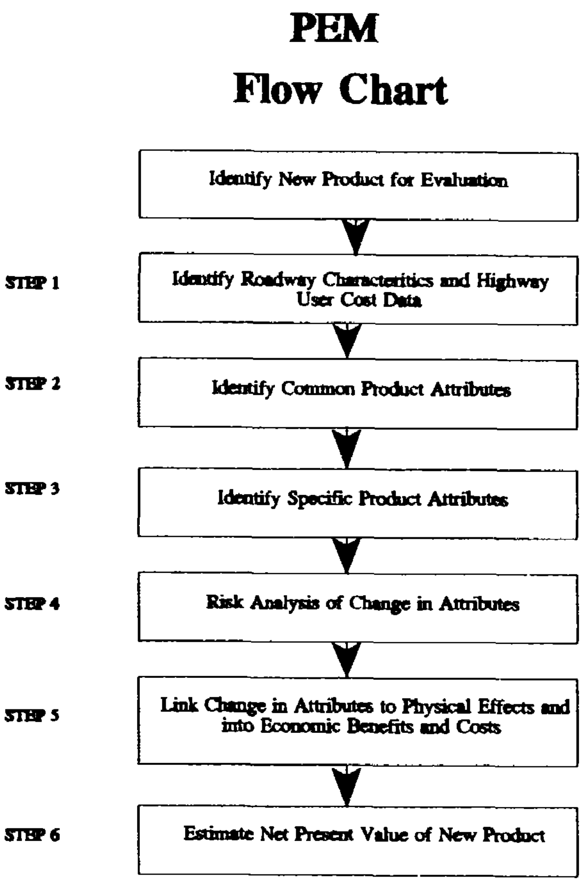
[1] A twenty five year time period is commonly used in the evaluation of transportation projects and investments.

[2] The Net Preset Value (NPV) of economic benefits is defined as the discounted, present day value of all benefits minus all costs.

Figure 1.1 Flow Chart of the PEM Process



FRAMEWORK FOR ANALYSIS

This section sets forth the analytical framework for PEM. Its two sections describe the principal analytical processes used by the model to estimate the probable range of net economic benefits associated with a new product. The first section outlines the cost-benefit approach to new products, while the second section discusses the risk analysis process and how it is incorporated in PEM. Taken together, these two processes form the foundation of PEM, and an understanding of these analytical tools is needed to interpret the model's output.

The Cost-Benefit Analytic Framework

The cost-benefit analytic framework serves as an objective tool to evaluate the economic merits of new products. The process measures all economic effects (costs and benefits) associated with the Base Case, or the current product in use, and compares these values with the New Product case, or the product under evaluation. The results of a cost-benefit analysis can then be used by the ATRC to better facilitate purchasing decisions among alternative products.

The standard techniques of cost-benefit analysis developed for assessing prospective transportation projects are used by PEM to evaluate the candidate products for evaluation by ATRC. The costs of transportation products and services are measured by the cost of real resources, or the equivalent value of these resources employed in an alternative use. These costs are determined through market prices, where such product markets exist, while the intangible costs associated with the product are estimated according to accepted statistical values such as: the value of time savings, life and injury (see the Technical Appendix). Aesthetic and environmental costs, in particular, require special attention in assigning monetary values to them. All costs are projected over the product life-cycle and are discounted to arrive at the NPV that can be directly compared with the NPV costs of the current product.

The PEM cost-benefit framework considers all reductions in costs as economic benefits. PEM explicitly accounts for eight categories of economic costs: safety, value of time savings, vehicle operating costs, disruption costs, productivity costs, capital expenditures, maintenance costs and liability costs. PEM indirectly accounts for environmental and aesthetic costs through a threshold analysis. A product whose attributes lead to reduced vehicle operating costs, and time savings, for example, produces user cost savings or economic benefits in these cost categories. These benefits (or costs) are forecasted over the entire analysis period and then discounted to reflect their present-day equivalent values. A new product may simultaneously produce both benefits and incur extra costs across different economic effect categories, but PEM is designed to sum these economic categories to produce a *net* benefit estimate of all economic categories. PEM's forecast of the NPV of economic benefit estimates can be used to make a direct comparison between products or to rank a series of products based on the relative NPV of economic benefits.

Data Requirements for Cost Benefit Analysis

PEM guides the analyst to enter the appropriate information to conduct the cost-benefit analysis. There are three types of input variables that the analyst must enter to run the model: roadway characteristics, highway user cost and ADOT policy data, and the metrics of common and specific attributes of new products. The first two types of input variables establish the background for the cost-benefit analysis while the third input variable group deals exclusively with the attributes of the new product. A short description of the types of input variables is presented below, while a detailed explanation of each variable in PEM is presented later in the User's Guide.

- ***Roadway Characteristics***
  These variables define the facility that will affect the area where the new products will be used or implemented.

- ***Highway User Cost and ADOT Policy Data***
  These are variables that reflect either policy-defined values for certain transportation-related inputs, such as the average value of time, or market prices for common transportation inputs, such as the price of fuel and tires, that will impact economic benefits.

- ***Metrics of Common and Specific Attributes of New Products***
  These are variables that measure the common and specific attributes of new products. They are typically obtained from vendor specification sheets, in-house laboratory testing or from other government agencies and associations.

The Risk Analysis Process

The purpose of risk analysis is to develop a range of outcomes and the probability of achieving them. The risk analysis process (RAP) component of PEM is designed to deal simultaneously with the risk of the multiple variables that affect product performance. PEM's RAP component operates on two functional levels: at the basic level, where the ATRC analyst inputs product data and self-generates a risk analysis simulation to forecast net economic benefits, and at the more advanced RAP level, where company representatives, industry experts and ADOT personnel are invited to deliberate the probability ranges surrounding central variables of the model and to comment on the resulting forecasts of economic benefits. This section briefly explains RAP and how it is used in PEM. A more detailed explanation of the risk analysis process is contained in the Reference Manual.

Variables and the Analysis of Risk

Many of the input values, or variables, used in PEM's cost-benefit analysis contain an element of uncertainty. To capture these real-world variations, a risk analysis, which develops a probability range for each variable, is introduced in PEM. The risk analysis *process* (RAP) employed in PEM refers to the *specific methodology* by which data relating to product attributes is subjected to a risk analysis. The RAP component of PEM adds a important dimension to the standard benefit-cost analysis since it accounts for the variation of values between variables and produces a range of potential economic benefits rather than a single net present value estimate.

A variable is assigned a range of uncertainty only if that uncertainty is a legitimate object of the analysis. For instance, uncertainty over the failure rate of a patching material should be accounted for in the analysis. However, the values associated with roadway characteristics, for example, should remain firm since they set the physical framework for the risk analysis. In addition to these variables, some of ADOT's transportation policies will be subject to uncertainty. The uncertainty in these variables, which reflect management judgment, should reflect uncertainty associated with their impacts and the uncertainty regarding which policy will be adopted.

The result of PEM's risk analysis is a forecast of the range of net economic benefits associated with the use of a new product, and the probability, or odds, that the product will produce a given level of net benefits. PEM's forecast of a product's net benefits allows ADOT planners and decision-makers to select the level of risk within which they are willing to plan and make commitments with regards to the testing or purchasing of new products.

PLAN OF THE MANUAL AND USER'S GUIDE

This reference manual and user's guide provides background information on the model and a step-by-step explanation of the process used to evaluate the economic effects (costs and benefits) of new products within a risk analysis framework. Section 2, the Reference Manual to PEM, provides the context for the PEM analysis, by specifying the types and sources of data needed run the model as well as a graphical and textual explanation of how PEM's variables interact to develop a forecast net economic benefits. Section 3, the User's Guide to PEM, provides a step-by-step account of how to operate PEM, from loading the software to editing a risk analysis scenario and running multiple simulations. Section 4 presents a PEM tutorial which uses actual product data to forecast the net benefits of six competing products. The final section of the manual, the Technical Appendix, contains information on the Highway User Cost Data used in the model.

2.0 REFERENCE MANUAL

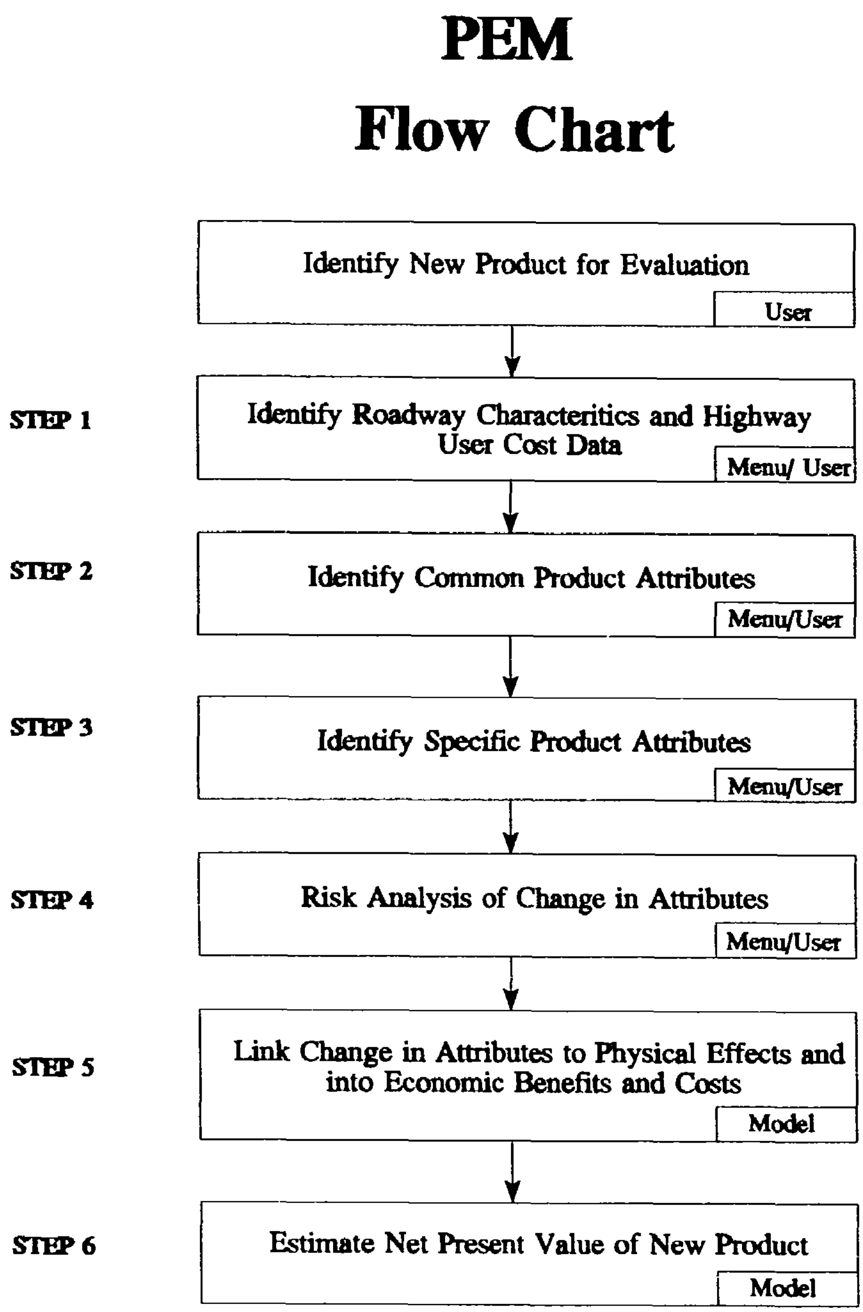
INTRODUCTION

PEM is designed to assist in the evaluation of new products in the ATRC's PRIDE program by providing a forecast of the net economic benefits associated with the use of each product. PEM requires the user to first input data on common and specific attributes, and then to make judgements concerning risk (either alone or with the aid of a RAP session) in order to assign probability ranges around the product data. PEM uses this information to forecast the probability range of net economic effects (benefits or costs) associated with the new product which can then be interpreted and used by the ATRC to aid in testing or purchasing recommendations.

The Reference Manual is designed to develop the context of the benefit-cost analysis. This section describes the process that the analyst should use in preparing the product information for PEM and in interpreting its forecasts. The section proceeds sequentially, starting with the steps that require the user to input data directly into the PEM software interface (see Figure 2.1). Following the description of the data input steps, the section focuses on the final steps of the PEM process and explains how the model uses product information to forecast economic costs and benefits in a risk analysis framework.

The reference manual assumes no prior risk analysis experience on the part of the user, nor does it require a background in economics to understand the benefit and cost

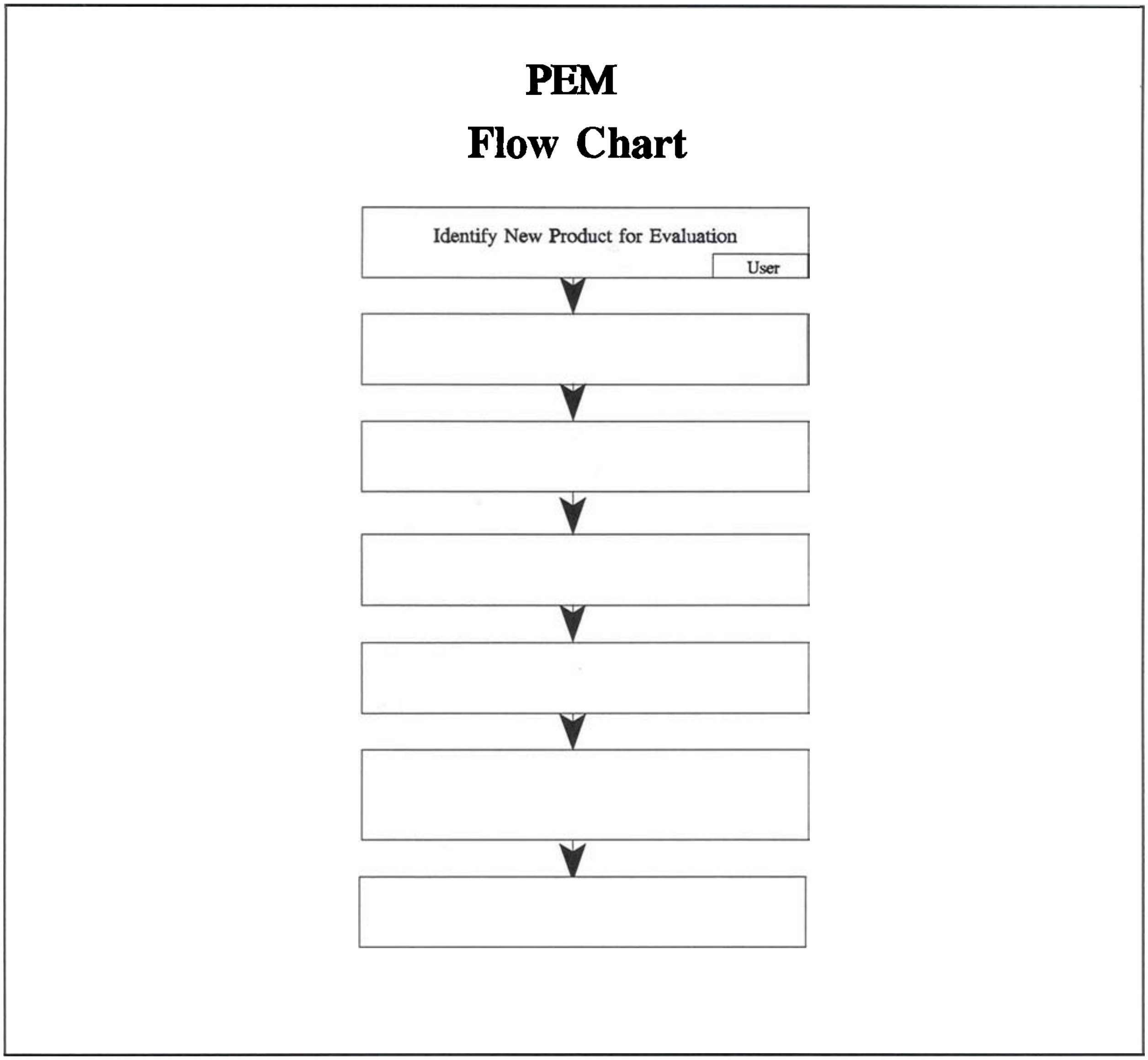
Figure 2.1: Flow Chart of the Six Steps of the PEM Process



forecasts generated by the model. Its main objective is to provide suggestions and techniques to obtain the necessary data for PEM, explain how that data is used by the model, and to interpret PEM's forecasts of economic benefits and costs. Wherever possible, graphics and structure and logic diagrams are used to illustrate the links between user inputs and model outputs.

Throughout the section, the PEM flow-chart motif is used to divide the sequential steps that comprise the PEM process. Each rectangular box represents a basic step in the modelling process, with the smaller box on the lower right-hand side of each box indicating the primary responsibilities for each step. "User" refers to the independent responsibility of the ATRC analyst to make a decision or action. "Menu/User" refers to the responsibility of the user to input product data according to the model's menu-driven, input screens. "Model" refers to PEM's independent calculation of economic benefits and costs based on the previously provided product data.

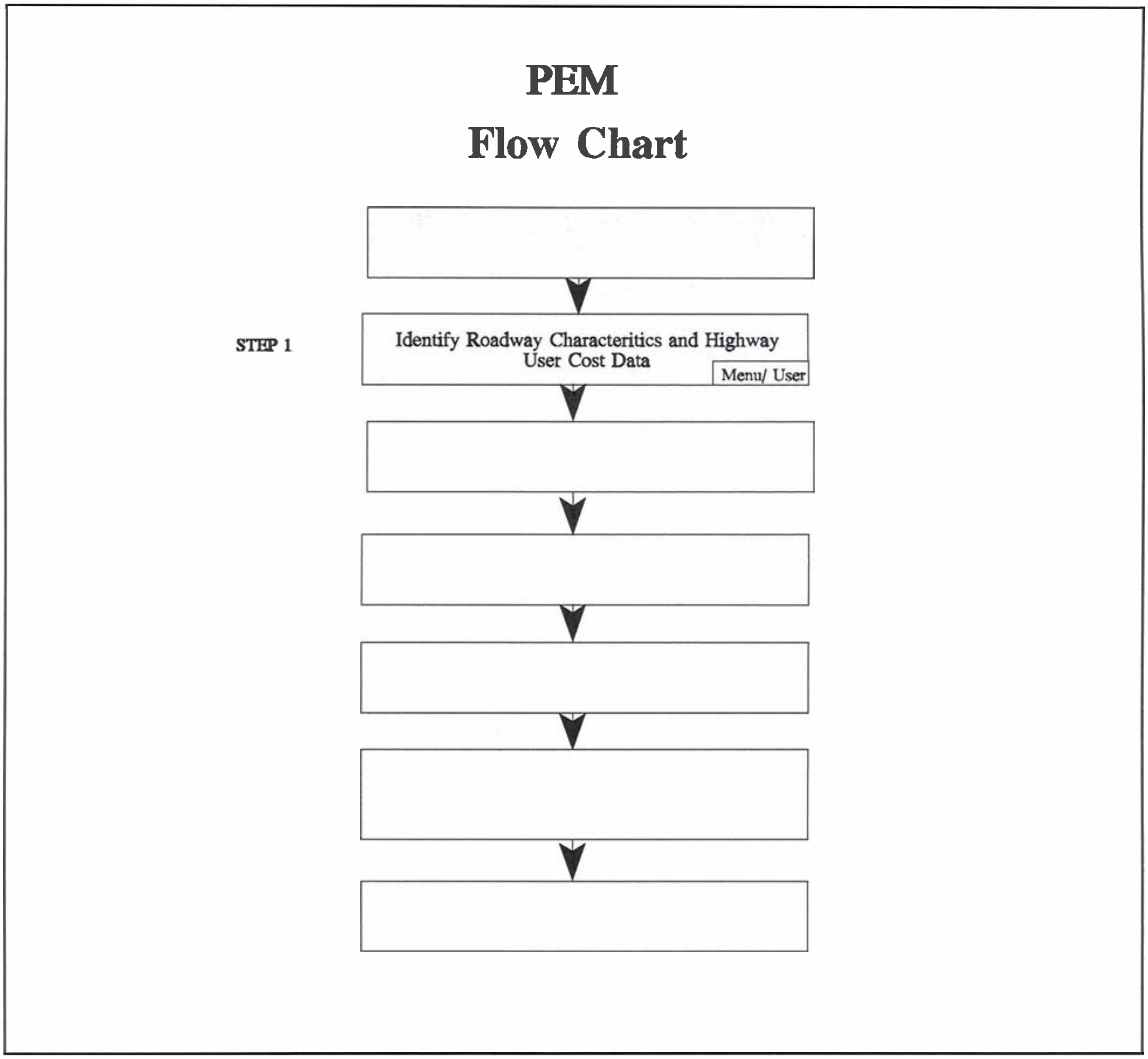
IDENTIFICATION OF NEW PRODUCT FOR EVALUATION



Before the PEM process can begin, the ATRC must identify a new product for evaluation. This is largely an internal ADOT process dependent on a variety of decision-making criteria. Typically, the process involves reacting to one of the numerous product approval applications that are received annually by ADOT.

Prior to using PEM, the ATRC (or the analyst) should decide how they intend to use PEM forecast of net economic benefits. The distinction between evaluating a product for further testing by ADOT and purchasing the product outright for immediate use implies different standards for judging the model's forecast. A proto-type product with limited field experience, for example, might have to demonstrate a relatively high probability of achieving a level of net economic benefits before it should be tested further by ADOT. Conversely, a new variation of a product already in use by ADOT, might be held to a less stringent standard, since the risk associated with the product performance is known and accepted, and any improvements would be made at the margin.

PEM STEP 1



In step 1 of PEM, the user is asked to identify the roadway characteristics and highway user cost and ADOT policy data that will be used in the cost benefit analysis. This data is used to set the physical framework and default user cost values for the analysis (for a complete listing of the variables in each category, refer to the User's Guide). It is important to carefully prepare the inputs for these variables, since inaccurate entries at this stage can significantly impact the model's benefit forecasts. The following two sections describe the data needed for this step and the potential sources for obtaining it.

Roadway Characteristics

Roadway characteristics define the facility where the new products will be used or implemented. The analyst should know, for example, whether a particular product is planned to be used on a four-lane highway or on smaller, rural roads. This basic distinction affects the potential traffic disruption effects, for example, since they are proportionately tied to the size of roadway facilities as well as to the kilometer length of the highway and Average Annual Daily Traffic (AADT).

Sources of Data

The principal sources for obtaining roadway characteristics data are from ADOT personnel. ADOT District Engineers and maintenance crews are familiar with the types of roads and conditions where most products are used and they can usually supply ample anecdotal and factual information for several inputs in this section. For variables dealing with Highway Design or Facility Type, ADOT Engineering Supervisors are a source of information, as well as the personnel from the contracting divisions that draft specifications for ADOT construction contracts.

Highway User Cost and ADOT Policy Data

Highway User Cost and ADOT Policy Data reflects either policy-defined values for certain transportation-related inputs, such as the average value of time, or market prices for common transportation inputs, such as the price of fuel and tires, that will impact economic benefits. Once these values are agreed upon, they remain constant for the PEM analysis. A complete listing of the Highway User Cost Variables is presented in the User's Guide, as well as the default values, which are contained in the Technical Appendix.

Sources of Data

Values for the Highway User Cost Data come from the body of federal and state transportation research. The cost figures, such as fuel costs, the value of time, and various accident costs were compiled from national data and through an extensive research project into highway user costs completed for the National Cooperative Highway Research Program by Hickling[3]. The physical effects, such as the maximum impact of pavement conditions on speed and accident rates are from Hickling experience.

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[3] NCHRP Project 2-18: Research Strategies for Improving Highway User Cost-Estimating Methodologies (1993)

The model equations, which result in user cost estimates in the areas of speed (value of time), safety, and vehicle operating costs, are derived from separate sources. The safety equations are based on data tables incorporated in the Highway Economic Requirements System (HERS)[4]. The vehicle operating cost equations are based on the Technical Memorandum to NCHRP project 7-12, Microcomputer Evaluation of Highway User Benefits, by the Texas Transportation Institute (Technical Memorandum)[5]. The equations are based on empirical relationships derived by Thawat Watanada et. al[6]. during the late 1970's and early 1980's.

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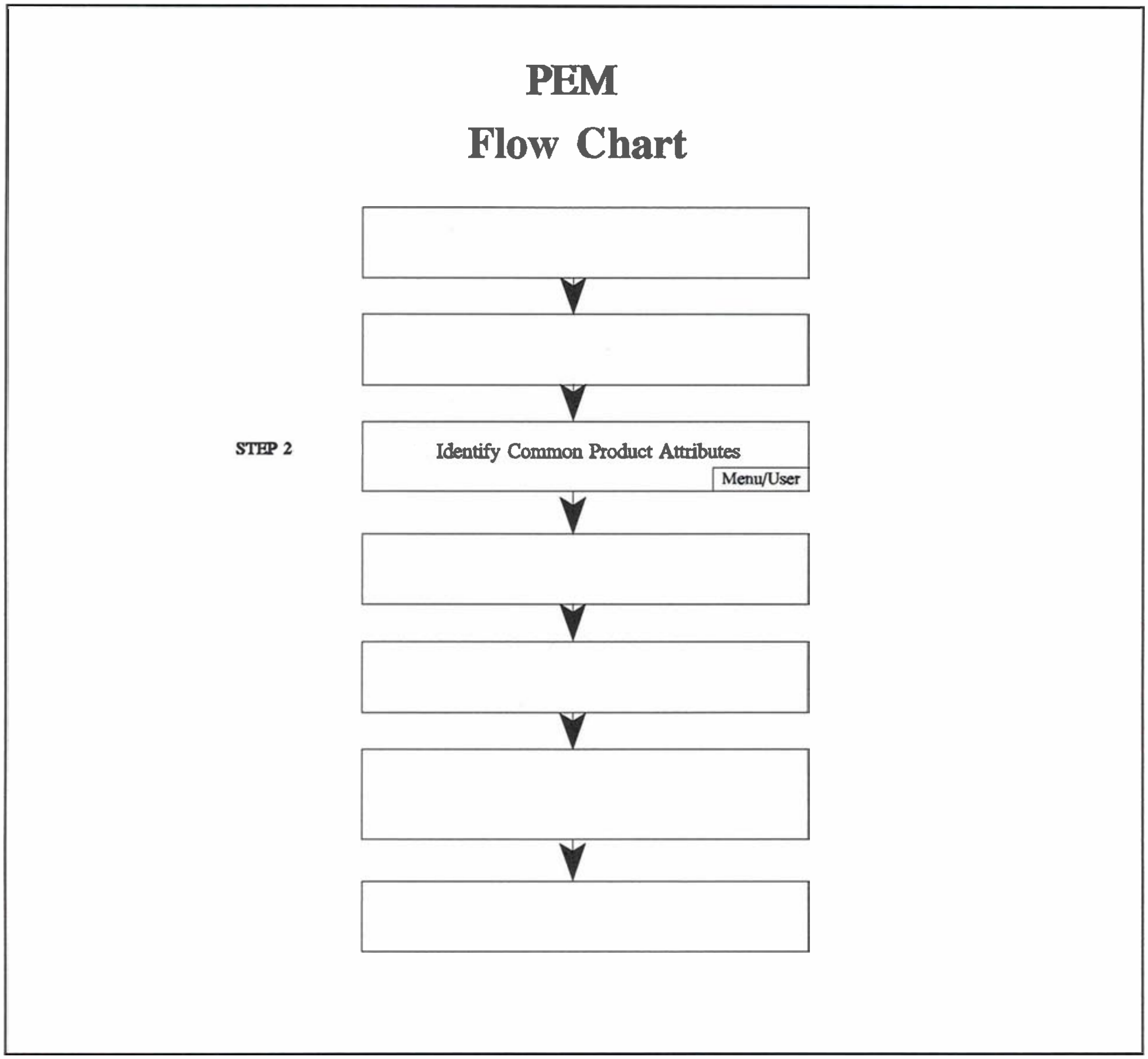
[4] Jack Faucett Associates, The Highway Economic Requirements System (HERS) Technical Report. prepared for the U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., June, 1991.

[5] Texas Transportation Institute, Technical Memorandum on Tasks 1 and 2 of NCHRP Project 7-12 "Microcomputer Evaluation of Highway User Benefits," 1990.

[6] Watanada, Thawat et al. Vehicle Speeds and Operating Costs: Models for Road Planning and Management. (Washington, D.C.: The World Bank) 1987.

PEM STEP 2: COMMON PRODUCT ATTRIBUTES



In step 2 of PEM, the user identifies common product attributes which refer to the standard qualities or features of a product that are used in the cost-benefit analysis. The main task of the analyst, at this point in the PEM process, is to develop a Base Case, or the set of values for common product attributes that are associated with the current product. Once these values are established, the analyst can then use PEM to compare the set of values of common product attributes associated with the *new* product to determine whether it produces net economic benefits.

PEM distinguishes between those attributes which are "common" to all products, such as unit cost, useful economic life, and labor and equipment costs and "specific," those attributes which are particular to certain products, which is presented in the next section. Examples of common product attributes used in PEM are listed below (an explanation of each product attribute is presented in the User's Guide):

- Useful Economic Product Life;
- Inventory and Carrying Costs;
- Disposal and Salvage Costs;
- Testing and Evaluation Costs; and
- Failure Rate Path (the pattern of product failures over time).

Sources of Data, Base Case

Data for the Base Case can normally be obtained from ADOT and other sources. The following sections briefly explain the types of data that is available from each source.

ADOT Sources . Several sources within ADOT provide practical information on product use and maintenance which can be used to develop the Base Case. ADOT divisions that either actively plan or budget routine maintenance and construction procedures are one source of useful Base Case product cost information, as are the implementing divisions, such as district engineers, that have had direct experience with specific products or procedures. The following is a sample list of the ADOT sources that maintain the type of data needed to run PEM:

ADOT Maintenance Group

The division's PECOS II Maintenance Management System provides basic historical cost data on material, labor, equipment, installed inventory, and productivity according to pre-defined maintenance categories. This database system can provide median common product attribute estimates for the Base Case. Considering the specific product and other performance information, the analyst can then assign probability ranges around these estimates to develop the probability distributions for use in PEM's RAP component.

The following table illustrates the common product attribute data contained in the PECOS II Maintenance Management System:

Table 2.1: Common Product Attributes; Maintenance Activity 115, Spall Repair PCC Pavement

Data Category	Value	Units
Work Quantity	189.4	Cubic ft.
Inventory	774.0	12 ft. lane miles
Quantity STD	.2	Cu. ft./lane mile
Labor Hours	1702.5	Labor hour
Productivity	.11	Cu. ft/labor hour
Total Cost	$71,792.54	Dollars
Unit Cost	$379.05	Dollars/labor hour

Using the information in the Table 2.1, the analyst develops the Base Case common product attributes by adding probability ranges to each of the variables used in PEM. According to the table, labor productivity is .11 cu.ft. per labor hour across all ADOT maintenance organizations. The ATRC analyst, however, based on research and interviews with ADOT engineers, may feel that labor productivity for this activity and the current product could reach .2 and will seldom drop below .10 cu. ft. per labor hour. PEM inputs for Base Case product labor productivity, therefore, would be .2 for 10% upper range .11 for median estimate, and .10 for the lower 10% range (this process is explained further in the section 2.6).

ADOT Office of Risk Management

To determine the Liability Risks associated with a product, the analyst should contact the ADOT Office of Risk Management. Generally, the manager of this office will be able to provide some information on the liability costs associated with a given product, even through product liability cases tend to be less frequent than design or maintenance liability cases. For those products that do have a history of liability costs, such as concrete patching materials, the analyst will be able to develop a Base Case liability cost scenario. The following table summarizes the Base Case liability variables associated with a concrete patching material:

Table 2.2: Common Product Attributes; Liability Variables Associated with Concrete Patching Materials

Liability Variable	Value	Units
Number of Claims per 100 Failures	10	Claims
Percent of Claims Settled	30-40	Percent
Percent of Claims Not Pursued	60	Percent
Average Settlement Costs	500-750	$ per Settlement plus Admin. Costs
Court Costs	$15,000	$ per Trial plus Admin. Costs

Based on Table 2.2, the Base Case liability costs for concrete patching materials are likely to be small on an annual basis, but may be considerable over the analysis period used in PEM. The percentage of product failures is the most difficult variable to estimate, since accurate data on product failures is difficult to obtain. In this example, only 10 percent of product failures result in claims against ADOT. Of these claims, 30 to 40 percent result in settlement, with the majority being claims not pursued, either because the claim was denied or dropped. For those claims that result in court cases, which is imputed by PEM, ADOT can incur substantial costs of up to $15,000 in this example.

Other Sources. Other, non-ADOT, sources of information are effective for developing the Base Case set of common product attribute variables. The Transportation Research Information Services (TRIS) section of the Transportation Research Board (TRB) of the National Academy of Sciences maintains an extensive database of all ongoing domestic and foreign transportation research. Current and past studies of transportation-related products and/or their use and application are listed from several state and federal research programs. Studies such as, Implementation Strategies for Sign Retroreflectivity Standards, NCHRP Report 346, provide product information on several types of retro-reflective sign sheeting, including average product cost, units per mile (per kilometer) of rural and urban signs and typical maintenance costs. Data from such credible sources can readily be used to supplement or substitute the Base Case set of common product attributes variables.

Sources of Data, New Product

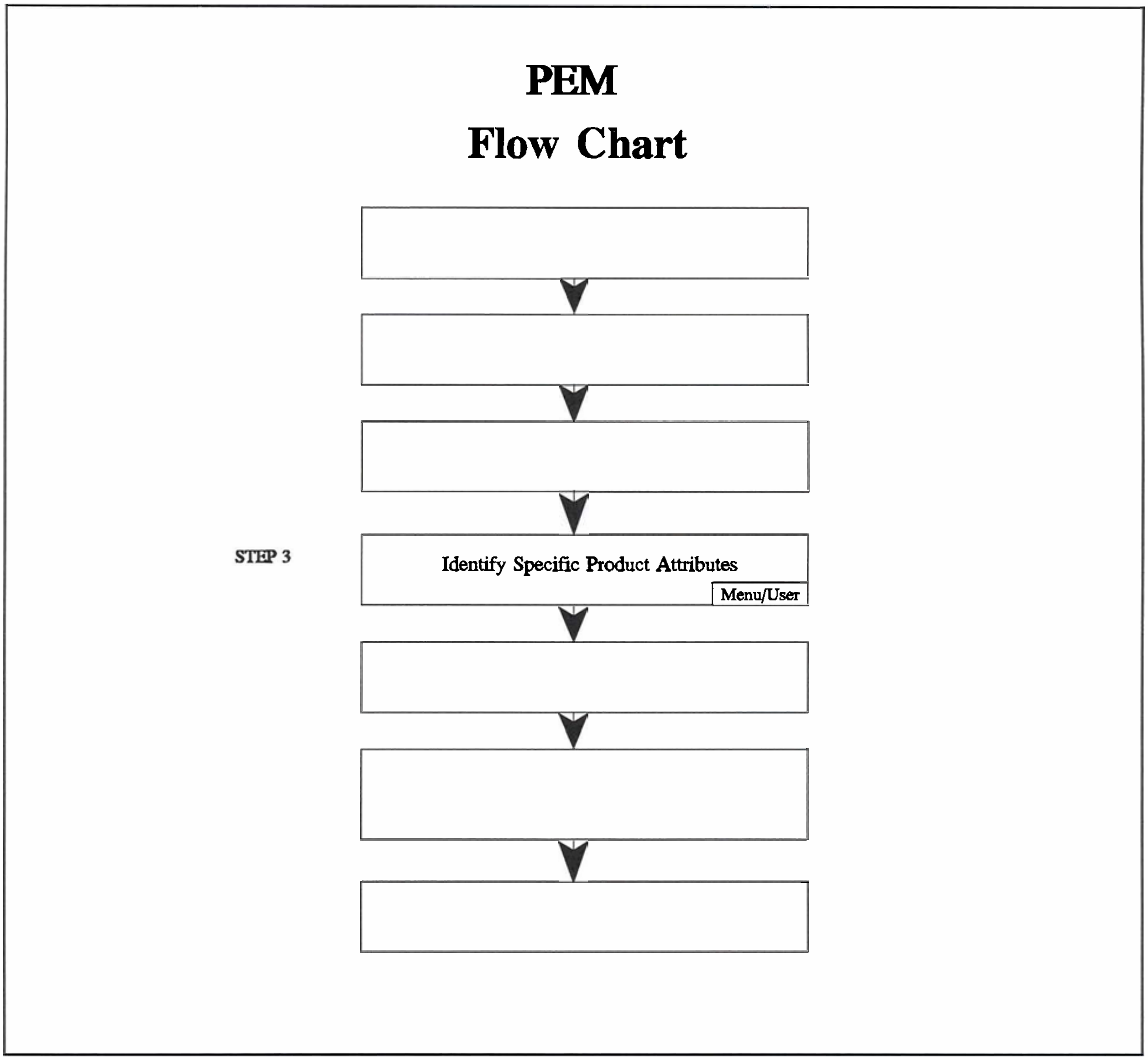
To evaluate a **new** product with PEM, the analyst must obtain information corresponding to the common product attributes developed for the Base Case product. Although vendor sheets occasionally specify the typical labor and equipment costs associated with a product, these estimates may be based on ideal conditions and therefore may exaggerate the values. Nevertheless, these values can be used as a basis for the initial median estimates, around which probability ranges can be developed. When utilizing vendor data the probability range around the median estimate is likely to be larger for this reason (a more detailed explanation of assigning probability ranges is explained in section 2.6). The following sections describe the principal sources for new product information:

Product Vendor Sheets. As explained in the earlier, product vendor sheets and official company submissions are the primary source of general product information for PEM's product attributes data fields. Following the ATRC's "Checklist for New Proposals" (see Technical Appendix), the manufacturer must provide product information ranging from independent lab tests to the manufacturers' cost sharing in ADOT product testing and evaluation. These submissions contain the basic information, such as unit cost, equipment requirements (costs), and productivity estimates that allows the ATRC analyst to begin the cost-benefit analysis using PEM. In some cases, these vendor sheets contain extra information that can readily be used by PEM, such as product life cycle estimates and direct comparisons with competing products. Local contractors and product representatives are also an obvious source to solicit common product attribute information.

Other Sources. State and federal transportation agencies routinely conduct new product evaluations. State DOTs typically obtain technical information and product specifications from in-house testing, reliance on vendor presentations and demonstrations, and reference to new product information from other State DOTs and industry publications. Information exchange is also facilitated by the American Association of State Highway Transportation Officials (AASHTO) in cooperation with the Federal Highway Administration (FHWA) through a computer database of new product information entitled the Special Product Evaluation List (SPEL).

The Strategic Highway Research Program (SHRP) is also an important source for new product information. Created in 1987 to improve the performance and durability of U.S. roadways, the SHRP program, with support from the Federal government, State DOTs, AASHTO and the Transportation Research Board (TRB), investigated 130 new highway products in four areas: highway operations, concrete and structures, asphalt and long term pavement performance. The SHRP report entitled, Innovative Materials Development and Testing; Volume 5; Partial Depth Spall Repair; (SHRP H-356), for instance, contains extensive information on brand-name materials and optimal application procedures for the partial spall repair of Portland Concrete that can be used in PEM.

PEM STEP 3: SPECIFIC PRODUCT ATTRIBUTES



In step 3 of PEM, the user identifies the specific product attributes associated with a given product. Like common product attributes, they refer the qualities or characteristics that are used in the cost-benefit analysis, but in this case, they refer to the unique properties of a product that are not necessarily found in all products. For example, pavement materials share many common product attributes, such as unit price and product life cycle, but they also have specific attributes that affect the smoothness of the pavement, a trait that can be mapped into user benefits, such as Vehicle Operating Costs. The important point to note is that these attributes are *not common to all products.*

PEM is equipped to deal with certain specific common attributes. While it is not necessary to input data for each of these categories, they can bring a important additional level of detail to PEM's cost-benefit analysis.

Some of the specific product attributes contained in PEM include:

- PSI of Pavement with New Product;
- Expected Pavement Life with New Product;
- Resurfacing Costs with New Product;
- Percent Administrative Improvement Realized;
- Percent Reduction in Fatal Accidents with New Product; and
- Percent Improvement in Speed/Flow with New Product.

The specific product attributes outlined above apply to two basic categories of products. The first three specific attributes apply to those products that affect pavement condition, which as described earlier, can lead to benefits in Vehicle Operating Costs, as well as the Value of Time and Safety. The last four specific attributes refer products that in some manner affect Productivity, Safety or the Value of Time. These attributes are more subjective than the first set, and can consist of multiple factors that together impact the benefit category (A full description of each specific product attribute appears in the User's Guide).

Sources of Data, Base Case

ADOT Sources. As with common product attributes, sources within ADOT can provide practical information on product use and maintenance which can be used to develop the Base Case. ADOT divisions that deal with pavement maintenance and construction procedures are one source of useful Base Case information, as are the implementing divisions, such as district engineers, that have had direct experience with specific products or procedures.

Sources of Data, New Product

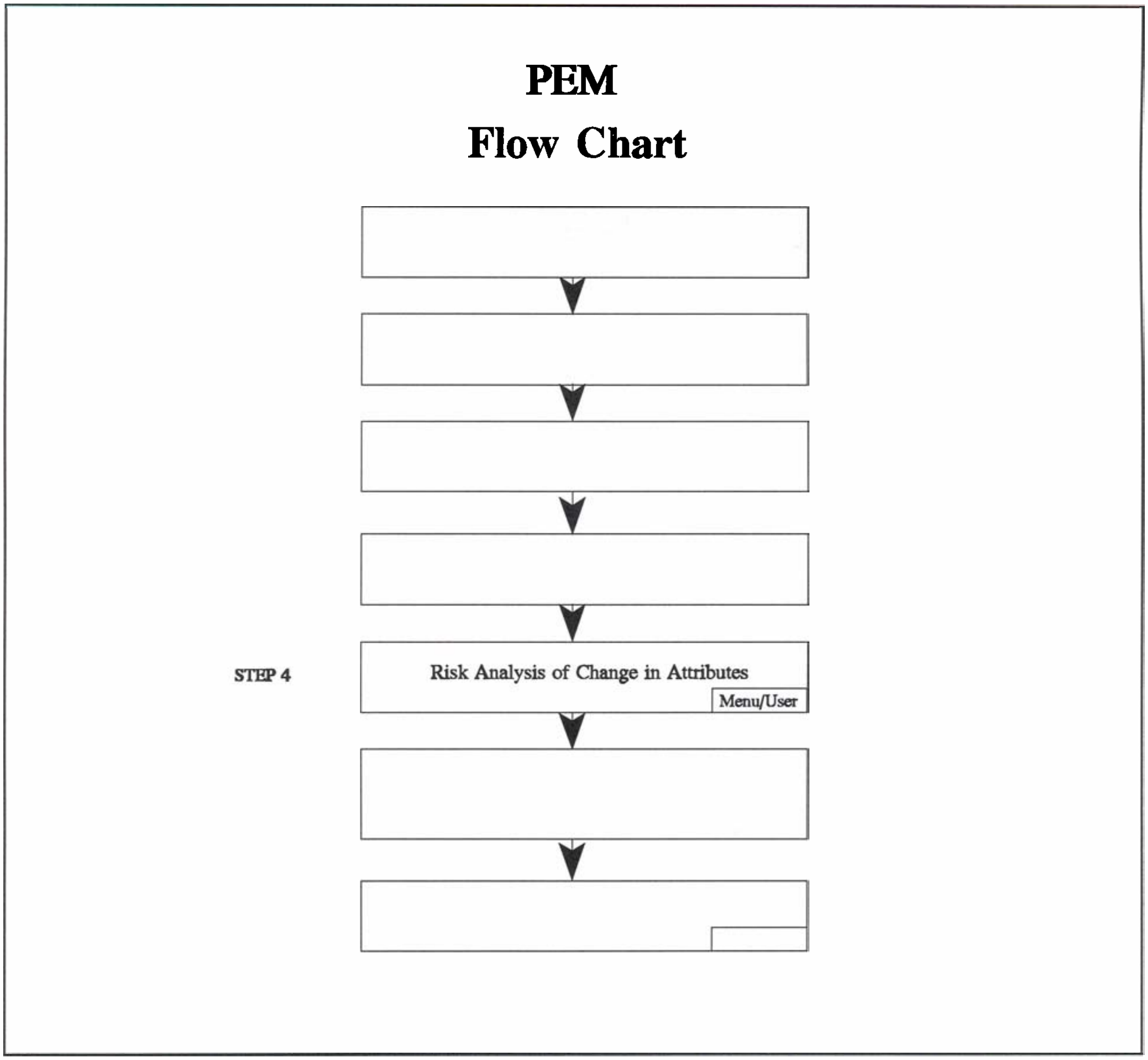
There are generally two sources for obtaining information on the specific product attributes of new products.

Product Vendor Sheets. As described with common product attributes, product vendor sheets usually contain basic information on product characteristics that can be used in PEM. With regards to specific attributes, some manufacturers may tout a certain advantage of their product over others. This documented information can be brought into PEM through the specific attribute variables, such as reduction in accident incident rates. Often, however, it is useful to check the source/study that is behind the manufacturer's claim.

Other Sources. State and federal transportation agencies routinely conduct product evaluations which contain information that can be used to support values for specific product variables. As in the example above, a manufacturer may claim that his product has certain impact on accident rates which may or may not be confirmed by current studies.

In the event that a value can not be confirmed or supported by any current study, the uncertainty surrounding that value will be greatly increased. This heightened uncertainty will be reflected in the probability range assigned to that value by the user or the RAP panel. This increased uncertainty will reduce the impact of the variable in the model. A more detailed explanation of this process is contained in section 2.6. It is with these types of variables that RAP panels, consisting of experts in the product field, are most useful in determining what the value should be and the probability to attach to it. The RAP panel in this case, would provide the confirmation and support for the estimate that could not be provided by current studies.

PEM STEP 4



In PEM Step 4, the user assesses the degree to which a new product's attributes will lead to a measurable change in metrics and forecasts the potential variation of that change. To deal with the uncertainty surrounding new product performance, the analyst places probability ranges around each variable subject to real-world fluctuation based on both objective and subjective data sources, which leads to a more accurate forecast of the potential economic benefits stemming from a new product. This section presents the background on the Risk Analysis Process (RAP) and how it is applied in the Cost-Benefit framework of PEM.

Risk Analysis and the Benefit-Cost Model

The goal of a cost-benefit analysis is to determine the effect of a change (or changes) in the resource allocation associated with the introduction of a new product or process. A new product which reduces maintenance costs (a maintenance savings) through its durability, for example, produces an economic benefit in the PEM analysis, and is preferred over the existing resource allocation. The critical analytical role in this step is determining the actual change in physical effects that will occur with each new product attribute as well as the timing for these changes. Since product performance is often unpredictable, a risk analysis of the central variables in the cost-benefit framework adds an important, real-world dimension to the analysis.

The RAP component of PEM includes two variations. Variation one is the basic level screening process in which the ATRC analyst inputs median estimates of common and specific product attributes and assigns probability ranges. A risk analysis simulation is then conducted on one or several products to determine the relative NPV of the economic benefits associated with each product. Variation two, the expanded version of RAP, involves the same process as variation one, but adds a step in which the probability ranges around product data variables are open to discussion at a RAP panel session. The steps involved in both variations are outlined in the following sections.

The Basic RAP, Variation One

Variation one of PEM's RAP component allows the **analyst** to attach probability functions to the uncertain estimates associated with the Base Case and ne product common product attributes. This process addresses the fact that the further into the future product performance is forecast, the more uncertainty there is and the greater the risk becomes of producing forecasts that deviate from actual outcomes. Projections in PEM, therefore, need to be made with a range of input values to allow for this uncertainty and for the probability that alternative economic, demographic, technological and environmental conditions may prevail that affect the set of common product attribute variables.

The ATRC analyst collects data for the RAP component of PEM starting with the steps 2 and 3 of the PEM process. Special data sheets, created by the ATRC and similar to the one pictured in Figure 2.2, are used to record the common and specific product attribute estimates, which can vary according the quality of the product data, outside testing information, ADOT anecdotal experience, or other pertinent factors. The analyst should combine this objective and subjective data into data sheets for each variable. In Figure 2.2, a sample data sheet provides space for an initial median estimate in the first column, and the second and third columns define a range which represents "an 80 percent confidence interval" -- the range within which we can be 80 percent confident of forecasting the product performance. If the analysts is very uncertain of the forecast of product performance, a wider probability range is used (and vice versa). This process ensures that all risks are properly reflected in the PEM forecasting process.

Figure 2.2: Sample of a Data Sheet for the Risk Analysis Process

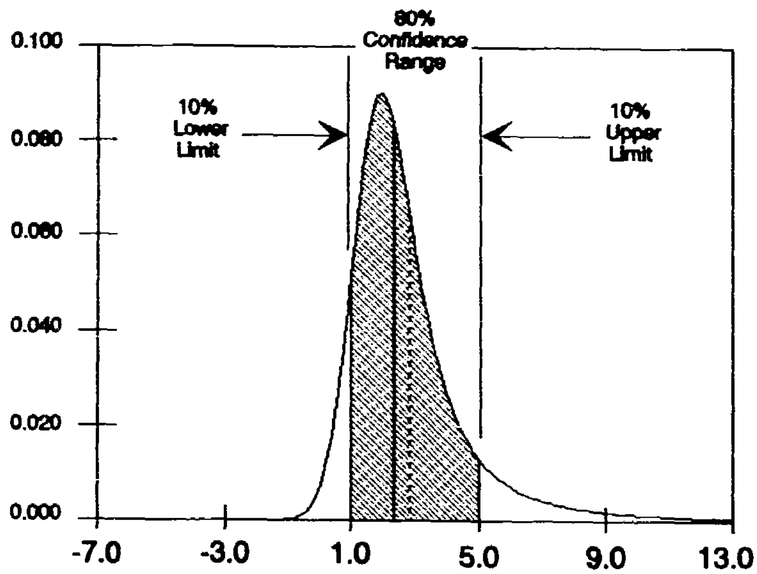
Annual Training and Equipment Costs
(Annual $)

Product	Median Estimate	10 % Lower Limit (%)	10 % Upper Limit (%)
New Product	$3,800	$3,420	$4,180
Current Product	$4,000	$3,800	$4,500

Probability ranges need not be normal or symmetrical -- that is, there is no need to assume the bell shaped normal probability curve. The bell curve assumes an equal likelihood of being too low and being too high in forecasting a particular value. It might well be, for example, that additional training and equipment costs, as presented in Figure 2.2, are more likely to exceed the median estimate than to not attain it. The RAP process places no restrictions on the degree of "skew" in the specified ranges and thus maximizes the extent to which the Risk Analysis reflects reality.

Although the computer program will transform all ranges into formal "probability density functions", they do not have to be determined or presented in either mathematical or graphical form. All that is required is the entry of upper and lower limits of an 80 percent confidence interval in the Data Sheets. The risk analysis software will then use numerical analysis to translate these entries into a uniquely defined statistical probability distribution automatically (see Figure 2.3). This liberates the non-statistician from the need to appreciate the abstract statistical depiction of probability and thus enables administrators,

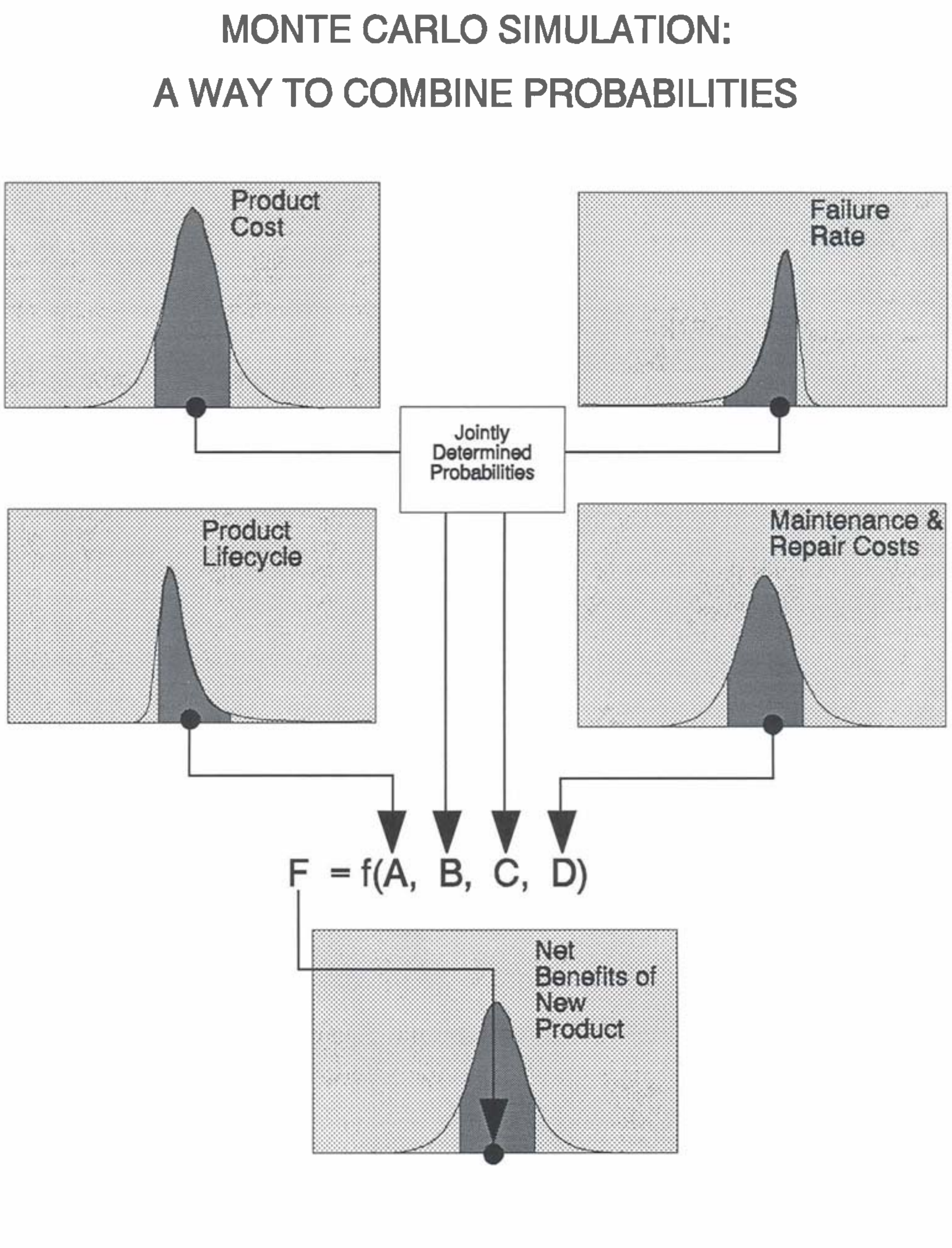
Figure 2.3: RAP Generated Probability Distribution



stakeholders and decision-makers to understand and participate in the process whether or not they possess statistical training.

Once the probability distributions for all changes in common and specific product attribute variables are entered into PEM, the risk analysis software produces probability distributions for each metric. Values for each variable are based on these distributions and are incorporated into the model to yield a final result. (see Figure 2.4). The result of this process represents both a forecast of the net economic benefits and quantification of the probability that the forecast will be achieved.

Figure 2.4: Monte Carlo Simulation: A Way to Combine Probabilities

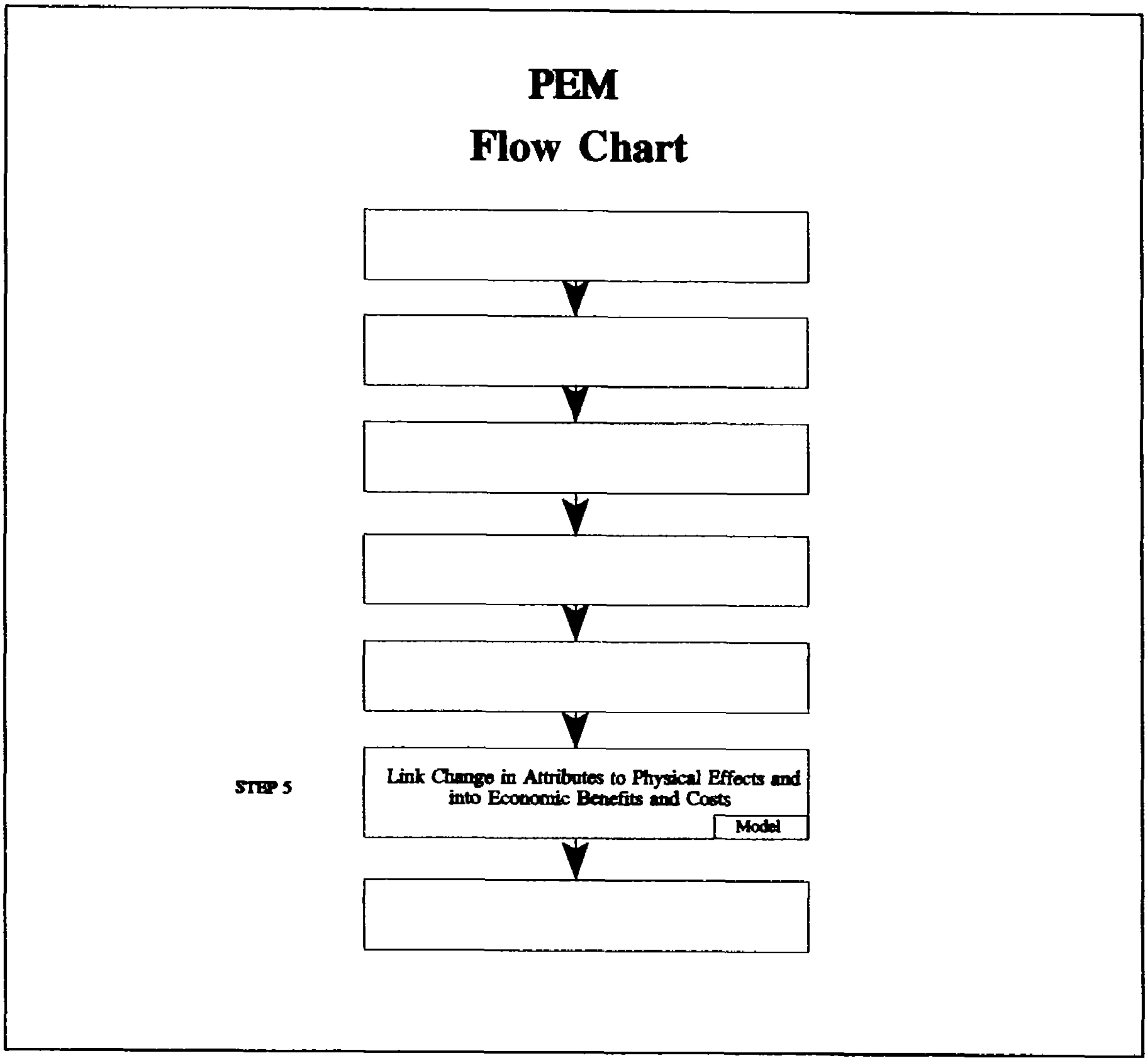


The Expanded RAP, Variation Two

Variation two of PEM's RAP component follows the same steps as variation one, but is geared towards a **panel discussion** of the probability ranges around common and specific product attributes. The RAP panel session, facilitated by the ATRC, is conducted as a structured workshop to further evaluate the costs and benefits associated with a given product. ADOT personnel, company representatives and industry experts are invited to the RAP session to evaluate the forecasting assumptions and the estimated probabilities associated with product data. PEM can be used for real-time modelling during the RAP session to test alternative product performance scenarios which incorporates the judgement of panel members and builds confidence in the forecasts.

Expanded RAP sessions can be held on an ad hoc or regular basis depending on the desires of the ATRC. Participants in a RAP session should receive a briefing book in advance containing information on the product and suggested probability ranges around common and specific product attribute variables. During the session, panelists review PEM (via the Structure-and-Logic Models, graphical diagrams of the relationships between model variables, which are located at the end of Section 2.7) and review and comment upon each Data Sheet containing the product information. This approach facilitates consensus building in the underlying forecasting assumptions and associated probabilities concerning product performance.

PEM STEP 5



In PEM step 5, the model calculates the economic benefits of new highway and construction products based on the inputs of earlier stages of the PEM process and the large body of transportation research data. To determine the economic benefits and costs associated with a specific new product, the analyst follows the steps 1-4 of the PEM process, which solicit median and probability ranges for the main product variables used in the cost-benefit analysis. PEM then maps the values for the Base Case and New Product variables into the economic effect categories defined in transportation and economics literature.

PEM explicitly considers eight categories of economic effect areas, and indirectly considers two further categories based on a threshold analysis. Each explicit category has an individual Structure & Logic diagram which charts the interaction between quantitative inputs for roadway characteristics, highway user cost data and common and specific product attributes and their resulting net benefit outputs. PEM accounts for following economic effects:

Explicit Economic Effect Categories

- Safety;
- Value of Time;
- Vehicle Operating Costs;
- Disruption Costs;
- Productivity Costs;
- Capital Expenditures;
- Maintenance Costs; and
- Liability Costs;

Indirect Economic Effect Categories

- Environmental Costs; and
- Aesthetic Costs.

The following sections present an explanation of the economic effect categories in PEM and are meant to accompany the Structure and Logic Diagrams. A detailed description of each input variable in the Structure and Logic Diagrams is presented in the User's Manual.

Safety

PEM considers safety-related costs as the statistical value of human life as well the value of non-fatal accidents and property damage. Accident rates are calculated separately for three events: "property damage-only" accidents, injuries (as opposed to injury-producing accidents) and fatalities. The specific values for these three types of events are taken from The Cost of Highway Crashes[7] prepared for the Federal Highway Administration by the Urban Institute. The methodology and calculation of the accident incident rate for each event is explained in further detail in the User's Guide.

A fundamental safety-related issue revolves around the valuation of life and injuries. Measuring safety benefits (or accident costs) per incident involves correctly identifying (1)

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[7] The Urban Institute, The Costs of Highway Crashes (Washington D.C.: The Urban Institute, 1991). (prepared under FHWA contract DTFH61-85-C-00107).

losses involved and (2) the value of the benefit to the population stemming from the change in its exposure to physical risk. The first part, identifying losses is a fairly direct process involving compilation and analysis of existing data. The second, however, involves the indirect measurement of what people will pay for safety benefits. A near consensus exists on the methodology to be employed in measuring safety benefits using the willingness to pay approach, but the "value of life" approach is also gaining acceptance. Since the willingness to pay for risk reduction may vary for individuals both with respect to income and risk profile, a framework for evaluating safety benefits is needed, so that the "value of life" and measures of risk exposure can be identified or refined.

In a benefit-cost analysis of a highway improvement, reliable predictions of accident frequency and severity are as significant in determining total accident costs as is the estimation of the unit costs of accidents, broken down by degree of severity.

Value of Time

PEM considers the value of time as an important economic effect category related to the use of a product. Highway investment proposals, for instance, typically derive most of their appraised benefits from estimated savings in costs associated with travel time delays. A new product which produces a similar reduction in delays, through increased productivity or a shorter application time, for example, may also lead to savings in the value of time. How to place a value on the time lost through highway delays has long been a significant issue in the estimation of highway user costs.

The value of delay and time savings has long been known to be a significant element of highway user cost. Current thinking and state-of-the-art studies hold that the value of travel time represents the marginal rate of substitution of money for travel time, i.e., travel time values are based upon estimates of the amount of money decision-makers are willing to pay for a reduction in the amount of time that they, or a shipped commodity, spend in travel.

PEM uses speed/flow formulae to first determine the average vehicle speed for given facility types and traffic volumes. These formulae are consistent with the view of traffic speed/flow presented in the AASHTO Redbook (1977)[8]. The specific data used to derive the coefficients for these formulae comes from HERS[9], and from the Texas Transportation Institute[10]. The monetary values applied to time savings in PEM are

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[8] American Association of State Highway and Transportation Officials. A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements 1977. (Washington D.C.: 1978)

[9] Ibid, The Highway Economic Requirements System.

[10] Ibid, Technical Memorandum for NCHRP 7-12.

derived from information supplied from the Maricopa Association of Governments, Transportation and Planning Office which combines the percentage of person-trips by purpose obtained from household travel surveys with the average wage rate per sector and the occupancy rate per purpose to determine an average value of time for person/trips.

Vehicle Operating Costs

PEM considers vehicle operating costs as the cost of fuel, oil, maintenance and repairs, tire wear and highway-related vehicle depreciation. Generally speaking, vehicle operating costs are calculated based on posited mechanistic relationships between consumption rates for vehicle operating cost components on one hand, and highway conditions and traffic characteristics on the other. Information on these costs, as well as the methodology used to obtain them, can be found in HERS[11] and the Technical Memorandum to NCHRP 7-12[12].

In existing economic evaluation models for estimating highway operating costs, the prices associated with the consumption of key components are used only to convert quantity-based consumption rates developed in the models to an economic metric. Those models do not reflect the impact of price changes on changes in the levels of consumption of a particular cost component or cluster of components. Nor do they reflect the influence of other economic factors like changes in income levels.

Disruption Effects

In PEM, disruption effects are linked to the amount of time and the potential impact the disruption has on traffic during product installation or maintenance. The net disruption cost savings measures the incremental effects of disruption, or the additional costs or savings to highway users associated with the installation or maintenance of a new product.

The variables affecting the net disruption costs affect three economic effect areas under PEM: Safety, Value of Time and Vehicle Operating Costs. A Base Case product that currently requires a 30 minute installation time, for example, impacts these three areas through the disruption's direct effect on each category. For Safety, the percentage of AADT affected by the disruption as well as the maximum effect of the disruption on accident rates are used to forecast the Safety Disruption Costs. The Value of Time and Vehicle Operating Costs, derived from the Technical Memorandum to NCHRP 7-12[13], are dependent upon on the percentage of AADT affected by the disruption and the length the disruption time. The sum of these three effect categories provides Base Case net

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[11] Ibid, The Highway Economic Requirements System.

[12] Ibid, Technical Memorandum for NCHRP 7-12.

[13] Ibid, Technical Memorandum to NCHRP Report 7-12.

disruption costs. A new product which reduces the disruption time, and/or the amount of traffic affected by disruption and the disruption's maximum effect on accident rates, leads to a net savings in disruption costs and an economic benefit to the driver.

Productivity Effects

ADOT productivity effects refer to the overall reduced costs associated with a new product. A new, durable pavement that leads to a reduction in annual maintenance costs may contribute to ADOT productivity only if this new product does not increase other cost categories, such as associated capital expenses on new equipment. The important aspect of this benefit category is accounting for all administrative, as well as fabrication and maintenance and operating costs associated with existing products. PEM accounts for productivity effects in three areas of potential improvements, namely: administrative, fabrication, and maintenance and operating costs.

The basic methodology used to obtain productivity data for all areas considered by PEM is the same. It involves observing the number of units of a new product installed or applied in one hour divided by the number of workers. The resulting figure is the number of units per person per hour or the productivity associated with a given product. Productivity estimates for Administrative and Fabrication are obtained from ADOT groups directly affected by the use of the product. The PECOS II data system calculates productivity for all ADOT maintenance activities and many vendors provide similar calculations for their products. Graphical representations of the three elements of productivity: product units, time, and workers, and the process used to place a value on productivity improvements are presented in the "Net Productivity Savings," "Product Demand," "Net Maintenance and Operating Costs," and "Net Fabrication Costs" Structure and Logic Diagram presented at the end of this section.

Annual Capital Expenditures

PEM's Annual Capital Expenditures category is dependent on both ADOT management purchasing and inventory decisions as well as common product attributes and product performance. The interaction of these factors produces the Base Case and New Products which is incorporated into the Annual Capital Expenditures category.

The Product Demand model solicits information on current and projected inventory, phase-in/phase-out periods, and product performance in terms of useful and maximum useful economic life. These values are used to derive estimates of the Base Case purchasing and inventory patterns for the current product, as well as to calculate the costs associated with phasing-in a new product while simultaneously phasing-out the current product. The product demand sub-model results in outputs for annual Base Case and phase-in/phase-out product purchases which are used in the drive the forecasts in the Annual Captial Expenditures.

PEM's Annual Capital Expenditures economic effect category uses specific cost data for Base Case and New Products combined with previously derived product demand functions to forecast the annual capital expenditures associated with a specific product. Inventory and Carrying Costs, as well as Salvage and Disposal Costs are added to the model, depending upon the number of units held in inventory and the annual product failures, respectively. Like the Product Demand model, this model forecasts the Annual Capital Expenditures associated with the Base Case product and compares this figure to the combined Annual Capital Expenditures associated with the phasing-in of a new product and the phase-out of the current product.

Maintenance Costs

PEM's Maintenance Costs effect category considers a host of variables that are typically linked to the maintenance and upkeep of an installed product. The common product attributes which comprise maintenance costs include: hourly equipment costs, labor productivity, fabrication productivity, average ADOT labor wage, as well as the annual number of product replacements which is based on failure rate and the knock-down/vandalism rate. Specific product attributes which affect pavement condition are also considered in this category, since these products may affect ADOT's pavement maintenance costs. The sum of these two types of maintenance activities is an estimate of the annual Maintenance Costs associated with a specific product. A new product which reduces the costs in either maintenance activity, such as through reduced equipment costs, for example leads to overall maintenance cost savings and economic benefit associated with the product.

Liability Costs

Product liability and the cost of litigation associated with product failures represents an important economic benefit category to State DOTs. A new highway product that reliably and consistently provides the same or superior user benefits compared to current technology may decrease the claims against the state and, ultimately, liability costs. Although the probability of related accidents due to a specific product attribute may be very small, the model addresses their statistical occurrence based on the number of claims per 100 product failures, and considers the costs incurred for those cases that are settled and those cases that go to trial. This basic accounting of liability costs provides a monetary measure of the potential liability risks associated with the use of a new product. In instances where little or no reliable data is available for this benefit category, the user should contact ADOT Risk Management for an opinion on the product's potential liability costs, if any.

Environmental and Aesthetic Costs

PEM addresses the environmental and aesthetic costs associated with a product via a threshold analysis which indirectly places a monetary value on environmental and aesthetic benefits. This approach was adopted since modelling the environmental and aesthetic costs associated with each product depends upon a myriad of independent factors that cannot be easily generalized and incorporated into a model with the scope of PEM.

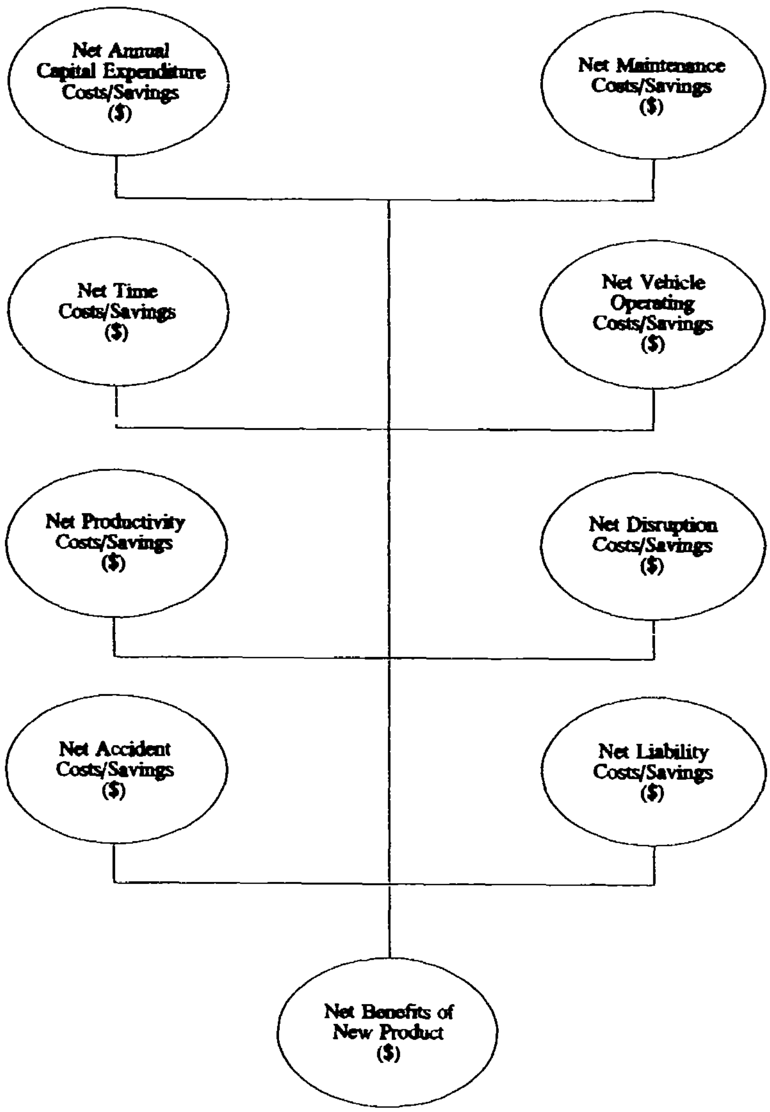
PEM's environmental and aesthetic costs threshold is based on 80 percent of the net economic benefits associated with a given product. A new product which produces a net economic cost, or negative benefit can potentially overcome this evaluation if it is determined that the environmental and aesthetic benefits associated with the product are at least equal to or exceed 80 percent of the net economic costs.

PEM's approach to environmental and aesthetic costs is ideally suited for variation two of the RAP component, although it can also be performed in variation one. As explained in PEM step 5, variation two is the expanded version of RAP in which ADOT personnel, company representatives and industry experts are invited to deliberate the probability ranges around central variables and to interpret PEM's forecasts. PEM's indirect estimation of environmental and aesthetic benefits provides the panel a starting point for discussing and forming a consensus about the value of these effects and their relationship to the product under consideration. Of course, PEM's threshold analysis of environmental and aesthetic costs associated with a product can also be evaluated by a single analyst, although this approach may limit the range of opinion concerning the value of these benefits.

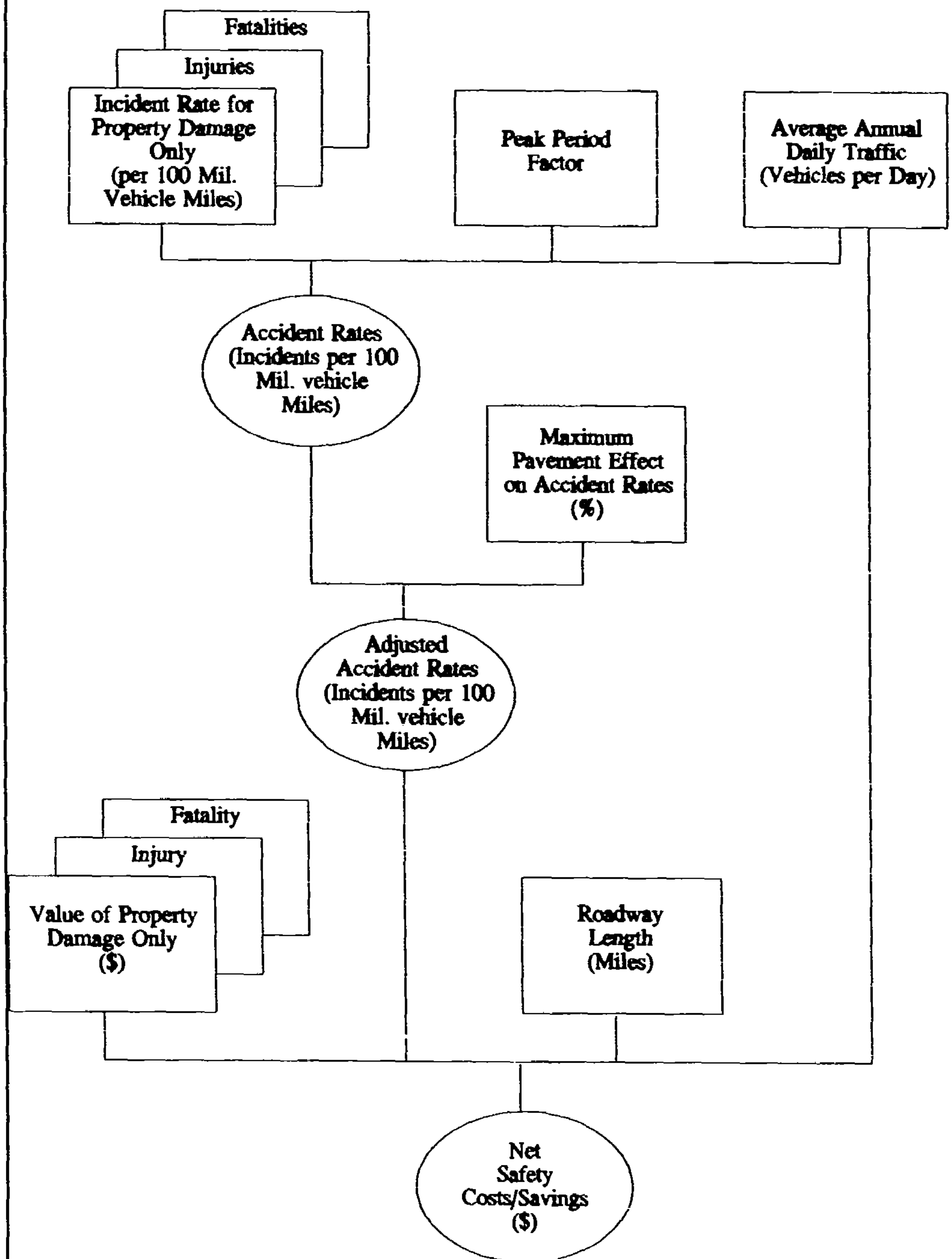
Structure and Logic Diagrams

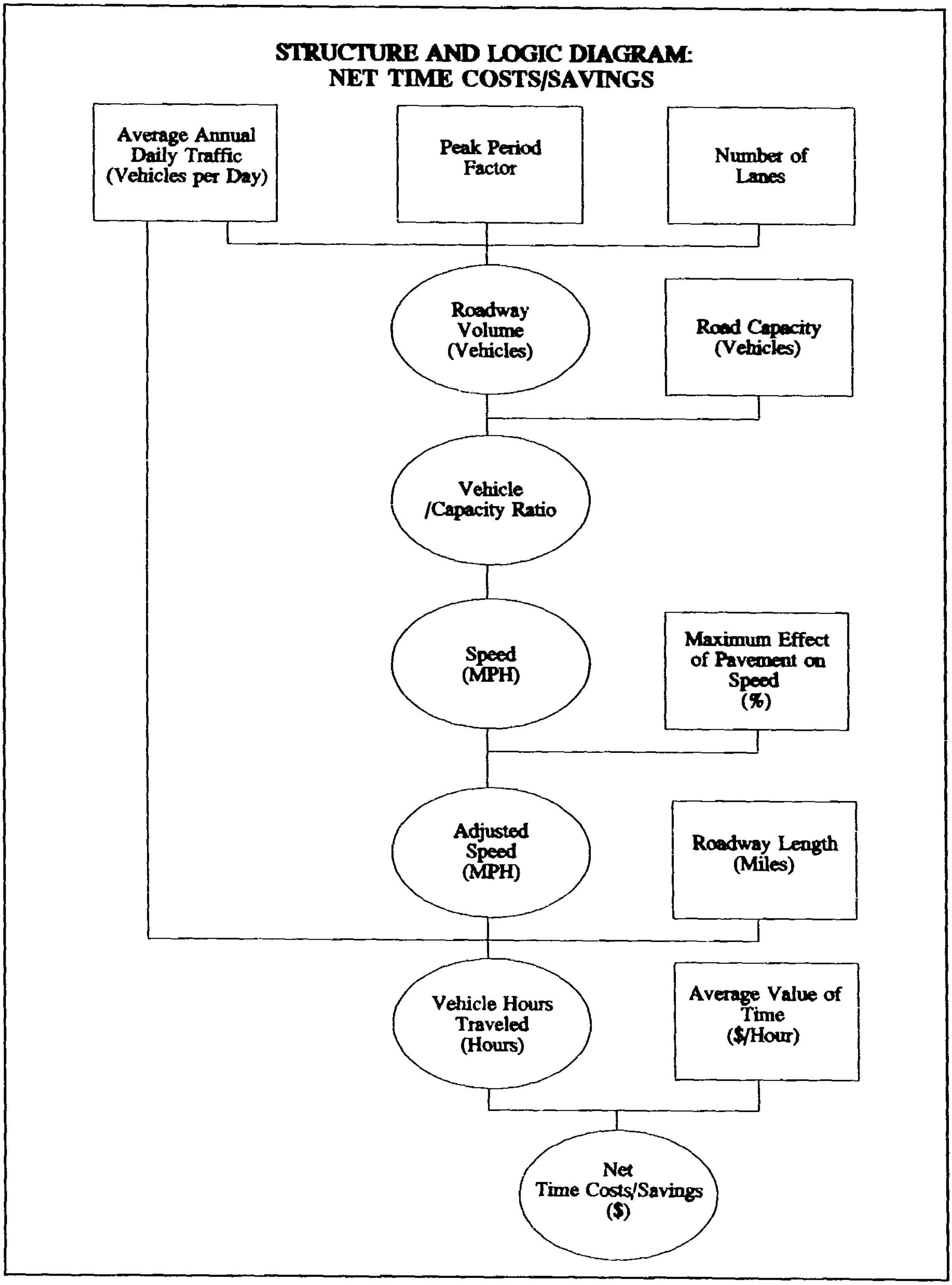
The following pages present the Structure and Logic Diagrams for each of the economic effect categories explained above. In each diagram, squares represent inputs to the model, while ovals represent outputs or outcomes from the relationships in the model. By using these diagrams, the user will be able to trace the path from the model inputs to the economic benefit categories.

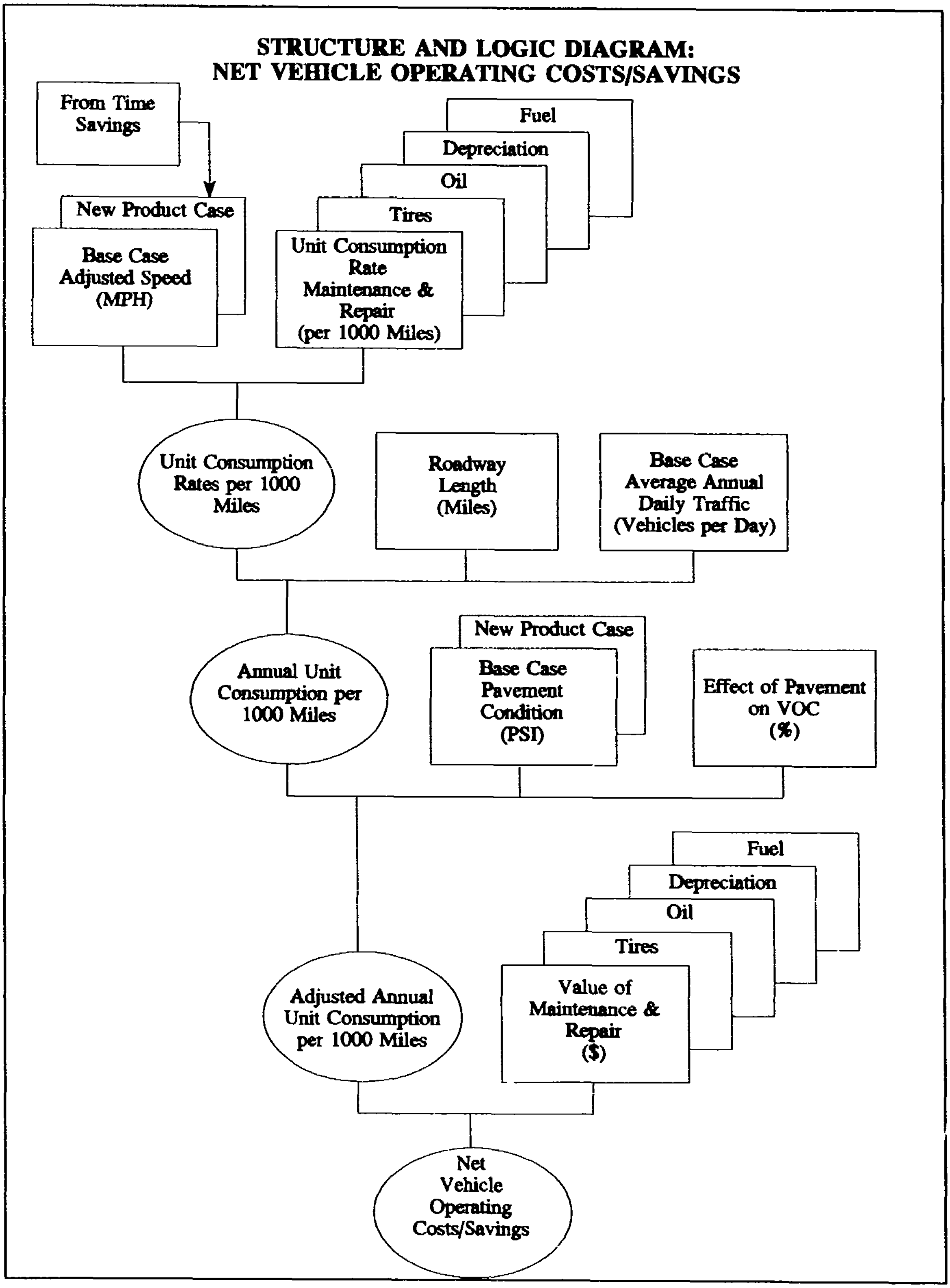
**STRUCTURE AND LOGIC DIAGRAM:
OVERVIEW OF THE BENEFIT- COST ANALYSIS**



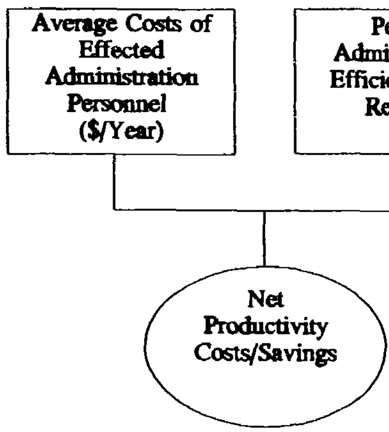
STRUCTURE AND LOGIC DIAGRAM:
NET SAFETY COSTS/SAVINGS

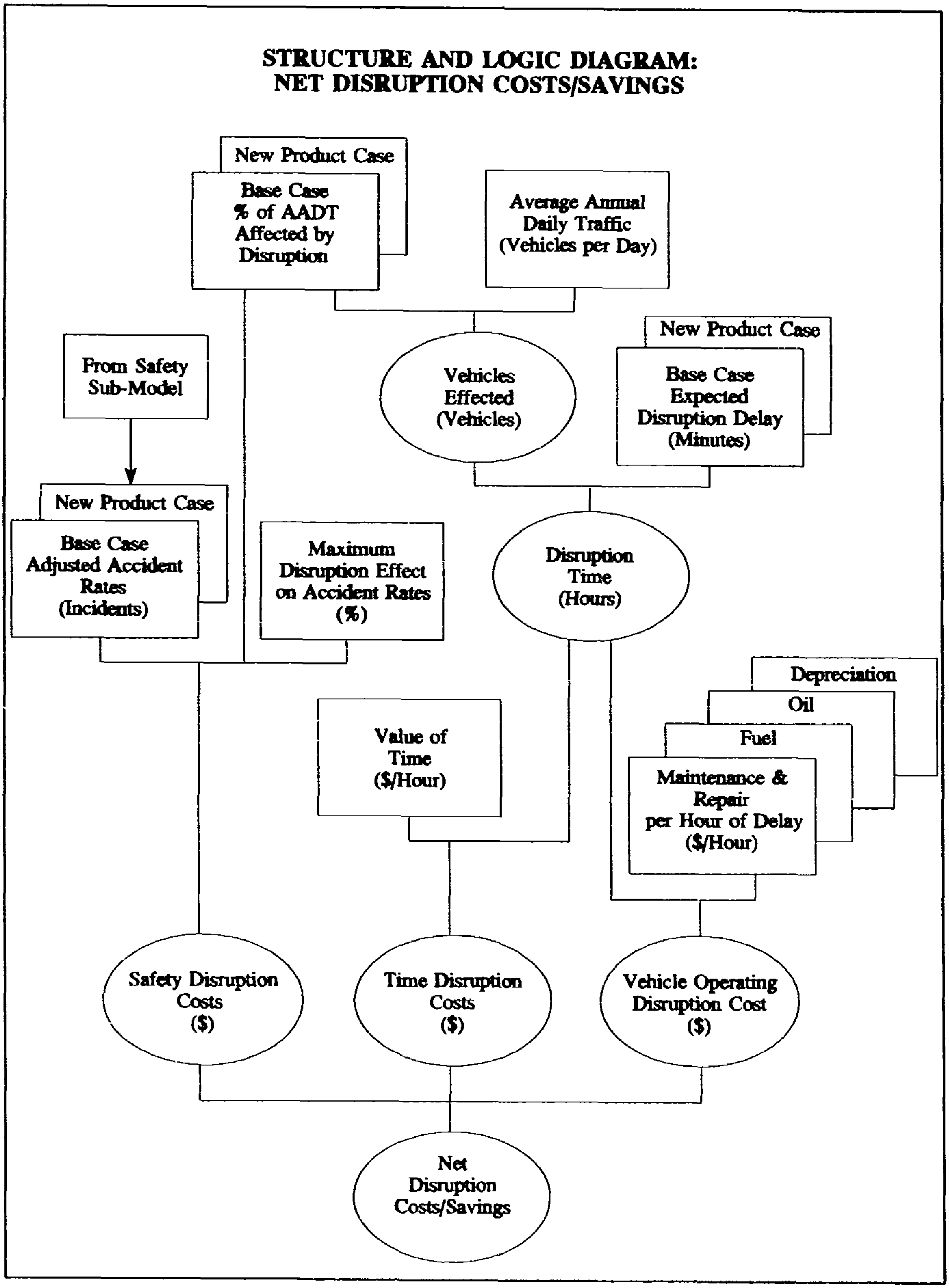


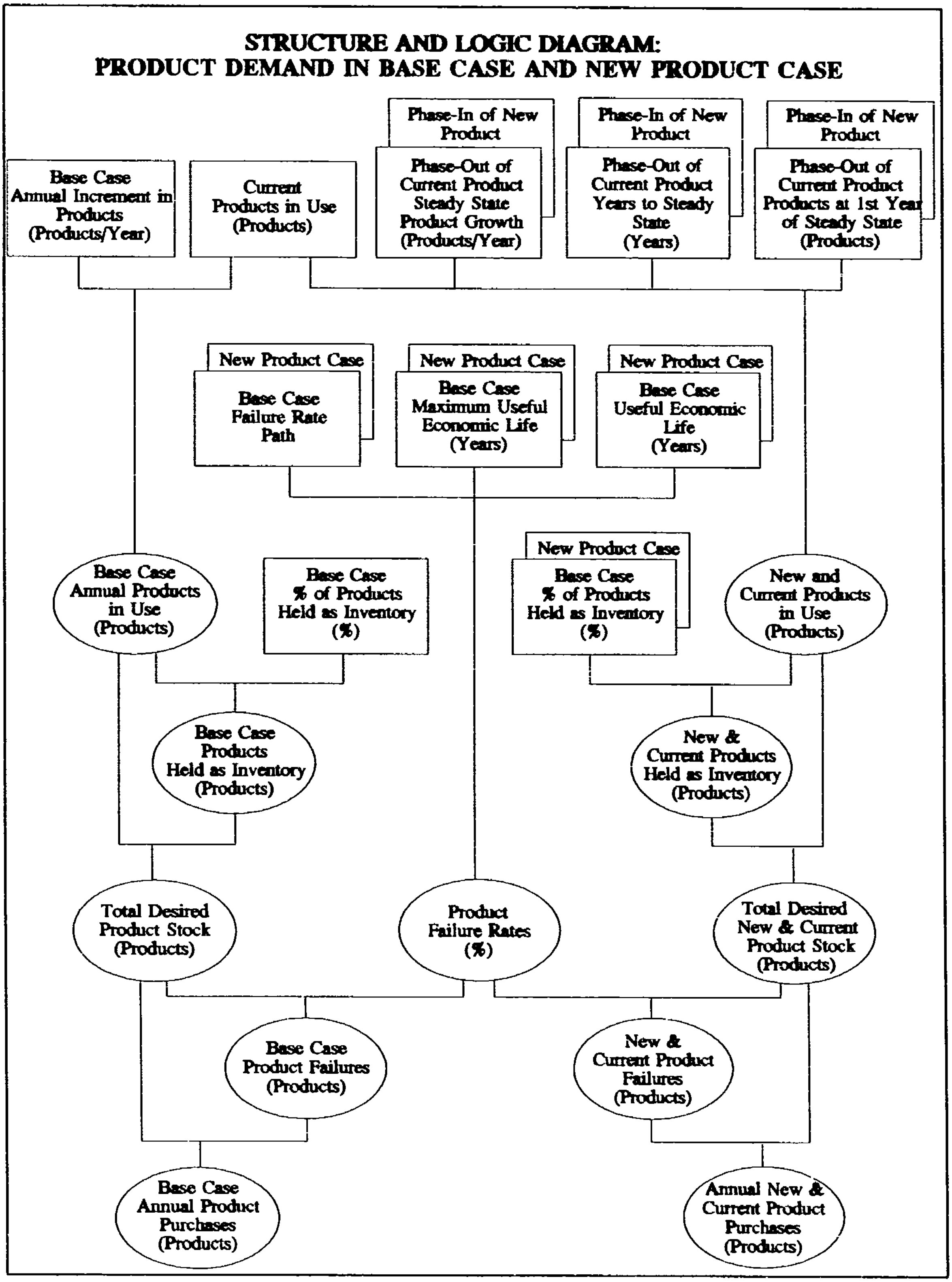

STRUCTURE AND LOGIC DIAGRAM:
NET TIME COSTS/SAVINGS
Average Annual Daily Traffic (Vehicles per Day)
Peak Period Factor
Number of Lanes
Roadway Volume (Vehicles)
Road Capacity (Vehicles)
Vehicle /Capacity Ratio
Speed (MPH)
Maximum Effect of Pavement on Speed (%)
Adjusted Speed (MPH)
Roadway Length (Miles)
Vehicle Hours Traveled (Hours)
Average Value of Time ($/Hour)
Net Time Costs/Savings ($)

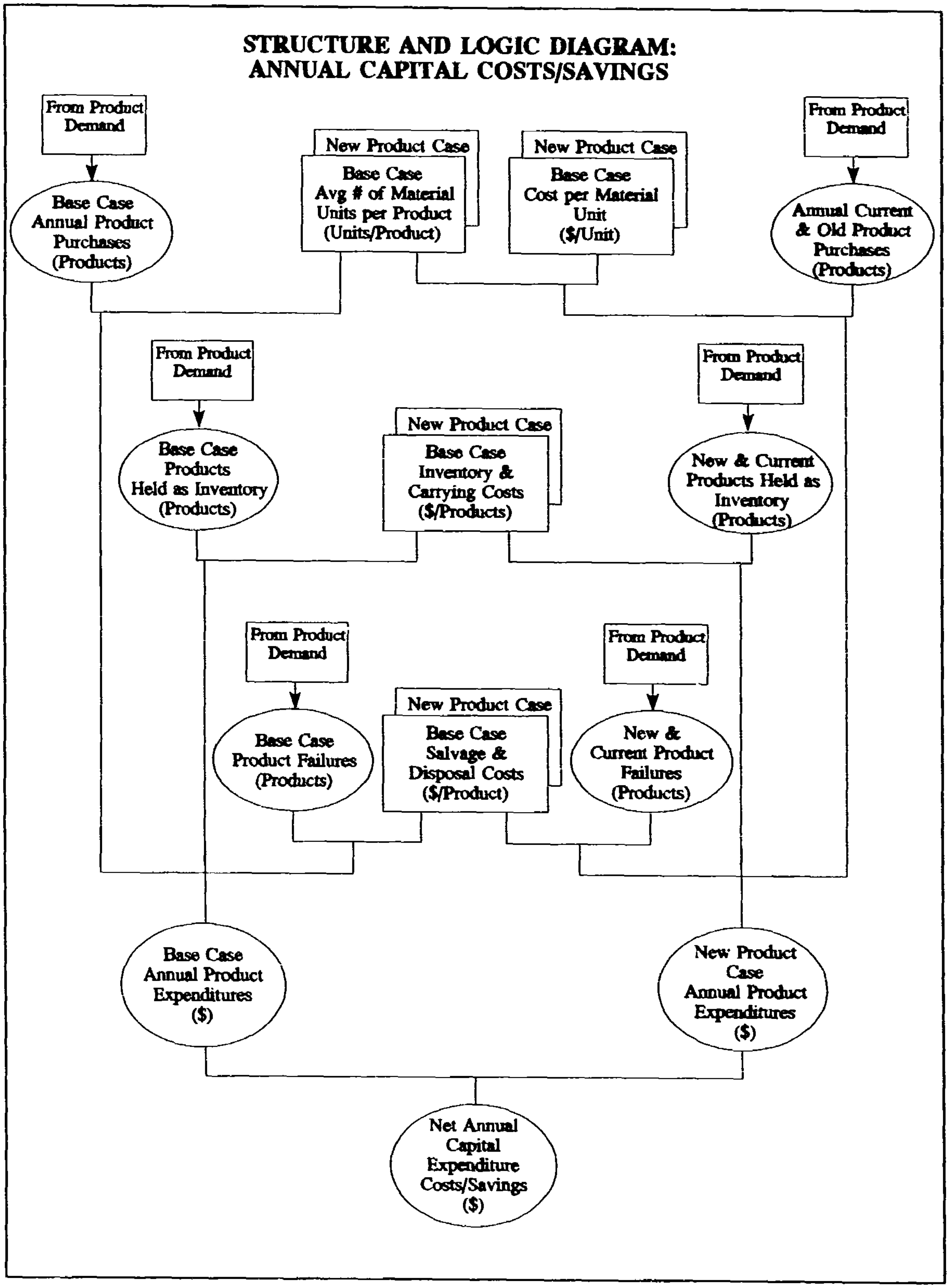

STRUCTURE AND LOGIC DIAGRAM:
NET VEHICLE OPERATING COSTS/SAVINGS
From Time Savings
New Product Case
Base Case Adjusted Speed (MPH)
Fuel
Depreciation
Oil
Tires
Unit Consumption Rate Maintenance & Repair (per 1000 Miles)
Unit Consumption Rates per 1000 Miles
Roadway Length (Miles)
Base Case Average Annual Daily Traffic (Vehicles per Day)
Annual Unit Consumption per 1000 Miles
New Product Case
Base Case Pavement Condition (PSI)
Effect of Pavement on VOC (%)
Fuel
Depreciation
Oil
Tires
Value of Maintenance & Repair ($)
Adjusted Annual Unit Consumption per 1000 Miles
Net Vehicle Operating Costs/Savings

STRUCTURE AND LOGIC DIAGRAM:
NET PRODUCTIVITY COSTS/SAVINGS

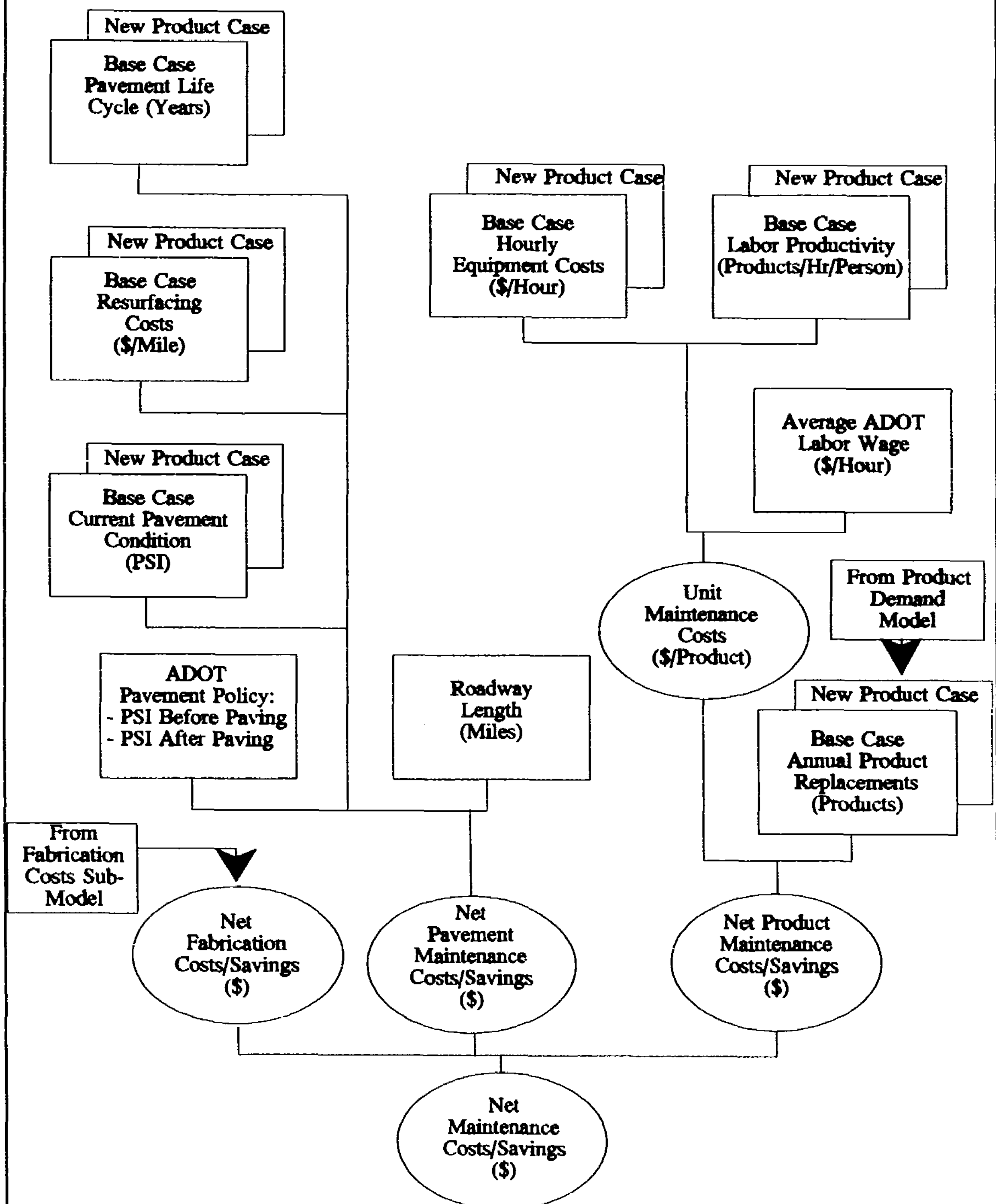



STRUCTURE AND LOGIC DIAGRAM:
NET DISRUPTION COSTS/SAVINGS
New Product Case
Base Case
% of AADT
Affected by
Disruption
Average Annual
Daily Traffic
(Vehicles per Day)
From Safety
Sub-Model
Vehicles
Effected
(Vehicles)
New Product Case
Base Case
Expected
Disruption Delay
(Minutes)
New Product Case
Base Case
Adjusted Accident
Rates
(Incidents)
Maximum
Disruption Effect
on Accident Rates
(%)
Disruption
Time
(Hours)
Depreciation
Oil
Fuel
Maintenance &
Repair
per Hour of Delay
($/Hour)
Value of
Time
($/Hour)
Safety Disruption
Costs
($)
Time Disruption
Costs
($)
Vehicle Operating
Disruption Cost
($)
Net
Disruption
Costs/Savings

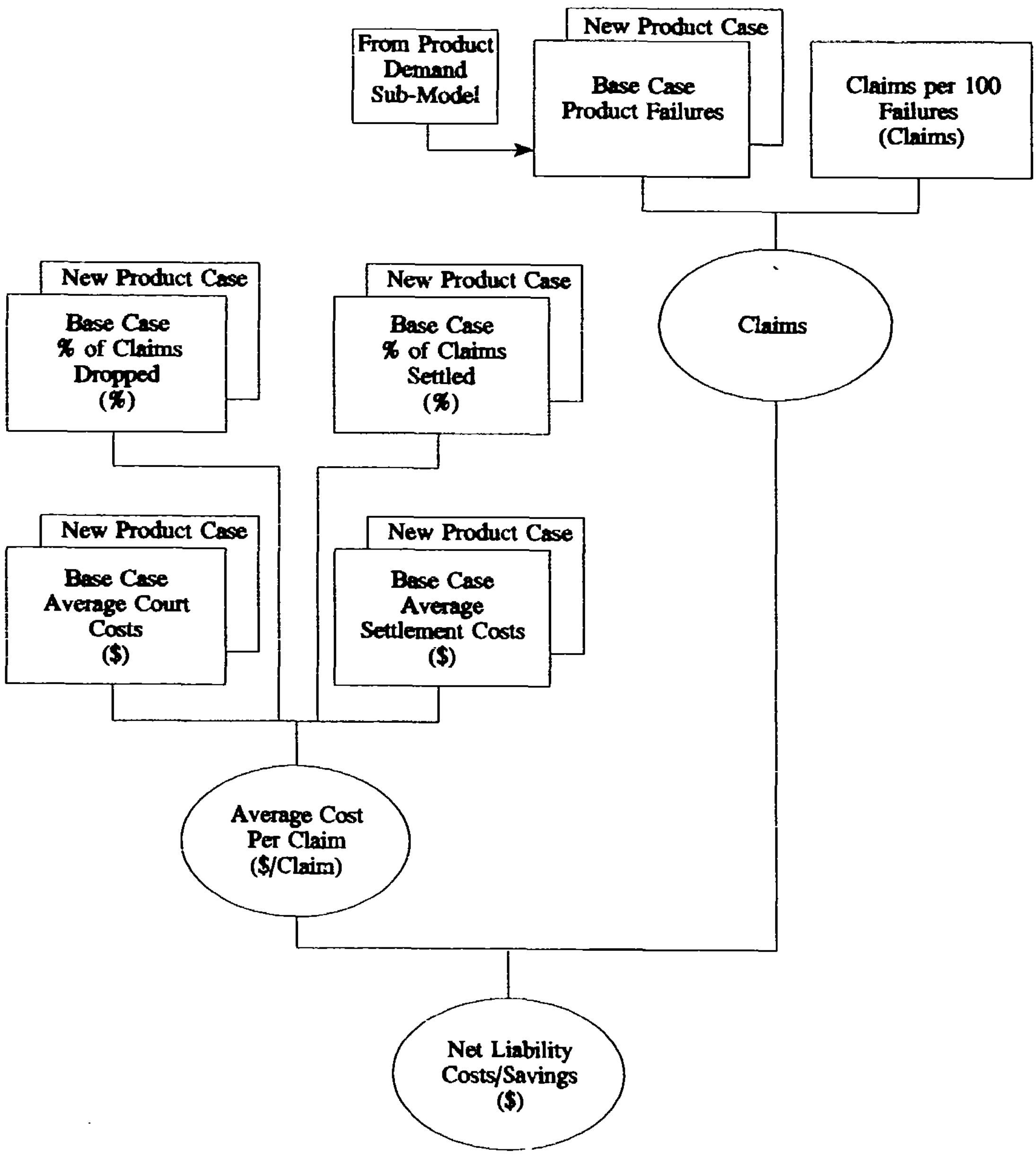

STRUCTURE AND LOGIC DIAGRAM:
PRODUCT DEMAND IN BASE CASE AND NEW PRODUCT CASE
Phase-In of New Product
Phase-Out of Current Product Steady State Product Growth (Products/Year)
Phase-In of New Product
Phase-Out of Current Product Years to Steady State (Years)
Phase-In of New Product
Phase-Out of Current Product Products at 1st Year of Steady State (Products)
Base Case Annual Increment in Products (Products/Year)
Current Products in Use (Products)
New Product Case
Base Case Failure Rate Path
New Product Case
Base Case Maximum Useful Economic Life (Years)
New Product Case
Base Case Useful Economic Life (Years)
Base Case Annual Products in Use (Products)
Base Case % of Products Held as Inventory (%)
New Product Case
Base Case % of Products Held as Inventory (%)
New and Current Products in Use (Products)
Base Case Products Held as Inventory (Products)
New & Current Products Held as Inventory (Products)
Total Desired Product Stock (Products)
Product Failure Rates (%)
Total Desired New & Current Product Stock (Products)
Base Case Product Failures (Products)
New & Current Product Failures (Products)
Base Case Annual Product Purchases (Products)
Annual New & Current Product Purchases (Products)


STRUCTURE AND LOGIC DIAGRAM:
ANNUAL CAPITAL COSTS/SAVINGS
From Product Demand
Base Case Annual Product Purchases (Products)
New Product Case
Base Case Avg # of Material Units per Product (Units/Product)
New Product Case
Base Case Cost per Material Unit ($/Unit)
From Product Demand
Annual Current & Old Product Purchases (Products)
From Product Demand
Base Case Products Held as Inventory (Products)
New Product Case
Base Case Inventory & Carrying Costs ($/Products)
From Product Demand
New & Current Products Held as Inventory (Products)
From Product Demand
Base Case Product Failures (Products)
New Product Case
Base Case Salvage & Disposal Costs ($/Product)
From Product Demand
New & Current Product Failures (Products)
Base Case Annual Product Expenditures ($)
New Product Case Annual Product Expenditures ($)
Net Annual Capital Expenditure Costs/Savings ($)

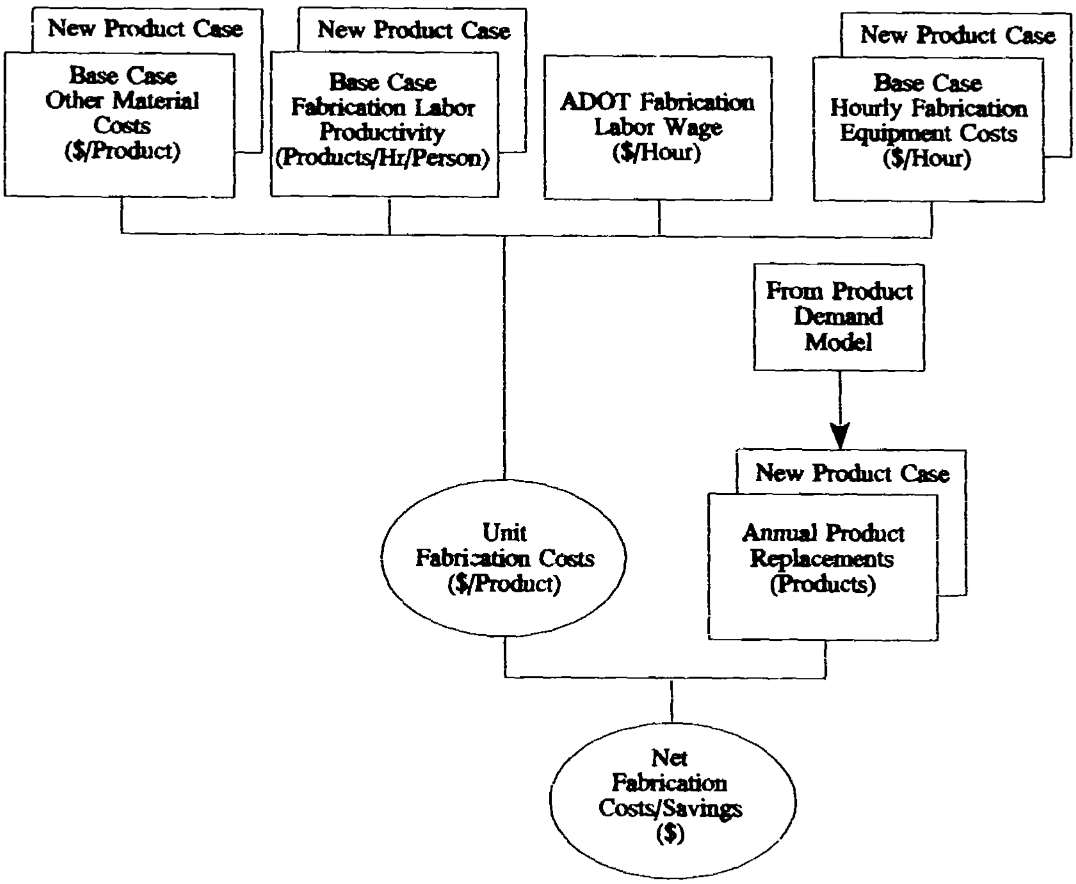
STRUCTURE AND LOGIC DIAGRAM:
NET MAINTENANCE COSTS/SAVINGS



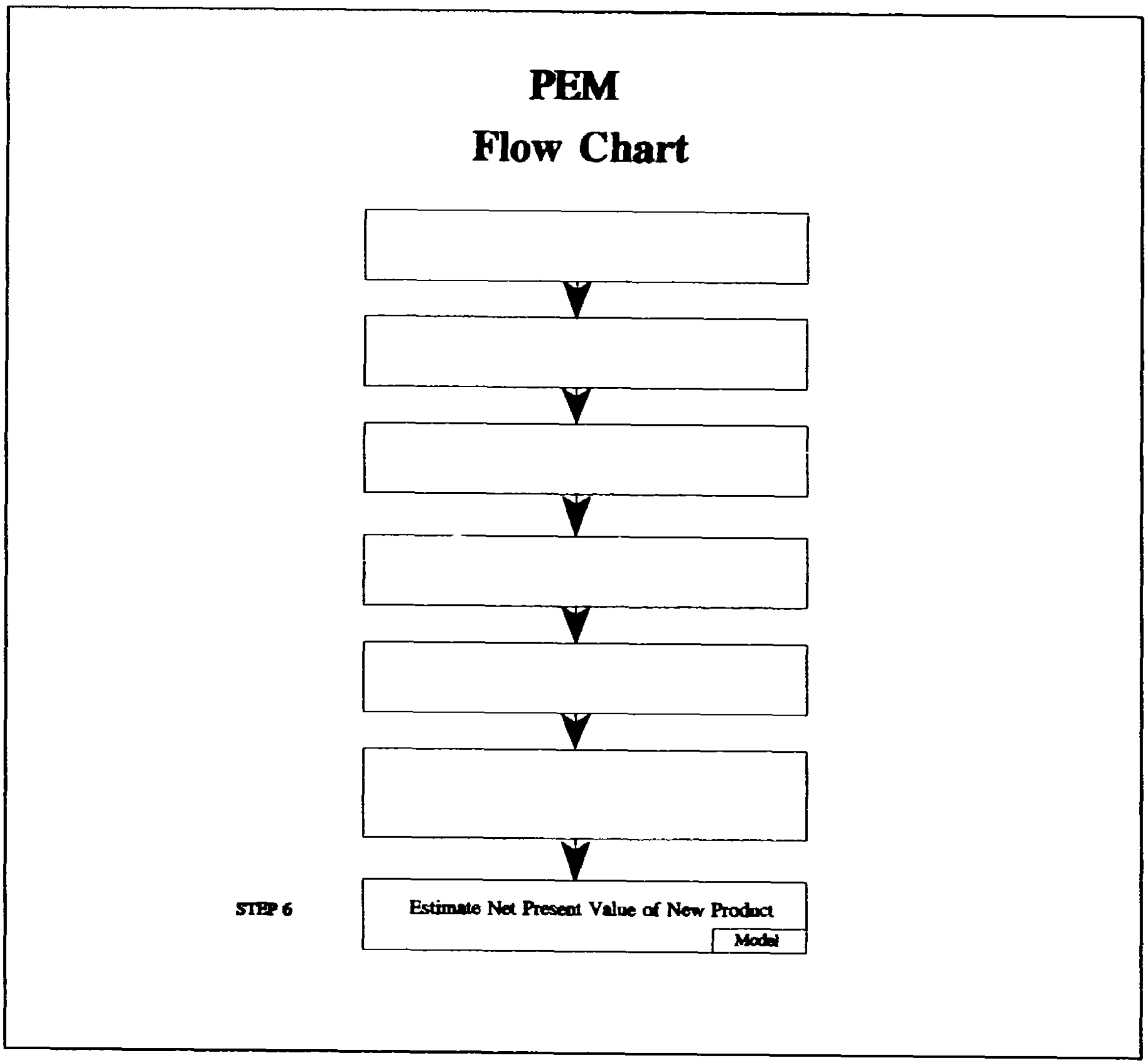
STRUCTURE AND LOGIC DIAGRAM: NET LIABILITY COSTS/SAVINGS



STRUCTURE AND LOGIC DIAGRAM:
NET FABRICATION COSTS/SAVINGS



PEM STEP 6



The final step of the PEM process is the estimation of the Net Present Value of the New Product. The model calculates this value by taking the net economic benefits derived in step 5 and "discounting" this value by the user defined discount rate, over the user defined analysis period[14]. Those products that yield a net present value of zero or above reflect an economic return of over five percent for the period studied, and are therefore economically justified. Those with negative values, conversely, are not economically justified.

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[14] The AASHTO Redbook (1977) recommends a discount rate of 5 percent for transportation project investments.

The model's final output of net present value gives the ATRC analyst a useful analytical tool for ranking and prioritizing new highway products. Given several products to screen, the analyst can compare the net present values and select only those products that yield relatively high net present values for further investigation. Alternatively, the analyst can also view the probabilities of achieving certain levels of economic benefits through the de-cumulative distribution option in the PEM risk analysis software (see the User's Guide for further instruction).

Using this information, the analyst can supplement the ATRC product selection process with a risk-adjusted, economic case for either ADOT product testing or purchasing. If a certain product warrants more investigation, the PEM results can be exposed to experts in a full RAP session to more thoroughly examine the economic costs and benefits associated with a new product.

3.0 USER'S GUIDE

The following section provides general information about PEM and basic instructions for running it. The step-by-step instructions provide all the basic information necessary to load the software, create a model scenario, modify input data, run a risk analysis statistical simulation, and analyze the model's outputs.

PEM is composed of two software programs. The first program serves an interface and database manager, while the second program is used for running risk analysis simulations. The software interface is used to generate new scenario files and to retrieve old scenarios. It is designed to run in any standard spreadsheet software program, such as Excel, Lotus 123, or Quatro Pro. The second program is the actual risk analysis simulation software, which runs in DOS.

The remainder of this section is divided into six sub-sections which focus on the step-by-step procedures for using the PEM software. The six sub-sections are:

- Loading the interface software;
- Creating a scenario file;
- Loading the risk analysis simulation software;
- Modifying inputs;
- Running a simulation; and
- Analyzing results.

LOADING THE INTERFACE SOFTWARE

1) Loading the Interface Software

From any standard spreadsheet software program, retrieve or open the spreadsheet called MAKER.WK1. The initial screen that appears is pictured in Figure 3.1. The software must be in a sub-directory called RAP.

2) Activating the Main Menu

Hitting ***CTRL+A*** activates the main menu. The main menu is pictured in Figure 3.2. To make a selection, use the up and down directional arrow keys to center the cursor over the corresponding number to the left of the appropriate menu item and hit ***Enter***.

Figure 3.1: Initial Software Interface Screen

Maker.wk1

NEW PRODUCT SCENARIO GENERATOR
AND DATABASE MANAGER
FOR RISK ANALYSIS

PREPARED FOR
ARIZONA DEPARTMENT OF TRANSPORTATION
(ADOT)

<<<CTRL + A for Main Menu>>>

CREATING A SCENARIO FILE

There are two steps to creating a new scenario file. The first step requires inputting or altering scenario data. The scenario data is broken up into four categories: roadway characteristics data; highway user cost and ADOT policy data; common product attribute data; and specific product attribute data. These categories correspond to menu selections 1 through 4, respectively, which are pictured in Figure 3.2.

The second step requires inputting a filename and entering a description of the product. This step is accomplished by hitting ***Enter*** with the cursor over main menu option 6, as pictured in Figure 3.2.

Entering Input Data

The procedure for entering data in any of the four categories is identical. Once the correct selection is made from the main menu, the cursor will automatically move to the first data input field for that category. A sample data entry screen is pictured in Figure 3.3. To enter a new data value, simply key in the new value and hit ***Enter***. The user must utilize the directional arrow keys as well as the ***Page Up*** and ***Page Down*** keys to move to each data field. When the user is done altering the data, ***CTRL + A*** returns the cursor to the main menu.

Each of these data categories and associated inputs will be explained in detail later in this section.

It is suggested that new users refer to the variable descriptions in Section 3.3 for proper descriptions of each data input.

Entering the Scenario Filename and Product Description

Once all the appropriate scenario data has been entered, the user must select main menu option 6, as pictured in Figure 3.2. The user will then be prompted to enter a filename. This filename should be no more than eight characters. All the relevant scenario data and results will be saved under this filename. Secondly, the user will be prompted to input the name of the product being evaluated. This name will appear as the scenario name when the user runs a simulation using the risk analysis simulation software.

Figure 3.2: Software Interface Main Menu

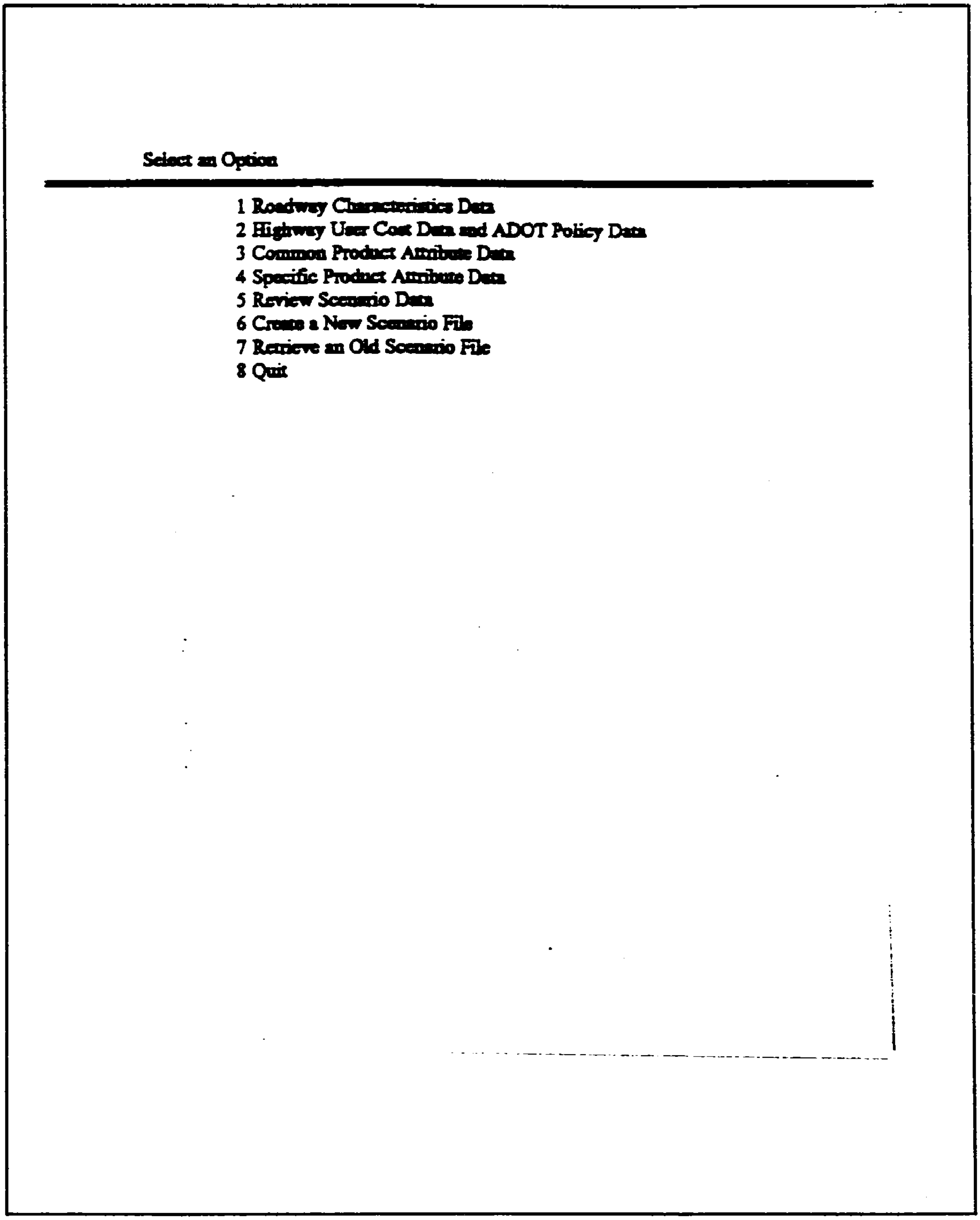

Figure 3.3: Sample Data Input Screen

COMMON PRODUCT ATTRIBUTES	Units	Median Value	Lower 10%	Upper 10%
# of Units per Product - BC	(# of Units)	9.00	8.00	10.00
# of Units per Product - NP	(# of Units)	9.00	8.00	10.00
Material Cost per Unit - BC	($/Unit)	0.88	0.73	0.93
Material Cost per Unit - NP	($/Unit)	3.74	3.72	3.75
Current Products in Use - BC	(Products)	1000	900	1100
Annual Inc. in Products - BC	(Products)	100	90	110
% of Prod. Vand/Hit per Yr-BC	(%)	0.0527	0.0473	0.0577
% of Prod. Vand/Hit per Yr-NP	(%)	0.0527	0.0473	0.0577
Useful Economic Life- BC	(Years)	6.36	5.00	8.40
Useful Economic Life- NP	(Years)	10.30	8.40	13.10
Max Useful Economic Life - BC	(Years)	9.45	7.05	13.75
Max Useful Economic Life - NP	(Years)	15.70	11.40	20.10
% of Prod. Held as Inv. - BC	(%)	0.00	0.00	0.00
% of Prod. Held as Inv. - NP	(%)	0.00	0.00	0.00
Phase-Out- Prod at Steady State	(Products)	0	0	0
Phase-Out- Yrs to Steady State	(Years)	2.00	1.75	3.00
Phase-Out- S. S. Stock Growth	(Products)	0.00	0.00	0.00
Phase-In - Prod at Steady State	(Products)	1000	900	1100
Phase-In - Yrs to Steady State	(Years)	2.00	1.75	3.00
Phase-In - S.S. Stock Growth	(Products)	100	90	110
Start-up Equipment Costs	($)	4000.00	3000.00	5000.00
Start-up Training Costs	($)	0.00	0.00	0.00
Ann Training & Equipment Costs	($/Year)	0.00	0.00	0.00
Testing & Evaluation Costs	($)	0.00	0.00	0.00

Additional Interface Functions

Reviewing the Scenario Data. Option 5, as seen in Figure 3.2, allows the user to peruse the scenario data before it is exported as a scenario file. Using the up and down directional arrow keys allows the user to page through the data. When done hitting ***CTRL + A*** returns the cursor to the main menu.

The data can not be modified at this time, if the user desires to change any of the data he/she must return to the main menu ***(CTRL + A)*** and then select the appropriate category.

Retrieving an Old Scenario File. To rerun an old scenario utilizing the risk analysis simulation software requires that the user retrieve the old file by selecting option 7 from the main menu, see Figure 3.2. The user will be prompted to select the old file, which will automatically be imported into the simulation software, and will be ready to run once the user loads the simulation software.

DATA INPUT DESCRIPTIONS

Roadway Characteristics

As seen in Figure 3.2, roadway characteristics data represents the first category of data inputs needed to run a simulation. These inputs are required and essential to defining the base case against which the new product is to be evaluated. There are no specific values for these variables. They will depend upon the physical characteristics of the road on which the products under evaluation are to be used. These characteristics can significantly impact the entire range of economic benefits associated with each product and should remain constant between similar product scenarios, unless there is compelling evidence to support a change. The following is a complete list of the data inputs in this category:

- Metric Conversion;
- Facility Type;
- Number of Lanes;
- Roadway Length;
- Average Annual Daily Traffic;
- Annual Increment in Average Annual Daily Traffic; and
- Current Pavement Condition.

Metric Conversion

The metric conversion toggle allows the user to switch between metric units and U.S. units as the base unit of analysis. This switch will not change any prices. The user must manually convert them.

The following is a complete list of the prices that must be changed when converting from metric to a U.S. based unit system:

	U.S. System	**Metric**
Fuel	$/gallon	$/liter
Oil	$/quart	$/liter
Maintenance & Repair	% Avg Cost/1000 mi	% Avg Cost/1000 km
Resurfacing Costs	$/mile	$/kilometer

Typical values for these prices have been included in the Technical Appendix.

Facility Type

A total of twelve different facilities have been included in the model (7 urban, and 5 rural), each of which has a unique number code. The facility types and their corresponding codes are listed below. The user is required to input a number code, corresponding to the facility type in the base case and with the new product. The facility designation codes <u>should be</u> the same for both cases since it is highly unlikely that any new product would change the facility type.

The facility type drives the speed/value of time analysis as well as the safety/accident cost analysis. Each facility type has a unique speed flow curve and a unique accident rate data array. The vehicle operating cost analysis is driven by the determination of the average speed and is therefore also directly effected by the facility type.

The twelve facility types included in the model are:

1. 4 Lane Full Access Control, Urban
2. 6 or More Lane Full Access Control, Urban
3. 4 Lane Partial Access Control, Urban
4. 6 or More Lane Partial Access Control, Urban
5. 2 or 3 Lanes, Urban
6. Multilane Undivided No Access Control, Urban
7. Multilane Divided No Access Control, Urban
8. Multilane Full Access Control, Rural
9. Multilane Partial Access Control, Rural
10. 2 or 3 Lanes, Rural
11. Multilane Undivided No Access Control, Rural
12. Multilane Divided No Access Control, Rural

Number of Lanes

This is a straight forward, roadway specific input. The user must ensure that the number of lanes specified is compatible with the chosen facility types. The number of lanes should be the same for both cases since it is highly unlikely that any new product would change the number of lanes.

The number of lanes primarily effects speed/flow. Speed/flow is driven by the volume to capacity ratio which is a function of the average annual daily volume and the capacity of the road, which naturally depends on the number of lanes.

Pavement Condition

This value must be specified for the roadway in the base case. Pavement condition is specified through use of the pavement service index (PSI), which operates on a scale of 0.1 to 5.0. A PSI of 5.0 represents the best pavement condition, and 0.1, the worst.

Pavement condition has a direct effect on all three of the major user cost categories, speed/flow, safety, and vehicle operating costs.

PSI (pavement service index) values range from 3.0 to 4.5 for typical U.S. highways.

Roadway Length

This value must be input in kilometers. It refers to the length of road facility under analysis. This value will depend upon the analysis and product under evaluation.

Average Annual Daily Traffic

This value refers to the average annual daily traffic (AADT) on the facility under consideration. AADT is defined in the Highway Capacity Manual, Transportation Research Board Special Report 209,[15] as "the total volume passing a point or segment of a highway facility, in both directions, for one year, divided by the number of days in the year." This value will depend upon the facility type chosen. Some typical AADT values are listed below.

		Low	High
1.	4 Lane Full Access Control	35,000	80,000
2.	6 or More Lane Full Access Control	80,000	120,000
3.	4 Lane Partial Access Control	20,000	75,000
4.	6 or More Lane Partial Access Control	80,000	120,000
5.	2 or 3 Lanes	3,000	10,000
6.	Multilane Undivided No Access Control	35,000	45,000
7.	Multilane Divided No Access Control	45,000	55,000
8.	Multilane Undivided No Access Control	8,000	10,000
9.	Multilane Divided No Access Control	15,000	25,000
10.	Multilane Full Access Control, Rural	15,000	25,000
11.	Multilane Partial Access Control, Rural	25,000	35,000
12.	2 or 3 Lanes, Rural	1,600	8,000

Annual Increment in Average Annual Daily Traffic

This value refers to the increase in vehicles a facility may undergo over time. This value is specific to the facility type chosen by the user. The increment may be zero or even negative.

Highway User Cost Data and ADOT Policy Data

Highway user cost data and ADOT policy data reflect either policy-defined values for certain transportation-related inputs, such as the average value of time, or market prices for common transportation inputs, such as the price of fuel and tires. The values for these variables should be agreed upon beforehand and remain constant throughout a product evaluation. The prices should also be consistent with the desired convention (i.e. metric vs. U.S. system). This is necessary in order to have a common set of prices for the evaluation of all economic impacts.

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[15] Transportation Research Board, National Research Council, Highway Capacity Manual, Special Report 209. (Washington, D.C.: 1985).

The Highway User Cost Data and ADOT Policy Data contained in PEM includes:

- PSI Before Resurfacing;
- PSI After Resurfacing;
- Expected Base Case Pavement Life;
- Base Case Resurfacing Costs;
- Highway Capacity;
- Peak Period Factor;
- Value of Life;
- Value of Injury;
- Value of Property Damage Only Accident;
- Value of Time;
- Maximum Pavement Effect on Accident Rates;
- Maximum Pavement Effect on Speed;
- Disruption Effect on Accident Rates;
- Fuel Price;
- Tire Price;
- Maintenance and Repair Costs;
- Depreciation Costs;
- Discount Rate; and
- Period of Analysis.

Values for these variables have been provided and are presented in the Technical Appendix of this manual.

PSI Before and After Resurfacing

Pavement preservation policy data, available from the ADOT Materials Group, is used to develop the pavement condition profile over the analysis period, as well as allocate resurfacing costs in each relevant year.

The variable ***PSI After Resurfacing*** is used in conjunction with the variables ***PSI Before Resurfacing*** and ***Expected Pavement Life*** to generate the pavement condition for each year. The pavement condition deteriorates at a constant rate (linearly) until it reaches the PSI level before resurfacing, at which time it is assumed that resurfacing occurs. After resurfacing, PSI is set to the value indicated for PSI after resurfacing and the cycle repeats.

The level at which resurfacing occurs is specific to the pavement preservation policy in place. A target PSI of 4.0 to 4.5 is normally expected after resurfacing.

Expected Base Case Pavement Life

This variable represents the time it takes the pavement to deteriorate from the PSI level after resurfacing to the PSI level at which resurfacing takes place.

This variable is dependent on the type of pavement and the PSI level at which resurfacing occurs and therefore has no typical value.

Base Case Resurfacing Costs

The cost of resurfacing represents the cost, in dollars per kilometer, incurred each time the roadway is resurfaced.

This value is dependent on many things, including the type of resurfacing required, the degree of improvement expected and the thickness of the surface. These are all dependent on the pavement preservation policy and therefore there is no typical value.

Highway Capacity

Highway capacity is defined in the Highway Capacity Manual,[16] as "the maximum rate of flow at which persons or vehicles can be reasonably expected to traverse a point or segment of a lane or roadway during a specified time period...usually expressed as vehicles per hour or persons per hour." The value recommended in the manual for use in planning decisions 2000 vehicles per hour. This value is not likely to change and should remain constant for all product evaluations.

This variable effects the vehicle to capacity ratio, which is the main driver behind speed/flow and vehicle operating costs.

Peak Period Factor

The peak period factor is defined in the Highway Capacity Manual,[17] as "the hourly volume during the maximum volume hour of the day divided by the peak 15-minute rate of flow within the peak hour." This value was calculated by Hickling for prior work done for ADOT on the Phoenix freeway system. This value is not likely to change and should remain constant for all product evaluations.

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[16] Ibid, The Highway Capacity Manual.

[17] Ibid, The Highway Capacity Manual.

Value of Life, Injury, and Property Damage Only Accident

Safety-related costs include the statistical value of human life, as well as, the value of non-fatal accidents and property damage. The costs of the three types of accidents were calculated from The Cost of Highway Crashes prepared for the Federal Highway Administration.[18] Accident rates are calculated separately for three events: "property damage-only" accidents; injuries (as opposed to injury-producing accidents); and fatalities. Accidents costs are applied to the corresponding incident rate to derive Net Safety Costs.

The incident rate cost formulae are derived using a regression of accident rate data based on a logistic curve. The accident rate data comes from HERS.[19] The formula is in the following form:

$$Rate_i = A_i + B_i\left(\frac{1}{\exp^{(\alpha_i+\beta_i*AADT)}}\right)$$

Where:

A	=	maximum (or minimum) value. If B is negative, A is a maximum, otherwise A is the minimum.
B	=	difference between maximum and minimum value.
α&ß	=	coefficients that determine the shape of the logistic curve.
i	=	the three accident incident types: property damage only (PDO), injuries and fatalities.

The values for A, B, α, and ß vary according to the facility type.

Average Value of Time

The speed/flow formulae are used to calculate an average speed given the facility type and the volume of traffic. The formulae represent two distinct curve sections, which is in line with the way in which speed/flow is currently viewed and is consistent with the AASHTO Redbook (1977).[20] The first section is relatively flat, with a linear slope. This region represents conditions which are relatively free of congestion. The second section is dominated by congestion and speed drops off rapidly as a result of increased volume, until

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[18] Ibid, The Cost of Highway Crashes. Note: the "statistical value of life" currently used in PEM is for demonstrating the validity of the model only. Other values may substituted according to ADOT policy.

[19] Ibid, The Highway Economic Requirements System.

[20] Ibid, AASHTO Manual on User Benefit Analysis.

the speed reaches a minimum speed (crawl speed). The data used to derive these coefficients comes from HERS[21] and the Texas Transportation Institute.[22]

During low volume periods speed is defined as a function of the volume/capacity ration as follows:

$$Speed = Free\,Flow\,Speed - B * v/c$$

Where:

Free Flow Speed	=	The theoretical maximum speed that can be attained on the roadway.
Slope	=	The effect of traffic on speed during low volume periods. This value is expressed as the change in speed proportional to the increase in the volume to capacity ratio.

During periods of high volume the speed is defined as:

$$Speed = \alpha + \beta * v/c^{Power}$$

Where:

α	=	The speed at the transition from low volume to high volume.
ß	=	The effect of traffic on speed during low volume periods. This value is expressed as the change in speed proportional to the increase in the volume to capacity ratio (raised to the power).
Power	=	The power of the effect of the volume to capacity ratio on speed.

The values for free flow speed, B, α, ß, power and the transition point vary according to facility type.

Effects on Accident Rates, Speed, and Vehicle Operating Costs

These percentage effects, are used to scale the three major cost estimating models, speed, safety, and vehicle operating costs. For instance, the pavement condition of the road is used in conjunction with the variable ***Maximum Pavement Effect on Accident Rates*** to scale accident rates according to the condition of the road.

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[21] Ibid, The Highway Economic Requirements System.

[22] Ibid, Technical Memorandum to NCHRP Project 7-12.

The formulas and values utilized in the model were derived from HERS[23] the Texas Transportation Institute,[24] and Designing Safer Roads, TRB Special Report 214.

The following is a complete list of all the percentage effects utilized by PEM:

- Maximum Pavement Effect on Accident Rates;
- Maximum Pavement Effect on Speed;
- Disruption Effect on Accident Rates;

Values for these variables were have been provided and can be found in the Technical Appendix.

Price of Fuel, Tires, Maintenance and Repair Costs, and Depreciation Costs

Table 3.1 lists the vehicle operating cost components and the factors which influence those costs. The actual formulae are complex empirical relationships and are not specified here but are based on work completed by Hickling for NCHRP Project 7-12. Information on these costs can be found in HERS[25] the Texas Transportation Institute's Technical Memorandum.[26] The five user cost components are:

- Fuel Consumption - measured in liters;
- Tire Wear - measured in % of a tire;
- Oil Consumption - measured in liters of oil;
- Maintenance and Repair - measured in % average cost/1000 kilometers; and
- Depreciation - measured in % of average depreciable value.

[23] Ibid, The Highway Economic Requirements System.

[24] Ibid, Technical Memorandum to NCHRP Project 7-12.

[25] Ibid, The Highway Economic Requirements System.

[26] Ibid, Technical Memorandum to NCHRP Project 7-12.

Table 3.1 - Matrix of Factors for Vehicle Operating Costs

Cost Factor	Vehicle Operating Cost Component				
	Fuel	Tire	Oil	M&R	Depr.
Uniform Speed Costs					
Speed	•	•	•	•	•
Speed Cycling Costs					
Speed	•	•	•	•	•
Cycling Range[27]	•	•	•	•	•
Cycling Rate[28]	•	•	•	•	•
Pavement Condition[29]	•	•	•	•	•

27 The speed cycling range is fixed as 5 MPH above and below the average speed. This is consistent with traditional cost methodologies.

28 The cycling rate is calculated based on the volume to capacity ratio for the roadway.

29 The pavement condition effect is applied as a single factor to the final operating cost value. This is consistent with data generated using the MicroBENCOST relationships and is also supported by the HERS relationships.

Discount Rate

This value represents the rate at which future benefits and costs are discounted into current values. This is necessary to accurately reflect consumers' preference for present over future benefits and for the fact that forecasts are inherently uncertain. This rate is very powerful and should remain constant throughout the course of an evaluation.

The AASHTO Redbook (1977),[30] as well as Texas Transportation Institute's Technical Memorandum[31]contain recommendations of discount rates for use in highway planning. Hickling recommends a rate of 5% which is consistent with both studies. ADOT is capable of changing this rate in the model but should be forewarned that using a rate that is too low will raise the present value of benefits and result in economically undesirable products being selected. Conversely, a discount rate that is too high will tend to favor projects that have a shorter payback period.

Period of Analysis

The period of analysis refers to the number of years over which annual costs will be calculated and discounted to the present. This is a ADOT specific value. The maximum number of years for which an analysis can be conducted is 50. The recommended number of years is 25. This variable must be specified beforehand and should remain constant when analyzing similar products.

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30 Ibid, AASHTO Manual on Estimating User Benefits.

31 Ibid, Technical Memorandum to NCHRP Project 7-12.

Common Product Attributes

Common product attributes are distinguished from specific product attributes simply by the fact that common product attributes apply to all products, while specific attributes may or may not apply to a product. While it is not necessary to input a value for each variable, the level of detail and confidence of the analysis will be reduced proportionately. It will be indicated, for each variable, how the variable effects the model and how it's omission would reduce potential costs and benefits.

Common product attributes contained in PEM include:

- Average Number of Material Units per Product;
- Material Unit Cost;
- Current Products in Use;
- Annual Increase in Products;
- Percent of Products Vandalized/Knocked Down per Year;
- Useful Economic Life of the Product;
- Maximum Useful Economic Life of the Product;
- Percent of Products Held as Inventory;
- Products at First Year of Steady State;
- Years to Steady State;
- Steady State Product Growth;
- Start-up Training and Equipment Costs;
- Annual Training and Equipment Costs;
- Testing And Evaluation Costs;
- Inventory and Carrying Costs;
- Disposal And Salvage Costs;
- Number of Claims per 100 Failures;
- Percent of Claims Settled;
- Percent of Claims Dropped;
- Average Settlement and Court Costs;
- ADOT Fabrication Labor Wage;
- Fabrication Labor Productivity;
- Hourly Fabrication Equipment Costs;
- Other Material Cost;
- Overhead Rate;
- Scrap Rate;
- ADOT Maintenance Labor Wage;
- Maintenance Labor Productivity;
- Hourly Maintenance Equipment Costs;
- Expected Disruption Delay;
- Percent of AADT Affected by Disruption; and
- Failure Rate Path.

Average Material Units per Product

The value for this variable refers to the average number of material units that are utilized to make one product. For example, 16 square feet of sign sheeting is used to make one roadway sign or .5 cubic meters of patching material is used for one patch. It may be the case that each material unit is used directly. For example, one guardrail reflector is the material unit and the product. In this case the ratio is 1 to 1. The model requires data for both the base case and the new product case. Without values for this variable, annual capital expenditures cannot be calculated.

Material Unit Cost

Material unit cost is the dollar cost of the material used to make the product or used directly in an application. For instance, in the case of sign sheeting, the product is the sign and the material is the sign sheeting. The material comes in square feet and through the use of the previous variable, ***Average Material Units per Product***, this material is turned into the product. The material unit cost must be in dollars per the unit base (square feet, cubic yards, etc...) used in the previous variable. The model requires cost data for both the base case and the new product case. Without values for this variable, annual capital expenditures cannot be calculated.

Current Products in Use

This value represents the current products in use. It is the starting point for determining product growth in the base case and the phase-out period in the new product case. This variable affects yearly product expenditures. Data for this variable is only required for the base case, as there is no current stock of a new product. This variable impacts annual capital expenditures.

It may not always be possible to determine this value. A convenient alternative is to determine the number of products in use over a 1 kilometer stretch of rural/urban road. For example, NCHRP Report 346, Implementation Strategies for Sign Retroreflectivity Standards uses a figure of 18 regulatory signs per mile of rural road. To utilize this figure in the analysis, the variable ***Roadway Length*** would become 1 mile. The final net benefits would be in dollars per mile. These values can also be easily converted to metric simply by multiplying then by 0.6214.

Annual Increase in Products

This variable is utilized to develop the annual product stock for the base case. The value for this variable must be entered in products per year and could be 0 or even negative. This variable impacts annual capital expenditures.

Percent of Products Vandalized/Knocked Down per Year

This value refers to the percent of products in use that need to be replaced due to vandalism or are destroyed by accidents during a given year. These products that need to be replaced fall outside the normal product life-cycle and are not accounted for by the product failure rate, which is a function of the useful life of the product. This variable is not essential for calculating annual product demand and expenditures, but it can add an additional level of detail to the analysis if utilized.

Useful Economic Life of Product

The useful economic life of the product is defined as the time at which 50% of the products installed at the same point in time have failed or ceased to perform their desired function. The model requires data for both the base case and the new product case. Both values for this variable must be entered in years. This variable is essential for calculating the product failure rate which impacts annual capital expenditures.

Maximum Economic Life of Product

The maximum useful economic life of the product is defined as the time at which 99% of the products installed at the same point in time have failed, or ceased to perform their desired function. The model requires data for both the base case and the new product case. Both values for this variable must be entered in years. This variable is essential for calculating the product failure rate which impacts annual capital expenditures.

Percent of Products Held as Inventory

This percentage reflects the percent of products in use held as inventory during a given year. It may be that no inventory of the product is maintained, in which case, the percentage would be zero. This percentage, along with the other product stock variables, are used to determine the desired level of product stock for a given year. The model requires data for both the base case and the new product case. This variable impacts annual capital expenditures.

Products at First Year of Steady State

Steady state is defined as the point at which the product stock tends to remain steady or relatively constant. In the event a new product is approved for use by ADOT, existing old products are not immediately replaced, instead they are phased-out as the new product is phased-in. This phase-in and phase-out period characterizes the new product case, the scenario against which the base case is compared. Conversely, the base case is characterized by no phase-in or phase-out period. This variable, along with the variable ***Years to Steady State***, characterizes this phase-in and phase-out period. The model requires data inputs for both the old product and the new product during this period. This variable impacts annual capital expenditures and is essential for its proper calculation.

Years to Steady State

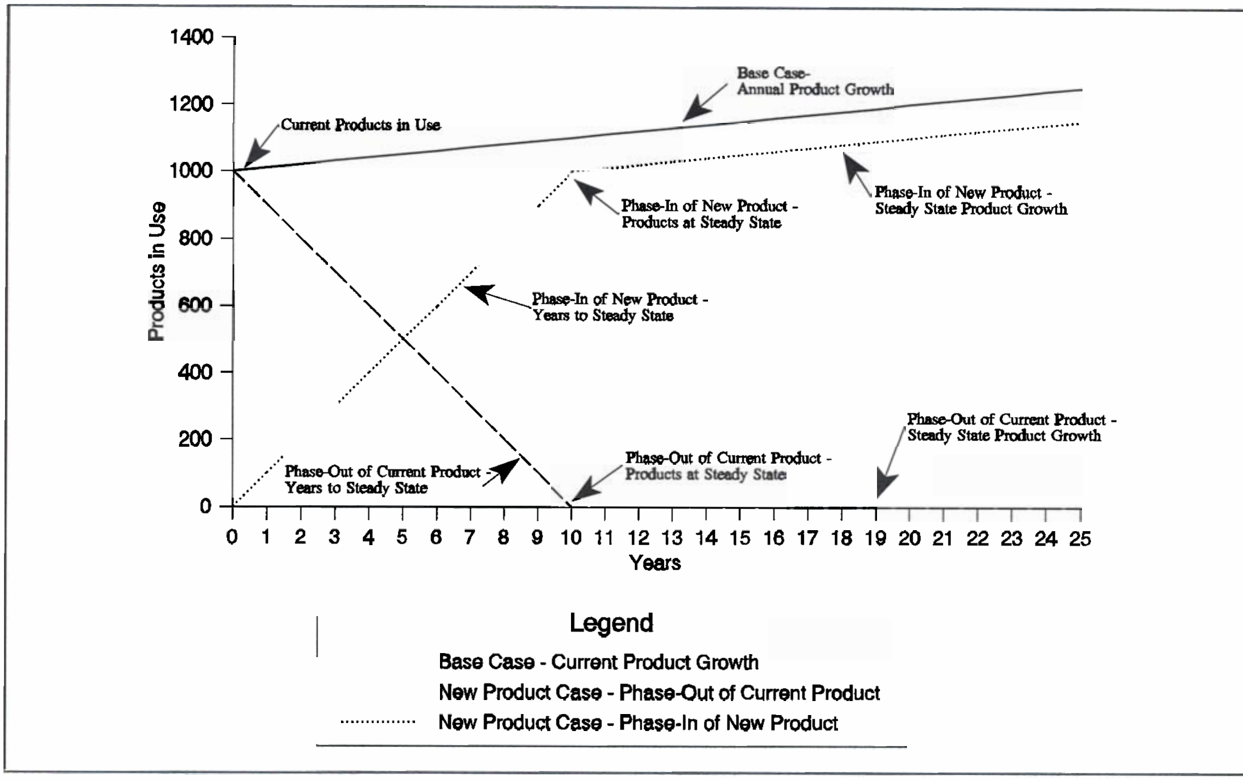
This variable represents the time period in years over which the old product is phased-out and the new product phased-in. There is no unique value for this variable, instead it will depend upon the product in question and current and past ADOT usage of the product. The model requires data inputs for the behavior of both the old product and the new product during this period. This variable impacts annual capital expenditures and is essential for its proper calculation.

Steady State Product Growth

Once steady state is reached, it capital stock may continue to grow marginally or contract each year. This variable captures the change the capital stock may undergo over time, which may be zero or negative. The model requires data inputs for both the base case (which may be 0) and the new product case. This variable impacts annual capital expenditures.

Figure 3.4 describes the relationship between ***Current Products in Use, Annual Increase in Products, Products at first Year of Steady State, Years to Steady State, Steady State Product Growth,*** and how they are utilized to describe the base case and new product case.

Figure 3.4 Base Case and New Product Demand over a 25 Year Analysis Period



Start-Up Equipment and Training Costs

These variables indicate the costs, in dollars per year, associated with implementing a new product. Start-up equipment costs includes any special machinery or equipment which is required to maintain and install a new product. This variable ***does not*** include the use of standard ADOT equipment services that are included in unit maintenance costs. It refers specifically to those products that require a special instrument or handling procedure that necessitates the use of special equipment that ADOT does not currently own or operate. This category also includes any compliance or compatibility expenses that are involved with the new product. Current products do not have additional special equipment needs. This variable is only required for the new product case.

Additional training costs, in dollars per year, are those expenses associated with the instruction of ADOT personnel to install, use and maintain a new product. These costs are typically a one-time, up front expense that varies according to the complexity of the product and the number of ADOT personnel that will ultimately use the product. There are no additional training costs associated with the base case.

Both these variables, while not essential to the calculation of annual capital expenditures, can add a significant detail to the costs involved with phasing-in a new product.

Annual Training and Equipment Costs

Annual training and equipment costs, in dollars per year, specifically refers to those costs which are likely to be incurred each year due to the adoption of a new product. These are expenses that are incurred each year after the first year and do not reflect start-up costs which are accrued in the first year of implementation. There are no additional annual training and equipment costs associated with the base case. This variable is not essential to the calculation of annual capital expenditures, but can add a significant level of detail to the costs involved with phasing-in a new product.

Testing and Evaluation Costs

Testing and evaluation costs, in dollars, reflect those expenses incurred by ADOT to test, inspect, and evaluate a new product. It is assumed that these costs are accrued in the first year of a product's implementation. The testing and evaluation costs associated with existing products are not included in the model, as such, this cost is accounted for only in the new product case. This variable is not essential to the calculation of annual capital expenditures, but can add a significant level of detail to the costs involved with phasing-in a new product.

Inventory and Carrying Costs

Annual inventory costs measure the cost of maintaining a product in warehouse inventory. The cost is input in dollars per product per year. The model requires data inputs for both the base case and the new product case. This variable is not essential to the calculation of annual capital expenditures, but can add a significant level of detail to the analysis.

Disposal and Salvage Costs

This variable concerns the salvage and disposal costs, in dollars per product, that occur when a product is replaced. The model requires data inputs for both the base case and the new product case. This variable is not essential to the calculation of annual capital expenditures but can add a significant level of detail to the analysis.

Number of Claims per 100 Failures

This variable relates the number of product failures that result in legal action/claims, against ADOT. This value is dependent upon the product itself and prior experience at ADOT or other transportation departments. The model requires estimates for both the base case and the new product case. This variable is essential for calculating annual liability costs.

Percent of Claims Settled

The majority of claims against ADOT do not result in court cases. Those that do not are either settled or dropped. This percent represents the percent of claims that are settled. The model requires percentages for both the base case and the new product case. This variable is essential for calculating annual liability costs.

Percent of Claims Dropped/Not Pursued

Those claims which are dropped incur no cost to ADOT. This percent along with the ***Percent of Claims Settled*** jointly determine the number of claims going to court. The model requires percentages for both the base case and the new product case. This variable is essential for calculating annual liability costs.

Average Settlement and Court Costs

These variables relate the average court or settlement costs, in dollars per claim, associated with a claim against ADOT. While relatively few claims actually result in court cases, there are significant costs associated with processing claims, legal fees and adverse settlements. Average court costs depend upon the legal exposure characteristics of the product itself. This cost is one component of total liability costs. The model requires data inputs for both the base case and the new product case.

Average settlement costs characterizes the costs associated with a settled claim. It includes costs associated with processing the claim and paying the settlement. This cost is the second component of total liability costs. The model requires costs for both the base case and the new product case.

ADOT Fabrication Labor Wage

The hourly labor wage, input as dollars per hour, is used to calculate product fabrication costs, as well as, any fabrication productivity savings that may arise from the use of a new product.

Fabrication Labor Productivity

This variable concerns the productivity of ADOT fabrication workers with regards to the base case and the new product case. Productivity must be entered as products per hour per person or fractional products per hour per person, if the product requires more than one person to fabricate. This variable is essential for correctly calculating labor fabrication productivity and fabrication costs.

Time until Fabrication Productivity Achieves 50 Percent of Expected Level

Productivity in the new product case may not be instantaneously achieved due to learning curve effects. For this reason, it is reasonable to assume that productivity will increase over time until the expected productivity level is reached. This variable characterizes the time it takes productivity to achieve 50 percent of its expected level. This value may be zero if there are no learning curve effects.

Change in Time until Fabrication Productivity Achieves 95 percent of Expected Level

This variable refers to the time, in years, it will take to have productivity increase from 50 percent of its expected level to 95 percent. This variable is also input in years, or in fractional years, as the case may be. This value may be zero if there are no learning curve effects.

Hourly Fabrication Equipment Costs

Hourly fabrication equipment costs refer to the expenses incurred to ADOT in using equipment or machinery for the fabrication of the product, for example building a new sign. This value, in conjunction with user-defined fabrication productivity and fabrication labor wage values, provides a fabrication expense estimate for each product. The model requires hourly fabrication equipment estimates for both the base case and new product case. This variable is essential for correctly calculating annual product fabrication costs.

Other Material Costs

This value refers to any additional materials that are necessary for the fabrication of one product. Data for this variable must be entered as dollars per product. This variable is not essential for the proper calculation of fabrication costs, but it can add a significant level of detail to the analysis.

Overhead Rate

This rate, in dollars per product, refers to the overhead costs involved with many fabrication processes. The user must be careful to differentiate equipment costs and overhead costs, to avoid double counting. This variable is not essential for the proper calculation of fabrication costs and may be zero.

Scrap Rate

The rate entered as a percent of waste per product, refers to the unavoidable waste that occurs during many fabrication process. This variable is not essential for the proper calculation of fabrication costs and may be zero.

ADOT Maintenance Labor Wage

The hourly labor wage, input as dollars per hour, is used to calculate product maintenance costs, as well as, any maintenance productivity savings that may arise from the use of a new product.

Maintenance Labor Productivity

This variable concerns the productivity of ADOT laborers with regards to the base case and the new product case. Productivity must be entered as products per hour per person or fractional products per hour per person, if the product requires more than one person to maintain. This variable is essential for correctly calculating labor productivity and maintenance costs.

Time until Labor Productivity Achieves 50 Percent of Expected Level

Labor productivity in the new product case may not be instantaneously achieved due to learning curve effects. For this reason, it is reasonable to assume that productivity will increase over time until the expected productivity level is reached. This variable characterizes the time it takes productivity to achieve 50 percent of its expected level. This value may be zero if there are no learning curve effects.

Change in Time until Labor Productivity Achieves 95 percent of Expected Level

This variable refers to the time, in years, it will take to have productivity increase from 50 percent of its expected level to 95 percent. This variable is also input in years, or in fractional years, as the case may be. This value may be zero if there are no learning curve effects.

Hourly Maintenance Equipment Costs

Hourly equipment costs refer to the expenses incurred to ADOT in using equipment or machinery for the routine maintenance and upkeep of a product. This figure, in conjunction with user-defined ADOT productivity and labor wage values provides a maintenance expense estimate for each product. The model requires hourly equipment estimates for both the base case and new product case. This variable is essential for correctly calculating annual product maintenance costs.

Expected Disruption Delay

Disruptions in highway users' travel times are likely to occur when ADOT or ADOT contractors maintain or install products. The expected disruption time in minutes per vehicle is used in conjunction with the ***Percent of AADT Affected*** to calculate disruption hours and total disruption costs. The model requires minute delay estimates for both the base case and new product case. This variable is essential for calculating annual disruption costs.

Percent of AADT Effected by Disruption

This percent refers to the percent of cars annually effected by the maintenance activities associated with a particular product. For example if 10,000 vehicles a day are affected by the disruption and the disruption occurs 10 times a year, a total of 100,000 vehicles a year are effected. If AADT on the road is 100,000, then 365,250,00 vehicles a year (AADT * 365.25) travel on that particular facility. The percent of AADT effected is 0.003 (Total AADT/Vehicles Effected). This variable is essential for calculating annual disruption costs.

Failure Rate Path

The user has four different types of failure rate paths to choose from. The four choices are: a linear failure rate path; a logistic failure rate path; an exponential failure rate path; and an option to specify that replacement of a product only takes place when the maximum useful product life has been reached. These four options correspond to option numbers 1 through 4. The failure rate path impacts annual capital expenditures and at least one selection must be chosen.

Specific Product Attributes

Specific product attributes only apply to certain products. A user must correctly determine if the product under analysis effects any of these attributes. While it is not necessary to input values for each of these attributes, they can bring a important level of detail to the analysis.

The specific product attributes contained in PEM include:

- Annual Personnel Costs of Effected Employees;
- Percent Administrative Improvement Realized;
- PSI of Pavement with New Product;
- Expected Pavement Life with New Product;
- Resurfacing Costs with New Product;
- Percent Reduction in Property Damage Only Accidents with New Product;
- Percent Reduction in Injury Accidents with New Product;
- Percent Reduction in Fatal Accidents with New Product; and
- Percent Improvement in Speed/Flow with New Product.

Annual Personnel Costs of Effected Employees

A new product may potentially impact administrative efficiency at ADOT. The value for this variable is used in conjunction with ***Percent Administrative Improvement Realized*** to calculate the administrative savings due to a new product. It is important to note that this dollar value represents the yearly dollar costs of all the employees effected by any administrative efficiency improvement.

Percent Administrative Improvement Realized

This percent refers to the administrative efficiency gain that may be realized with a new product. It is important to note that this gain must be realized. This refers to the fact that actual savings must be realized. A task that may have required the hiring of a new employee that now can be done without the additional personnel cost is a realized savings. A task that may have required two administrators, which now requires one, is not a realized savings unless that one administrator is released. This variable impacts productivity savings and is essential to calculate administrative productivity savings.

Time until Administrative Efficiency Reaches 50 Percent of Expected Level

Administrative productivity may not instantaneously improve due to learning curve effects. For this reason it is reasonable to assume that efficiency will improve over time until the expected efficiency level is reached. This variable characterizes the time it takes to reach 50 percent of the expected efficiency improvement. This value may be zero if there are no learning curve effects.

Time until Administrative Efficiency Reaches 95 percent of Expected Level

This variable refers to the time, in years, it will take for administrative efficiency to increase from 50 percent of its expected level to 95 percent. This variable is also input in years, or in fractional years, as the case may be. This value may be zero if there are no learning curve effects.

PSI of Pavement with New Product

A new product may improve the pavement condition of a roadway. This variable will capture that change. Such a change will result in pavement maintenance savings to ADOT and savings to highway users in the areas of vehicle operating costs and time savings.

Expected Pavement Life with New Product

A new product may also prolong the life of a particular road. This type of change will reduce repaving expenses incurred by ADOT over the analysis period and create highway user cost savings in the areas of vehicle operating costs and time savings.

Resurfacing Costs with New Product

Any product that reduces resurfacing costs associated with a kilometer of roadway will be captured here. This type of change will reduce paving expenses incurred by ADOT over the analysis period.

Percent Reduction in PDO, Injury and Fatal Accidents with New Product

Any new product may reduce accidents, resulting in considerable highway user savings. A product may reduce accidents in all three accident categories or it may reduce one type of accident but increase accidents in another category. For example, more reflective sheeting would reduce all types of accidents. This percentage will impact safety costs.

Supporting data for this variable may not be readily available. Vendor sheets and expert opinions may be required to reach a consensus on what the proper value of this variable should be, if any.

Percent Improvement in Speed/Flow with New Product

Any new product may improve speed/flow, resulting in considerable time and vehicle operating cost savings. The improvement in speed/flow must be from an improvement other than from an improvement in pavement condition. A change in pavement condition can also effect speed/flow, therefore, the user must be careful avoid double counting.

Supporting data for this variable may not be readily available. Vendor sheets and expert opinions may need to be required to reach a consensus on what the proper value of this variable should be, if any.

LOADING THE RISK ANALYSIS SIMULATION SOFTWARE

1) **System Requirements**

In order to load the simulation software a minimum of 560 K of conventional memory is necessary, as well as a math co-processor. It is recommended that the computer have a 486 processor. The software can run on a computer with a 386 processor, but simulations are computed much more slowly.

2) **Loading the Simulation Software**

Once a scenario has been created with the interface software, a Monte Carlo simulation can be run with the risk analysis software. To do so requires going to the correct subdirectory on the computer hard-drive and typing **RAP** followed by hitting ***Enter***.

3) **Selecting the Model and Scenario**

The screen that appears in Figure 3.5 will appear after the software is loaded. Select **Read** from the menu. This can be accomplished by either moving the cursor with the direction arrow keys to the correct menu selection and hitting ***Enter*** or by typing the first letter of the menu item, ***R*** in this case. The screen pictured in Figure 3.6 will appear. Choose the only available model by pressing 1 then ***Enter***. The screen in Figure 3.7 will appear. Select **Read** from this menu. The screen in Figure 3.8 will appear. Choose the correct scenario by typing the correct number, followed by ***Enter***.

4) **Navigating the Main Menu**

You are now at the main menu (see Figure 3.9). From this menu, you can: **Edit** data, view **Input** ranges, run a simulation (**Go**), **View** results tables, display **Results** graphs, return to the **Main** model selection menu, or **Exit**.

Figure 3.5 Initial Simulation Software Screen

```
Risk Analysis Process                          Mon Jul 18 17:43:09 1994
(c) 1994 Hickling Corporation
---------------------------------------------------------------------------
Read  Define  Batch
Read a currently defined model


Do you wish to define a new model or read it in from disk
```

Figure 3.6 Selecting the Simulation Model

```
Risk Analysis Process                              Mon Jul 18 17:46:17 1994
(c) 1994 Hickling Corporation
-----------------------------------------------------------------------------
Model Number  | Model
              |
       1      |  ATRC New Product Risk Analysis
              |
-----------------------------------------------------------------------------
Please enter the number of the model that you wish to run.
Model number
```

Figure 3.7 Reading in a Scenario File

```
Risk Analysis Process                          Mon Jul 18 17:47:12 1994
(c) 1994 Hickling Corporation

Read  Define
Read in an already existing scenario

Do you wish to define a new scenario or read in an existing one
```

Figure 3.8 Selecting the Scenario File

```
Risk Analysis Process                                  Mon Jul 18 17:48:29 1994
(c) 1994 Hickling Corporation
--------------------------------------------------------------------------------
 Scen Number  |  Scenario
              |
      1       |   Set 45
      2       |   Durapatch
      3       |   Type III
      4       |   Percol Flex
      5       |   Calroc 1060
              |
--------------------------------------------------------------------------------
Please enter the number of the scenario you wish to use

Scenario number
```

Figure 3.9 Simulation Software Main Menu

```
Risk Analysis Process                         Mon Jul 18 17:50:50 1994
(c) 1994 Hickling Corporation
------------------------------------------------------------------------
Edit  Go  Input  Results  View  Write  Main  Quit
Edit the Current Scenario Parameters


  Current Model  : ATRC New Product Risk Analysis
Current Scenario : Set 43
```

MODIFYING INPUT RANGES

1) Selecting the Data to Edit

Select **Edit** from the main menu, as pictured in Figure 3.9. The next screen as pictured in Figure 3.10, displays the three categories of data which can be modified. These choices are **Scalar**, **Multi-Year**, and **Conditional**.

Scalar inputs are used in the model, therefore any changes must be made in this category. Conditional variables refer to correlation coefficients. Only two variables have correlation coefficients, ***Useful Economic Life of the Product*** and the ***Maximum Economic Life of the Product***. The correlation coefficient attached to each variable is 1.00. These coefficients should not be changed or modified. No multi-year variables were used in this model.

2) Editing Data

Select **Scalar** from the menu, as pictured in Figure 3.9. Go to the line(s) that you wish to modify using the directional arrow keys to move between lines and the ***Page Up*** and ***Page Down*** keys to move between data pages. If the desired input line is not on the screen, press page down (or page up) to locate the item, see Figure 3.11.

3) Changing Values

Modify the existing values by typing directly into the cell that contains the current value. This will overwrite the existing data. Press ***Enter*** after each cell is properly modified.

4) Exiting and Saving

When all the desired inputs have been modified, press ***CTRL + END*** (***CTRL*** and ***END*** keys simultaneously) to return to the editing menu. Select **Quit** and **Yes** to save the modifications and return to the main menu.

Figure 3.10 ´ Modifying Data Inputs Menu

```
Risk Analysis Process                         Mon Jul 18 17:51:50 1994
(c) 1994 Hickling Corporation
------------------------------------------------------------------------
Scalar  Multi-Year  Conditional  Random  Quit
Edit scalar parameters
```

Figure 3.11 - Modifying Data Inputs

Risk Analysis Process — Mon Jul 18 17:52:46 1994
(c) 1994 Hickling Corporation

Edit the scalar parameter values	Const or Median	St Dev or Lower 10%	Upper 10%	Mean
Facility Type - Base Case(C)	2.000			2.00
Facility Type - New Prod(C)	2.000			2.00
Number of Lanes - Base Case(C)	6.000			6.00
Number of Lanes - New Prod(C)	6.000			6.00
Design Speed - Base Case(C)	70.000			70.00
Design Speed - New Prod(C)	70.000			70.00
Roadway Length(C)	100.000			100.00
AADT in Year 0(C)	112000.00			112000.0
AADT - Annual Increment(C)	100.000			100.00
Current PSI - Base Case(C)	4.000			4.00
PSI before Resurfacing(C)	1.500			1.50
PSI after Resurfacing(C)	4.500			4.50
Exp. Pav. Life - Base Case(C)	10.000			10.00
Resurfacing Costs - Base Case(C)	10000.000			10000.00
Highway Capacity(C)	2000.000			2000.00

Use ^End when done, PgUp and PgDn to move between pages.
F1 Cum. Graph, F2 Prob. Den. Graph, F3 Cum. Table, F4 Decum. Table

RUNNING A SIMULATION

Running a Monte Carlo Simulation

Select **Go** from the main menu (Figure 3.9).

Type in the number of trials to perform. The number of trials is the number of times that the model samples each of the input ranges. The more trials that are run, the more accurately the results will reflect the "true" statistical outcome of the model. The minimum number of trials that can be run is 1 and the maximum is 2000. Running 500 trials will generally produce highly accurate results.

Select the number of bins. The number of bins selected determines the statistical precision of the output range. The minimum number of bins that can be chosen is 1 and the maximum is 50. Typically, 30 bins are used.

Confirm the output file names by pressing ***Enter*** twice. The output file names should not be changed from the model defaults. The model defaults will be the same file name as indicated by the user when the scenario was created. The software will run the simulation for the selected number of trials and return to the main menu.

VIEWING THE RESULTS: TEXT FILE

Viewing the Results

Select **View** from the main menu.

The results data from the most recent simulation of the current scenario will appear on the screen. This screen contains detailed information on each result which will be several pages long. Press the ***Space Bar*** to move through the pages. Information provided for each result in this screen includes:

- mean value, probability density, cumulative and de-cumulative probability values for each bin;
- expected value;
- upper and lower 10% probability values; and
- the de-cumulative probability table.

VIEWING THE RESULTS: STATISTICAL GRAPHS

1) Viewing Result Graphs

Select **Results** from the main menu.

2) Confirming the Output Filename

Press ***Enter*** once to confirm the output file name. The output file name should not be modified. The file name will be the same file name as indicated by the user when the scenario was created with the software interface, followed by the extension ".dat".

3) Selecting the Output Destination

Select **Screen** to view the statistical graphs on your monitor. Graphs can be printed on an HP compatible printer. The printing feature is covered Section 3.9.

4) Selecting the Type of Graph to View

Select one of the three available types of graphs: **Probability Density, De-Cumulative Probability**, and **Cumulative Probability**.

5) Selecting the Output to View

Type the number of the output you wish to see and press ***Enter***. If the result is not on the screen, press ***Page Down*** to see more available results.

6) Viewing other Graphs

Repeat steps 4) and 5) as desired.

7) Quitting

Selecting **Quit** will return you to the main menu.

PRINTING THE RESULTS: STATISTICAL GRAPHS

1) Printing Result Graphs

Select **Results** from the main menu.

2) Confirming the Output Filename

Press ***Enter*** once to confirm the output file name. The output file name should not be modified. The file name will be the same file name as indicated by the user when the scenario was created with the software interface, followed by the extension ".dat".

3) Selecting the Output Destination

Select **Printer** to print the statistical graphs on your printer. Graphs can be printed on an HP compatible printer.

4) Selecting the Type of Graph to Print

Select one of the three available types of graphs: **Probability Density, De-Cumulative Probability**, and **Cumulative Probability**.

5) Selecting the Output to Print

Type the number of the output you wish to print and press ***Enter***.

6) Confirming the Graph Titles

Confirm the titles and labels supplied by the software for the graph by pressing ***Enter*** four times. Modify the tiles and/or labels by typing directly over the existing text. When done press ***Enter*** four times.

7) Entering the Graph Filename

Enter the name of the file to which the graph data is to be printed (create your own unique file name).

8) Printing other Graphs

Repeat steps 4), 5), 6), and 7) as desired.

9) Printing the Graph Files

At the DOS prompt type **SET SPLINE=YES** then press ***Enter***, next type **SET PRINTER=HP** followed by pressing ***Enter***. Then type **GRAPH <Graph Filename>** followed by pressing ***Enter***. This will send the graph to the printer.

10) Quitting

Select **Quit** will return you to the main menu, then selecting **Quit** again gives you the option to quit to DOS, do so.

4.0 PEM TUTORIAL

INTRODUCTION

In this tutorial, PEM is applied to ADOT project EP-8606 to determine the relative economic benefits of six types of concrete patching materials. The main sources of data are discussed and a summary table of the data entered is presented. The PEM output is then presented in tables and graphical form. An analysis and interpretation of the results is then presented at the end of the tutorial.

DATA SOURCES

The data sources and assumptions used for the analysis are summarized in this section. Sources for the analysis range from ADOT personnel to the Strategic Highway Research Program (SHRP). An effort was made to use the most reliable information possible. In cases where data was unavailable, reasonable assumptions were made based on ADOT anecdotal experience and Hickling's research programs.

Printed Reports

Two main printed reports were used to supply data for the PEM analysis. A brief explanation of the two sources are presented below:

Draft Version of Project EP 8606

This draft contained essential project information that was used primarily to develop the roadway characteristics. For instance, the ***facility type***, "6 or more lanes, full access control urban," was determined from the Project Design section of the draft report. Product cost data, converted into costs per square foot, was also used. The project's one-year follow-up investigation also contained information on product performance that was incorporated in the analysis.

SHRP's Innovative Materials Development and Testing: Volume 5; Partial Depth Spall Repair

The recent report contained specific information on the procedures and materials currently used for spall repair. This report complemented ADOT report EP-8606 since it contained information on labor and equipment needs, productivity, and crew size for each product. Similar information from project EP-8606 was difficult to extract because the same crew worked on all product installations.

ADOT Sources

Interviews with several ADOT personnel provided anecdotal and factual information which helped to frame the analysis. The various divisions of ADOT that supplied the information are listed below:

ADOT Materials Group

The ADOT Materials Group has first-hand information on many of the concrete patching materials used in the field. Estimates on the installation and disruption time associated with installing concrete patches, the maximum useful life and the number of patches per mile come from this division.

ADOT Risk Management

The product liability estimates come from ADOT Risk Management. The number of claims resulting from concrete patching failures, the number of claims settled, the number of claims dropped or denied, and the average settlement and court costs all come from this division.

ADOT Maintenance Planning

ADOT Maintenance Planning's PECOS II database provided some of the cost values for the analysis. Hourly equipment and labor costs, for instance, come directly from this source.

DATA SHEETS

The following data sheets contain information for each product that was used in the PEM analysis. The product name appears in the upper, left hand corner of each sheet.

UPM	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq ft)	$2.60	$2.34	2.86
Useful Economic Life (Years)	2.5	2.0	3.0
Maximum Useful Life (Years)	5.0	4.5	5.5
Average Units of Material per Patch (Units/Patch)	3.0	2.5	3.5
Current Patches in Use (#)	560	500	620
Annual Increase in Patches (#)	56	50	62
Patches at First Year of Steady State (#)	0	0	0
Years to Steady State (Years)	2	1.75	3
Steady State Product Growth (#)	0	0	0
# of Claims per 100 Failures	10	9	12
% of Claims not Pursued (% in decimal form)	.64	.60	.68
% of Claims Settled (% in decimal form)	.35	.30	.40
Average Settlement Costs ($)	$500	$450	$550
Average Court Costs ($)	$15,000	$10,000	$17,000
Labor Productivity (#/HR/Person)	4.67	4.2	5.14
Labor Wage	$13.68		
Hourly Equipment Costs ($/HR)	$74.12	$70.39	$77.79
Exp. Disruption Delay (minutes)	5	3	7
Annual AADT Effected (%)	0.001	0.000	0.002
Failure Rate	1		

Celroc 10-60	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq ft)	$9.64	$8.68	$10.6
Useful Economic Life (Years)	1	.5	1.25
Maximum Useful Life (Years)	1.5	1.25	1.75
Average Units of Material per Patch (Units/Patch)	3	2.5	3.5
Patches at First Year of Steady State (#)	560	500	620
Years to Steady State (Years)	2	1.75	3
Steady State Product Growth (#)	56	50	62
# of Claims per 100 Failures	10	9	12
% of Claims not Pursued (% in decimal form)	.64	.60	.68
% of Claims Settled (% in decimal form)	.35	.3	.4
Average Settlement Costs ($)	$500	$450	$550
Average Court Costs ($)	$15,000	$10,000	$17,000
Labor Productivity (Units/HR/Person)	5.0	4.5	5.5
Labor Wage	$13.68		
Hourly Equipment Costs ($/HR)	$84.56	$80.33	$88.79
Exp. Disruption Delay (minutes)	20	15	25
Annual AADT Effected (%)	0.001	0.000	0.002
Failure Rate Path	1		

Set 45	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq Ft)	$10.15	$9.14	$11.17
Useful Economic Life (Years)	1	.5	1.25
Maximum Useful Life (Years)	1.5	1.25	1.75
Average Units of Material per Patch (Units/Patch)	3	2.5	3.5
Patches at First Year of Steady State (#)	560	500	620
Years to Steady State (Years)	2	1.75	3
Steady State Product Growth (#)	56	50	62
# of Claims per 100 Failures	10	9	12
% of Claims not Pursued (% in decimal form)	.64	.60	.68
% of Claims Settled (% in decimal form)	.35	.3	.4
Average Settlement Costs ($)	$500	$450	$550
Average Court Costs ($)	$15,000	$10,000	$17,000
Labor Productivity (Units/Hr/Person)	5.0	4.5	5.5
Labor Wage ($/HR)	$13.68		
Hourly Equipment Costs ($/HR)	$84.56	$80.33	$88.79
Exp. Disruption Delay (minutes)	20	15	25
Annual AADT Effected (%)	0.001	0.000	0.002
Failure Rate Path	1		

Percol Flex	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq Ft)	$9.61	$8.65	$10.57
Useful Economic Life (Years)	1	.5	1.25
Maximum Useful Life (Years)	1.5	1.25	1.75
Average Units of Material per Patch (Units/Patch)	3	2.5	3.5
Patches at First Year of Steady State (#)	560	500	620
Years to Steady State (Years)	2	1.75	3
Steady State Product Growth (#)	56	50	62
# of Claims per 100 Failures	10	9	12
% of Claims not Pursued (% in decimal form)	.64	.60	.68
% of Claims Settled (% in decimal form)	.35	.3	.4
Average Settlement Costs ($)	$500	$450	$550
Average Court Costs ($)	$15,000	$10,000	$17,000
Labor Productivity (Units/Hr/Person)	3.25	2.93	3.58
Labor Wage ($/HR)	$13.68		
Hourly Equipment Costs ($/HR)	$67.95	$64.55	$71.35
Exp. Disruption Delay (minutes)	5	3	7
Annual AADT Effected (%)	0.002	0.001	0.003
Failure Rate Path	1		

Type III	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq Ft)	$3.08	$2.77	$3.39
Useful Economic Life (Years)	1	.5	1.25
Maximum Useful Life (Years)	1.5	1.25	1.75
Average Units of Material per Patch (Units/Patch)	3	2.5	3.5
Patches at First Year of Steady State (#)	560	500	620
Years to Steady State (Years)	2	1.75	3
Steady State Product Growth (#)	56	50	62
# of Claims per 100 Failures	10	9	12
% of Claims not Pursued (% in decimal form)	.64	.60	.68
% of Claims Settled (% in decimal form)	.35	.3	.4
Average Settlement Costs ($)	$500	$450	$550
Average Court Costs ($)	$15,000	$10,000	$17,000
Labor Productivity (Units/Hr/Person)	1.43	1.29	1.57
Labor Wage ($/HR)	$13.68		
Hourly Equipment Costs ($/HR)	$86.88	$82.54	$91.27
Exp. Disruption Delay (minutes)	40	35	45
Annual AADT Effected (%)	0.002	0.001	0.003
Failure Rate Path	1		

Durapatch	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq Ft)	$10.25	$9.23	$11.28
Useful Economic Life (Years)	1	.5	1.25
Maximum Useful Life (Years)	1.5	1.25	1.75
Average Units of Material per Patch (Units/Patch)	3	2.5	3.5
Patches at First Year of Steady State (#)	560	500	620
Years to Steady State (Years)	2	1.75	3
Steady State Product Growth (#)	56	50	62
# of Claims per 100 Failures	10	9	12
% of Claims not Pursued (% in decimal form)	.64	.60	.68
% of Claims Settled (% in decimal form)	.35	.3	.4
Average Settlement Costs ($)	$500	$450	$550
Average Court Costs ($)	$15,000	$10,000	$17,000
Labor Productivity (Units/Hr/Person)	5.0	4.5	5.5
Labor Wage ($/HR)	$13.68		
Hourly Equipment Costs ($/HR)	$84.56	$80.33	$88.79
Exp. Disruption Delay (minutes)	20	15	25
Annual AADT Effected (%)	0.001	0.000	0.002
Failure Rate Path	1		

PEM OUTPUT; TABULAR AND GRAPHICAL

PEM's output is a result of a Monte Carlo simulation technique which varies each variable randomly within a user-defined probability range and then sums the results to provide an estimate of the range of net economic benefits associated with a product. PEM's results, therefore, are in the form of probability distributions, such as the decumulative probability distribution, which provides median, upper and lower bound estimates of the potential economic benefits associated with the use of a new product.

PEM's output from project EP-8606 is presented in the following table and graphs. The table is simply a ranking, by median NPV benefits, of the five concrete patching materials compared against U.P.M. The six decumulative probability distribution graphs, indicate the potential for potential economic benefits to move within these boundaries, based on real world conditions and the combined impact of many factors on product performance. These decumulative distributions can also be used to express the probability of achieving a given level of net economic benefits.

Table 4.1: Ranking of Concrete Patching Materials (NPV of economic benefits in $ million per mile)

Product	Expected Mean Value of Economic Benefits
Type III	-8.03
Durapatch	-2.10
Celroc 1060	-2.07
Set 45	-1.68
Percol Flex	-1.61

Table 5.1 presents a ranking of the expected mean value of economic benefits associated with five concrete materials over a twenty five year period. Each product was directly compared with the Base Case product, UPM, to estimate the median change in net benefits associated with the product.

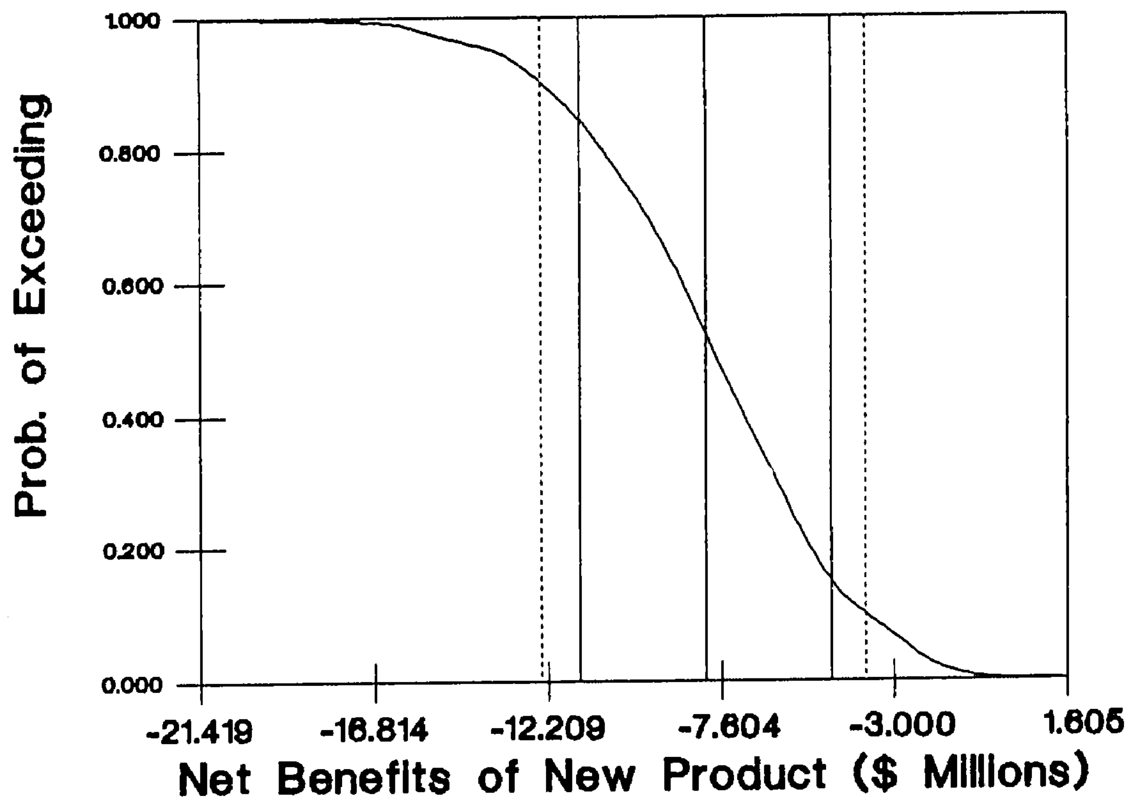
ANALYSIS AND INTERPRETATION

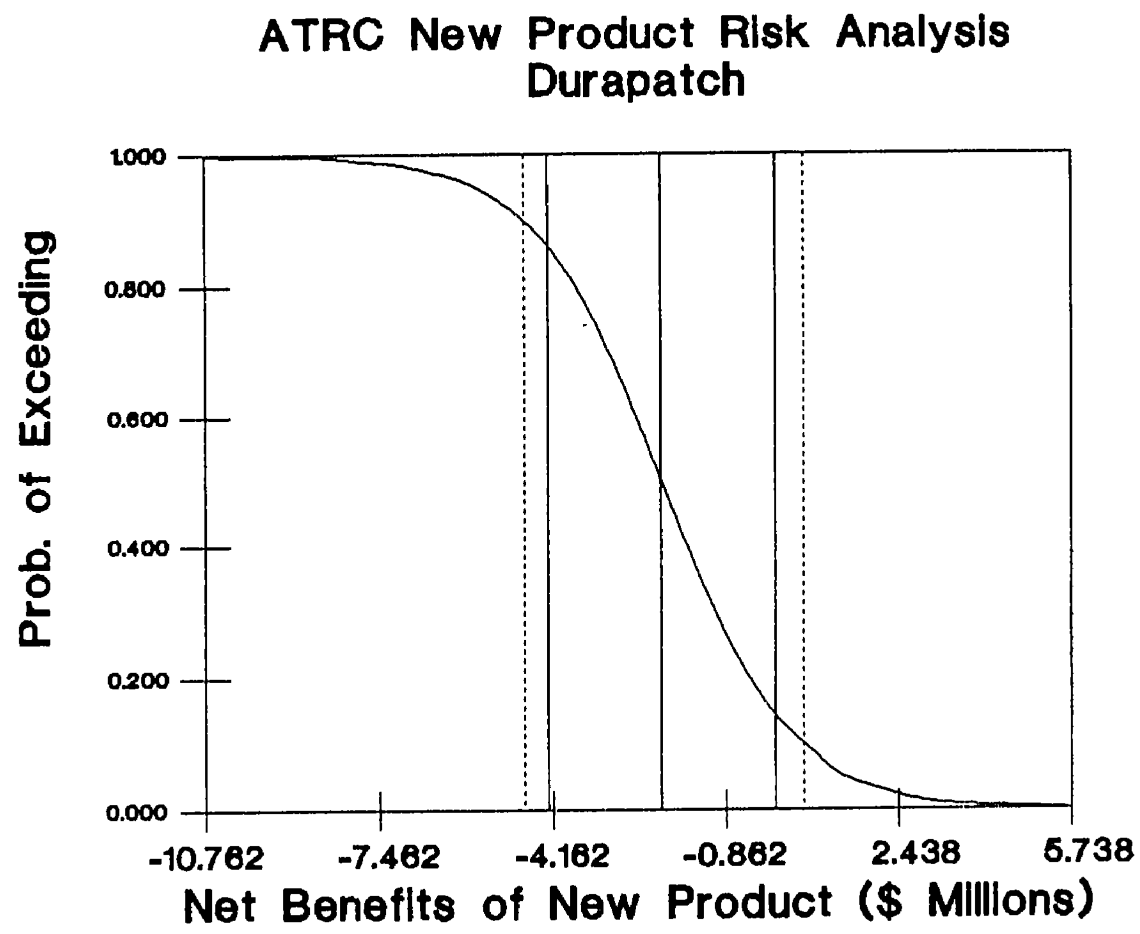
The PEM analysis of the concrete patching materials used in ADOT Project EP-8606 is relatively straightforward. Aside from product cost, the principal economic cost factors affecting the analysis of any concrete patching material are its longevity and its impact on traffic disruption via the installation time. PEM's consideration of economic benefit categories, such as maintenance, vehicle operating costs, and the value of time savings, is such that those materials that have a long product life and quick installation period tend to perform better than other materials. Those products in PEM that have longer installation periods, on the other hand, lead to traffic disruptions which quickly produce economic costs to highway users.

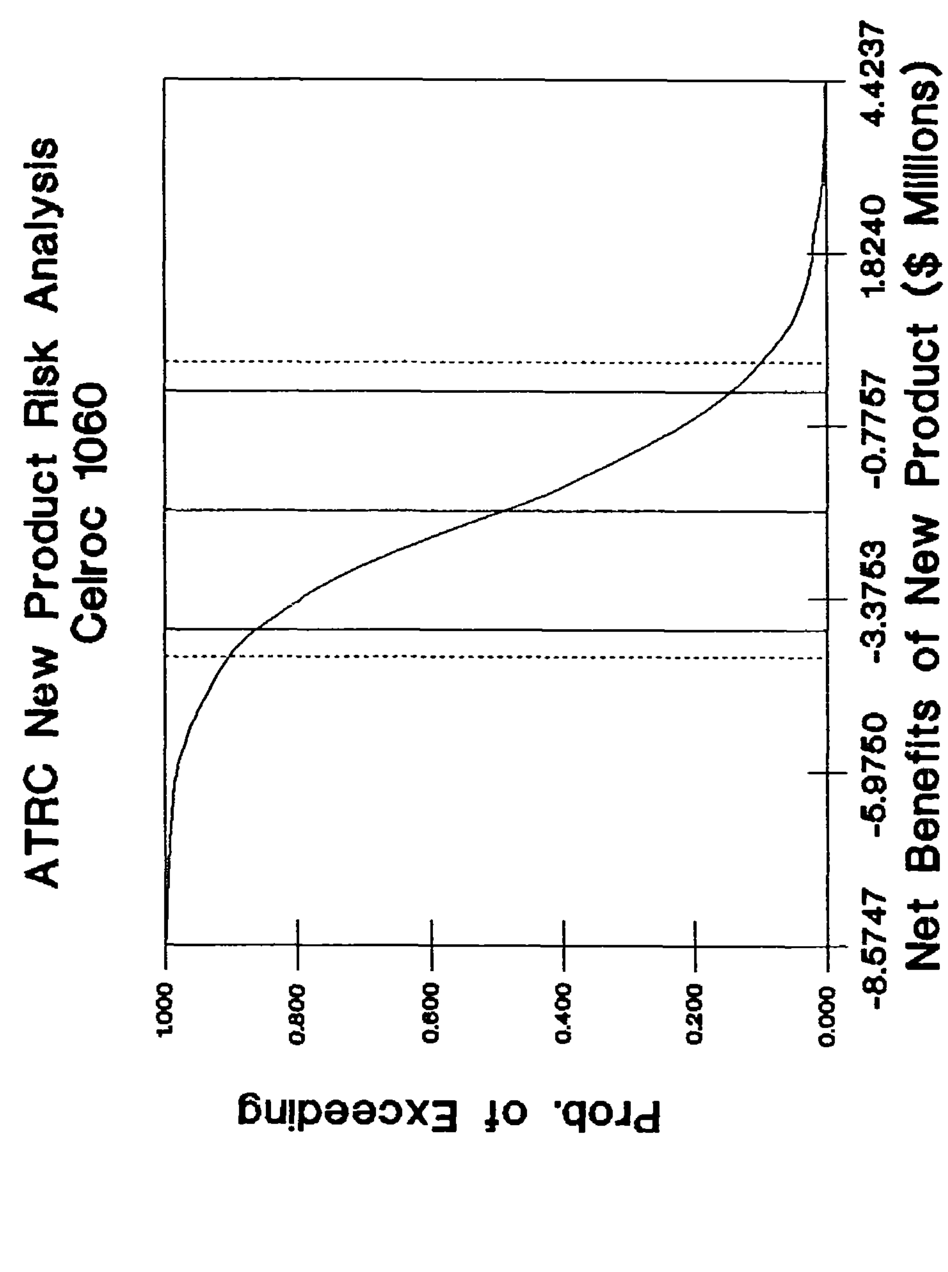
U.P.M.'s relatively low cost, quick installation time and durability contribute to make it the overall "winner," in terms of the NPV of economic benefits for project EP-8606. Three of the four concrete patching material lose, principally because of their relatively high cost and average set times. Percol Flex, which comes in second in the analysis, achieves a relatively better NPV because of its quick installation time and productivity figures. Type III portland concrete finished last in the analysis, principally due to the long set time and its impact on traffic disruption.

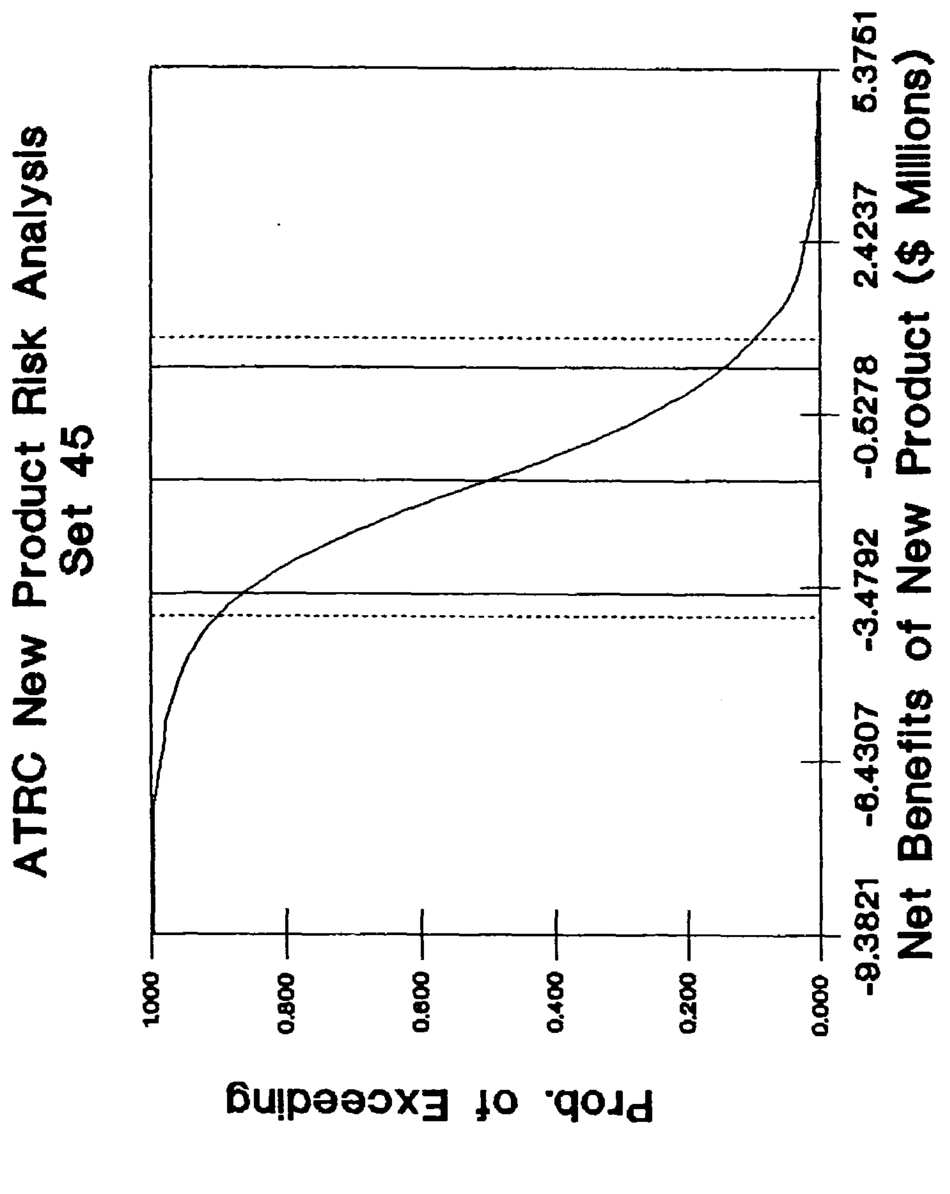
Graphs of the risk analysis of achieving net economic benefits for each product are presented at the end of this tutorial. The graphs present decumulative probability curves which chart the "Probability of (the product) Exceeding" (a given percentage) along the Y axis and the "Net Economic Benefits of the New Product" (in millions of U.S. Dollars) along the X axis. The solid, vertical center line represents the "median" estimate of net benefits, or the midpoint at which 50 percent of the mean estimates of net economic benefits fall above or below the median line. The two vertical dotted lines on either side of the median line represent the 10% lower and 10% upper limits (reading from left to right), or the points at which, respectively, there is only a 10 percent probability of the mean economic benefits estimate falling outside of these boundaries. The center region between the two dotted lines comprises the 80% confidence level, or area in which there is an 80 percent probability of the mean estimate of net economic benefits occurring within this region. The two vertical solid lines close to the solid lines represent the value of one standard deviation from the median estimate..

ATRC New Product Risk Analysis
Type III

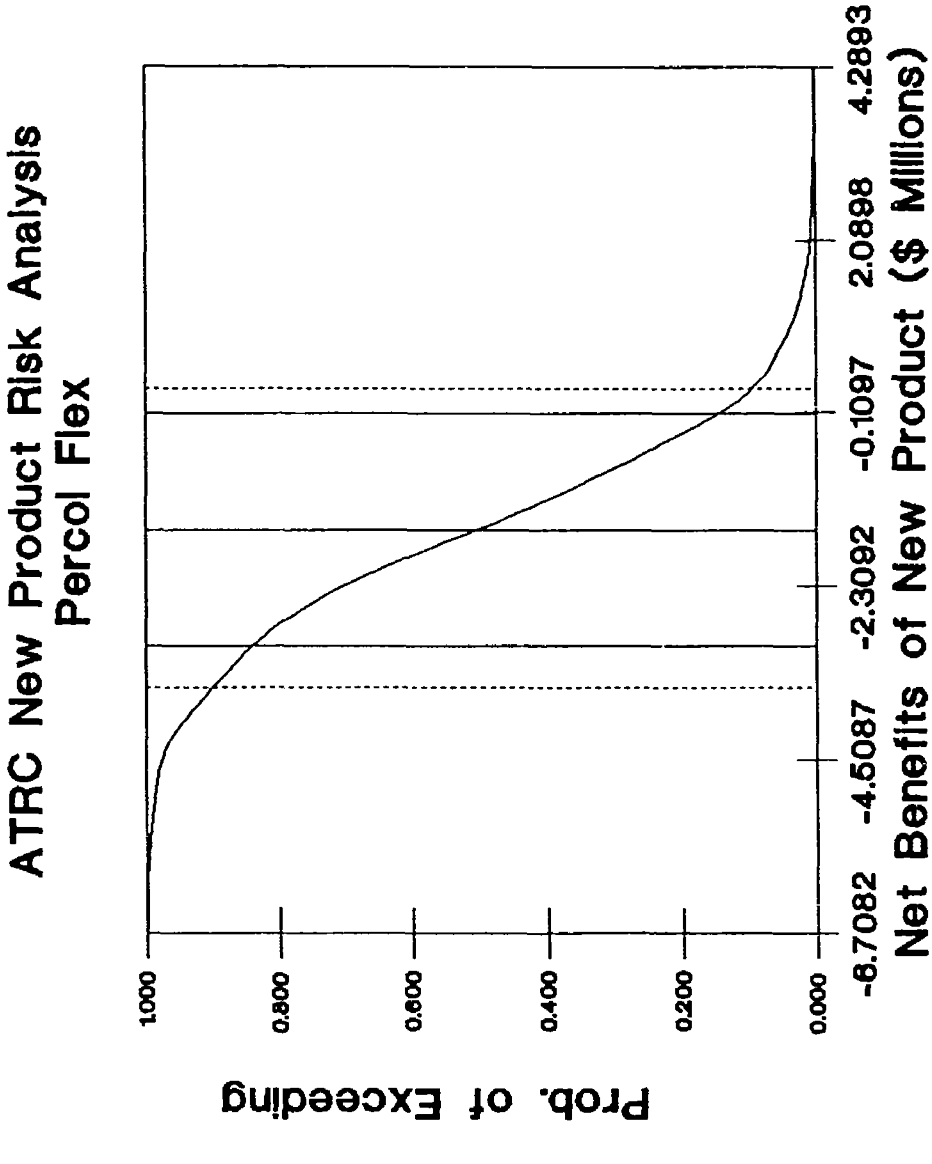



ATRC New Product Risk Analysis
Durapatch
Prob. of Exceeding
1.000
0.800
0.600
0.400
0.200
0.000
-10.762
-7.462
-4.162
-0.862
2.438
5.738
Net Benefits of New Product ($ Millions)


ATRC New Product Risk Analysis
Celroc 1060
Prob. of Exceeding
1.000
0.800
0.600
0.400
0.200
0.000
-8.5747
-5.9750
-3.3753
-0.7757
1.8240
4.4237
Net Benefits of New Product ($ Millions)



ATRC New Product Risk Analysis
Set 45
Prob. of Exceeding
1.000
0.800
0.600
0.400
0.200
0.000
-9.3821
-6.4307
-3.4792
-0.5278
2.4237
5.3751
Net Benefits of New Product ($ Millions)


ATRC New Product Risk Analysis
Percol Flex
Prob. of Exceeding
1.000
0.800
0.600
0.400
0.200
0.000
-6.7082
-4.5087
-2.3092
-0.1097
2.0898
4.2893
Net Benefits of New Product ($ Millions)

5.0 TECHNICAL APPENDIX

RAP SESSION DOCUMENTATION FOR PEM SIGN SHEETING MATERIAL COST-BENEFIT ANALYSIS

This section of the Technical Appendix contains the documentation that each participant in the reflective sign sheeting RAP session received, the values that were recorded, and the probability distribution graphs of the results. Together, these documents represent the full-scale risk analysis component of the PEM process. The results of this particular session are summarized at the end of Volume I, in the PEM verification section.

Each participant at the reflective sign sheeting material RAP session received the following documentation:

- **The Risk Analysis Primer**, a section explaining the Risk Analysis Process;
- **Structure and Logic Models**, diagrams of the economic benefit submodels; and
- **RAP Input Variables**, which are described in more detail below.

For each input variable there are two sheets:

Cover Sheet is identified at the top with the variable name and metric, and includes the following information:

Description

This section contains a brief description of the variable and how it is applied in the model.

How the Variable Affects the Model

The role the variable has in determining the output is described in this section. In other words, a explanation of how changes to the value of the variable affect the results.

Baseline Assumptions

This section supplies the data sources and assumptions of the model with regards to the input variables and on the data sheet. The sources and references contained in this section, such as vendor specification sheets and laboratory test results, contain information that is used to describe the common and specific attribute of new products. The initial estimate represents the value that we believe is the most likely to occur.

Major Uncertainties

Factors that could affect the realization of the median estimate are presented in this section. The initial estimate is taken from the best available information and is used to forecast the median value. The selection of an appropriate median forms the basis for the development of the probability ranges that will ultimately surround the value. A column for alternative values is also included on the data sheet to provide space for estimates that differ from the initial estimates.

Data Sheet is identified at the top with the same variable and metric as the accompanying cover sheet. The values in the data sheets represent the initial estimates and ranges prepared by Hickling analysts.

Risk Analysis Primer

The result of a Risk Analysis is a forecast of future events and the probability, or odds, of their occurrence. Not unlike modern weather forecasting, in which the likelihood of rain is projected with a statement of probability ("there is a 20 percent chance of rain tomorrow"), Risk Analysis is intended to provide planners and decision-makers with a sense of perspective on the likelihood of future events. Risk Analysis allows planners and decision-makers to select the level of risk within which they are willing to plan and make commitments.

Forecasting and the Analysis of Risk

The further into the future projections are made, the more uncertainty there is and the greater the risk is of producing forecasts that deviate from actual outcomes. Projections need to be made with a range of input values to allow for this uncertainty and for the probability that alternative economic, demographic, technological and environmental conditions may prevail. The difficulty lies in choosing which combinations of input values to use in computing forecasts, and how to use those forecasts to produce a final estimate.

Forecasts traditionally take one of two forms: first, a single "expected outcome", or second, one in which the expected outcome is supplemented by alternative scenarios, often termed "high" and "low" cases. Both approaches fail to provide adequate perspective with regard to probable versus improbable outcomes.

The limitation of a forecast with a single expected outcome is clear -- while it may provide the single best guess, it offers no information about the range of probable outcomes. The problem becomes acute when uncertainty surrounding the underlying assumptions of the forecast is especially high.

The high case-low case approach can actually exacerbate this problem because it gives no indication of how likely it is that the high and low cases will actually materialize. Indeed, the high case usually assumes that most underlying assumptions deviate in the same direction from their expected value; and likewise for the low case. In reality, the likelihood that all underlying factors shift in the same direction simultaneously is just as remote as everything turning out as expected.

A common approach to providing added perspective on reality is through "sensitivity analysis", whereby key forecast assumptions are varied one at a time in order to assess their relative impact on the expected outcome. A problem here is that the assumptions are often varied by arbitrary amounts. But a more serious flaw in this approach is that in the real world, assumptions do not veer from actual outcomes one at a time; it is the impact of simultaneous differences between assumptions and actual outcomes that would provide true perspective on a forecast. Risk analysis provides a way around the problems outlined above. It helps avoid the lack of perspective in "high" and "low" cases by measuring the probability or "odds" that an outcome will actually materialize. This is accomplished by attaching ranges (*probability distributions*) to the forecasts of each input variable. The approach allows all inputs to be varied simultaneously within their distributions, thus avoiding the problems inherent in conventional sensitivity analysis. The approach also recognizes interrelationships between variables and their associated probability distributions. The result of a risk analysis is both a forecast and a quantification of the probability that the forecast will be achieved.

To improve confidence in the forecasts, the Risk Analysis Process also involves outside experts in evaluating the forecasting assumptions and the estimated probabilities associated with their accuracy.

Risk Analysis in Application to Cost Benefit Analysis

The Risk Analysis Process of the cost-benefit analysis of sign sheeting materials involves four steps:

Step 1. The integration of product vendor and ADOT maintenance data (in appropriate metrics) into the Risk Analysis framework;

Step 2. Assignment of estimates and ranges (probability distributions) to each variable and assumption in the forecasting process;

Step 3. Expert and public evaluation and involvement, including revision of estimates and ranges developed in Step 2 (if necessary); and

Step 4. Risk Analysis.

Step 1. Integration of Product Testing and Experimental Data into RAP Software

The process begins with the development of "Structure-and-Logic Models" depicting the interaction of product testing and experimental data with each defined economic benefit submodel. A Structure-and-Logic Model depicts the methodology non-mathematically, indicating how all variables and assumptions combine to yield an economic effect, (benefits net of costs). The models provide detailed documentation of how the methodologies are characterized for Risk Analysis. They also provide a clear and uncomplicated means of explaining the economic benefit categories to outside experts, stakeholders and others in an expert panel session.

Once the structure-and-logic of the model is properly represented, it is programmed into the Risk Analysis software.

Step 2. Central Estimates and Probability Distributions

Each variable is assigned a central estimate and a range (a probability distribution) to represent the degree of uncertainty.

Special data sheets are used (see Figure 1) to record the estimates. In this case, the first column provides space for an initial median estimate, and the second and third columns

Figure 5.1: Sample of a Data Sheet for the Risk Analysis Process

DATA SHEET:
Maximum Economic Life
(Years)

Product	Median Estimate	10 % Lower Limit (%)	10 % Upper Limit (%)
Base Case	7	4	12
New Product	12	10	15

define a range which represents "an 80 percent confidence interval" -- the range within which we can be 80 percent confident of finding the actual outcome. Thus the greater the uncertainty associated with a forecast variable, the wider the range will be (and vice versa). This process ensures that all risks are properly reflected in the forecasting process.

Ranges need not be normal or symmetrical -- that is, there is no need to assume the bell shaped normal probability curve. The bell curve assumes an equal likelihood of being too low and being too high in forecasting a particular value. It might well be, for example, that if projected inflation rates deviate from expectations, they are more likely to be higher rather than lower. The RAP process places no restrictions on the degree of "skew" in the specified ranges and thus maximizes the extent to which the Risk Analysis reflects reality.

Probability ranges for the variables in-question are established on the basis of both statistical analysis and subjective probability. Factors considered in the analysis include:

- Product vendor sheets and other state Departments of Transportation;
- Existing road conditions and the performance of similar products; and
- Federal studies on sign sheeting properties.

Although the computer program will transform all ranges into formal "probability density functions", they do not have to be determined or presented in either mathematical or graphical form. All that is required is the entry of upper and lower limits of an 80 percent confidence interval in the Data Sheets. The RAP software will then use numerical analysis to translate these entries into a uniquely defined statistical probability distribution automatically. This liberates the non-statistician from the need to appreciate the abstract statistical depiction of probability and thus enables administrators, stakeholders and decision-makers to understand and participate in the process whether or not they possess statistical training.

Step 3. Expert Evaluation and Consensus Building

Facilitated by the Hickling team, a RAP Session is conducted as a structured workshop. Participants receive a briefing book in advance and during the session they review the model (via the Structure-and-Logic Models) and review each Data Sheet. This approach facilitates consensus building in the underlying forecasting assumptions and associated probabilities.

Step 4. Risk Analysis

Once the Data Sheets are finalized, the RAP software transforms ranges given in the Data Sheets into statistical probability distributions (see Figure 2).

These distributions are combined using simulation techniques that allow all variables to vary simultaneously from their expected values (Figure 3). The result is a cost forecast together with estimates of the probability of achieving alternative outcomes given uncertainty in the underlying assumptions.

Figure 5.2: RAP Generated Probability Distribution

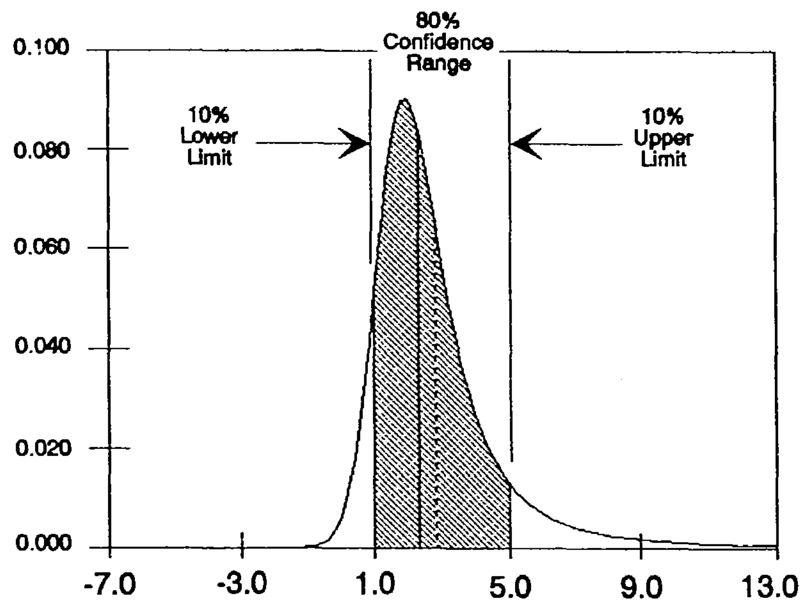
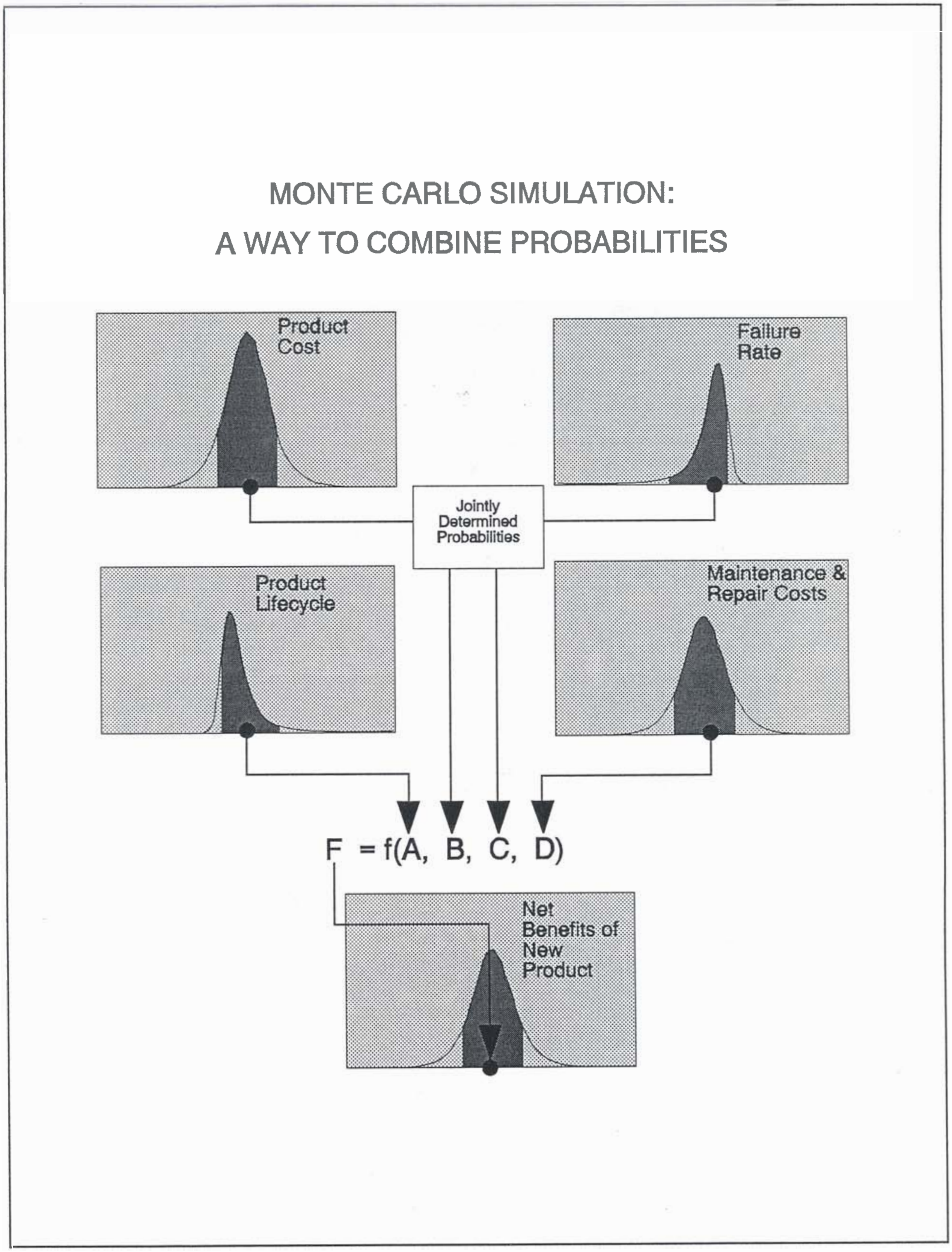


Figure 5.3: Monte Carlo Simulation: A Way to Combine Probabilities



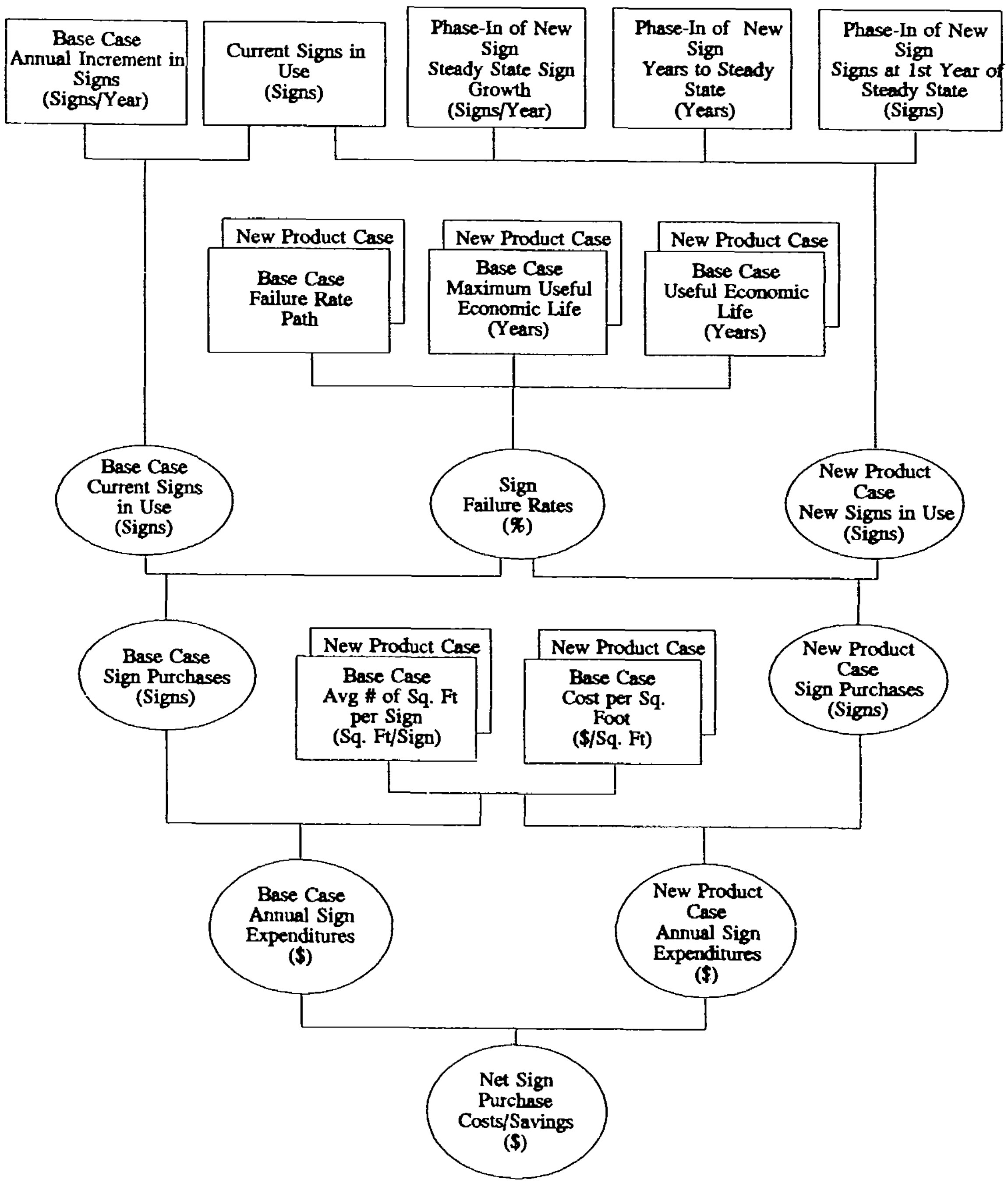
Structure and Logic Diagrams

The following structure and logic diagrams refer to the economic benefit sub-models that are integrated into the larger net benefit-cost model. Using these diagrams, the panelist will observe the fundamental analytical relationships that drive the model.

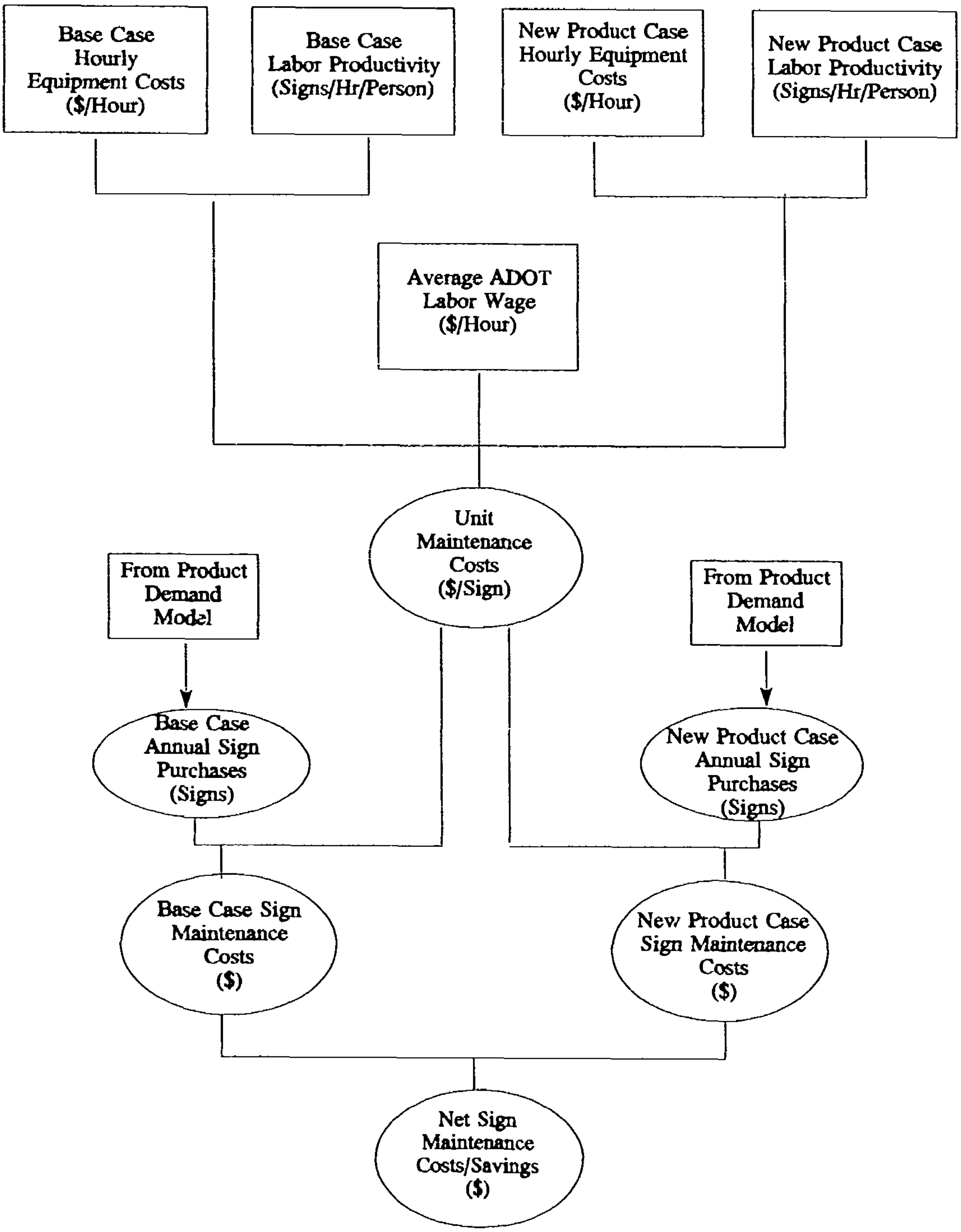
OVERVIEW OF SIGN SHEETING BENEFIT-COST ANALYSIS

	Net Sign Purchase Costs/Savings
+	Net Sign Maintenance Costs/Savings
+	Benefits from Improved Accident Rates due to Sign Sheeting
+	Benefits from Improved Speed/Flow due to Sign Sheeting
+	Benefits from Improved Driver's Sense of Security due to Sign Sheeting
=	Net Benefit of New Sign Sheeting

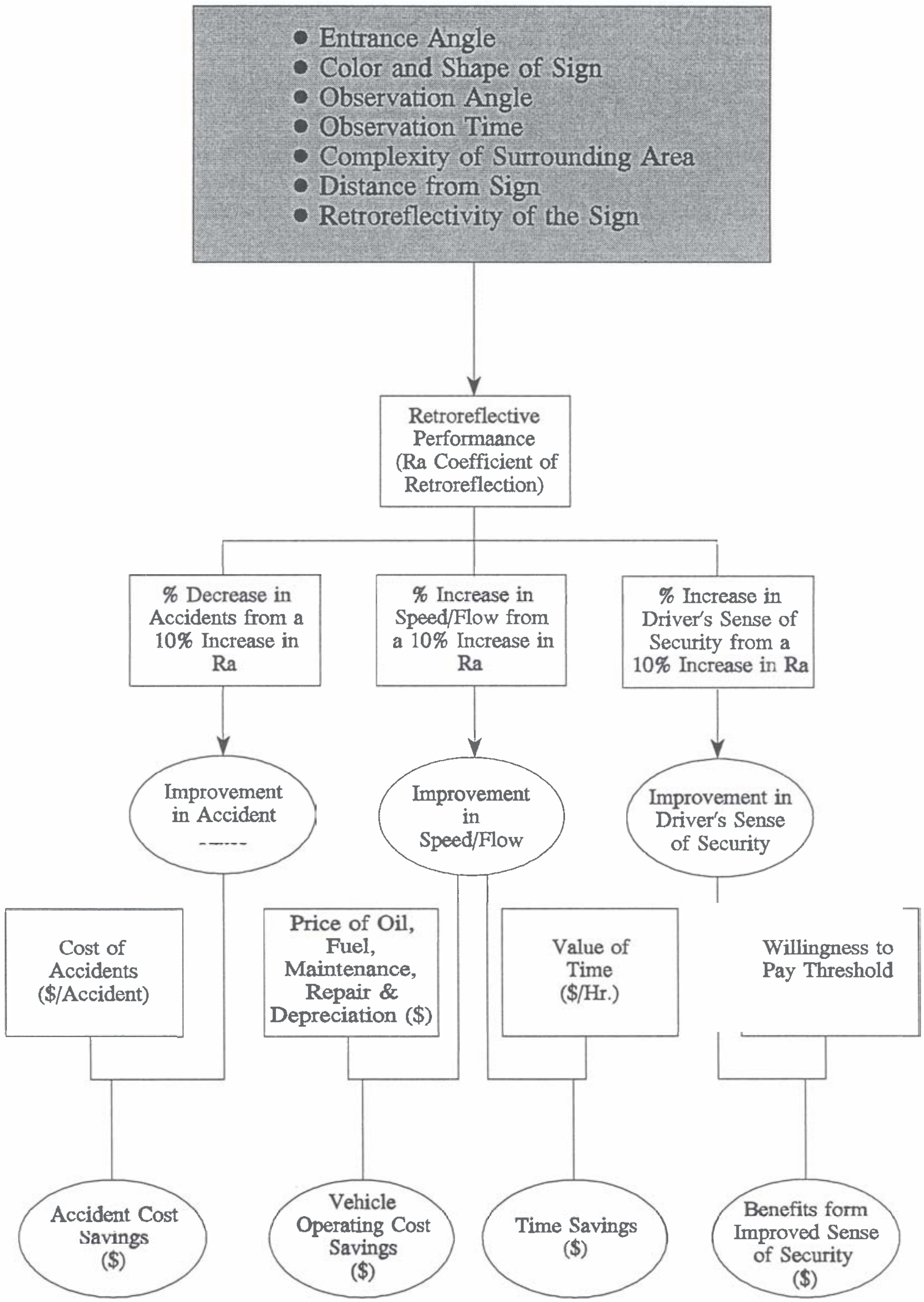
STRUCTURE AND LOGIC DIAGRAM: NET SIGN PURCHASE COSTS/SAVINGS



STRUCTURE AND LOGIC DIAGRAM: NET MAINTENANCE COSTS/SAVINGS



STRUCTURE AND LOGIC DIAGRAM: IMPACT OF RETROREFLECTIVITY ON HIGHWAY USER COSTS



RAP Input Variables

The following section contains a set of data sheets for each input variable in the model that will be considered during the RAP session. The first variable data sheet contains a variable description, an explanation of how the variable affects the model, the baseline assumptions used in constructing the model, and the major uncertainties associated with the particular variable. The second variable data sheet contains an initial median estimate of metric and upper and lower probability ranges for each variable based on available vendor specification sheets and other product data.

The risk analysis will focus on two specific types of warning and regulatory signs due to the multiple colors, sizes and positions used for different traffic control purposes. During the RAP session, it will be assumed that the participants are considering the material attributes of a right-hand side, ground-mounted, yellow warning sign with a black legend and a right-hand side, ground-mounted, white regulatory sign with a black legend.

VARIABLE:
Average Units of Material per Sign
Square Feet

Description

The value for this variable refers to the average number of material units that are utilized to make one product. For example, an average of 16 square feet of sign sheeting is used to make one roadway sign. The model requires data for both the Base Case and the New Product case. Without values for this variable, annual capital expenditures cannot be calculated.

How the Variable Affects the Model

This value is initially used in conjunction with the cost per square foot of material to determine material cost per sign. This value, in turn, is used with estimates for annual purchases, inventory size, and sign failures to forecast the value of annual sign capital purchases for both the Base Case and the New Product case.

Baseline Assumptions

Warning and regulatory signs are made in several sizes and shapes, from 36" X 36" to larger signs of 48" X 60" and upwards. In this example, 16 square feet will be used as an average sign size, based on an ADOT internal memorandum comparing sign costs. Further discussions with the ADOT sign shop indicate that this is an acceptable average size unit.

Major Uncertainties

As explained above, warning and regulatory signs come in a wide variety of sizes and shapes which may differ significantly from the average sign size.

DATA SHEET:
Average Units of Material per Sign
Square Feet

Warning Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	16	15	17
Super Engine. Grade	16	15	17
High Intensity	16	15	17
High Intensity, prismatic	16	15	17

Regulatory Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	9	8	10
Super Engine. Grade	9	8	10
High Intensity	9	8	10
High Intensity, prismatic		8	10

VARIABLE:
Material Unit Cost
$

Description

Material unit cost is the dollar cost of the sign sheeting material used to fabricate one warning or regulatory sign. The material cost must be in dollars per unit of the previous variable. In this example, the material cost is in dollars per square foot to correspond with the units used in "Average Units of Material per Sign," (16 square feet). The model requires cost data for both the Base Case and the New Product case. Without values for this variable, annual capital expenditures cannot be calculated.

How the Variable Affects the Model

This value is initially used in conjunction with the average number units of material to determine material cost per sign. This value, in turn, is used with estimates for annual purchases, sign failures to forecast the value of annual sign capital expenditures for both the Base Case and the New Product case.

Baseline Assumptions

PECOS II cost estimates are used for Engineering Grade sign sheeting. Data supplied from vendors, for Super Engineering, and High Intensity (encapsulated bead and prismatic). In addition to basic material cost, a standard cost of $1.13 for substrate (from PECOS II data) is added to each price to account for sign fabrication. For initial discussion purposes, a 10% upper and lower price range was assumed.

Major Uncertainties

Competitive pricing practices by major manufacturers may influence the costs of various grades of sign sheeting material. In addition, the expected expiration of the patent on High Intensity (encapsulated bead) sign sheeting material by 3M may affected material prices in this grade of sign sheeting.

DATA SHEET:
Material Unit Cost
$

Warning Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	$1.98	$1.78	$2.18
Super Engine. Grade	$3.28	$2.95	$3.61
High Intensity	$4.38	$3.94	$4.82
High Intensity, prismatic	$4.87	$4.38	$5.36

Regulatory Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	$1.98	$1.78	$2.18
Super Engine. Grade	$3.28	$2.95	$3.61
High Intensity	$4.38	$3.94	$4.82
High Intensity, prismatic	$4.87	$4.38	$5.36

VARIABLE:
Useful Economic Life of Product
Years

Description

The useful economic life of the sign is defined as the time at which 50% of the products installed at the same point in time have failed or ceased to perform their desired function. With regards to sign sheeting, this definition does not distinguish between product failure due to physical deterioration or to the inability to meet a minimum standard of retro-reflectivity. The model requires data for both the Base Case and the New Product case. Both values for this variable must be entered in years.

How the Variable Affects the Model

The value for this variable is used in conjunction with the maximum useful life variable and the user specified failure rate path to forecast the product failure rate. The product failure rate combined with the total desired capital stock estimate is used to project annual product purchases, replacements, and, ultimately, the effect on annual purchases.

Baseline Assumptions

For sign sheeting materials, this period can be estimated by ADOT experience. An ADOT internal memorandum indicates that warning and regulatory signs last on average four years. A *mean* estimate of seven years was assumed for the
for the Super-Engineering and High Intensity sheetings based on product literature and warranty periods.

Major Uncertainties

The average useful economic life of a warning or regulatory signs is debatable, as evidenced in the Baseline Assumptions. Until accurate sign inventories are established and a systemic review is performed, these forecasts are speculative. In addition, depending upon ADOT's future policy regarding minimum standards for retro-reflectivity, the useful economic life of sign sheeting material (as determined by the coefficient of retroreflectivity) may, in fact, become shorter than the physical life of the product.

DATA SHEET: Useful Economic Life of Product Years

Warning Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	3.5	3	4
Super Engine. Grade	7	6	8
High Intensity	7	6	8
High Intensity, prismatic	7	6	8

Regulatory Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	3.5	3	4
Super Engine. Grade	7	6	8
High Intensity	7	6	8
High Intensity, prismatic	7	6	8

VARIABLE:
Maximum Useful Economic Life of Product
Years

Description

The maximum useful economic life of the product is defined as the time at which 99% of the products installed at the same point in time have failed, or ceased to perform their desired function. With regards to sign sheeting, this definition does not distinguish between product failure due to physical deterioration or to the inability to meet a minimum standard of retro-reflectivity. The model requires data for both the Base Case and the New Product case to be entered in years.

How the Variable Affects the Model

The value for this variable is used in conjunction with the useful economic life variable and the user specified failure rate path to forecast the product failure rate. The product failure rate combined with the total desired capital stock estimate is used to project annual product purchases, replacements, and, ultimately, the effect on capital costs.

Baseline Assumptions

Estimates regarding the maximum useful life come from ADOT maintenance experience and vendor claims. Currently, ADOT does not have a codified system or policy to replace signs at a set point in time, therefore many signs remain in place several years after their warranty periods expire before replacement. The time estimates for sign sheeting material come from ADOT memoranda. The manufacturers of three out of four sign grades maintain warranty periods of ten years, but claim service lives of 14 years.

Major Uncertainties

The useful life of sign sheeting material ideally depends both on the physical deterioration of the product as well as the decay rate of retro-reflectivity. Depending upon ADOT's policy regarding minimum standards for retro-reflectivity, the maximum useful economic life of sign sheeting material may be equal or less than the physical life of the product.

DATA SHEET:
Maximum Useful Life of Product
Years

Warning Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	7	4.5	12.4
Super Engine. Grade	14	13	15
High Intensity	14	13	15
High Intensity, prismatic	14	13	15

Regulatory Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	7	4.5	12.4
Super Engine. Grade	14	13	15
High Intensity	14	13	15
High Intensity, prismatic	14	13	15

VARIABLE:
Current Signs in Use
Signs

Description

This variable refers to the total number of signs in use, or the total capital stock. This variable is dependent upon the facility type and number of roadway miles specified by the user. It is the starting point for determining product growth in the Base Case. Data for this variable is only required for the Base Case, as it assumed that there is no current stock of a new product.

How the Variable Affects the Model

This variable is used in conjunction with the annual increase in signs to determine the Base Case annual signs in use. When adjusted for sign failures, this variable becomes the Base Case annual purchases.

Baseline Assumptions

ADOT does not currently have accessible data on the current number of signs in use. In lieu of this data, estimates from the National Cooperative Highway Research Program (NCHRP) Report 346, Implementation Strategies for Sign Retroreflectivity Standards, will be used. According to the report, there are approximately 18 regulatory and 10 warning signs per mile in an urban area. (4 signs each, respectively, in a rural area). The model will initially use urban values. These base estimate are multiplied by 100 to present a realistic scenario based on 100 miles of roadway.

Major Uncertainties

Depending on specific conditions in Arizona and current signing policies, the actual number of warning and regulatory signs can vary. Additionally, different quantities for each color of sign sheeting material exist within the warning and regulatory sign categories.

DATA SHEET:
Current Signs in Use
Signs

Warning Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	1800	1700	1900

Regulatory Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	1000	900	1100

VARIABLE:
Annual Increase in Signs
Signs

Description

This variable is used to develop the annual sign stock for the Base Case. It simply reflects the expected increase in sign purchases per year. This variable impacts annual capital expenditures.

How the Variable Affects the Model

This variable is used in conjunction with the current signs in use to determine the total Base Case annual signs in use. When adjusted for sign failures, this variable becomes the Base Case annual purchases which ultimately impacts annual capital expenditures.

Baseline Assumptions

Based on conversations with the ADOT sign shop, it was determined that approximately 10 percent of annual sign production is devoted to new sign installations.

Major Uncertainties

This variable depends largely on the need for new signs, either due to new roadway construction or other factors.

DATA SHEET:
Annual Increase in Signs
Signs

Warning Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	180	170	190

Regulatory Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	100	90	110

VARIABLE:
Phase-In of New Product Signs at First Year of Steady State Signs

Description

This variable specifies the quantity of signs of that ADOT plans to maintain at steady state once the phase in period is complete. It may be a one-for-one replacement of the Base Case product, depending on ADOT policy. This variable, along with the variable *Years to Steady State*, defines the phase-in period and impacts annual sign purchases.

How the Variable Affects the Model

This variable is used in conjunction with two other variables related to the phase in of a new product. The principal concept affecting all three variables is the steady state, which is defined as the point in time at which the product stock tends to remain steady or in equilibrium, given all product purchases and installations. The combination of these three variables develop the costs over time associated with the phase-in of a new product. This accounting is important to the cost-benefit analysis because of the extra inventory and capital costs associated with phasing-in a new product and phasing-out the current product.

Baseline Assumptions

In interviews with the ADOT sign sheeting shop and the Traffic Engineering Group, estimates of future phase-in variables were obtained based on the current phase-in of High-Intensity sign sheeting. A one-to-one replacement is initially assumed for the number of signs at the first year of Steady State.

Major Uncertainties

The timing of a phase-in is dependent upon many variables, including ADOT policy, product availability, and the speed with which the new product can adapted into maintenance and construction procedures and contracts.

VARIABLE:
Phase-In of New Product Signs at First Year of Steady-State Signs

Warning Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	1800	1700	1900
Super Engine. Grade	1800	1700	1900
High Intensity	1800	1700	1900
High Intensity, prismatic	1800	1700	1900

Regulatory Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	1000	900	1100
Super Engine. Grade	1000	900	1100
High Intensity	1000	900	1100
High Intensity, prismatic	1000	900	1100

VARIABLE:
Phase-In of New Product
Years to Steady State
Years

Description

This variable represents the number of the period in years over which the new product is to be phased-in. There is no unique value for this variable, instead it will depend upon the product in question and ADOT planning decisions. This variable impacts annual product purchases.

How the Variable Affects the Model

This variable is used in conjunction with two other variables related to the phase in of a new product. The principal concept affecting all three variables is the steady state, which is defined as the point in time at which the product stock tends to remain steady or in equilibrium, given all product purchases and installations. The combination of these three variables develop the costs over time associated with the phase-in of a new product. This accounting is important to the cost-benefit analysis because of the extra inventory and capital costs associated with phasing-in a new product and phasing-out the current product.

Baseline Assumptions

In interviews with the ADOT sign sheeting shop and the Traffic Engineering Group, estimates of future phase-in variables were obtained based on the current phase-in of High-Intensity sign sheeting. A median estimate of a two-year phase-in period was deemed appropriate.

Major Uncertainties

The timing of a phase-in is dependent upon many variables, including ADOT policy, product availability, and the speed with which the new product can adapted into maintenance and construction procedures and contracts.

VARIABLE:
Phase-In of New Product
Years to Steady-State
Years

Warning Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	2	1.75	3.0
Super Engine. Grade	2	1.75	3.0
High Intensity	2	1.75	3.0
High Intensity, prismatic	2	1.75	3.0

Regulatory Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	2	1.75	3
Super Engine. Grade	2	1.75	3
High Intensity	2	1.75	3
High Intensity, prismatic	2	1.75	3

VARIABLE:
Phase-In of New Product
Steady State Sign-Growth
Signs

Description

This variable refers to the growth of the capital stock figure once the phase-in of the new product has been completed. In a one-to-one replacement scenario, the New Product growth is expected to be approximately the same as the Base Case annual increase in signs. This variable impacts annual sign purchases.

How the Variable Affects the Model

This variable is used in conjunction with two other variables related to the phase in of a new product. The principal concept affecting all three variables is the steady state, which is defined as the point in time at which the product stock tends to remain steady or in equilibrium, given all product purchases and installations. The combination of these three variables develop the costs over time associated with the phase-in of a new product. This accounting is important to the cost-benefit analysis because of the extra inventory and capital costs associated with phasing-in a new product and phasing-out the current product.

Baseline Assumptions

In interviews with the ADOT sign sheeting shop and the Traffic Engineering Group, estimates of future phase-in variables were obtained based on the current phase-in of High-Intensity sign sheeting. It is assumed that steady state sign growth is approximately equal to current annual sign increases.

Major Uncertainties

The timing of a phase-in is dependent upon many variables, including ADOT policy, product availability, and the speed with which the new product can adapted into maintenance and construction procedures and contracts.

VARIABLE:
Phase-in of New Product Steady-State Sign-Growth Signs

Warning Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	180	170	190
Super Engine. Grade	180	170	190
High Intensity	180	170	190
High Intensity, prismatic	180	170	190

Regulatory Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	180	170	190
Super Engine. Grade	180	170	190
High Intensity	180	170	190
High Intensity, prismatic	180	170	190

VARIABLE:
Labor Productivity
Labor Hours

Description

This variable concerns the productivity of ADOT laborers with regards to the Base Case and the New Product Case. Productivity must be entered as products per hour per person or fractional products per hour per person, if the product requires more than one person to maintain. This variable is essential for correctly calculating labor productivity and maintenance costs.

How the Variable Affects the Model

This variable is used in conjunction with hourly equipment costs and average ADOT labor wage to determine unit maintenance costs for the Base Case and New Product. The value for unit maintenance costs, in turn, is used with Base Case annual replacements to estimate Base Case and New Product annual maintenance costs. A new product which leads to reduced annual maintenance costs results in a net benefit for this economic effect category.

Baseline Assumptions

The productivity figure for PECOS II Maintenance Category 0404, "Sign Inspection, Maintenance, Installation" in 1992/1993 was used for the analysis. The same productivity figure was used for all grades of sign sheeting material. This productivity figure assumes that a standard 16 square foot sign is installed or maintained in 1.85 labor hours.

Major Uncertainties

The productivity values in the PECOS II Maintenance Trends Summary vary significantly from 1990/1991 to 1992/1993. This may reflect the effects of the current phase-in of High-Intensity sign sheeting. Additionally, special handling and/or maintenance activities associated with a specific grade of sign sheeting material may also impact productivity.

DATA SHEET:
Labor Productivity
Labor Hours per Sign per Person

Warning Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	1.85	1.67	2.04
Super Engine. Grade	1.85	1.67	2.04
High Intensity	1.85	1.67	2.04
High Intensity, prismatic	1.85	1.67	2.04

Regulatory Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	1.85	1.67	2.04
Super Engine. Grade	1.85	1.67	2.04
High Intensity	1.85	1.67	2.04
High Intensity, prismatic	1.85	1.67	2.04

VARIABLE:
Years until Labor Productivity reaches 50%
Years

Description

This variable category concerns the timing of labor productivity associated with a new product. Maintenance and installation times may vary initially due to learning curve effects, therefore, it is reasonable to assume that productivity will increase over time until the expected productivity level is reached. This variable category captures the time it takes productivity to achieve 50 percent of its expected level. This value may be zero if there are no learning curve effects, but it must be entered for the model to function correctly.

How the Variable Affects the Model

This variable impacts the initial productivity level associated with a new product.
This variable is used in conjunction with labor productivity, hourly equipment costs and average ADOT labor wage to determine unit maintenance costs for the Base Case and New Product. The value for unit maintenance costs, in turn, is used with Base Case annual replacements to estimate Base Case and New Product annual maintenance costs. A new product which leads to reduced annual maintenance costs results in a net benefit for this economic effect category.

Baseline Assumptions

It is assumed that the labor productivity associated with new sign sheeting materials is approximately equal and that any learning curve period between the Base Case and New Product case is either instantaneous or negligible.

Major Uncertainties

It is possible for a new sign sheeting material to introduce special handling or application procedures that could impact the timing of labor productivity.

DATA SHEET:
Years until Labor Productivity reaches 50%

Warning Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	0		
Super Engine. Grade	0		
High Intensity	0		
High Intensity, prismatic	0		

Regulatory Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	0		
Super Engine. Grade	0		
High Intensity	0		
High Intensity, prismatic	0		

VARIABLE:
Years until Labor Productivity Reaches 95%
Years

Description

This variable category concerns the timing of labor productivity associated with a new product. Maintenance and installation times may vary initially due to learning curve effects, therefore, it is reasonable to assume that productivity will increase over time until the expected productivity level is reached. This variable category captures the time it takes productivity to achieve 50 percent of its expected level. This value may be zero if there are no learning curve effects, but it must be entered for the model to function correctly.

How the Variable Affects the Model

This variable impacts the initial productivity level associated with a new product.
This variable is used in conjunction with labor productivity, hourly equipment costs and average ADOT labor wage to determine unit maintenance costs for the Base Case and New Product. The value for unit maintenance costs, in turn, is used with Base Case annual replacements to estimate Base Case and New Product annual maintenance costs. A new product which leads to reduced annual maintenance costs results in a net benefit for this economic effect category.

Baseline Assumptions

It is assumed that the labor productivity associated with new sign sheeting materials is approximately equal and that any learning curve period between the Base Case and New Product case is either instantaneous or negligible.

Major Uncertainties

It is possible for a new sign sheeting material to introduce special handling or application procedures that could impact the timing of labor productivity.

DATA SHEET:
Years until Labor Productivity reaches 95%

Warning Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	0		
Super Engine. Grade	0		
High Intensity	0		
High Intensity, prismatic	0		

Regulatory Signs

Product	Median Estimate	10 % Lower Limit	10 % Upper Limit
Engineering Grade	0		
Super Engine. Grade	0		
High Intensity	0		
High Intensity, prismatic	0		

VARIABLE:
Failure Rate Path

Description

Four different types of failure rate paths describe the path of sign failures over time. The four choices are: a linear failure rate path; a logistic failure rate path; an exponential failure rate path; and an option to specify that replacement of a product only takes place when the maximum useful product life has been reached. These four options correspond to option numbers 1 through 4. The failure rate path impacts annual capital expenditures and at least one selection must be chosen for the model to function correctly.

How the Variable Affects the Model

The type of failure rate affects the rate at which the total desired stock of signs changes over time, which impacts Base Case annual sign purchases and total capital expenditures. A linear failure rate, for example, represents a relatively constant failure rate over the maximum life of the product. An exponential failure rate path, however, indicates a rapid increase in failures, which leads to increased product purchases and capital expenditures.

Baseline Assumptions

Based on conversations with the ADOT sign shop, and Traffic Engineering, a linear failure rate was chosen to model the pattern of product failures or replacements over time, since the percentage of failures remained at a relatively constant 10 % per year.

Major Uncertainties

The failure rate path for new products is not always known. The proportion of product failures and replacements relative to all ADOT installed signs may change with the adoption of a new sign sheeting material and may necessitate a reconsideration of the failure rate path. ADOT policy with regards to the minimum standards for retroreflectivity may also impact the shape of the failure rate path.

DATA SHEET: Failure Rate Path

Warning Signs

Product	Linear Curve	Logistic Curve	Exponential Curve	Replacement at End of Maximum Life
Engineering Grade	✓			
Super Engine. Grade	✓			
High Intensity	✓			
High Intensity, prismatic	✓			

Regulatory Signs

Product	Linear Curve	Logistic Curve	Exponential Curve	Replacement at End of Maximum Life
Engineering Grade	✓			
Super Engine. Grade	✓			
High Intensity	✓			
High Intensity, prismatic	✓			

VARIABLE:
Percent Change in Accident Rate due to a Change in the Retroreflectivity Coefficient

Description

This variable refers to the potential impact that a change in the coefficient of retroreflectivity (R_a) could have on accident rates, at the minimum required visibility distances (MRVD)'s as contained in the Federal Highway Administrations's recent report[32]. For purposes of discussion, a 10 % increase in R_a will be used during the RAP session to represent this change. The variable seeks to define how R_a (and the several factors that comprise it) impacts the driver's ability to: detect and recognize a sign, make a decision, initiate a maneuver and complete the maneuver safely.

How the Variable Affects the Model

This variable impacts the model through a percentage reduction in accidents which reduces overall accident costs.

Baseline Assumptions

There are currently no scientific studies indicating a definitive relationship between R_a and accident rates. It is the purpose of the RAP session to gain insights on this linkage from the professional and academic participants present.

Major Uncertainties

It is uncertain whether a causal link between R_a and accident rates exists, given the many variables that affect driver perception and performance.

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32 U.S. Department of Transportation, Federal Highways Administration, Minimum Retroreflectivity Requirements for Traffic Signs; Publication No. FHWA-RD-93-152, October, 1993.

DATA SHEET:
Percent Change in Accident Rate due to a Change in the Retroreflectivity Coefficient

	Median Value	10% Lower Limit	10% Upper Limit
Impact on Accident Rates: (No Impact=0%; Low=1 to 3%; Medium=3 to 10%; High=+10%)			

VARIABLE: Percent Change in Speed/Flow due to a Change in the Retroreflectivity Coefficient

Description

This variable refers to the potential impact that a change in the coefficient of retroreflectivity (R_a) could have on vehicle speed and traffic flow, at the minimum required visibility distances (MRVD)'s as contained in the Federal Highway Administrations's recent report. For purposes of discussion, a 10 % increase in R_a will be used during the RAP session to represent this change. The variable seeks to define how R_a (and the several factors that comprise it) impacts the driver's ability to: detect and recognize a sign, make a decision, initiate a maneuver and complete the maneuver safely.

How the Variable Affects the Model

This variable impacts the model through a percentage improvement in average vehicle speed, which affects vehicle operating costs and travel time.

Baseline Assumptions

There are no studies that indicate a definitive relationship between R_a and vehicle speed and traffic. It is the purpose of the RAP session to gain insights on this linkage from the professional and academic participants present.

Major Uncertainties

It is uncertain whether a causal link between R_a and speed/flow rates exists, given the many variables that affect driver perception and performance.

DATA SHEET:
Percent Increase in Speed/Flow due to a Change in the Retroreflectivity Coefficient

	Median Value	10% Lower Limit	10% Upper Limit
Impact on Speed/Flow: (No Impact=0%; Low=1 to 3%; Medium=3 to 10%; High=+10%)			

VARIABLE: Percent Change in Driver's Sense of Security due to a Change in the Retroreflectivity Coefficient

Description

This variable refers to the potential impact that a change in the coefficient of retroreflectivity (R_a) could have on the driver's sense of security, at the minimum required visibility distances (MRVD)'s as contained in the Federal Highway Administrations's recent report. For purposes of discussion, a 10 % increase in R_a will be used during the RAP session to represent this change.

A driver's "sense of security," is defined as the sum of all intangible factors that a driver would be willing to pay for that impact a driver's confidence to maneuver a vehicle safely and efficiently. The model uses a threshold analysis to estimate the willingness-to-pay amount for an increased sense of driver security due to a change in R_a. A percentage of the potential benefits derived from improvements in vehicle operating costs, safety and the value of time are used to forecast a threshold level value of benefits that a driver could be willing to pay for with a new sign sheeting material.

How the Variable Affects the Model

This variable does not directly impact the model, but rather, uses benefit estimates from economic effect categories to construct an indirect estimate for the value driver's would be willing- to-pay for an improved sense of driver security.

Baseline Assumptions

There are no studies that clearly indicate a relationship between R_a and vehicle speed and traffic. It is the purpose of the RAP session to gain insights on this linkage from the professional and academic participants present.

Major Uncertainties

It is uncertain whether drivers would be willing-to-pay for a sign-sheeting material with a certain level of R_a, given the many variables that affect driver perception and performance.

DATA SHEET:
Percent Change in Driver's Sense of Security due to 10% Increase in Retroreflectivity Coefficient

	Median Value	10% Lower Limit	10% Upper Limit
Impact on Driver's Sense of Security: (No Impact=0%; Low=1 to 3%; Medium=3 to 10%; High=+10%)			

Basic Assumptions of the RAP session

The analysis of sign sheeting materials was performed in accordance with the PEM methodology and the following assumptions:

1. A discount rate of 5% is used in the analysis.

2. The period of analysis is 30 years.

3. Estimates from the National Cooperative Highway Research Program (NCHRP) Report 346, Implementation Strategies for Sign Retroreflectivity Standards, were used to determine the number of regulatory and warning signs per mile in an urban area, 10 and 18 per mile, respectively.

4. The analysis used a 100 mile section of 6 lane interstate highway.

5. Average annual daily traffic was assumed to be 90,000.

6. Accident costs were calculated from data supplied in "The Costs of Highway Crashes", Federal Highway Administration, 1991. (see the Technical Appendix for more information)

7. The amount of sign sheeting material used for regulatory and warning signs was assumed to be 9 and 16 square feet, respectively.

8. Regulatory signs were assumed to represent black on white coloring and warning signs represented black on yellow. Data for each of the two types of signs was collected for these two color schemes.

9. The base case sign sheeting material was assumed to be engineering grade.

10. Bob pike at ADOT provided the data on centerline miles of interstate roadway in Arizona. The mileage is 1018 for rural interstates and 156 for urban interstates.

Data Sources

Arizona Department of Transportation

All of the necessary road characteristic data, as well as much of the highway user cost data and product attribute data was provided by Tom Huey at the ADOT sign factory, the PECOS II maintenance database, and other ADOT sources. Values for fabrication costs, which were solicited from the sign factory after the RAP session, are included in the technical appendix.

Vendor Sheets

Where available, vendor information sheets about each type of sign sheeting material were utilized to help derive the initial estimates for both the common and specific attributes.

Outside Experts

The experts that participated in the RAP session are listed in Table 1. These experts debated each product attribute variable and assigned the range of uncertainty around each of the attribute variables. The ranges and median estimates for each of these variables are located in the later in the Technical Appendix.

Many of the product attribute variables used in the cost-benefit analysis contain an element of uncertainty. To capture real-world variations in these variables, a risk analysis, which develops a probability range for each variable, was introduced. Each variable was assigned a range of uncertainty based on research and the opinions of experts in the field of sign sheeting materials.

Table 5.1
RAP Session Participants

Participant's Name	Title	Employer
Chuck Eaton	Arizona State Traffic Engineer	ADOT
Kevin Woudenberg	ATSSA Representative	Woudenberg Enterprises
Gene Hansen	Transportation Engineer	ADOT
Bill Putman	Heraeus DSET Laboratories	Heraeus
Gordon Pate		Zumar
Tom Huey	Sign Factory Supervisor	ADOT
David Elack	Assistant Traffic Engineer	ADOT
David Olivarez	Traffic Engineer	ADOT
Jeff Paniati	Program Manager	FHWA
Gerado Flintsh	Research Assistant	ADOT
Robert Skelton	Market Development	3M
Randall Akichika	National Sales Manager	Nippon Carbide
Ken Uding	Technical coordinator	Stimsonite

Other Sources

The model databases are the main analytical drivers for the final cost estimates, and therefore the final economic analysis. These databases represent average speed (used in value of time and vehicle operating costs), vehicle operating costs (in unit consumption rates), and incidence rates for accidents. The vehicle operating cost unit consumption databases are based on data from the MicroBENCOST model and Hickling's work with the NCHRP.

The general highway user cost data comes from a variety of sources. The cost figures, such as fuel costs, the value of time, and various accident costs were compiled from national data[33], Maricopa Association of Governments Transportation Planning Office data, and through an extensive research project into highway user costs completed for the National Cooperative Highway Research Program by Hickling[34].

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33 Sources include the Statistical Abstract of the United States 1992, U. S. Department of Commerce, Economics and Statistics Administration, Bureau of the Census, and "The Costs of Highway Crashes," Federal Highway Administration, 1991.

34 NCHRP Project 2-18: Research Strategies for Improving Highway User Cost-Estimating Methodologies (1993)

Data Inputs from RAP Session Participants

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Maintenance Labor Productivity - EG
NUMBER OF RESPONSES:
8

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.11	0.66	3.57

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.32	0.40	0.72

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.85	1.67	4.25

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.80	0.33	2.04

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.11	0.66	3.57

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Useful Economic Life of Sign - EG
NUMBER OF RESPONSES:
11

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	6.36	5.00	8.40

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.60	1.41	2.50

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.00	8.00	12.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.50	3.00	4.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	6.36	5.00	8.40

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Maximum Useful Economic Life of Sign - EG
NUMBER OF RESPONSES:
10

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.45	7.05	13.75

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.13	1.31	4.18

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	14.00	10.00	20.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	7.00	4.50	10.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.45	7.05	13.75

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Years Until Labor Productivity Reaches 50% - EG
NUMBER OF RESPONSES:
3

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Years Until Labor Productivity Reaches 95% - EG
NUMBER OF RESPONSES:
3

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Average Square Feet of Sign Material per Sign - EG
NUMBER OF RESPONSES:
3

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.00	8.00	10.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.00	8.00	10.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.00	8.00	10.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.00	8.00	10.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Sign-Sheeting Cost per Square Foot - EG
NUMBER OF RESPONSES:
6

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.88	0.73	0.93

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.11	0.07	0.11

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.10	0.90	1.15

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.75	0.70	0.80

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.88	0.73	0.93

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Maintenance Labor Productivity - SEG
NUMBER OF RESPONSES:
8

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.11	0.66	3.57

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.32	0.40	0.72

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.85	1.67	4.25

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.80	0.33	2.04

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.11	0.66	3.57

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Useful Economic Life of Sign - SEG
NUMBER OF RESPONSES:
11

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.55	7.36	11.64

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.30	1.15	1.87

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	11.00	10.00	15.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	7.00	6.00	8.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.55	7.36	11.64

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Maximum Useful Economic Life of Sign - SEG
NUMBER OF RESPONSES:
10

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	13.60	10.20	18.20

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.80	1.72	5.91

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	20.00	13.00	30.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.00	7.00	11.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	13.60	10.20	18.20

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Years Until Labor Productivity Reaches 50% - SEG
NUMBER OF RESPONSES:
3

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Years Until Labor Productivity Reaches 95% - SEG
NUMBER OF RESPONSES:
3

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Average Square Feet of Sign Material per Sign - SEG
NUMBER OF RESPONSES:
2

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.00	8.00	10.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.00	8.00	10.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.00	8.00	10.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.00	8.00	10.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Sign-Sheeting Cost per Square Foot - SEG
NUMBER OF RESPONSES:
6

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.11	1.95	2.35

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.02	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.15	1.95	2.35

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.10	1.95	2.35

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.11	1.95	2.35

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Average Square Feet of Sign Material per Sign - HI
NUMBER OF RESPONSES:
3

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	10.00	8.50	11.50

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.41	0.50	1.50

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	12.00	9.00	13.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.00	8.00	10.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	10.00	8.50	11.50

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Sign-Sheeting Cost per Square Foot - HI
NUMBER OF RESPONSES:
6

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.74	3.72	3.75

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.01	0.02

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.74	3.73	3.80

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.74	3.70	3.74

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.74	3.72	3.75

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Useful Economic Life of Sign - HI
NUMBER OF RESPONSES:
10

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	10.30	8.40	13.10

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.85	1.69	2.43

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	12.00	10.00	16.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	7.00	6.00	8.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	10.30	8.40	13.10

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Maximum Useful Economic Life of Sign - HI
NUMBER OF RESPONSES:
10

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	15.70	11.40	20.10

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.00	2.11	6.58

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	20.00	15.00	30.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	12.00	7.00	14.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	15.70	11.40	20.10

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Maintenance Labor Productivity - HI
NUMBER OF RESPONSES:
8

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.20	0.71	3.63

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.30	0.37	0.75

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.85	1.67	4.25

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.00	0.50	2.04

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.20	0.71	3.63

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Years Until Labor Productivity Reaches 50% - HI
NUMBER OF RESPONSES:
3

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Years Until Labor Productivity Reaches 95% - HI
NUMBER OF RESPONSES:
3

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Average Square Feet of Sign Material per Sign - HIP
NUMBER OF RESPONSES:
2

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.00	8.00	10.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.00	8.00	10.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.00	8.00	10.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.00	8.00	10.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Sign-Sheeting Cost per Square Foot - HIP
NUMBER OF RESPONSES:
6

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.74	3.71	3.75

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.02

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.74	3.71	3.80

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.74	3.70	3.74

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.74	3.71	3.75

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Useful Economic Life of Sign - HIP
NUMBER OF RESPONSES:
10

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.80	8.00	12.20

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.99	1.73	2.64

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	12.00	10.00	16.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	7.00	6.00	8.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.80	8.00	12.20

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Maximum Useful Economic Life of Sign - HIP
NUMBER OF RESPONSES:
10

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	15.00	10.70	19.40

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.79	2.57	7.21

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	20.00	15.00	30.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	8.00	6.00	10.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	15.00	10.70	19.40

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Maintenance Labor Productivity - HIP
NUMBER OF RESPONSES:
8

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.20	0.71	3.63

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.30	0.37	0.75

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.85	1.67	4.25

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.00	0.50	2.04

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.20	0.71	3.63

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Years Until Labor Productivity Reaches 50% - HIP
NUMBER OF RESPONSES:
3

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
REGULATORY SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Years Until Labor Productivity Reaches 95% - HIP
NUMBER OF RESPONSES:
3

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Maintenance Labor Productivity - EG
NUMBER OF RESPONSES:
8

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.03	1.02	3.76

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.21	0.29	0.68

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.50	1.67	4.25

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.85	0.75	2.04

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.03	1.02	3.76

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Sign-Sheeting Cost per Square Foot - EG
NUMBER OF RESPONSES:
8

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.87	0.73	0.92

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.09	0.07	0.09

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.10	0.90	1.15

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.75	0.70	0.80

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.87	0.73	0.92

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Useful Economic Life of Sign - EG
NUMBER OF RESPONSES:
11

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	6.36	5.10	8.10

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.60	1.45	2.39

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.00	8.00	12.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.50	3.00	4.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	6.36	5.10	8.10

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Maximum Useful Economic Life of Sign - EG
NUMBER OF RESPONSES:
10

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.45	7.05	13.75

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.13	1.31	4.18

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	14.00	10.00	20.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	7.00	4.50	10.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.45	7.05	13.75

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Years Until Labor Productivity Reaches 50% - EG
NUMBER OF RESPONSES:
4

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Years Until Labor Productivity Reaches 95% - EG
NUMBER OF RESPONSES:
4

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Average Square Feet of Sign Material per Sign - EG
NUMBER OF RESPONSES:
2

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	16.00	14.00	17.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	16.00	14.00	17.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	16.00	14.00	17.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	16.00	14.00	17.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Maintenance Labor Productivity - SEG
NUMBER OF RESPONSES:
8

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.03	1.28	3.76

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.21	0.81	0.68

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.50	3.30	4.25

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.85	0.75	2.04

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.03	1.28	3.76

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Useful Economic Life of Sign - SEG
NUMBER OF RESPONSES:
11

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.55	7.55	11.64

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.30	1.16	1.87

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	11.00	10.00	15.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	7.00	6.00	8.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.55	7.55	11.64

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Maximum Useful Economic Life of Sign - SEG
NUMBER OF RESPONSES:
10

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	13.60	10.20	18.20

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.80	1.72	5.91

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	20.00	13.00	30.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.00	7.00	11.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	13.60	10.20	18.20

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Years Until Labor Productivity Reaches 50% - SEG
NUMBER OF RESPONSES:
4

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Years Until Labor Productivity Reaches 95% - SEG
NUMBER OF RESPONSES:
4

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Average Square Feet of Sign Material per Sign - SEG
NUMBER OF RESPONSES:
2

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	16.00	14.00	17.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	16.00	14.00	17.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	16.00	14.00	17.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	16.00	14.00	17.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Sign-Sheeting Cost per Square Foot - SEG
NUMBER OF RESPONSES:
8

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.11	1.95	2.35

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.02	0.01	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.15	1.95	2.35

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.10	1.93	2.35

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.11	1.95	2.35

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Average Square Feet of Sign Material per Sign - HI
NUMBER OF RESPONSES:
3

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	16.00	14.00	17.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	16.00	14.00	17.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	16.00	14.00	17.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	16.00	14.00	17.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Sign-Sheeting Cost per Square Foot - HI
NUMBER OF RESPONSES:
8

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.74	3.72	3.75

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.01	0.02

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.74	3.73	3.80

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.74	3.70	3.74

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.74	3.72	3.75

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Useful Economic Life of Sign - HI
NUMBER OF RESPONSES:
11

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	10.45	8.55	13.18

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.83	1.67	2.33

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	12.00	10.00	16.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	7.00	6.00	8.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	10.45	8.55	13.18

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Maximum Useful Economic Life of Sign - HI
NUMBER OF RESPONSES:
10

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	15.70	11.40	20.10

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.00	2.11	6.58

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	20.00	15.00	30.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	12.00	7.00	14.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	15.70	11.40	20.10

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Maintenance Labor Productivity - HI
NUMBER OF RESPONSES:
8

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.09	1.08	3.82

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.19	0.25	0.71

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.50	1.67	4.25

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.85	0.75	2.04

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.09	1.08	3.82

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Years Until Labor Productivity Reaches 50% - HI
NUMBER OF RESPONSES:
4

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Years Until Labor Productivity Reaches 95% - HI
NUMBER OF RESPONSES:
4

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Average Square Feet of Sign Material per Sign - HIP
NUMBER OF RESPONSES:
2

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	16.00	14.00	17.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	16.00	14.00	17.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	16.00	14.00	17.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	16.00	14.00	17.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Sign-Sheeting Cost per Square Foot - HIP
NUMBER OF RESPONSES:
8

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.74	3.71	3.75

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.02

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.74	3.71	3.80

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.74	3.70	3.74

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.74	3.71	3.75

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Useful Economic Life of Sign - HIP
NUMBER OF RESPONSES:
10

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.80	8.00	12.20

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.99	1.73	2.64

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	12.00	10.00	16.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	7.00	6.00	8.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	9.80	8.00	12.20

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Maximum Useful Economic Life of Sign - HIP
NUMBER OF RESPONSES:
10

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	15.00	10.70	19.40

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	3.79	2.57	7.21

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	20.00	15.00	30.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	8.00	6.00	10.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	15.00	10.70	19.40

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Maintenance Labor Productivity - HIP
NUMBER OF RESPONSES:
8

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.09	1.08	3.82

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.19	0.25	0.71

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.50	1.67	4.25

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	1.85	0.75	2.04

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	2.09	1.08	3.82

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Years Until Labor Productivity Reaches 50% - HIP
NUMBER OF RESPONSES:
4

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

ADOT COST-BENEFIT AND RISK ANALYSIS OF
WARNING SIGN-SHEETING MATERIAL
SUMMARY OF RAP PANEL RANGES
VARIABLE:
Years Until Labor Productivity Reaches 95% - HIP
NUMBER OF RESPONSES:
4

	AVERAGE		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

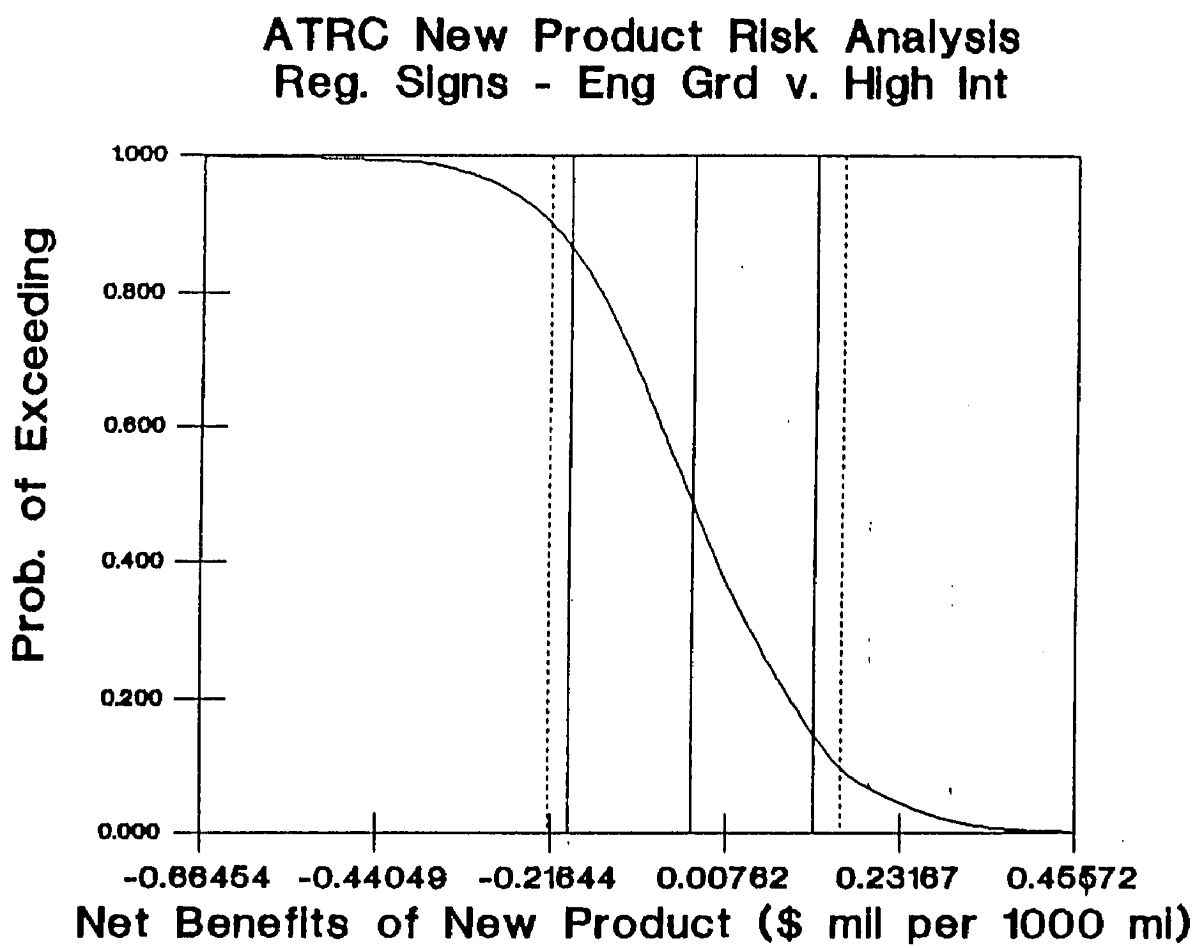
	STANDARD DEVIATION		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

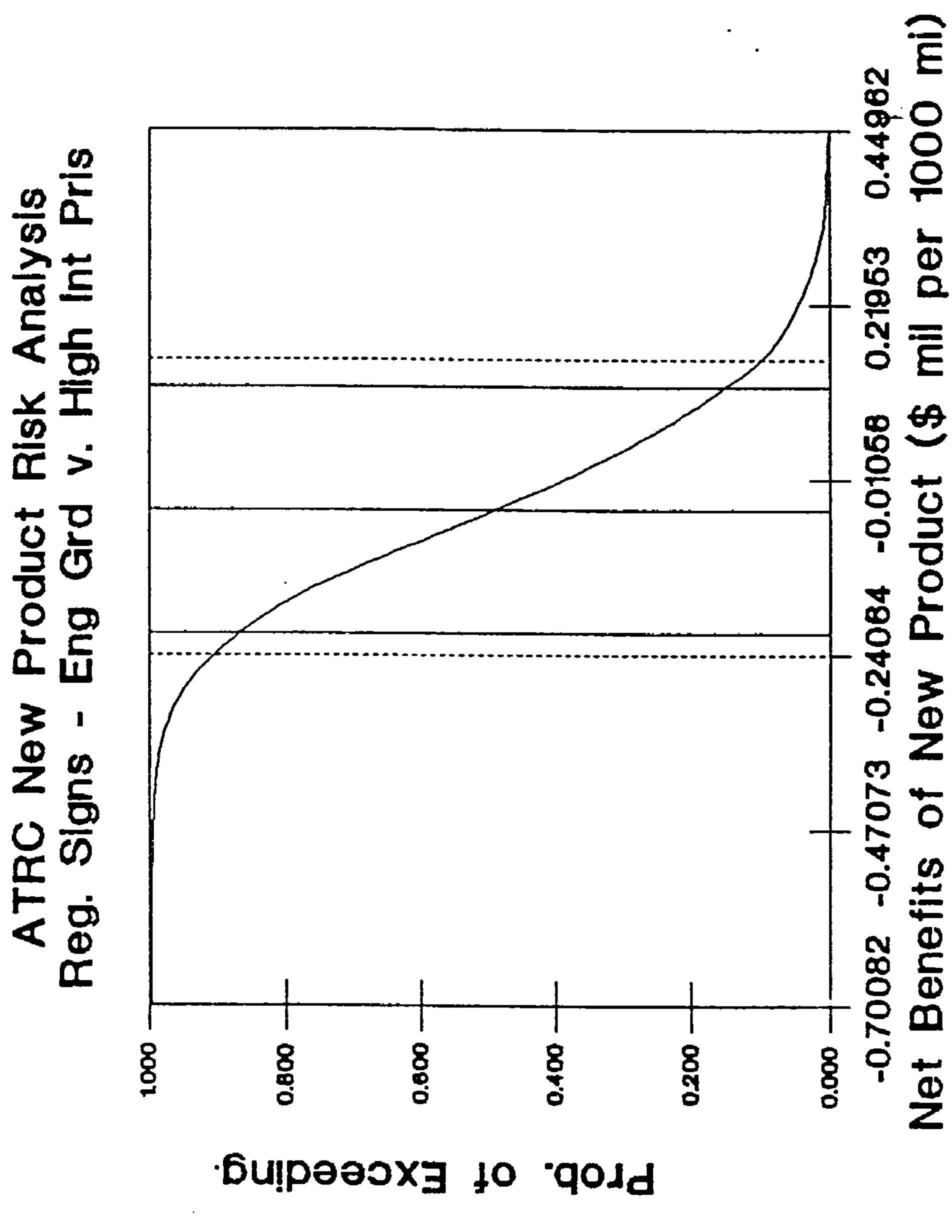
	MAXIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

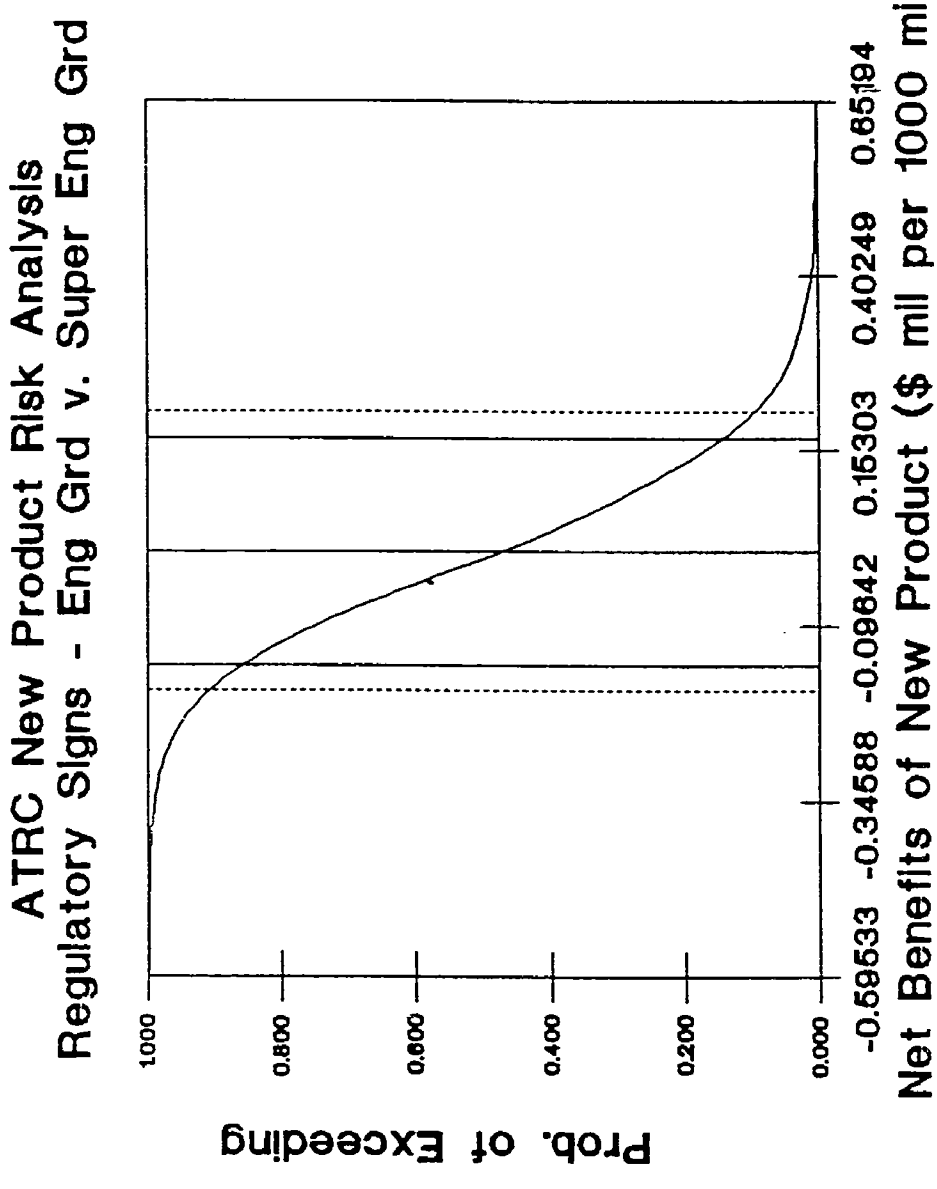
	MINIMUM		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

	VALUES REC. BY HICKLING		
	MEDIAN	LOWER 10%	UPPER 10%
1994	0.00	0.00	0.00

Probability Distribution Graphs of PEM Sign Sheeting Analysis

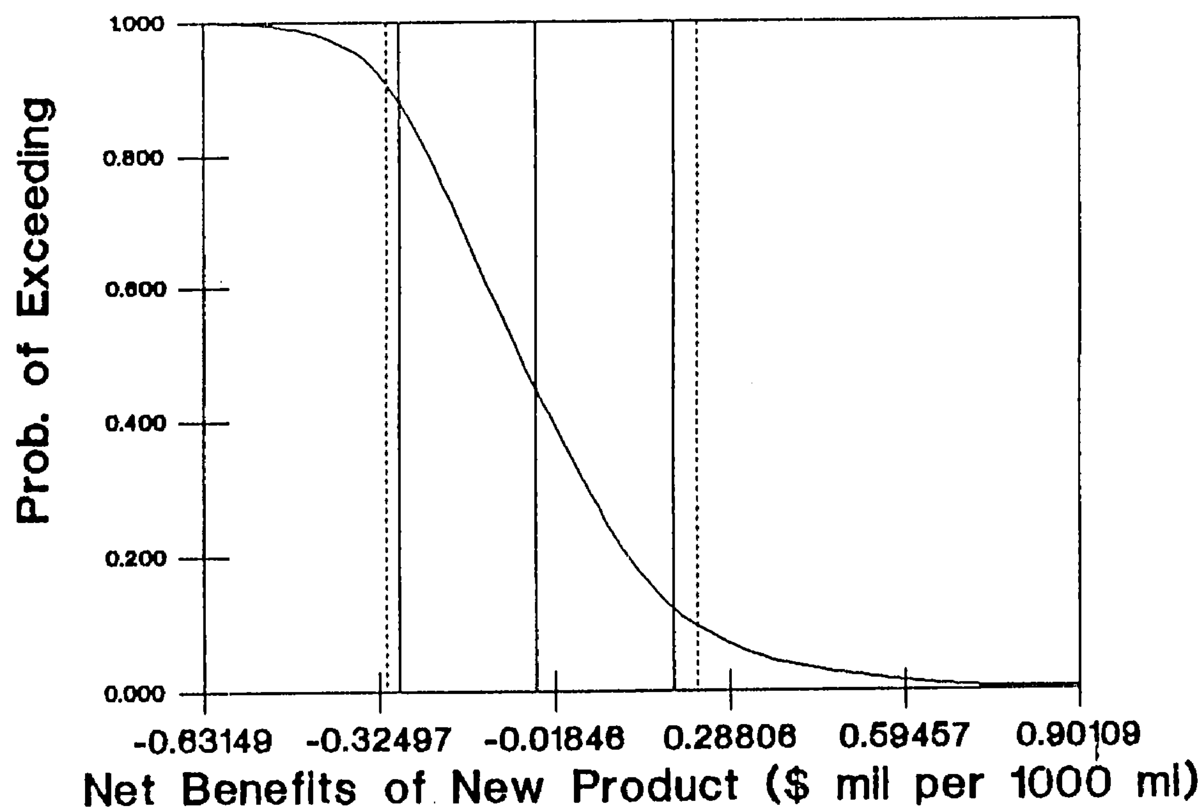

ATRC New Product Risk Analysis
Reg. Signs - Eng Grd v. High Int
Prob. of Exceeding
1.000
0.800
0.600
0.400
0.200
0.000
-0.66454
-0.44049
-0.21644
0.00762
0.23167
0.45572
Net Benefits of New Product ($ mil per 1000 ml)


ATRC New Product Risk Analysis
Reg. Signs - Eng Grd v. High Int Prls
Prob. of Exceeding
1.000
0.800
0.600
0.400
0.200
0.000
-0.70082
-0.47073
-0.24064
-0.01056
0.21953
0.44962
Net Benefits of New Product ($ mil per 1000 mi)

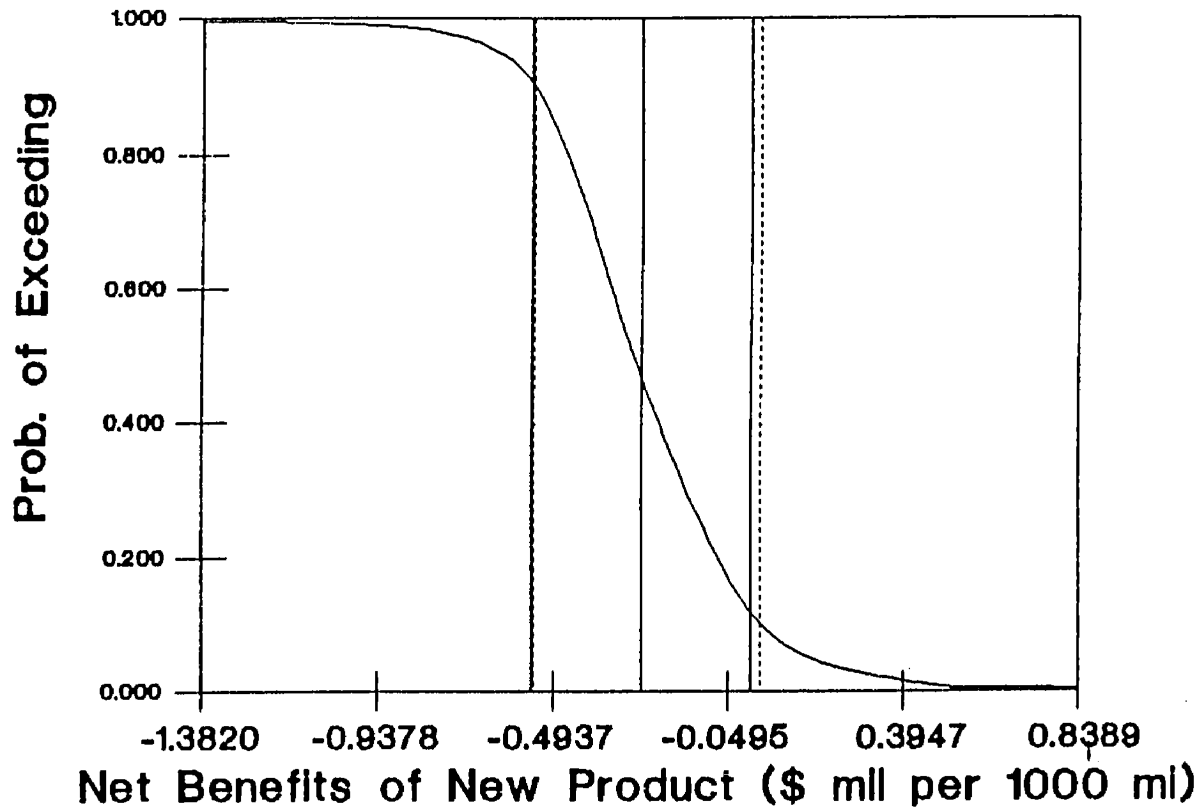


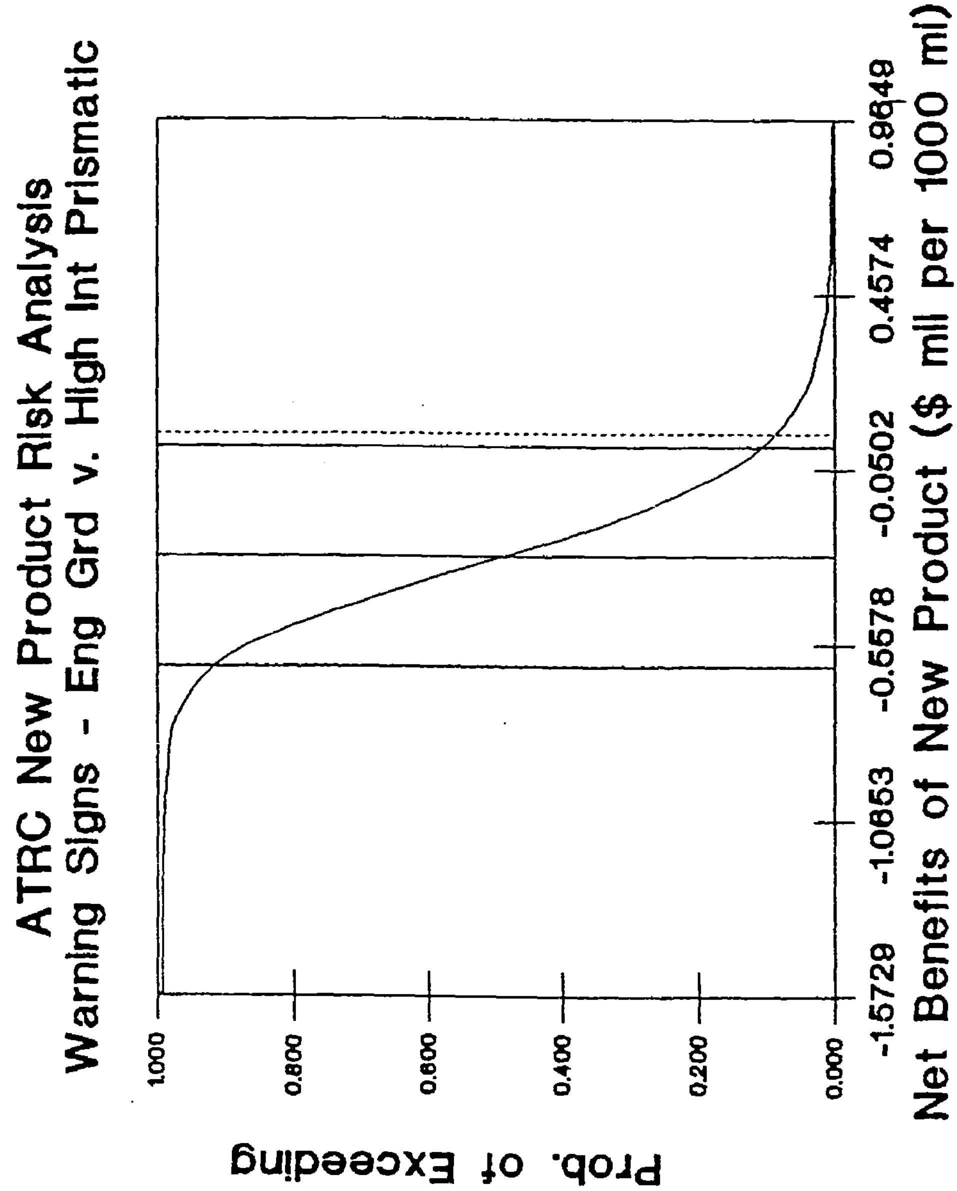
ATRC New Product Risk Analysis
Regulatory Signs - Eng Grd v. Super Eng Grd
Prob. of Exceeding
1.000
0.800
0.600
0.400
0.200
0.000
-0.59533 -0.34588 -0.09642 0.15303 0.40249 0.65194
Net Benefits of New Product ($ mil per 1000 mi)

ATRC New Product Risk Analysis
Warning Signs - Eng Grd v. Super Eng Grd



ATRC New Product Risk Analysis
Warning Signs - Eng Grd v. High Intensity




ATRC New Product Risk Analysis
Warning Signs - Eng Grd v. High Int Prismatic
Prob. of Exceeding
1.000
0.800
0.600
0.400
0.200
0.000
-1.5729
-1.0653
-0.5578
-0.0502
0.4574
0.9649
Net Benefits of New Product ($ mil per 1000 mi)

HIGHWAY USER COST DATA

	Value
Highway Capacity	2000
Peak Period Factor	1.0642
Value of Life	$2,987,054
Value of Injury	$57,574
Value of PDO Accident	$3,314
Average Value of Time	$7.86
Maximum Pavement Effect on Accident Rates	0.02
Maximum Design Speed Effect on Accident Rates	0.02
Maximum Pavement Effect on Speed	0.10
Maximum Design Speed Effect on Speed	0.00
Maximum Disruption Effect on Accident Rates	0.10
Maximum Security Effect on Accident Rates	0.00
Fuel Price	$1.00
Tire Price	$80.00
Oil Price	$3.40
Maintenance and Repair Costs	$69.96
Depreciation Costs	$10,057
Effect of Pavement on Vehicle Operating Costs, Slope	-0.1399
Effect of Pavement on Vehicle Operating Costs, Intercept	0.6643

Data needed for Cost Benefit Analysis
(for current product and new product)

Unit Product Cost (Material Cost)

Useful Economic Life (Years of Service)

Maximum Economic Life

Labor Productivity (how many units installed per day, etc...)

Equipment needed for installation and hourly cost

Crew size (and labor costs)

Time of day that installation or maintenance is performed

Estimated duration of traffic disruption .. lane closure/full width closure

Need for special start-up or additional equipment

Need for start-up training costs

The failure rate path (pattern of product failures over time).

PEM COMPUTER SOURCE CODES

```
$NOTRUNCATE
C
      SUBROUTINE MODEL0
C
C
$INCLUDE:'RA.INC'
C
      COMMON /PAR1/METRIC,FTBC,FTNP,LANEBC,LANENP,
     &  LENGTH,AADT0,AADTI,PSIBC,PSIRAM,PSIRPM,PLIFBC,PXBC,HICAP,PPF,
     &  VLIFE,VINJ,VPDO,VTIME,MPEAR,MPES,MDEAR,FUEL,TIRE,
     &  OIL,MANDR,DEPR,DRATE,PERIOD,UPABC,UPANP,
     &  XBC,XNP,UBC,IABC,VANBC,VANNP,EULBC,EULNP,MULBC,MULNP,PABC,
     &  PANP,INVBC,YRSSBC,SSGBC,INVNP,YRSSNP,SSGNP,ADDEX,ADDTX,ADDYR,
     &  TEXNP,ICCBC,ICCNP,DISCBC,DISCNP,PLEGBC,PLEGNP,PCSBC,PCSNP,
     &  PCDBC,PCDNP,ASCBC,ASCNP,ACCBC,ACCNP,FADOTW,FPRDBC,FPRDNP,
     &  T50PF,T95PF,FEQXBC,FEQXNP,FOMCBC,FOMCNP,FORBC,FORNP,FSRBC,
     &  FSRNP,ADOTWG,PRODBC,PRODNP,T50PYP,T95PYP,EQXBC,EQXNP,DDELBC,
     &  DDELNP,PADBC,PADNP,FRATP,FRATN,ADOTAW,ADPRO,T50APN,T95APN,
     &  PSINP,PLIFNP,PXNP,VISP,VISI,VISF,FLOW
      COMMON /RESOUT/NETB,BCAP,BMAIN,BVOC,BSAFE,BVOT,BLIA,BPRO,BDIS,
     &  BENV,SMCAPB,SMMANB,SMVOCB,SMSAFB,SMVOTB,SMLIAB,SMPROB,SMDISB,
     &  SMTCBC,SMCAPN,SMMANN,SMVOCN,SMSAFN,SMVOTN,SMLIAN,SMPRON,
     &  SMDISN,SMTCNP
      REAL METRIC,FTBC,FTNP,LANEBC,LANENP,LENGTH,AADT0,
     &  AADTI,PSIBC,PSIRAM,PSIRPM,PLIFBC,PXBC,HICAP,PPF,VLIFE,VINJ,
     &  VPDO,VTIME,MPEAR,MPES,MDEAR,FUEL,TIRE,OIL,MANDR,
     &  DEPR,DRATE,PERIOD,UPABC,UPANP,XBC,XNP,UBC,
     &  IABC,VANBC,VANNP,EULBC,EULNP,MULBC,MULNP,PABC,PANP,INVBC,
     &  YRSSBC,SSGBC,INVNP,YRSSNP,SSGNP,ADDEX,ADDTX,ADDYR,TEXNP,ICCBC,
     &  ICCNP,DISCBC,DISCNP,PLEGBC,PLEGNP,PCSBC,PCSNP,PCDBC,PCDNP,
     &  ASCBC,ASCNP,ACCBC,ACCNP,FADOTW,FPRDBC,FPRDNP,T50PF,T95PF,
     &  FEQXBC,FEQXNP,FOMCBC,FOMCNP,FORBC,FORNP,FSRBC,FSRNP,ADOTWG,
     &  PRODBC,PRODNP,T50PYP,T95PYP,EQXBC,EQXNP,DDELBC,DDELNP,PADBC,
     &  PADNP,FRATP,FRATN,ADOTAW,ADPRO,T50APN,T95APN,PSINP,PLIFNP,
     &  PXNP,VISP,VISI,VISF,FLOW
      REAL NETB,BCAP,BMAIN,BVOC,BSAFE,BVOT,BLIA,BPRO,BDIS,BENV,
     &  SMCAPB,SMMANB,SMVOCB,SMSAFB,SMVOTB,SMLIAB,SMPROB,SMDISB,
     &  SMTCBC,SMCAPN,SMMANN,SMVOCN,SMSAFN,SMVOTN,SMLIAN,SMPRON,
     &  SMDISN,SMTCNP
C
C -- INPUT VARIABLE DESCRIPTIONS
C METRIC      - Metric Convertion (0=No,1=Yes) (Independent)
C FTBC        - Facility Type (1-12) - BC (Independent)
C FTNP        - Facility Type (1-12) - NP (Independent)
C LANEBC      - Number of Lanes - Base Case (Independent)
C LANENP      - Number of Lanes - New Prod (Independent)
C LENGTH      - Roadway Length (Independent)
C AADT0       - AADT in Year 0 (Independent)
C AADTI       - AADT - Annual Increment (Independent)
C PSIBC       - Current PSI - Base Case (Independent)
C PSIRAM      - PSI Before Resurfacing (Independent)
C PSIRPM      - PSI After Resurfacing (Independent)
C PLIFBC      - Expected Pavement Life - BC (Independent)
C PXBC        - Resurfacing Costs - Base Case (Independent)
C HICAP       - Highway Capacity (Independent)
C PPF         - Peak Period Factor (Independent)
C VLIFE       - Value of Life (Independent)
C VINJ        - Value of Injury (Independent)
C VPDO        - Value of PDO Accident (Independent)
C VTIME       - Value of Time (Independent)
C MPEAR       - Max Pav. Eff. on Acc. Rates (Independent)
C MPES        - Max Pav. Eff. on Speed (Independent)
C MDEAR       - Disruption Eff. on Accident Rates (Independent)
C FUEL        - Fuel Price (Independent)
C TIRE        - Tire Price (Independent)
C OIL         - Oil Price (Independent)
C MANDR       - M&R Costs (Independent)
C DEPR        - Depreciation Costs (Independent)
C DRATE       - Discount Rate (Independent)
C PERIOD      - Period of Analysis (1 to 50) (Independent)
C UPABC       - # of Units per Product - BC (Independent)
C UPANP       - # of Units per Product - NP (Independent)
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 73 C XBC       - Material Cost per Unit - BC (Independent)
 74 C XNP       - Material Cost per Unit - NP (Independent)
 75 C UBC       - Current Products in Use - BC (Independent)
 76 C IABC      - Annual Increase in Products - BC (Independent)
 77 C VANBC     - % of Products Vand/Hit per Yr - BC (Independent)
 78 C VANNP     - % of Products Vand/Hit per Yr - NP (Independent)
 79 C EULBC     - Useful Economic Life - BC (Independent)
 80 C EULNP     - Useful Ecoomic Life - NP (Independent)
 81 C MULBC     - Max Useful Economic Life - BC (Dependent On eulbc)
 82 C MULNP     - Max Useful Economic Life - NP (Dependent On eulnp)
 83 C PABC      - % of Products Held as Inv - BC (Independent)
 84 C PANP      - % of Products Held as Inv - NP (Independent)
 85 C INVBC     - PO - Products at 1st YR of S.S. (Independent)
 86 C YRSSBC    - PO - Years to Steady State. (Independent)
 87 C SSGBC     - PO - Steady State Product Growth (Independent)
 88 C INVNP     - PI - Products at 1st Yr of S.S. (Independent)
 89 C YRSSNP    - PI - Years to Steady State (Independent)
 90 C SSGNP     - PI - Steady State Product Growth (Independent)
 91 C ADDEX     - Start-up Equipment Costs (Independent)
 92 C ADDTX     - Start-up Training Costs (Independent)
 93 C ADDYR     - Annual Training & Equipment Costs (Independent)
 94 C TEXNP     - Testing & Evaluation Costs - NP (Independent)
 95 C ICCBC     - Inventory & Carrying Costs - BC (Independent)
 96 C ICCNP     - Inventory & Carrying Costs - NP (Independent)
 97 C DISCBC    - Disposal & Salvage Costs - BC (Independent)
 98 C DISCNP    - Disposal & Salvage Costs - NP (Independent)
 99 C PLEGBC    - # of Claims per 100 Failures-BC (Independent)
100 C PLEGNP    - # of Claims per 100 Failures-NP (Independent)
101 C PCSBC     - % of Claims Settled - BC (Independent)
102 C PCSNP     - % of Claims Settled - NP (Independent)
103 C PCDBC     - % of Claims Dropped - BC (Independent)
104 C PCDNP     - % of Claims Dropped - NP (Independent)
105 C ASCBC     - Average Settlement Costs - BC (Independent)
106 C ASCNP     - Average Settlement Costs - NP (Independent)
107 C ACCBC     - Average Court Costs - BC (Independent)
108 C ACCNP     - Average Court Costs - NP (Independent)
109 C FADOTW    - ADOT Fabrication Labor Wage (Independent)
110 C FPRDBC    - Fab. Labor Productivity - BC (Independent)
111 C FPRDNP    - Fab. Labor Productivity - NP (Independent)
112 C T50PF     - Time to F. L. Prod.= 50% (Independent)
113 C T95PF     - Chg in Time to F. L. Prod.= 95% (Independent)
114 C FEQXBC    - Hourly Fab. Equip Costs - BC (Independent)
115 C FEQXNP    - Hourly Fab. Equip Costs - NP (Independent)
116 C FOMCBC    - Other Material Cost - BC (Independent)
117 C FOMCNP    - Other Material Cost - NP (Independent)
118 C FORBC     - Overhead Rate - BC (Independent)
119 C FORNP     - Overhead Rate - NP (Independent)
120 C FSRBC     - Scrap Rate - BC (Independent)
121 C FSRNP     - Scrap Rate - NP (Independent)
122 C ADOTWG    - ADOT Maintenance Labor Wage (Independent)
123 C PRODBC    - Main. Labor Productivity - BC (Independent)
124 C PRODNP    - Main. Labor Productivity - NP (Independent)
125 C T50PYP    - Time to M. L. Prod.= 50% (Independent)
126 C T95PYP    - Chg in Time to M. L. Prod.= 95% (Independent)
127 C EQXBC     - Hourly Main. Equip Costs - BC (Independent)
128 C EQXNP     - Hourly Main. Equip Costs - NP (Independent)
129 C DDELBC    - Expected Disruption Delay - BC (Independent)
130 C DDELNP    - Expected Disruption Delay - NP (Independent)
131 C PADBC     - % of AADT Effected by Dis. - BC (Independent)
132 C PADNP     - % of AADT Effected by Dis. - NP (Independent)
133 C FRATP     - Failure Rate Path-BC(1,2,3,4) (Independent)
134 C FRATN     - Failure Rate Path-NP(1,2,3,4) (Independent)
135 C ADOTAW    - Annual Pers. Cost of Eff. Emp. (Independent)
136 C ADPRO     - % Admin Improv. Realized (Independent)
137 C T50APN    - Time to Admin Prod = 50% (Independent)
138 C T95APN    - Chg in Time to Admin Prod=95% (Independent)
139 C PSINP     - PSI of Pav. with New Prod (Independent)
140 C PLIFNP    - Exp. Pav. Life with New Prod (Independent)
141 C PXNP      - Resurf. Costs with New Prod (Independent)
142 C VISP      - % Red. in PDO Accidents w/NP (Independent)
143 C VISI      - % Red. in Injury Accidents w/NP (Independent)
144 C VISF      - % Red. in Fatal Accidents w/NP (Independent)
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C FLOW          - % Impr. in Speed/Flow w/NP (Independent)
C
C -- OUTPUT RESULT DESCIPTIONS
C NETB          - Net Benefits of New Product
C BCAP          - Net Capital Savings
C BMAIN         - Net Maintenance Savings
C BVOC          - Net VOC Savings
C BSAFE         - Net Safety Savings
C BVOT          - Net Time Savings
C BLIA          - Net Liability Savings
C BPRO          - Net Productivity Savings
C BDIS          - Net Disruption Savings
C BENV          - A and E Threshold
C SMCAPB        - Base Case - Capital Costs
C SMMANB        - Base Case - Maintenance Costs
C SMVOCB        - Base Case - VOC Costs
C SMSAFB        - Base Case - Safety Costs
C SMVOTB        - Base Case - Time Costs
C SMLIAB        - Base Case - Liability Costs
C SMPROB        - Base Case - Productivity Costs
C SMDISB        - Base Case - Disruption Costs
C SMTCBC        - Base Case - Total Costs
C SMCAPN        - New Prod - Capital Costs
C SMMANN        - New Prod - Maintenance Costs
C SMVOCN        - New Prod - VOC Costs
C SMSAFN        - New Prod - Safety Costs
C SMVOTN        - New Prod - Time Costs
C SMLIAN        - New Prod - Liability Costs
C SMPRON        - New Prod - Productivity Costs
C SMDISN        - New Prod - Disruption Costs
C SMTCNP        - New Prod - Total Costs
C
C OTHER USEABLE VARIABLES:
C  NYEAR  -- NUMBER OF YEARS IN SCENARIO
C  ISYEAR -- START YEAR OF SCENARIO
C  RANDOM(NFACT+1) WILL RETURN A RANDOM NUMBER [0..1]
C
C
      INTEGER YR, I, J, K, L, AGE
      REAL AADT(50), PSIWEP(50), PSIWNP(50), VCBC(50), VCNP(50)
      REAL AVSPBC(50), AVSPNP(50) ,ADSPBC(50), ADSPNP(50), ADSSNP(50)
      REAL PDOINC(50), INJINC(50), FATINC(50), ADSFBC(50), SAFETY(50)
      REAL PDOINP(50), INJINP(50), FATINP(50), ADSFNP(50), SAFENP(50)
      REAL FUERTB(50), TIRRTB(50), OILRTB(50), MARRTB(50), DEPRTB(50)
      REAL FUERTN(50), TIRRTN(50), OILRTN(50), MARRTN(50), DEPRTN(50)
      REAL TOTVOC(50), VOTBC(50), VOTNP(50), PVVOTB(50), PVVOTN(50)
      REAL PVSAFB(50), PVSAFN(50), PVMXBC(50), PVMXNP(50), PRNP(50)
      REAL HISPDB(50), HISPDN(50), LOSPDB(50), TIME(50), RXNP(50)
      REAL LOSPDN(50), CYFUEB(50), CYTIRB(50), CYOILB(50), CYMARB(50)
      REAL CYDEPB(50), CYFUEN(50), CYTIRN(50), CYOILN(50), CYMARN(50)
      REAL CYDEPN(50), FUECCB(50), TIRCCB(50), OILCCB(50), MARCCB(50)
      REAL DEPCCB(50), FUECCN(50), TIRCCN(50), OILCCN(50), MARCCN(50)
      REAL DEPCCN(50), VOCBC(50), VOCNP(50), ADVOCB(50), ADVOCN(50)
      REAL PVVOCB(50), PVVOCN(50), PAMXBC(50), PAMXNP(50), DEC(50)
      REAL PSIDM1, PSIDM2, FR(50), TCAPBC, TCAPNP, REPBC(50), RXBC(50)
      REAL UMBC(50), UMNP(50), CAPBC(50), CAPNP(50), REPNP(50)
      REAL PVKBC(50), PVKNP(50), TLSBC(50), TLSNEW(50), PVASSN(50)
      REAL PVTLBC(50), PVTLNP(50), ACBC(50), PURBC(50), FPRNP(50)
      REAL LIXBC(50), PVLXBC(50), T1, T2, ACNP(50), PURNP(50)
      REAL LIXNP(50), PVLXNP(50), COLD(50), CNEW(50), DUMYR, APRNP(50)
      REAL PRMXBC(50), TMXBC(50), PRMXNP(50), TMXNP(50), DHRNP(50)
      REAL DXBC(50), DXNP(50), MHRBC(50), MHRNP(50), DHRBC(50)
      REAL TACBC(50), TACNP(50), TASBC(50), TASNP(50), PVTABC(50)
      REAL PVTANP(50), TAPBC, TAPNP, ALPHA, BETA, DISBC(50), DISNP(50)
      REAL VECBC(50), VECNP(50), DSBC(50), DSNP(50), DVCBC(50)
      REAL DVCNP(50), PVDISB(50), PVDISN(50), INVOLD(50), INVNEW(50)
      REAL TOLD(50), TNEW(50), PRECPB(50), PRECPN(50), ASSNP(50)
      REAL DTNP(50), DTBC(50), FDUMB, FDUMN, LIXNEW(50)
      REAL APPBC(50), PRECPO(50), TCAPOL, CAPOLD(50), PUROLD(50)
      REAL INVB(50), TCSBC(50), REPOLD(50), LPFNP(50), LPFBC(50)
      REAL TLSOLD(50), PRMXOL(50), PRMXNE(50), RXOLD(50), TACOLD(50)
      REAL ACNEW(50), ACOLD(50), LIXOLD(50), FRN(50), SCNP(50)
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      REAL VISP_YR(50), VISI_YR(50), VISF_YR(50), FLOW_YR(50), PI(50)

C ****************************************************
C ******************DATA STATEMENTS********************
      DIMENSION PDO(12,4)
      DIMENSION INJ(12,4)
      DIMENSION FAT(12,4)
      DIMENSION SPD(12,6)
      DIMENSION SPDCYC(6,6)
      DIMENSION VOC(5,4)

      DATA ((PDO(I,J),I=1,12), J=1,4)/-9.578875,-20.589380,
     & -11.304067,20.677735,-9.987993,8.496033,-14.017213,
     & -11.512925,-11.512925,-11.844491,-6.701941,-13.881860,
     & 0.000257,0.000286,0.000574,-0.000758,0.000847,-0.000501,
     & 0.000983,1.4109602E-23,1.4109602E-23,0.001374,0.001094,
     & 0.000980,65,90,275,375,345,590,415,65,130,185,175,175,
     & 75,30,100,140,315,195,175,0,0,55,55,45/

      DATA ((INJ(I,J),I=1,12), J=1,4)/-9.13355,-9.13355,-14.01721,
     & 20.67773,-10.17405,5.43785,-13.51453,-11.51292,-19.33034,
     & -11.61339,-6.34423,-11.14553,0.00031,0.00031,0.00098,
     & -0.00076,0.00085,-0.00042,0.00097,1.4109602E-23,0.00114,
     & 0.00137,0.00069,0.00057,35,35,185,225,195,335,275,45,120,
     & 150,150,150,25,25,35,140,200,245,60,0,30,45,80,75/

      DATA ((FAT(I,J),I=1,12), J=1,4)/14.96449,-11.5129,13.94088,
     & 20.67745,5.207635,8.100043,8.680754,16.08374,-11.5129,
     & 16.08390,16.08392,19.33007,-0.00065,1.4E-23,-0.00098,
     & -0.00076,-0.00062,-0.00050,-0.00051,-0.00157,1.4E-23,
     & -0.00157,-0.00157,-0.00114,1,1.5,2,2,2,2,2,1.5,2.5,3.5,
     & 3,3,1,0,1,0.5,2,4.5,2,0.5,0,1.5,2,0.5/

      DATA ((SPD(I,J),I=1,12), J=1,6)/-10.0,0.0,-14.0,-14.0,-8.8,
     & -19.1,-17.5,-13.8,-20.0,-15.0,-22.9,-19.4,60,60,60,60,35,48,
     & 48,55,55,60,60,60,0.8,0.0,0.5,0.5,0.9,0.8,0.8,0.8,0.8,0.9,
     & 0.3,0.3,86.45466,58.56514,50.45392,50.45392,35.83187,29.08889,
     & 34.40561,46.88923,41.89363,61.42606,51.91832,54.56714,
     & -58.49973,-27.31013,-22.33096,-22.33096,-15.62926,-12.50138,
     & -16.40951,-20.27812,-16.71812,-26.79303,-39.14072,-35.05980,
     & 3,10,10,10,10,10,10,10,10,10,3,3/

      DATA ((SPDCYC(I,J),I=1,6), J=1,6)/3.221,-17.604,1.121,0.006,
     & -1.717,0.006,0.442,0.657,0.085,0.000,0.110,0.000,-2.434,
     & 0.000,-0.792,0.000,0.000,-0.003,-0.253,0.000,-0.017,-0.001,
     & -0.024,-0.0002,0.000,0.000,0.000,0.000,0.000,0.000,0.000,
     & -0.006,-0.001,0.000,-0.001,0.000/

      DATA ((VOC(I,J),I=1,5), J=1,4)/65.46896,-2.24359,2.57939,
     & 45.27033,1.41670,-1.47217,0.05101,0.01924,0.23715,0.00000,
     & 0.00000,-0.30075,-0.83012,0.00000,-0.22743,0.02127,
     & 0.00000,0.00000,0.00580,0.00000/

C ****************************************************
C ********CONVERTION OF VOC PRICES INTO METRIC***********

      IF (METRIC.EQ.(1.0))  FUEL = FUEL * 3.7852
      IF (METRIC.EQ.(1.0))  OIL  = OIL  * 0.9463
      IF (METRIC.EQ.(1.0))  MANDR= MANDR* 0.6214

C ****************************************************
C **********TIME TREND ON SPEED AND SAFETY VARIABLES******

      DO 10 YR=1,PERIOD
      IF (YR.LT.YRSSNP) THEN
         PI(YR)=(0.99/YRSSNP) * (YR)
      ELSE
         PI(YR)=1.0
      ENDIF

        VISP_YR(YR) = VISP * PI(YR)
        VISI_YR(YR) = VISI * PI(YR)
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        VISF_YR(YR) = VISF * PI(YR)
        FLOW_YR(YR) = FLOW * PI(YR)
10    CONTINUE
C *****************************************************
C **************CALCULATNG ANNUAL AADT*******************
      DO 15 YR=1,PERIOD
         AADT(YR) = AADT0 + AADTI * (YR)
15    CONTINUE
C *****************************************************
C *****************PSI BY YEAR BASE CASE*****************
      DO 20 YR=1,PERIOD
      IF (YR.EQ.1) THEN
         PSIDM1 = PSIBC
      ELSE
         PSIDM1 = PSIWEP(YR-1)
      ENDIF
      IF (PSIDM1.GT.PSIRAM) THEN
         PSIWEP(YR) = PSIDM1+(PSIRAM-PSIRPM)/PLIFBC
      ELSE
         PSIWEP(YR) = PSIRPM
      ENDIF
20    CONTINUE
C **********PSI BY YEAR WITH NEW PRODUCT************
      IF (PSINP.EQ.(0.0))  PSINP = PSIBC
      IF (PLIFNP.EQ.(0.0)) PLIFNP = PLIFBC
      IF (PXNP.EQ.(0.0))   PXNP = PXBC
      DO 30 YR=1,PERIOD
      IF (YR.EQ.1) THEN
         PSIDM2 = PSINP
      ELSE
         PSIDM2 = PSIWNP(YR-1)
      ENDIF
      IF (PSIDM2.GT.PSIRAM) THEN
         PSIWNP(YR) = PSIDM2+(PSIRAM-PSIRPM)/PLIFNP
      ELSE
         PSIWNP(YR) = PSIRPM
      ENDIF
30    CONTINUE
C *****************************************************
C ************CALCULATING V/C RATIO BASE CASE*************
      DO 40 YR=1,PERIOD
         VCBC(YR) = AADT(YR) / 24 / LANEBC / HICAP
40    CONTINUE
C ************CALCULATING V/C RATIO WITH NP*************
      DO 45 YR=1,PERIOD
         VCNP(YR) = AADT(YR) / 24 / LANENP / HICAP
45    CONTINUE
C *****************************************************
C *************CALCULATING AVG SPD BASE CASE*************
      DO 60 YR=1,PERIOD
      IF (VCBC(YR).LE.SPD(FTBC,3)) THEN
         AVSPBC(YR) = SPD(FTBC,2) + SPD(FTBC,1) * VCBC(YR)
      ELSE
         AVSPBC(YR)=SPD(FTBC,4)+SPD(FTBC,5)*VCBC(YR)**SPD(FTBC,6)
      ENDIF
60    CONTINUE
C ************CALCULATING ADJ SPD BASE CASE*************
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      DO 70 YR=1,PERIOD
      IF (PSIWEP(YR).LT.1) THEN
         ADSPBC(YR)  = AVSPBC(YR)*(1-(5-1)/4*MPES)
      ELSE
         ADSPBC(YR)  = AVSPBC(YR)*(1-(5-PSIWEP(YR))/4*MPES)
      ENDIF
 70   CONTINUE

C ********************************************************
C ****************CALCULATING AVG SPD WITH NP**************

      DO 80 YR=1,PERIOD
      IF (VCNP(YR).LE.SPD(FTNP,3)) THEN
         AVSPNP(YR)=(SPD(FTNP,2)+SPD(FTNP,1)*VCNP(YR))*
     &               (1.0+FLOW_YR(YR))
      ELSE
         AVSPNP(YR)=(SPD(FTNP,4)+SPD(FTNP,5)*VCNP(YR)**SPD(FTNP,6))
     &               *(1.0+FLOW_YR(YR))
      ENDIF
 80   CONTINUE

C *************CALCULATING ADJ SPD WITH NP***********

      DO 90 YR=1,PERIOD
      IF (PSIWNP(YR).LT.1) THEN
         ADSPNP(YR)=AVSPNP(YR)*(1-(5-1)/4*MPES)
      ELSE
         ADSPNP(YR)=AVSPNP(YR)*(1-(5-PSIWNP(YR))/4*MPES)
      ENDIF
 90   CONTINUE


C ********************************************************
C ***************CALCULATING SAFETY BASE CASE**************
C **************CALCULATING INCIDENTS BASE CASE***********

      DO 110 YR=1,PERIOD
         PDOINC(YR)= (PDO(FTBC,3) + PDO(FTBC,4) / (1 + EXP
     &                (-(PDO(FTBC,1) + PDO(FTBC,2) * AADT(YR)))))
     &                / 100000000.
         INJINC(YR)= (INJ(FTBC,3) + INJ(FTBC,4) / (1 + EXP
     &                (-(INJ(FTBC,1) + INJ(FTBC,2) * AADT(YR)))))
     &                / 100000000.
         FATINC(YR)= (FAT(FTBC,3) + FAT(FTBC,4) / (1 + EXP
     &                (-(FAT(FTBC,1) + FAT(FTBC,2) * AADT(YR)))))
     &                / 100000000.
      IF (METRIC.EQ.0) THEN
         SAFETY(YR)= (PDOINC(YR)*VPDO)+(INJINC(YR)*VINJ)+
     &                (FATINC(YR)*VLIFE)
      ELSE
         SAFETY(YR)= ((PDOINC(YR)*0.6214)*VPDO)+((INJINC(YR)*0.6214)
     &                *VINJ)+ ((FATINC(YR)*0.6214)*VLIFE)
      ENDIF
 110  CONTINUE

C *************ADJUSTED SAFETY COSTS BASE CASE************

      DO 120 YR=1,PERIOD
      IF (5 - PSIWEP(YR).LT.4) THEN
         ADSFBC(YR)= SAFETY(YR) * (1 + (((5-PSIWEP(YR))/4)*MPEAR))
      ELSE
         ADSFBC(YR)= SAFETY(YR) * (1 + MPEAR)
      ENDIF
 120  CONTINUE

C ********************************************************
C ***************CALCULATING INCIDENTS WITH NP*************

      DO 130 YR=1,PERIOD
         PDOINP(YR)= (PDO(FTNP,3) + PDO(FTNP,4) / (1 + EXP
     &                (-(PDO(FTNP,1) + PDO(FTNP,2) * AADT(YR)))))
     &                / 100000000.
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          INJINP(YR)= (INJ(FTNP,3) + INJ(FTNP,4) / (1 + EXP
     &                (-(INJ(FTNP,1) + INJ(FTNP,2) * AADT(YR)))))
     &                / 100000000.
          FATINP(YR)= (FAT(FTNP,3) + FAT(FTNP,4) / (1 + EXP
     &                (-(FAT(FTNP,1) + FAT(FTNP,2) * AADT(YR)))))
     &                / 100000000.
       IF (METRIC.EQ.0) THEN
          SAFENP(YR)= (PDOINP(YR)*VPDO)+(INJINP(YR)*VINJ)+
     &                (FATINP(YR)*VLIFE)
       ELSE
          SAFENP(YR)= ((PDOINP(YR)*0.6214)*VPDO)+((INJINP(YR)*0.6214)
     &                *VINJ)+((FATINP(YR)*0.6214)*VLIFE)
       ENDIF
130    CONTINUE

C *************ADJUSTED SAFETY COSTS WITH NP***********

       DO 140 YR=1,PERIOD
       IF ((5 - PSIWNP(YR)).LT.4) THEN
          ADSFNP(YR)= SAFENP(YR) * (1 + (((5-PSIWNP(YR))/4)*MPEAR))
       ELSE
          ADSFNP(YR)= SAFENP(YR) * (1 + MPEAR)
       ENDIF
140    CONTINUE


C ******************************************************
C **************CALCULATING VOC COSTS BASE CASE***********

       DO 160 YR=1,PERIOD
          FUERTB(YR)= VOC(1,1)+VOC(1,2)*AVSPBC(YR)+VOC(1,3)*
     &                LOG10(AVSPBC(YR))+VOC(1,4)*AVSPBC(YR)**2
          TIRRTB(YR)= EXP(VOC(2,1)+VOC(2,2)*AVSPBC(YR)+VOC(2,3)*
     &                LOG10(AVSPBC(YR))+VOC(2,4)*AVSPBC(YR)**2)
     &                / 100.
          OILRTB(YR)= EXP(VOC(3,1)+VOC(3,2)*AVSPBC(YR)+VOC(3,3)*
     &                LOG10(AVSPBC(YR))+VOC(3,4)*AVSPBC(YR)**2)
          MARRTB(YR)= (VOC(4,1)+VOC(4,2)*AVSPBC(YR)+VOC(4,3)*
     &                LOG10(AVSPBC(YR))+VOC(4,4)*AVSPBC(YR)**2)
     &                / 100.
          DEPRTB(YR)= (VOC(5,1)+VOC(5,2)*AVSPBC(YR)+VOC(5,3)*
     &                LOG10(AVSPBC(YR))+VOC(5,4)*AVSPBC(YR)**2)
     &                / 100.
160    CONTINUE

C ******************************************************
C **************CALCULATING VOC COSTS WITH NP*************

       DO 165 YR=1,PERIOD
          FUERTN(YR)= VOC(1,1)+VOC(1,2)*AVSPNP(YR)+VOC(1,3)*
     &                LOG10(AVSPNP(YR))+VOC(1,4)*AVSPNP(YR)**2
          TIRRTN(YR)= EXP(VOC(2,1)+VOC(2,2)*AVSPNP(YR)+VOC(2,3)*
     &                LOG10(AVSPNP(YR))+VOC(2,4)*AVSPNP(YR)**2)
     &                / 100.
          OILRTN(YR)= EXP(VOC(3,1)+VOC(3,2)*AVSPNP(YR)+VOC(3,3)*
     &                LOG10(AVSPNP(YR))+VOC(3,4)*AVSPNP(YR)**2)
          MARRTN(YR)= (VOC(4,1)+VOC(4,2)*AVSPNP(YR)+VOC(4,3)*
     &                LOG10(AVSPNP(YR))+VOC(4,4)*AVSPNP(YR)**2)
     &                / 100.
          DEPRTN(YR)= (VOC(5,1)+VOC(5,2)*AVSPNP(YR)+VOC(5,3)*
     &                LOG10(AVSPNP(YR))+VOC(5,4)*AVSPNP(YR)**2)
     &                / 100.
165    CONTINUE

C ******************************************************
C ***************HIGH AND LOW SPEED BASE CASE************

       DO 170 YR=1,PERIOD
       IF (ADSPBC(YR).GT.10) THEN
          HISPDB(YR) = ADSPBC(YR) + 5.0
       ELSE
          HISPDB(YR) = ADSPBC(YR) * 1.5
```

```
      ENDIF
170   CONTINUE

      DO 180 YR=1,PERIOD
      IF (ADSPBC(YR).GT.10) THEN
         LOSPDB(YR) = ADSPBC(YR) - 5.0
      ELSE
         LOSPDB(YR) = ADSPBC(YR) * 0.5
      ENDIF
180   CONTINUE

C ****************HIGH AND LOW SPEED WITH NP***************

      DO 190 YR=1,PERIOD
      IF (ADSPNP(YR).GT.10) THEN
         HISPDN(YR) = ADSPNP(YR) + 5.0
      ELSE
         HISPDN(YR) = ADSPNP(YR) * 1.5
      ENDIF
190   CONTINUE

      DO 200 YR=1,PERIOD
      IF (ADSPNP(YR).GT.10) THEN
         LOSPDN(YR) = ADSPNP(YR) - 5.0
      ELSE
         LOSPDN(YR) = ADSPNP(YR) * 0.5
      ENDIF
200   CONTINUE

C ******************************************************
C *************SPEED CYCLING COSTS BASE CASE**************

      DO 220 YR=1,PERIOD
      IF (ADSPBC(YR).GT.40) THEN
         CYFUEB(YR)= SPDCYC(1,1) + SPDCYC(1,2) * HISPDB(YR) +
     &               SPDCYC(1,3) * LOG10(HISPDB(YR)) + SPDCYC(1,4)
     &               * LOSPDB(YR) + SPDCYC(1,5) * HISPDB(YR) ** 2
     &               + SPDCYC(1,6) * LOSPDB(YR) ** 2
      ELSE
         CYFUEB(YR)= SPDCYC(2,1) + SPDCYC(2,2) * HISPDB(YR) +
     &               SPDCYC(2,3) *LOG10(HISPDB(YR)) + SPDCYC(2,4)
     &               * LOSPDB(YR) + SPDCYC(2,5) * HISPDB(YR) ** 2
     &               + SPDCYC(2,6) * LOSPDB(YR) ** 2
      ENDIF
220   CONTINUE

      DO 230 YR=1,PERIOD
         CYTIRB(YR)=(SPDCYC(3,1)+SPDCYC(3,2)*HISPDB(YR)+SPDCYC(3,3)*
     &              LOG10(HISPDB(YR))+SPDCYC(3,4)*LOSPDB(YR)+
     &              SPDCYC(3,5)*HISPDB(YR)**2+SPDCYC(3,6)*
     &              LOSPDB(YR)**2) / 100.
         CYOILB(YR)=SPDCYC(4,1)+SPDCYC(4,2)*HISPDB(YR)+SPDCYC(4,3)*
     &              LOG10(HISPDB(YR))+SPDCYC(4,4)*LOSPDB(YR)+
     &              SPDCYC(4,5)*HISPDB(YR)**2+SPDCYC(4,6)*
     &              LOSPDB(YR)**2
         CYMARB(YR)=(SPDCYC(5,1)+SPDCYC(5,2)*HISPDB(YR)+SPDCYC(5,3)*
     &              LOG10(HISPDB(YR))+SPDCYC(5,4)*LOSPDB(YR)+
     &              SPDCYC(5,5)*HISPDB(YR)**2+SPDCYC(5,6)*
     &              LOSPDB(YR)**2) / 100.
         CYDEPB(YR)=(SPDCYC(6,1)+SPDCYC(6,2)*HISPDB(YR)+SPDCYC(6,3)*
     &              LOG10(HISPDB(YR))+SPDCYC(6,4)*LOSPDB(YR)+
     &              SPDCYC(6,5)*HISPDB(YR)**2+SPDCYC(6,6)*
     &              LOSPDB(YR)**2) / 100.
230   CONTINUE

      DO 240 YR=1,PERIOD
      IF (CYFUEB(YR).LT.0) THEN
         FUECCB(YR) = 0.
      ELSE
         FUECCB(YR) = CYFUEB(YR)
      ENDIF
      IF (CYTIRB(YR).LT.0) THEN
```

```
            TIRCCB(YR) = 0.
         ELSE
            TIRCCB(YR) = CYTIRB(YR)
         ENDIF
         IF (CYOILB(YR).LT.0) THEN
            OILCCB(YR) = 0.
         ELSE
            OILCCB(YR) = CYOILB(YR)
         ENDIF
         IF (CYMARB(YR).LT.0) THEN
            MARCCB(YR) = 0.
         ELSE
            MARCCB(YR) = CYMARB(YR)
         ENDIF
         IF (CYDEPB(YR).LT.0) THEN
            DEPCCB(YR) = 0.
         ELSE
            DEPCCB(YR) = CYDEPB(YR)
         ENDIF
 240     CONTINUE

C *******************************************************
C *************SPEED CYCLING COSTS WITH NP****************

         DO 250 YR=1,PERIOD
         IF (ADSPNP(YR).GT.40) THEN
            CYFUEN(YR)= SPDCYC(1,1) + SPDCYC(1,2) * HISPDN(YR) +
     &                  SPDCYC(1,3) * LOG10(HISPDN(YR)) + SPDCYC(1,4)
     &                  * LOSPDN(YR) + SPDCYC(1,5) * HISPDN(YR) ** 2
     &                  + SPDCYC(1,6) * LOSPDN(YR) ** 2
          ELSE
            CYFUEN(YR)= SPDCYC(2,1) + SPDCYC(2,2) * HISPDN(YR) +
     &                  SPDCYC(2,3) * LOG10(HISPDN(YR)) + SPDCYC(2,4)
     &                  * LOSPDN(YR) + SPDCYC(2,5) * HISPDN(YR) ** 2
     &                  + SPDCYC(2,6) * LOSPDN(YR) ** 2
         ENDIF
 250     CONTINUE

         DO 260 YR=1,PERIOD
            CYTIRN(YR)= (SPDCYC(3,1)+SPDCYC(3,2)*HISPDN(YR)+SPDCYC(3,3)*
     &                  LOG10(HISPDN(YR))+SPDCYC(3,4)*LOSPDN(YR)+
     &                  SPDCYC(3,5)*HISPDN(YR)**2+SPDCYC(3,6)*
     &                  LOSPDN(YR)**2) / 100.
            CYOILN(YR)= SPDCYC(4,1)+SPDCYC(4,2)*HISPDN(YR)+SPDCYC(4,3)*
     &                  LOG10(HISPDN(YR))+SPDCYC(4,4)*LOSPDN(YR)+
     &                  SPDCYC(4,5)*HISPDN(YR)**2+SPDCYC(4,6)*
     &                  LOSPDN(YR)**2
            CYMARN(YR)= (SPDCYC(5,1)+SPDCYC(5,2)*HISPDN(YR)+SPDCYC(5,3)*
     &                  LOG10(HISPDN(YR))+SPDCYC(5,4)*LOSPDN(YR)+
     &                  SPDCYC(5,5)*HISPDN(YR)**2+SPDCYC(5,6)*
     &                  LOSPDN(YR)**2) / 100.
            CYDEPN(YR)= (SPDCYC(6,1)+SPDCYC(6,2)*HISPDN(YR)+SPDCYC(6,3)*
     &                  LOG10(HISPDN(YR))+SPDCYC(6,4)*LOSPDN(YR)+
     &                  SPDCYC(6,5)*HISPDN(YR)**2+SPDCYC(6,6)*
     &                  LOSPDN(YR)**2) / 100.
 260     CONTINUE

         DO 270 YR=1,PERIOD
         IF (CYFUEN(YR).LT.0) THEN
            FUECCN(YR) = 0.
         ELSE
            FUECCN(YR) = CYFUEN(YR)
         ENDIF
         IF (CYTIRN(YR).LT.0) THEN
            TIRCCN(YR) = 0.
         ELSE
            TIRCCN(YR) = CYTIRN(YR)
         ENDIF
         IF (CYOILN(YR).LT.0) THEN
            OILCCN(YR) = 0.
         ELSE
            OILCCN(YR) = CYOILN(YR)
```

```
      ENDIF
      IF (CYMARN(YR).LT.0) THEN
         MARCCN(YR) = 0.
      ELSE
         MARCCN(YR) = CYMARN(YR)
      ENDIF
      IF (CYDEPN(YR).LT.0) THEN
         DEPCCN(YR) = 0.
      ELSE
         DEPCCN(YR) = CYDEPN(YR)
      ENDIF
270   CONTINUE

C ******************************************************
C ****************TOTAL VOC COSTS BASE CASE**************

      DO 280 YR=1,PERIOD
      IF (METRIC.EQ.0) THEN
         VOCBC(YR)=((FUERTB(YR)+FUECCB(YR))*FUEL+
     &              (TIRRTB(YR)+TIRCCB(YR))*TIRE+
     &              (OILRTB(YR)+OILCCB(YR))*OIL+
     &              (MARRTB(YR)+MARCCB(YR))*MANDR+
     &              (DEPRTB(YR)+DEPCCB(YR))*DEPR)/1000.
      ELSE
         VOCBC(YR)=(((FUERTB(YR)+FUECCB(YR))*0.6214)*FUEL+
     &              ((TIRRTB(YR)+TIRCCB(YR))*0.6214)*TIRE+
     &              ((OILRTB(YR)+OILCCB(YR))*0.6214)*OIL+
     &              ((MARRTB(YR)+MARCCB(YR))*0.6214)*MANDR+
     &              ((DEPRTB(YR)+DEPCCB(YR))*0.6214)*DEPR)/1000.
      ENDIF
280   CONTINUE

C **************ADJUSTED VOC COSTS BASE CASE**************

      DO 290 YR=1,PERIOD
      IF ((5-PSIWEP(YR)).LT.4) THEN
         ADVOCB(YR)=VOCBC(YR)*(1.0+(0.24*((5.0-PSIWEP(YR))/4.0)))
      ELSE
         ADVOCB(YR)= VOCBC(YR) * (1.0 + 0.24)
      ENDIF
290   CONTINUE

C ******************************************************
C *****************TOTAL VOC COSTS WITH NP****************

      DO 300 YR=1,PERIOD
      IF (METRIC.EQ.0) THEN
         VOCNP(YR)= ((FUERTN(YR)+FUECCN(YR))*FUEL +
     &              (TIRRTN(YR)+TIRCCN(YR))*TIRE +
     &              (OILRTN(YR)+OILCCN(YR))*OIL +
     &              (MARRTN(YR)+MARCCN(YR))*MANDR +
     &              (DEPRTN(YR)+DEPCCN(YR))*DEPR) / 1000.
      ELSE
         VOCNP(YR)= (((FUERTN(YR)+FUECCN(YR))*0.6214)*FUEL+
     &              ((TIRRTN(YR)+TIRCCN(YR))*0.6214)*TIRE+
     &              ((OILRTN(YR)+OILCCN(YR))*0.6214)*OIL+
     &              ((MARRTN(YR)+MARCCN(YR))*0.6214)*MANDR+
     &              ((DEPRTN(YR)+DEPCCN(YR))*0.6214)*DEPR)/1000.
      ENDIF
300   CONTINUE

C **************ADJUSTED VOC COSTS WITH NP****************

      DO 310 YR=1,PERIOD
      IF ((5-PSIWNP(YR)).LT.4) THEN
         ADVOCN(YR)=VOCNP(YR)*(1.0+(0.24*((5.0-PSIWNP(YR))/4.0)))
      ELSE
         ADVOCN(YR)= VOCNP(YR) * (1.0 + 0.24)
      ENDIF
310   CONTINUE
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C ****************************************************
C ***************CALCULATING VOT BC AND NP***************

      DO 320 YR=1,PERIOD
      IF (METRIC.EQ.0) THEN
         VOTBC(YR) = (1 / ADSPBC(YR)) * VTIME
         VOTNP(YR) = (1 / ADSPNP(YR)) * VTIME
      ELSE
         VOTBC(YR) = (1 / (ADSPBC(YR)*0.6214)) * VTIME
         VOTNP(YR) = (1 / (ADSPNP(YR)*0.6214)) * VTIME
      ENDIF
320   CONTINUE


C ****************************************************
C *******CALCULATION OF BASE CASE FAILURE RATE***********

      IF (FRATP.EQ.1) THEN
         DO 330 YR=1,PERIOD
            IF (YR.LE.EULBC) THEN
               FR(YR)=(0.5/EULBC)*(YR)
            ELSE
               FR(YR)=(0.49/(MULBC-EULBC))*(YR-EULBC)+0.5
            ENDIF
            IF (FR(YR).GT.(.99)) FR(YR) = 1.0
330   CONTINUE
      ELSEIF (FRATP.EQ.2) THEN
         ALPHA = ((LOG(1.0)*MULBC)-(LOG(99.0)*EULBC))
     &            /(MULBC-EULBC)
         BETA  = (LOG(99.0)-LOG(1.0))/(MULBC-EULBC)
       DO 340 YR=1,PERIOD
          FR(YR) = 1.0 / (1.0+(EXP(-(ALPHA+BETA*(YR)))))
340   CONTINUE
      ELSEIF (FRATP.EQ.3) THEN
         BETA = (LOG(0.5) - LOG(0.99)) / (EULBC - MULBC)
         ALPHA = 0.5 / EXP(BETA * EULBC)
            DO 350 YR=1,PERIOD
               FR(YR) = ALPHA * EXP(BETA * (YR))
            IF (FR(YR).GT.(.99)) FR(YR) = 1.0
350   CONTINUE
      ELSEIF (FRATP.EQ.4) THEN
         DO 360 YR=1,PERIOD
            FR(YR)=(0.99/MULBC) * (YR)
            IF (FR(YR).LT.(0.99)) FR(YR) = 0.0
            IF (FR(YR).GE.(0.99)) FR(YR) = 1.0
360   CONTINUE
      ENDIF

C ****************************************************
C *******CALCULATION OF NEW PRODUCT FAILURE RATE*********

      IF (FRATN.EQ.1) THEN
         DO 371 YR=1,PERIOD
            IF (YR.LE.EULNP) THEN
               FRN(YR)=(0.5/EULNP)*(YR)
            ELSE
               FRN(YR)=(0.49/(MULNP-EULNP))*(YR-EULNP)+0.5
            ENDIF
            IF (FRN(YR).GT.(.99)) FRN(YR) = 1.0
371   CONTINUE
      ELSEIF (FRATN.EQ.2) THEN
         ALPHA = ((LOG(1.0)*MULNP)-(LOG(99.0)*EULNP))
     &            /(MULNP-EULNP)
         BETA  = (LOG(99.0)-LCG(1.0))/(MULNP-EULNP)
      DO 372 YR=1,PERIOD
         FRN(YR)   = 1.0 / (1.0+(EXP(-(ALPHA+BETA*(YR)))))
372   CONTINUE
      ELSEIF (FRATN.EQ.3) THEN
         BETA = (LOG(0.5) - LOG(0.99)) / (EULNP - MULNP)
         ALPHA = 0.5 / EXP(BETA * EULNP)
            DO 373 YR=1,PERIOD
               FRN(YR) = ALPHA * EXP(BETA * (YR))
```

```
                IF (FRN(YR).GT.(.99)) FRN(YR) = 1.0
 373      CONTINUE
          ELSEIF (FRATN.EQ.4) THEN
             DO 374 YR=1,PERIOD
                FRN(YR)=(0.99/MULNP) * (YR)
                IF (FRN(YR).LT.(0.99)) FRN(YR) = 0.0
                IF (FRN(YR).GE.(0.99)) FRN(YR) = 1.0
 374      CONTINUE
          ENDIF

C *****************************************************
C ************PRODUCT STOCK - BASE CASE*****************

          DO 379 YR=1,PERIOD
             APPBC(YR)   = UBC + (IABC*(YR))
             INVB(YR) = APPBC(YR) * PABC
             TCSBC(YR)   = APPBC(YR) + INVB(YR)
 379      CONTINUE

C *****************************************************
C ************PHASE OUT OF OLD PRODUCT STOCK*************

          DO 380 YR=1,PERIOD
          IF (YR.LT.YRSSBC) THEN
             COLD(YR) = ((INVBC - UBC)/(YRSSBC)) * (YR) + UBC
          ELSE
             COLD(YR) = INVBC + (SSGBC * (YR - YRSSBC))
          ENDIF
             INVOLD(YR) = COLD(YR) * PABC
             TOLD(YR) = COLD(YR) + INVOLD(YR)
 380      CONTINUE

C *****************************************************
C ************PHASE IN OF NEW PRODUCT STOCK**************

          DO 390 YR=1,PERIOD
          IF (YR.LT.YRSSNP) THEN
             CNEW(YR) = (INVNP / YRSSNP) * (YR)
          ELSE
             CNEW(YR) = INVNP + (SSGNP * (YR - YRSSNP))
          ENDIF
             INVNEW(YR) = CNEW(YR) * PANP
             TNEW(YR) = CNEW(YR) + INVNEW(YR)
 390      CONTINUE


C *****************************************************
C *******ANNUAL PRODUCT EXPENDITURES - BASE CASE*********

          DO 400 AGE=1,MULBC
          PRECPB(AGE) = UBC / MULBC * (1 - VANBC)
 400      CONTINUE
          DO 410 YR=1,PERIOD
          TCAPBC = 0.
            DO 420 AGE=2,MULBC
               CAPBC(AGE) = PRECPB(AGE-1) * (1 - ((FR(AGE) - FR(AGE-1))
     &                      / (1 - FR(AGE-1))))
               TCAPBC = TCAPBC + CAPBC(AGE)
 420      CONTINUE
             IF ((TCSBC(YR)-TCAPBC).LT.0) THEN
                PURBC(YR) = 0.
             ELSE
                PURBC(YR) = TCSBC(YR) -  TCAPBC
             ENDIF
             IF ((PURBC(YR)-INVB(YR)).LT.0) THEN
                REPBC(YR) = 0.
             ELSE
                REPBC(YR) = PURBC(YR) - INVB(YR)
             ENDIF
             CAPBC(1) = PURBC(YR)
          DO 430 AGE=1,MULBC
             PRECPB(AGE) = CAPBC(AGE) * (1 - VANBC)
```

```
430   CONTINUE
410   CONTINUF

C *******BASE CASE - OLD PRODUCT FAILURES**************

      DO 440 YR=1,PERIOD
      IF (YR.EQ.1) THEN
         FDUMB = UBC * (1 + PADBC)
      ELSE
         FDUMB = TCSBC(YR-1)
      ENDIF
         RXBC(YR) = PURBC(YR) + (FDUMB - TCSBC(YR))
         IF (RXBC(YR).LT.(0.0)) RXBC(YR) = 0.0
         TACBC(YR)=(((PURBC(YR)*UPABC)*(1+FSRBC))*XBC)+
     &             (((PURBC(YR)*UPABC)*(1+FSRBC))*FOMCBC)+
     &             (RXBC(YR)*DISCBC)+(INVB(YR)*ICCBC)
440   CONTINUE


C ******************************************************
C *******PHASE OUT - OLD PRODUCT ANNUAL EXPENDITURES******

      DO 490 AGE=1,MULBC
      PRECPO(AGE) = UBC / MULBC * (1 - VANBC)
490   CONTINUE
      DO 500 YR=1,PERIOD
      TCAPOL = 0.
        DO 510 AGE=2,MULBC
          CAPOLD(AGE) = PRECPO(AGE-1) * (1 - ((FR(AGE) - FR(AGE-1))
     &                  / (1 - FR(AGE-1))))
          TCAPOL = TCAPOL + CAPOLD(AGE)
510   CONTINUE
         IF ((TOLD(YR)-TCAPOL).LT.0) THEN
            PUROLD(YR) = 0.
         ELSE
            PUROLD(YR) = TOLD(YR) -  TCAPOL
         ENDIF
         IF ((PUROLD(YR)-INVOLD(YR)).LT.0) THEN
           REPOLD(YR) = 0.
         ELSE
           REPOLD(YR) = PUROLD(YR) - INVOLD(YR)
         ENDIF
         CAPOLD(1) = PUROLD(YR)
      DO 515 AGE=1,MULBC
         PRECPO(AGE) = CAPOLD(AGE) * (1 - VANBC)
515   CONTINUE
500   CONTINUE

C *******PHASE OUT - OLD PRODUCT FAILURES****************

      DO 517 YR=1,PERIOD
      IF (YR.EQ.1) THEN
         FDUMB = UBC * (1 + PADBC)
      ELSE
         FDUMB = TOLD(YR-1)
      ENDIF
         RXOLD(YR) = PUROLD(YR) + (FDUMB - TOLD(YR))
         IF (RXOLD(YR).LT.(0.0)) RXOLD(YR) = 0.0
         TACOLD(YR)=(((PUROLD(YR)*UPABC)*(1+FSRBC))*XBC)+
     &              (((PUROLD(YR)*UPABC)*(1+FSRBC))*FOMCBC)+
     &              (RXOLD(YR)*DISCBC)+(INVOLD(YR)*ICCBC)
517   CONTINUE

C ******************************************************
C ********PHASE IN - NEW PRODUCT ANNUAL EXPENDITURES******

      DO 519 AGE=1,MULNP
      PRECPN(AGE) = 0.
519   CONTINUE
      DO 520 YR=1,PERIOD
      TCAPNP = 0.
        DO 530 AGE=2,MULNP
```

```
             CAPNP(AGE) = PRECPN(AGE-1)*(1-((FRN(AGE)-FRN(AGE-1))
     &                    /(1-FRN(AGE-1))))
             TCAPNP = TCAPNP + CAPNP(AGE)
 530    CONTINUE
           IF ((TNEW(YR)-TCAPNP).LT.0) THEN
               PURNP(YR) = 0.
           ELSE
               PURNP(YR) = TNEW(YR) -  TCAPNP
           ENDIF
           IF ((PURNP(YR)-INVNEW(YR)).LT.0) THEN
              REPNP(YR) = 0.
           ELSE
              REPNP(YR) = PURNP(YR) - INVNEW(YR)
           ENDIF
           CAPNP(1) = PURNP(YR)
        DO 535 AGE=1,MULNP
           PRECPN(AGE) = CAPNP(AGE) * (1 - VANNP)
 535    CONTINUE
 520    CONTINUE

C *************PHASE IN - NEW PRODUCT FAILURES**********

        DO 540 YR=1,PERIOD
        IF (YR.EQ.1) THEN
           FDUMN = 0.
        ELSE
           FDUMN = TNEW(YR-1)
        ENDIF
           RXNP(YR) = PURNP(YR) + (FDUMN - TNEW(YR))
           IF (RXNP(YR).LT.(0.0)) RXNP(YR) = 0.0
           TACNP(YR)=(((PURNP(YR)*UPANP)*(1+FSRNP))*XNP)+
     &               (((PURNP(YR)*UPANP)*(1+FSRNP))*FOMCNP)+
     &               (RXNP(YR)*DISCNP)+(INVNEW(YR)*ICCNP)
 540    CONTINUE

C ******************************************************
C ************CALCULATING LABOR PRODUCTIVITY**************

        T1 = T50PYP
        T2 = T50PYP + T95PYP
        IF (T1.EQ.T2) THEN
           DO 550 YR=1,PERIOD
              PRNP(YR) = PRODNP
 550    CONTINUE
        ELSE
           DO 560 YR=1,PERIOD
              IF (YR.LT.T2) THEN
                 TIME(YR) = (0.99 - 0.5) / (T2 - T1) * (YR)
              ELSE
                 TIME(YR) = 1.0
              ENDIF
           PRNP(YR) = PRODNP * TIME(YR)
 560    CONTINUE
        ENDIF

C ******************************************************
C ************CALCULATING ADMIN PRODUCTIVITY**************

        T1 = T50APN
        T2 = T50APN + T95APN
        IF (T1.EQ.T2) THEN
           DO 600 YR=1,PERIOD
              APRNP(YR) = ADPRO
 600    CONTINUE
        ELSE
           DO 610 YR=1,PERIOD
              IF (YR.LT.T2) THEN
                 TIME(YR) = (0.99 - 0.5) / (T2 - T1) * (YR)
              ELSE
                 TIME(YR) = 1.0
              ENDIF
           APRNP(YR) = ADPRO * TIME(YR)
```

```
 610    CONTINUE
        ENDIF

C ******************************************************
C *************FABRICATION LABOR PRODUCTIVITY************

        IF (FPRDBC.EQ.(0.0)) FPRDBC = 1.0
        IF (FPRDNP.EQ.(0.0)) FPRDNP = 1.0

        T1 = T50PF
        T2 = T50PF + T95PF
        IF (T1.EQ.T2) THEN
           DO 632 YR=1,PERIOD
              FPRNP(YR) = FPRDNP
 632    CONTINUE
        ELSE
           DO 633 YR=1,PERIOD
              IF (YR.LT.T2) THEN
                 TIME(YR) = (0.99 - 0.5) / (T2 - T1) * (YR)
              ELSE
                 TIME(YR) = 1.0
              ENDIF
           FPRNP(YR) = FPRDNP * TIME(YR)
 633    CONTINUE
        ENDIF

C ******************************************************
C ***********CALCULATING PRODUCTIVITY SAVINGS************

        DO 639 YR=1,PERIOD
           TLSBC(YR)= ((((1/PRODBC)*REPBC(YR))*ADOTWG)+
      &               (((1/FPRDBC)*REPBC(YR))*FADOTW))/1000000.
           TLSNEW(YR)=((((1/PRNP(YR))*REPNP(YR))*ADOTWG)+
      &               (((1/FPRNP(YR))*REPNP(YR))*FADOTW))/1000000.
           TLSOLD(YR)=((((1/PRODBC)*REPOLD(YR))*ADOTWG)+
      &               (((1/FPRDBC)*REPOLD(YR))*FADOTW))/1000000.
           TASBC(YR) = 0.
           TASNP(YR) = (APRNP(YR) * ADOTAW) / 1000000.
 639    CONTINUE

C ******************************************************
C ********PRODUCT MAINTENANCE/FABRICATION COSTS*********

        DO 640 YR=1,PERIOD
           PRMXBC(YR)=(((ADOTWG+EQXBC)*(1/PRODBC))*REPBC(YR))+
      &               (((FEQXBC+FORBC+FADOTW)*(1/FPRDBC))*REPBC(YR))

           PRMXNE(YR)=(((ADOTWG+EQXNP)*(1/PRNP(YR)))*REPNP(YR))+
      &               (((FEQXNP+FORNP+FADOTW)*(1/FPRNP(YR)))*REPNP(YR))

           PRMXOL(YR)=(((ADOTWG+EQXBC)*(1/PRODBC))*REPOLD(YR))+
      &               (((FEQXBC+FORBC+FADOTW)*(1/FPRDBC))*REPOLD(YR))
 640    CONTINUE

C ******************************************************
C *************PAVEMENT MAINTENANCE COSTS****************

        DO 650 YR=1,PERIOD
        IF (PSIWBP(YR).EQ.PSIRPM) THEN
           PAMXBC(YR) = PXBC
        ELSE
           PAMXBC(YR) = 0.
        ENDIF

        IF (PSIWNP(YR).EQ.PSIRPM) THEN
           PAMXNP(YR)= PXNP
        ELSE
           PAMXNP(YR)= 0.
        ENDIF
 650    CONTINUE

C ******************************************************
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C ***********TOTAL MAINTENANCE COSTS *********************

      DO 660 YR=1,PERIOD
         TMXBC(YR) = (PAMXBC(YR) + PRMXBC(YR)) / 1000000.
         TMXNP(YR) = (PAMXNP(YR)+PRMXNE(YR)+PRMXOL(YR)) / 1000000.
660   CONTINUE

C ******************************************************
C ***********CALCULATION OF DISRUPTION COSTS**************

      DO 670 YR=1,PERIOD
         VECBC(YR) = (AADT(YR) * 365.25) * PADBC
         DHRBC(YR) = (DDELBC/60.0) * VECBC(YR)
         DTBC(YR) = DHRBC(YR) * VTIME
         DSBC(YR) = (ADSFBC(YR)*LENGTH*AADT(YR)*365.25)*
     &              (MDEAR * PADBC)
         DVCBC(YR)=((0.54*DHRBC(YR))*FUEL)+((5.23*(DHRBC(YR)/1000.0))
     &             *OIL)+((0.0073*(DHRBC(YR)/1000.0))*DEPR)+((0.583*
     &              (DHRBC(YR)/1000.0))*MANDR)
         DISBC(YR) = (DTBC(YR) + DSBC(YR) + DVCBC(YR)) / 1000000.

         VECNP(YR) = (AADT(YR) * 365.25) * PADNP
         DHRNP(YR) = (DDELNP/60.0) * VECNP(YR)
         DTNP(YR) = DHRNP(YR) * VTIME
         DSNP(YR) = (ADSFNP(YR)*LENGTH*AADT(YR)*365.25)*
     &              (MDEAR * PADNP)
         DVCNP(YR)=((0.54*DHRNP(YR))*FUEL)+((5.23*(DHRNP(YR)/1000.0))
     &             *OIL)+((0.0073*(DHRNP(YR)/1000.0))*DEPR)+((0.583*
     &              (DHRNP(YR)/1000.0))*MANDR)
         DISNP(YR) = (DTNP(YR) + DSNP(YR) + DVCNP(YR)) / 1000000.
670   CONTINUE

C ******************************************************
C ***********CALCULATION OF LIABILITY COSTS***************

      DO 800 YR=1,PERIOD
         ACBC(YR) = RXBC(YR) * (PLEGBC/100.0)
         LPFBC(YR)= ((PCSBC*ASCBC)+((1-(PCSBC+PCDBC))*ACCBC))
         LIXBC(YR)= (ACBC(YR)*LPFBC(YR))/1000000.

         ACNEW(YR) = RXNP(YR) * (PLEGNP/100.0)
         ACOLD(YR) = RXOLD(YR) * (PLEGBC/100.0)
         LPFNP(YR) = ((PCSNP*ASCNP)+((1-(PCSNP+PCDNP))*ACCNP))
         LIXNEW(YR)= (ACNEW(YR)*LPFNP(YR))/1000000.
         LIXOLD(YR)= (ACOLD(YR)*LPFBC(YR))/1000000.

800   CONTINUE

C ******************************************************
C ***********CALCULATION OF NP ACCIDENT SAVINGS***********

      DO 820 YR=1,PERIOD
         IF (METRIC.EQ.0) THEN
          SCNP(YR)=((PDOINP(YR)*(1-VISP_YR(YR)))*VPDO)+
     &             ((INJINP(YR)*(1-VISI_YR(YR)))*VINJ)+
     &             ((FATINP(YR)*(1-VISF_YR(YR)))*VLIFE)
         ELSE
          SCNP(YR)=(((PDOINP(YR)*(1-VISP_YR(YR)))*0.6214)*VPDO)+
     &             (((INJINP(YR)*(1-VISI_YR(YR)))*0.6214)*VINJ)+
     &             (((FATINP(YR)*(1-VISF_YR(YR)))*0.6214)*VLIFE)
         ENDIF
       IF ((5 - PSIWNP(YR)).LT.4) THEN
         ADSSNP(YR)= SCNP(YR) * (1 + (((5-PSIWNP(YR))/4)*MPEAR))
       ELSE
         ADSSNP(YR)= SCNP(YR) * (1 + MPEAR)
       ENDIF
          ASSNP(YR)=(ADSSNP(YR)*LENGTH*AADT(YR)*365.25)/1000000.
820   CONTINUE

C ******************************************************
C *************CALCULATING NET PRESENT VALUE**************

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```
      DO 900 YR=1,PERIOD
         PVVOCB(YR)=((ADVOCB(YR)*LENGTH*AADT(YR)*365.25)
     &             /(1+DRATE)**(YR))/1000000.
         PVVOCN(YR)=((ADVOCN(YR)*LENGTH*AADT(YR)*365.25)
     &             /(1+DRATE)**(YR))/1000000.
         PVSAFN(YR)=((ADSFNP(YR)*LENGTH*AADT(YR)*365.25)
     &             /(1+DRATE)**(YR))/1000000.
         PVSAFB(YR)=((ADSFBC(YR)*LENGTH*AADT(YR)*365.25)
     &             /(1+DRATE)**(YR))/1000000.
         PVVOTB(YR)=((VOTBC(YR)*LENGTH*AADT(YR)*365.25)
     &             /(1+DRATE)**(YR))/1000000.
         PVVOTN(YR)=((VOTNP(YR)*LENGTH*AADT(YR)*365.25)
     &             /(1+DRATE)**(YR))/1000000.
         PVMXBC(YR) = TMXBC(YR) / (1 + DRATE) ** (YR)
         PVMXNP(YR) = TMXNP(YR) / (1 + DRATE) ** (YR)
         PVLXBC(YR) = LIXBC(YR) / (1 + DRATE) ** (YR)
         PVLXNP(YR) = (LIXNEW(YR)+LIXOLD(YR))/(1+DRATE)**(YR)
         PVTLBC(YR) = TLSBC(YR) / (1 + DRATE) ** (YR)
         PVTLNP(YR) = (TLSNEW(YR)+TLSOLD(YR))/(1+DRATE)**(YR)
         PVTABC(YR) = TASBC(YR) / (1 + DRATE) ** (YR)
         PVTANP(YR) = TASNP(YR) / (1 + DRATE) ** (YR)
         PVKBC(YR) = (TACBC(YR)/(1+DRATE)**(YR))/1000000.
      IF (YR.EQ.1) THEN
         PVKNP(YR) = ((TACNP(YR)+TACOLD(YR)+ADDEX+ADDTX+TEXNP)
     &             /(1+DRATE)**(YR))/1000000.
      ELSE
         PVKNP(YR) = ((TACNP(YR)+TACOLD(YR)+ADDYR)/(1+DRATE)**(YR))
     &             /1000000.
      ENDIF
         PVDISB(YR)= DISBC(YR) / (1 + DRATE) ** (YR)
         PVDISN(YR)= DISNP(YR) / (1 + DRATE) ** (YR)
         PVASSN(YR)= ASSNP(YR) / (1 + DRATE) ** (YR)
 900  CONTINUE

      SMCAPB = 0.
      SMCAPN = 0.
      SMLIAB = 0.
      SMLIAN = 0.
      SMMANB = 0.
      SMMANN = 0.
      SMPROB = 0.
      SMPRON = 0.
      TAPBC = 0.
      TAPNP = 0.
      SMSAFN = 0.
      SMSAFB = 0.
      SMVOTB = 0.
      SMVOTN = 0.
      SMVOCB = 0.
      SMVOCN = 0.
      SMDISB = 0.
      SMDISN = 0.
      DO 910 YR=1,PERIOD
         SMCAPB = SMCAPB + PVKBC(YR)
         SMCAPN = SMCAPN + PVKNP(YR)
         SMLIAB = SMLIAB + PVLXBC(YR)
         SMLIAN = SMLIAN + PVLXNP(YR)
         SMMANB = SMMANB + PVMXBC(YR)
         SMMANN = SMMANN + PVMXNP(YR)
         SMPROB = SMPROB + PVTLBC(YR) + PVTABC(YR)
         SMPRON = SMPRON + PVTLNP(YR) + PVTANP(YR)
         TAPBC = TAPBC + PVTABC(YR)
         TAPNP = TAPNP + PVTANP(YR)
         SMVOCB = SMVOCB + PVVOCB(YR)
         SMVOCN = SMVOCN + PVVOCN(YR)
         SMVOTB = SMVOTB + PVVOTB(YR)
         SMVOTN = SMVOTN + PVVOTN(YR)
         SMSAFB = SMSAFB + PVSAFB(YR)
         SMSAFN = SMSAFN + PVSAFN(YR) - (PVSAFN(YR) - PVASSN(YR))
         SMDISB = SMDISB + PVDISB(YR)
         SMDISN = SMDISN + PVDISN(YR)
 910  CONTINUE
```

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C ******************************************************
C *******************CALCULATING NET SAVINGS**************

        BVOC = SMVOCB - SMVOCN
        BLIA = SMLIAB - SMLIAN
        BVOT = SMVOTB - SMVOTN
        BSAFE = SMSAFB - SMSAFN
        BPRO = (SMPRAB + SMPRLB)  - (SMPRAN + SMPRLN)
        BMAIN = SMMANB - SMMANN
        BCAP = SMCAPB - SMCAPN
        BDIS = SMDISB - SMDISN

C ******************************************************
C ***************TOTAL COSTS BASE CASE********************

        SMTCBC = SMVOCB+SMVOTB+SMSAFB+SMMANB+SMCAPB+SMDISB+SMLIAB
     &          +TAPBC

C ******************************************************
C ***************TOTAL COSTS NEW PRODUCT******************

        SMTCNP = SMVOCN+SMVOTN+SMSAFN+SMMANN+SMCAPN+SMDISN+SMLIAN
     &          +TAPNP

C ******************************************************
C ***************CALCULATING TOTAL NET BENEFITS************

        NETB = BVOC+BSAFE+BVOT+BCAP+BLIA+(TAPBC-TAPNP)+BDIS+BMAIN

C ******************************************************
C ***************AESTH & ENV THRESHOLD*********************

        BENV = NETB * 0.80

C ******************************************************
C ****************PRINTING DATA TO A FILE*****************

C       OPEN(113,FILE='DAT1.DAT',STATUS='OLD')
C       WRITE(113,*)(PI(YR), YR=1,PERIOD)
C       WRITE(113,*)(VISP_YR(YR), YR=1,PERIOD)
C       WRITE(113,*)(VISI_YR(YR), YR=1,PERIOD)
C       WRITE(113,*)(VISF_YR(YR), YR=1,PERIOD)
C       WRITE(113,*)(FLOW_YR(YR), YR=1,PERIOD)
C       CLOSE(UNIT=113)

C ***********END PRINTING DATA TO A FILE***********

        RETURN
        END
```