ARIZONA DEPARTMENT OF TRANSPORTATION

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

Volume I
Product Evaluation Model
Final Report

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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 first in a series of two. Volume II contains the Reference Manual and User's Guide for the Product Evaluation Model (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.

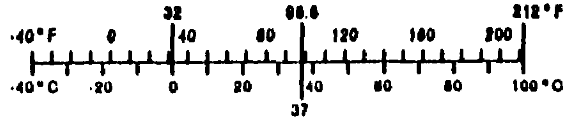
Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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 PROBLEM STATEMENT

The objective of Arizona Transportation Research Center (ATRC) Project SPR-PL-1(45) 372, is to develop a quantitative procedure to assess the cost-benefit ratio and risk assessment for new products and technologies entering the ADOT Product Resource Investment Deployment and Evaluation (PRIDE) program. The impetuous for this study arises from the limited funding and staffing resources available at ADOT and the need to prioritize and selectively choose among new products for further testing and evaluation. The goal of the project is to introduce an objective, quantitative procedure to screen new products and to provide a risk analysis of those products which produce social and economic benefits to ADOT and the public.

PROJECT BACKGROUND

The ATRC new product evaluation process currently absorbs a great deal of resources, in terms of labor, time and other expenses. This is true whether a product is seeking acceptance based on current specifications, a change in specifications or field testing. Constant innovation in the marketplace and relentless pressure to improve the quality of roadways and roadway services has lead to the large increase in the number of product evaluation application requests since the establishment of the PRIDE program. As a result of these trends, the demands for product testing and integration will far outstrip the supply of ATRC resources and the resources of those who participate in the Product Evaluation Program (including committee members, the Materials Testing Laboratory, the Specifications and Standard Drawings Review Committee and the Experimental Projects Program).

The address this problem, Hickling Corporation was retained to develop an analytic tool to rank and prioritize highway and construction products either seeking entry to or being evaluated in the ATRC's PRIDE program. This goal was accomplished by the development of the Product Evaluation Model (PEM) and its associated analytic process, which accounts for all economic effects associated with new highway products and the potential benefits that accrue to both highway users and to the ADOT. Importantly, this analytic framework also includes a risk analysis component which captures the experimental nature of new products. Using this analytic model, ADOT personnel will be able to take a new highway product and forecast the economic benefits associated with its use and implementation.

The PEM analytical process is divided into the following six integrated steps:

- **The selection of a product for evaluation;**

  This is an internal ADOT process dependent on a variety of decision-making criteria and the interaction of the ATRC, the Materials Products and Traffic Products Evaluation Committees.

- **The identification of common product attributes;**

  This step involves obtaining the available information on attributes that are common to all products. Based on past ADOT evaluations and a survey of new highway products, these attribute are: product cost, life cycle, additional training costs, failure rate, change in person-hours, and the need for special equipment. The information and specific data for this step is obtained from the vendor, testing labs, or experimental data obtained from state or federal DOTs.

- **The identification of specific product attributes;**

  This step elicits information on attributes that are specific to certain products. Selected specific product attributes include pavement smoothness, (measured in PSI), and other attributes the may lead to reduced pavement resurfacing costs or accident severity.

- **The risk analysis of the change in attributes;**

  This step involves the user assessing the degree to which a new product's attributes will lead to a change in physical effect. The analyst will be asked to interpret experimental and other testing data in order to place probability ranges around the change in metric associated with the new highway product. A new pavement mixture with improved durability, for example, might have an expected additional life cycle of 5 years, which could vary by one year to give an additional life cycle **range** of from 4 to 6 years. **The risk analysis process then uses this probability range to forecast economic benefits.**

- **The linkage of the change in attributes to economic benefits and costs model; and**

  This step links the change in metrics associated with a new product with a set of pre-defined user economic benefits. Benefits calculated in the model include: Safety, Vehicle Operating Costs, Productivity, Value of Time, Disruption, Capital Expenditures, Maintenance, Productivity, Environmental and Aesthetics. Benefits are defined as cost savings compared to current technology and may accrue both to the community (of all drivers and residents) as well as to ADOT.

- **The estimation of the Net Present Value of the new product.**

  This final step involves the model summing the results of individual benefit models to obtain a single probability of a new product achieving a net present value of benefits. The net present value of benefits is calculated by taking the net benefits of a product and discounting this value by 5 percent over a 25 year period. Those products which yield a net present value of zero or above reflect an economic rate of return of over five percent for the period and are therefore economically justified.

Using this information, ATRC managers can set a minimum standard for a new product achieving a desired net present value of benefits, such as 80 percent, and then screen out all those products that fail to meet this economic criteria. Once these standards are defined, the RAP allows ATRC officials to rank and prioritize products for evaluation and, in the process, efficiently allocate scarce research center resources. In addition, ADOT personnel will be better able to pinpoint factors which impact the relative benefits of a given highway product.

Expert opinion and decision making committees can observe the likelihood that a product will make a positive net contribution to ADOT objectives by expressing the net benefits estimate as a probability range. Similarly, decision making committees can observe the risk that the net benefits of the project will be negative (ie, the probability that its costs will exceed its benefits over the roadway and product life-cycle. Using such risk-based Benefit-Cost information, the committees can prioritize products:(i) in relation to their estimated pay-offs for ADOT and the public, (ii) in relation to the risk of such pay-offs failing to materialize, and (iii) in relation to particular risks, such as incidental risks to public safety and welfare during product shake-out.

2.0 LITERATURE REVIEW

The existing literature on new highway products and their contribution to economic benefits represents a small, specialized field of knowledge. While there is extensive data on new products produced from technical and engineering methods and testing systems, there are no economic cost-benefit methodologies in place at State DOTs to evaluate new products. Indeed, the experimental nature of new products data makes their future performance and economic benefits that much more difficult to measure and evaluate. New highway products, however, can be evaluated by using a process that uses experimental test data and also draws upon findings from the transportation economics field.

REVIEW OF CURRENT PRACTICE

New product evaluations are based on a combination of technical test results and input from state and federal transportation agencies. State DOTs 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. Funding for the original SHRP program officially expired in 1993, but the FHWA, under authorization from the 1991 Intermodal Surface Transportation Efficiency Act, has begun a six-year program to implement the findings of the SHRP through a variety of marketing, public information and organizational support measures. Three relevant SHRP publications are referenced in this paper's bibliography.

THE APPLICATION OF TRANSPORTATION ECONOMICS LITERATURE

An approach to evaluate the economic effects of new highway and construction products can be conducted by using the large body of transportation research data. The TRB publishes a host of studies that measure and investigate such areas as transportation, productivity and economic development. To determine the economic benefits and costs associated with a specific new highway product, therefore, the analyst assesses the attributes of the product, calculates the net physical effect that these attributes will generate, and then maps these changes into the economic effect categories defined in the transportation literature.

There are six *general* categories of economic benefits that the can be modelled when evaluating new products. Economic benefits are defined as cost savings compared to current technology and may accrue both to the community (of all drivers and residents) as well as to ADOT. The six general economic effect categories are given below:

- Safety;
- Value of Time;
- Vehicle Operating Costs;
- Productivity;
- Liability Costs; and
- Environmental and Aesthetic Costs.

These general economic categories are addressed by PEM and are explained in the following sections.

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[1] prepared for the Federal Highway Administration by the Urban Institute.

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) 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.

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

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)[2]. The specific data used to derive the coefficients for these formulae comes from HERS[3], and from the Texas Transportation Institute[4]. The monetary values applied to time savings in PEM are 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

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[2] 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)

[3] Ibid, The Highway Economic Requirements System.

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

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[5] and the Technical Memorandum to NCHRP 7-12[6].

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.

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.

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, PEM addresses their statistical occurrence based on the number of claims per

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[5] Ibid, The Highway Economic Requirements System.

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

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.

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.

3.0 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.

- ***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.

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.

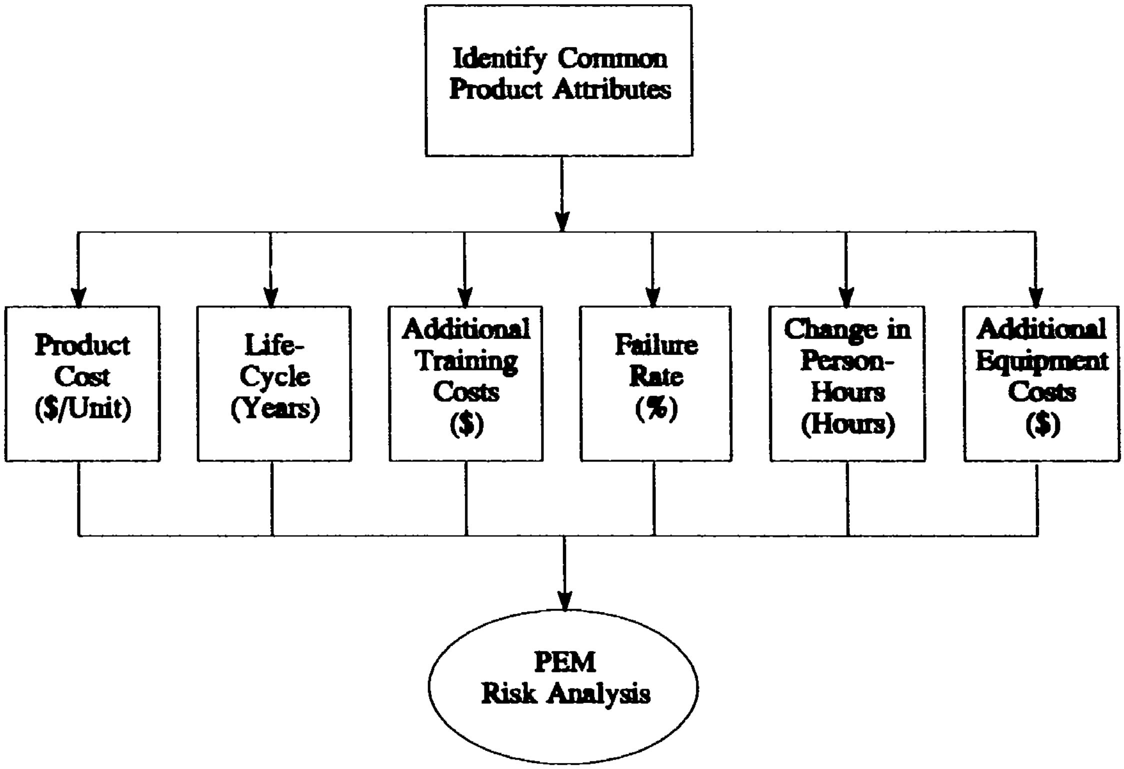
The result of PEM's risk analysis is a forecast of the range of net economic benefits associated with the use of a new product, and the probability, or odds, that the product will produce a given level of net benefits. PEM's forecast of a product's net benefits allows ADOT planners and decision-makers 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.

4.0 IDENTIFICATION OF COMMON PRODUCT ATTRIBUTES

It is the product attributes and characteristics that ultimately create the economic benefits associated with any given new highway or construction product. Clearly distinguishing the full range of attributes connected with a product can be a difficult task, but PEM will allows for two tiers of product data input points that capture the basic information needed to perform a benefit-cost analysis.

Figure 4.1 graphically illustrates the process of identifying *common product attributes*. The model carries forward data on product classification and presents a menu of six common product attributes and the metrics, or units of measure, used to quantify them. The user, at this point, must obtain data on: the product cost, life cycle, additional training costs, failure rate, change in person-hours and additional equipment costs. These metrics will eventually be used by the model to estimate one or several of the economic benefits associated with a new product.

Figure 4.1: The Identification of Common Product Attributes



THE SIX COMMON PRODUCT ATTRIBUTES

The six product attributes presented in Table 4.1 encompass the basic economic information associated with new products. Product cost is fundamental, and must be accompanied by the quantity of units employed to be used in the economic analysis. Product life-cycle is an important characteristic of new highway and construction products and is one of the important drivers in estimating operating and maintenance benefits over time. Additional training costs refers to those new products that require the retraining of personnel before product implementation and which generally retard immediate user benefits. Failure rate is a critical value in experimental data and is used to forecast several user benefit categories. Change in person-hours is the estimated change in maintenance or implementation associated with new products and leads to benefits in ADOT productivity. Finally, the need to purchase special equipment refers to new products that directly or indirectly force transportation officials to make new investments in machinery.

Table 4.1: Common Attributes of Highway Products

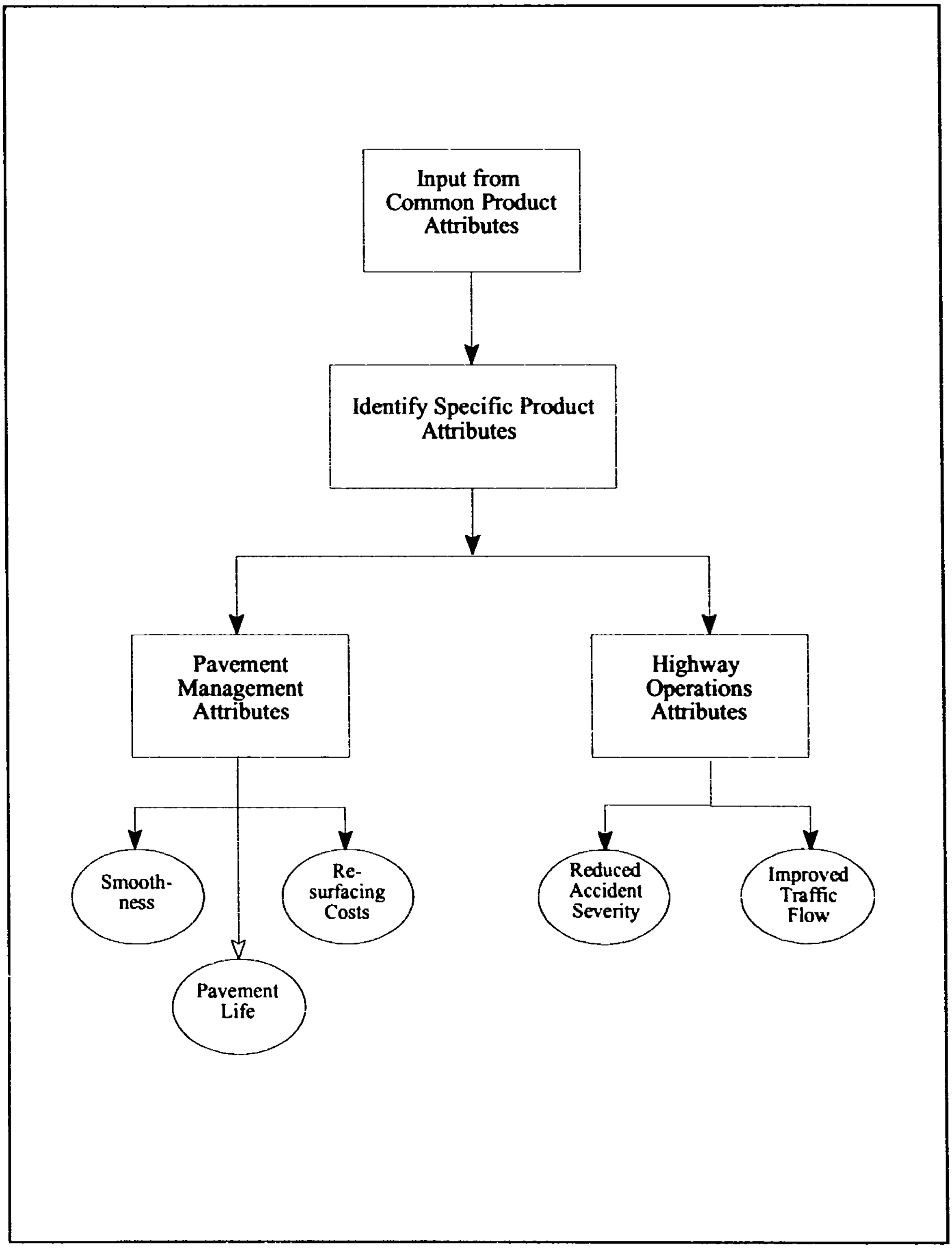
Attribute	Unit of Measure	Economic Benefit Category
Product Cost	$ per unit	Change in Capital Costs
Product Life Cycle	Discounted Cash Flow $	Change in Operating/Maintenance Costs
Additional Training Costs	$	Capital Costs
Failure Rate	Probability of failure multiplied by the number of product installations	Liability, Cap Costs, Operating/Maintenance Costs
Change in Person-Hours	Person-Hours	ADOT Productivity
Need for Special Equipment	$	Change in Capital Costs

5.0 IDENTIFICATION OF SPECIFIC PRODUCT ATTRIBUTES

More specific product attributes are added to the economic information about new products in this step. The products falling into Pavement Management and Highway Operations functional categories generally share additional attributes that can be quantified and entered as specific metrics into the model. The economic information gathered in this step is used to better forecast net benefits and costs that are not captured in the six common product attributes and is graphically depicted in Figure 5.1.

The following sections present attributes for functional category and a brief explanation.

Figure 5.1: The Identification of Specific Product Attributes



SPECIFIC PRODUCT ATTRIBUTES OF PAVEMENT MANAGEMENT

Table 5.1 presents the three fundamental attributes of pavement products: smoothness, resurfacing costs and pavement life. Smoothness refers to the condition of the pavement and its affect on vehicle speed. In theory, a smooth, well-maintained road leads to a higher average vehicle speed than a rough, poorly-maintained road. The ADOT PSI index captures the condition of pavement and reflects the degree of smoothness. A new highway product that improves pavement smoothness, as indicated by PSI, can lead to economic benefits in VOC, VOT, Safety, Environment and Productivity.

Table 5.1: Specific Product Attributes; Pavement Management

Attribute	Unit of Measure	Economic Benefit Category
Smoothness	PSI	VOC/VOT/Safety/Productivity
Resurfacing Costs	Person-Hours	ADOT Productivity
Pavement Life	Maintenance Costs	VOC/VOT/Safety/Productivity

Resurfacing costs, in Table 5.1, refers to the costs needed to maintain a section of pavement that requires repair and rehabilitation. This attribute is the amount of ADOT person-hours needed to rehabilitate the pavement materials. A new product which reduces the amount of person-hours required to apply the pavement or product leads to an improvement in ADOT productivity.

Pavement life, in Table 5.1, is the ability of a pavement or pavement material to withstand the impact and use of the road section over time. Maintenance cost is the metric used to measure this attribute since a relatively durable pavement tends to be more durable and require less maintenance under equal traffic conditions than a less durable pavement. The economic benefits derived from a pavement or pavement material with a high load carrying capacity include improved ADOT productivity as well as reduced VOC, and improved VOT and Safety.

SPECIFIC PRODUCT ATTRIBUTES OF HIGHWAY OPERATIONS

Table 5.2 presents three attributes that are common to highway operations products, namely attributes that lead to reduced accident severity and improved traffic flow. A product with distinct visibility attributes tends to be more apparent to drivers. This quality could be due to brighter paint or reflective material. This attribute is a safety-related attribute, since, for instance, a highly visible guardrail reflector may lead to a more clearly defined road and fewer night-time accidents. The metric for this category is percentage of reduced accident severity and the benefits include safety, ADOT productivity and liability.

New product traffic-related attributes refer to those products which affect traffic volume and congestion. The metric used for this attribute is derived from traffic volume estimates which ultimately lead to user benefits in VOC, VOT, safety, environment and productivity.

Table 5.2: Specific Product Attributes; Highway Operations

Attribute	Unit of Measure	Economic Benefit Category
Greater Visibility	Reduced Accident Severity	Safety/ADOT Productivity/Liability
Traffic Management Functions	Traffic Flow	VOC/VOT/Safety/Productivity

6.0 RISK ANALYSIS AND THE CHANGE IN ATTRIBUTES

The classification and identification steps presented in the previous chapters act as initial filters for organizing and assessing the attributes of new highway and construction products. The model, however, relies upon specific data input to generate the net benefits minus costs associated with a given new product. This section presents the background and the process that the model will use, based on user-provided information, to estimate net new product benefits and to assess the risk of achieving those benefits.

PEM models the expected change in physical effect that the new product's attributes will produce. The data used to forecast this change is based on testing or experimental data supplied with the product, or in-house, ADOT testing. To deal with the uncertainty surrounding new product data, the analyst uses the best information available and employs the risk analysis component of the model. The risk analysis component is combined with the change in metric data. The output of this component is a risk-analysis of the potential change in metric associated with a new product's attributes.

THE CHANGE IN ATTRIBUTE AND THE BENEFIT-COST MODEL

The goal of a Benefit-Cost 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 through its durability, for example, while supplying equal or superior user benefits, is preferred to 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.

Each new product submitted for economic evaluation will have at least six common and several specific product attributes that will be used in the Benefit-Cost analysis. The ATRC analyst must use the required metrics specified in the product attribute modules to enter values that reflect the change in physical effect that the new product attributes will produce. For example, the improved curing time for a new concrete, (the attribute) will lead to a decrease in person-hours (the metric). The difference in curing time between the existing product and the new concrete, then, is the change in physical effect, measured in person-hours, of the product attribute. The summed series of this and similar estimates, adjusted for real-life risk factors, ultimately will be used to compute the economic benefits minus costs.

The level of uncertainty surrounding the change in physical effect is magnified with new products. Most data concerning product attributes and performance is experimental and has not been tested over long periods of time. As a consequence, the projected change in physical effect associated with new product attributes can vary significantly from testing data or product information. This is compounded when one allows for the uncertain timing of product implementation.

Figure 6.1 illustrates the effect of the change in metric over time associated with a product attribute. The total change in metric is graphed along the Y-axis and represents the change in physical effect that the new product is expected to have based on testing information. The timing of this change in metric is graphed along the X-axis. Point A represent the point at which 50 percent of the desired change in metric occurs, in this case at three years. Point B represents the timing of the full effect of the change in metric at five years. In the model, the analyst will input data for these three variables: the expected change in metric and the timing for achieving 50 and 100 percent of the change in metric. To account for the uncertainty surrounding these estimates, however, a risk analysis will also be performed on these points.

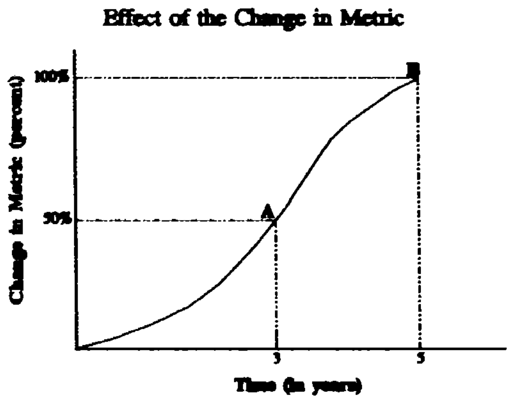


Figure 6.1: Percent Change in Metric over Time

RISK ANALYSIS AND THE CHANGE IN ATTRIBUTES

The risk analysis component of the model attaches probability functions to the uncertain variables associated with the change in metric for each product attribute. This function allows the analyst to specify ranges around data that is experimental, or likely to fluctuate. The probability functions for all changes in metrics and independent factors, such as time, are then simultaneously varied to produce a probability distribution for the change in metric. The sum of these probability functions for the change in metric for each product attribute, then, represents the likely physical effects that the new product will engender which can then be mapped into economic benefits.

Panel discussions are a supplemental part to the model's risk analysis. In addition to experimental and test data that forecast the change in physical effect that will occur with the use of a new product, ADOT personnel, transportation officials and academics are invited to discuss the range of factors that will likely affect the performance of certain product attributes. This information is then considered when determining the probability ranges to place around the change in metric estimates.

7.0 LINKAGE OF THE CHANGE IN PHYSICAL EFFECT AND ECONOMIC BENEFITS

The linkage of the change in product attribute metrics to economic benefits and costs is the heart of PEM. This is the point at which the risk-adjusted, change in metrics are combined into a quantity that can be translated by the model into the six general economic benefit categories defined in the transportation economics literature. The end result of this process is the calculation of the series of economic benefits that will be used in the next step to estimate the net present value of a given highway product.

ENGINEERING AND ECONOMIC ALGORITHMS

The economic benefits from the use of new highway products are dependent upon two independent functions, the engineering and economic algorithms. The "engineering" algorithm consists of the series of calculations that estimate the change in physical effect, as measured by the appropriate metric, for each new product attribute. The first five steps of the PEM process are devoted to obtaining and quantifying this information. The "economic" algorithm takes the information obtained in the first five steps and translates these quantities into defined economic benefit and cost categories. Like the uncertainty surrounding the expected changes in product attribute metrics, the relationship between physical data and economic benefits is also variable. The model takes this uncertainty into account, and uses a series of defined equations to asses user benefits from new products.

The principal economic algorithms and data sources used to calculate product benefits in the model are presented in the following sections. The general highway user cost data used in the sub-models 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 and through an extensive research project into highway user costs completed for the National Cooperative Highway Research Program by Hickling[7]. The physical effects, such as the maximum impact of pavement conditions on speed and accident rates are from professional experience.

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 and defined below.

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[7] NCHRP Project 2-18: Research Strategies for Improving Highway User Cost-EstimatingMethodologies (1993)

Safety

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.[8] 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.[9] The formula is in the following form:

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

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.

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).[10] 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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[8] 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.

[9] Ibid, The Highway Economic Requirements System.

[10] 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[11] and the Texas Transportation Institute.[12]

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

$$\mathit{Speed} = \mathit{FreeFlowSpeed} - B * v/c$$

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:

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

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.

Vehicle Operating Costs

Table 7.1 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[13] the Texas Transportation Institute's Technical Memorandum.[14] The five user cost components are:

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[11] Ibid, The Highway Economic Requirements System.

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

[13] Ibid, The Highway Economic Requirements System.

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

- 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.

Table 7.1 - 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[15]	•	•	•	•	•
Cycling Rate[16]	•	•	•	•	•
Pavement Condition[17]	•	•	•	•	•

RISK ANALYSIS AND ECONOMIC BENEFITS

The risk analysis component of the model is also applied to the economic algorithms to factor the uncertainty associated with achieving economic benefits. Since Benefit-Cost analysis involves the summing of all economic benefits and costs, the probabilities for achieving these benefits must similarly be summed to provide the probability distribution of net benefits associated with a new product. The implication of this process is that ADOT personnel will be able to set a standard, for example, an 95 percent probability, of achieving a defined level of net economic benefits with the use of given new product. Products that do not meet this standard, therefore, can be screened out of the ATRC Product Evaluation Program.

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

[16] The cycling rate is calculated based on the volume to capacity ratio for the roadway.

[17] 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.

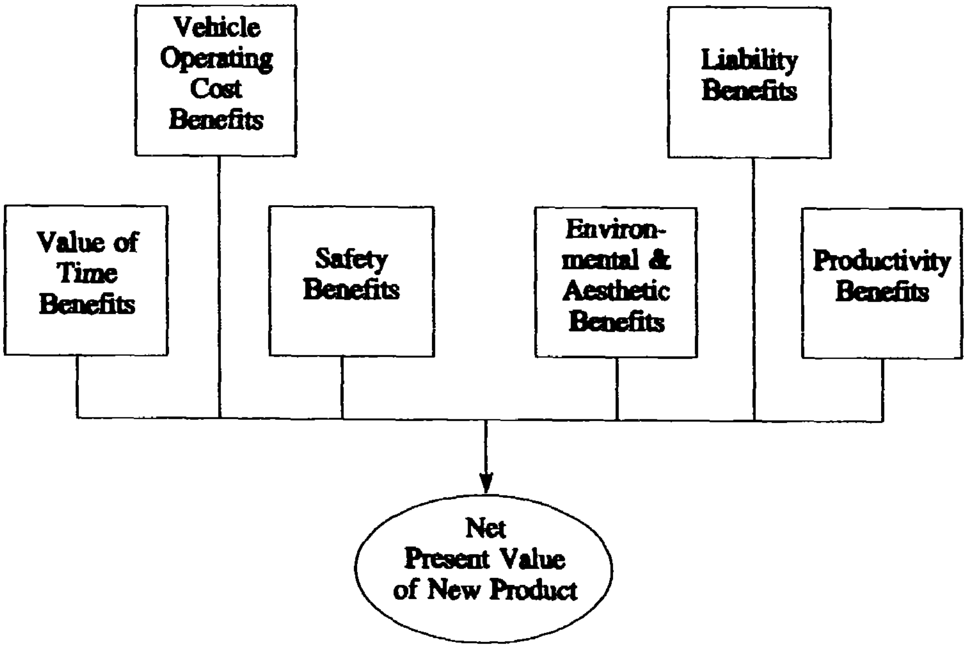
8.0 ESTIMATION OF NET PRESENT VALUE OF THE NEW PRODUCT

The final step of the model is the estimation of the Net Present Value of the New Product. The model calculates this value by taking the probability distribution of net economic benefits and "discounting" this value by five percent over a twenty five year period. 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.

Figure 8.1 illustrates this process. The model sums the probabilities of achieving benefits in the six general economic effect categories into the probability of achieving the net economic benefits associated with a new product. This value, as explained above, is discounted over twenty five years to determine the net present value of the new product.

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. Using this information, the analyst can supplement the product selection process with an economic case for resource allocation.

Figure 8.1: Estimation of Net Present Value of the New Product



9.0 MODEL VERIFICATION

PRODUCTS REVIEWED BY PRIDE IN 1993

PEM was effectively used to perform an economic screening of the 1993 PRIDE products. Although not all products were evaluated due to a lack of adequate data or other factors, the PEM process demonstrated that the model can be used to screen a series of products based on a minimum amount of economic data. The quality of the economic benefit forecasts improves the availability of and confidence in reliable data sources.

The initial screening of 1993 PRIDE products provides a basic demonstration of how PEM will function when it is fully integrated into the PRIDE program. Hickling's experience with data collection for the analysis of PRIDE products, therefore, provides only a cursory indication of the current data available for PEM forecasts of economic benefits. As PEM becomes a standard feature of the PRIDE program, the full contribution of ADOT experience and engineering expertise will be incorporated in the development of Base Case and New Product cases for PEM evaluations. This will allow even prototype products to be assessed, using the risk estimates provided by the ADOT staff that will ultimately use, maintain and witness the economic benefits of new products.

This section presents the data sources and basic assumptions that were used to evaluate the 1993 PRIDE products. For those products where sufficient data was available to conduct the PEM analysis, a short summary of the main factors affecting the analysis is presented. For those products where the lack of sufficient data prevented the use of PEM, a brief statement explains why the analysis was not performed.

PRIDE Products with Sufficient Data for PEM Analysis

Adequate data to conduct a basic PEM analysis was available for 12 PRIDE products. The main assumptions and data sources used during the PEM process are summarized in the following sections. Data sheets and decumulative probability distribution graphs for each product are presented in the Technical Appendix.

Eonite

Eonite is used as the Base Case product for rock varnish and staining. The product has a history of use with ADOT and sufficient price and usage data is available to conduct the PEM analysis. Its two-step approach, however, necessitates roughly twice the labor and equipment used to apply it to a given area of square feet, thus decreasing productivity by half when compared to a one-step rock varnish procedure. A two-man crew[18] with a weed sprayer (used in lieu of a dedicated rock varnish applicator) from the ADOT maintenance

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[18] A two-man crew is used in the analysis according to vendors' product sheets and comments.

crew is used in the analysis. A 100,000 square foot area over one mile was chosen as the basis for comparison. A maximum life of 100 years is taken from the product literature.

Permeon 501

Permeon 501 is a direct competitor with Eonite and is used as the New Product case in PEM analysis. Price data was obtained from product vendor sheets, as well as a telephone conversation with a vendor from Advanced Concrete Technologies. Further information on crew size, productivity, equipment, etc... was also obtained from the vendor. Permeon's one step approach effectively halves the resources needed to apply the product. Permeon's maximum life and test square foot area are assumed to be the same as the Base Case product.

Polymer Concrete Handhole

The essential product cost information for the Polymer Concrete Handhole was available from the product vendor sheets. Data on productivity and potential maximum life was derived from conversations with ADOT Electrical Engineering. The box size used for comparison was the size 7 box. It was assumed that lighter pull boxes might lead to one or two more installations per day over the current procedures, due chiefly to the ease of handling and the need for less precaution to prevent injury. The product life was assumed to be at least 5 years.

Quazite Composolite Service Box

The essential product cost information for the Quazite Composolite Service Box was available from the product vendor sheets. Data on productivity and potential maximum life was derived from conversations with ADOT Electrical Engineering. The box used for comparison was the size 7 box, without the floor. It was assumed that lighter pull boxes might lead to one or two more installations per day over the current procedures, due chiefly to the ease of handling and the need for less precaution to prevent injury. The product life was assumed to be at least 5 years.

QPR 2000

QPR is presented as a direct competitor to U.P.M. In product literature, as well as other references, its performance roughly equaled that of U.P.M. In this analysis, all performance variables, (durability, productivity, etc...) were considered equal, as were there areas of application. In a more in-depth analysis, these variables might diverge.

Rapid Set 3/8" Concrete Mix

According to product literature, the product has many of the same properties as Set 45 concrete patching material. In lieu of more product specific data, the values for SET 45 variables, as contained in the Strategic Highway Research Project (SHRP) report, Innovative Materials Development and Testing: Volume 5: Partial Depth Spall Repair were uses as a proxy. U.P.M. was used as the Base Case.

Uretek Method

Conversations with an ADOT engineer present during product testing provided most of the information for this product evaluation. This case, in fact, is not so much a product as it is a new technique. Therefore, the traditional unit cost, etc. were not readily available for this "product." The engineer, however, discussed that when compared to the traditional grout slab lifting, the Uretek method was approximately 4 times as efficient, in terms of labor and equipment. He estimated that the Uretek method could complete the task in one work shift costing between $8,000 and $10,000, while the traditional method would require 4 shifts to complete. These aggregate figures were applied to 1 mile of state highway with full width closures to determine the user costs associated with each case. The maximum product life was assumed to be forever, and no product failures.

Soff Cut

Conversations with the Soff-Cut saw manufacturers and reference the PRIDE product application formed the basis for this analysis. Like the Uretek method, this product represents the introduction of a new technique and product, rather than just a new product, therefore the traditional common product attributes were not all used. The main benefit of the Soff-Cut technique is through the time reduction and productivity increase associated with the early cutting time as well as the clean cutting process which allegedly does not require the clean up associated with Base Case wet saw techniques. The analysis used the cost information provided in the PRIDE product annual report applied to a 25,000 square foot surface with a productivity rate of 4:1 to perform the analysis.

Pro Flag

The product information for Pro Flag was generally sufficient for the PEM analysis. The principal assumption in the analysis, however, was that the Pro-Flag device was a one-to-one replacement with standard flagging paddles. All other factors were held constant between the Base Case and the New Product. One area that may increase the benefits associated with the Pro-Flag are the two product specific attributes included in PEM. If it can be demonstrated that the use of the Pro-Flag has a discernable impact on accident rates or speed/flow, then the basic cost-benefit analysis may be altered. This scenario, however, was out of the scope of this screening.

PCBM

The product cost information and maintenance figures for the Portable Concrete Barrier Marker (PCBM) are from the manufacturer. ADOT sources were unable to determine many of the variables needed for this analysis. It is assumed that all common product information for the New Product case, PCBM, are the same for the Base Case, in lieu of more compelling information. A one mile test section is assumed and a one hour traffic disruption, to perform the analysis.

Koch BJS

Information for this comparison comes primarily from a vendor response to a request for further data. Labor productivity, equipment, crew size, estimated duration of traffic disruption were all based on vendor information. The prices for the two types of bridge joints comes from the 1993 PRIDE Annual Report.

Hot Tape

The PEM analysis for Hot Tape was conducted based on vendor information and ADOT anecdotal information for solid line tape. The maximum product life for Hot Tape was taken from the manufacturer's warranty period. A one person crew was assumed to be capable of applying the Hot Tape, while a two person crew was assumed for conventional striping. Productivity, in square feet per hour, however, was taken from PECOS II, "special pavement marking 0403," and assumed to be approximately the same in both cases.

PRIDE Products with Insufficient Data for PEM Analysis

PEM analyses on the following products were not performed due to a lack of useful data or the absence of an appropriate Base Case product for comparison at the time of the analysis. In some instances, further investigation of the products using ADOT experience and engineering expertise, may produce basic median estimates for PEM that can be used within large probability ranges reflecting the degree of uncertainty with each estimate.

Protector

This surge protector was not evaluated for two reasons: An appropriate Base Case product for comparison could not be determined from the available information. In the 1993 PRIDE Annual Report, the cost of the Protector is compared to 4 different protectors, surge arrestors. In addition, the economic life of the Protector could not be determined based on product information or ADOT anecdotal experience. Finally, an ADOT electrical engineer claimed that the Protector would probably have no clear advantage over standard protectors during a lightning storm and was not worth the extra expense.

GlasGrid

This product was not evaluated because of the lack of information on product life, application time, and useful Base Case information. From conversations with ADOT Engineers, it was unclear how many miles of road use road reinforcement mesh, or the labor or equipment typically associated with this operation.

Direction Beacon System

This product was not evaluated because of a lack of information concerning product life, productivity, and the number of installations per mile. Additionally, constructing an adequate Base Case for comparison was not possible.

Xenon Guidelight System

This product was not evaluated because of a lack of information concerning product life, productivity, and the number of installations per mile. Additionally, constructing an adequate Base Case for comparison was not possible.

db Minus Sound Wall

This product is unique and cannot be compared directly with other concrete barrier walls. In addition, adequate information on product life, the number of installations per mile, required equipment and labor, were not available for this product.

Traffic Light Change Anticipation System

This product was not evaluated because it could not accurately be compared to existing technology. According to ADOT Risk Management, the implementation of the device would require extensive revisions of federal specifications and traffic laws. The nature of the product and the benefits that it seeks to provide, (less traffic accidents at intersections) were beyond the scope of this initial economic screening.

Lorant Group Products

The Lorant Group, Inc. has submitted several bridge and engineering products to the ATRC for evaluation. Unfortunately, since all of this products are proto-types and have no field testing experience, an adequate cost-benefit analysis cannot be performed. Telephone conversations with the vendor did not produce any further information on basic information required for PEM, such as labor and equipment required to install the product, the amount of time required for installation, the projected useful economic life, etc.. In addition, ADOT personnel from the Bridges and Structures Group were unable to produce essential Base Case data on several products

Factors Affecting the Evaluation of PRIDE Products

Two essential factors affected the ability to perform the PEM analysis on the 1993 Pride Products: product class and the availability of data.

Product Class

There are essentially three different classes of products in the 1993 PRIDE program. These classes do not refer to the type of product or to its function, but rather to its relationship to ADOT experience. A standard product which is currently used by ADOT typically has documented data on cost, performance and productivity. New products which claim to be improvements to this product, can easily be compared against this **Base Case** product with a high degree of confidence, in terms of common and specific product attributes. The other products, may have limited or no field experience, and therefore little relationship with ADOT experience. The uncertainty associated with these latter products requires larger probability ranges in PEM, and therefore may produce a wider forecast range of economic benefits. The three classes of products are defined as follows:

Class 1	These types of products are typically improved versions of standard products that are already in use by ADOT. Base Case and New Product Case information is relatively easy to obtain.
Class 2	These are products that have limited field experience or are currently employed by other State Departments of Transportation. Usually, information for the Base Case and New Product case can be constructed, from interviews with manufacturers and/or reference to other product evaluations.
Class 3	These are products that are in the prototype stage and have no real field experience. Often, these products involve new technologies or techniques that cannot be immediately compared to **Base Case** products or conditions. Developing a cost-benefit framework for these products may require more extensive preparation of data for PEM.

Based on this taxonomy of product classes, the number of PRIDE products in each class is summarized in the following table:

Table 9.1: 1993 PRIDE Products, by Class

Product Class	Number of 1993 PRIDE Products
Class 1	7
Class 2	5
Class 3	12
Total	24

Availability of Data

The availability of data for each product affected the analysis of 1993 PRIDE products. Current, useful data for each product is often linked to product class, but in several instances, the availability of data for Class 1 and 2 products was either poor or limited. Extensive use of the ADOT Maintenance Planning system (PECOS II) data was used to estimate productivity and average labor and equipment costs associated with new products. For products used in construction, data was obtained from vendors and contractors.

PEM Results

The following table summarizes the results of the PEM analysis of 1993 PRIDE products where sufficient data was available.

Table 9.2: Initial Screening of PRIDE Products with Sufficient Data for PEM Analysis

Product	PEM Analysis; Median NPV of Economic Benefits[19] ($ millions)	PEC Decision
Eonite	0	Approved
Permeon	0.065	Approved
Polymer Concrete Handhole	4.16	Approved
Quazite Composolite Service Box	2.60	Approved
QPR 2000	0.03	Testing Required
Rapid Set 3/8" Concrete Mix	(0.05)	Testing Required
Uretek Method	2.01	Testing Required
Soff Cut	3.84	Testing Required
ProFlag	(1.47)	Testing Denied
PCBM	(0.17)	Approved[20]
Koch BJS	(0.36)	Testing Required
HoTape	.004	Approved

PEM's preliminary results provide a indication of the performance of 1993 PRIDE products, based on strictly economic criteria. Eight of the twelve products evaluated produced positive forecasts of median NPV benefits, indicating a positive return on investment. (The assumptions and data used to perform the analysis for these products are listed in section 3). The remaining four products, however, produced negative forecasts of median NPV benefits, and therefore were not economically justified.

In comparison with the Products Evaluation Committees' (PEC's) actions on the same PRIDE products, PEM results correspond with final decisions in all but one case. The Portable Concrete Barrier Marker (PCBM) produced negative economic effects (costs) when compared to the Base Case product, and therefore was not economically justified. In the five cases where the PEC decided on further testing, PEM produced positive results for three products and negative NPV benefits for the remaining two products. The basic nature of the economic

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[19] Numbers in Parentheses are Negative.

[20] Approved for use below 3,500 ft.

screening process used in this analysis, however, should be kept in mind when interpreting these results, since only limited data was used in the evaluation.

Implications of 1993 PRIDE Product Screening

The availability of accurate, useful data is critical to the PEM analysis. Although data for this particular analysis was scant, it is believed that as the PEM process is adapted into the PRIDE program framework, more timely and useful data sources will be developed in ADOT, perhaps through the development of a PEM database. Additionally, a vendor checklist geared towards providing information for PEM could become a standard feature of the PRIDE program (a sample checklist is included in the Technical Appendix).

REFLECTIVE SIGN SHEETING RAP SESSION

Warning and regulatory road signs serve significant safety and informational functions for roadway users. How long and how well a sign performs its desired function also has important implications for operating and maintenance costs. A benefit-cost analysis, utilizing the PEM and the Risk Analysis Process (RAP), was convened in July, 1994 to help determine the most cost-effective sign sheeting material for warning and regulatory signs.

The different types of sign sheeting were evaluated against engineering grade sign sheeting, which is the type currently used by ADOT. The NPVs of economic benefits of each are compared and a ranking developed. For instance, if the NPV of high intensity sign sheeting is positive, then from an economic perspective, it offers greater value than the base case, engineering grade sign sheeting. In addition, the NPV to capital invested financial ratio can be used to assess the benefit per dollar of capital expenditure, or the "value per additional dollar spent."

PEM Results

The mean expected values of the NPV of economic benefits are displayed in Tables 9.3 and 9.4. Based on the data collected at the RAP session, the results of the PEM analysis indicate that super engineering regulatory sign sheeting is more cost-effective than the current sign sheeting used by ADOT.

Table 9.3 Net Benefits of Regulatory Sign Sheeting Material

Type of Sign Sheeting Material	$/100 Roadway Miles (Mean Expected Value)
Super Engineering Grade	$7,300
High Intensity	($37,860)
High Intensity Prismatic	($51,500)

Although the analysis indicates that there are positive net benefits associated with super engineering regulatory sign sheeting, this estimate is not significantly different than estimates for the other materials. In fact, none of the results in the two categories of signs differed by any acceptable degree of significance.

Table 9.4 Net Benefits of Warning Sign Sheeting Material

Type of Sign Sheeting Material	$/100 Roadway Miles (Mean Expected Value)
Super Engineering Grade	($52,470)
High Intensity	($271,570)
High Intensity Prismatic	($303,980)

Tables 9.5 and 9.6 display the NPV of economic benefits to capital invested ratios for each type of sign sheeting analyzed. The ratios indicate the benefits per additional dollar of capital invested.

Table 9.5 NPV to Capital Invested Ratio for Regulatory Signs

Type of Sign Sheeting Material	Net Present Value ($/100 Roadway Miles)	Additional Capital Invested ($)	NPV/Capital Invested ($)
Super Engineering Grade	$7,300	$36,570	0.20
High Intensity	($37,860)	$115,670	(0.33)
High Intensity Prismatic	($51,500)	$123,010	(0.42)

These results also indicate that there are positive social benefits, $0.20 per each additional dollar of capital invested, from switching to super engineering grade regulatory sign sheeting.

Table 9.6 NPV to Capital Invested Ratio for Warning Signs

Type of Sign Sheeting Material	Net Present Value ($/100 Roadway Miles)	Additional Capital Invested ($)	NPV/Capital Invested ($)
Super Engineering Grade	($52,470)	$124,060	(0.42)
High Intensity	($271,570)	$369,830	(0.73)
High Intensity Prismatic	($303,980)	$396,850	(0.77)

Tables 9.7 and 9.8 display the expected net benefits for the entire Arizona urban and rural interstate roadway system. These values also represent the dollar amount of accident cost savings required, over the entire Arizona interstate road network, in order to justify the additional capital investment required to switch to another sign sheeting material. For instance, if ADOT believes that super engineering warning sign sheeting on rural roads will reduce accident costs by $213,658 over the 30 year analysis period, then switching to super engineering grade sign sheeting for rural warning signs is justified.

These results indicate that switching to super engineering grade regulatory signs in urban areas is justified on a benefit-cost basis. These results also reveal that super engineering grade, in all categories, requires the least accident cost savings to justify a change in sign sheeting material.

These values, for required accident cost savings in Tables 9.7 and 9.8, could be achieved with saving just one life over the 30 year analysis period. In fact, if super engineering rural regulatory signs prevented just one injury only accident, it would more than compensate for the additional capital expenses associated with super engineering sign sheeting. (see the Technical Appendix for more information about accident costs).

Table 9.7 Net Benefits of Regulatory Sign Sheeting Material for All Urban and Rural Roads

Type of Sign Sheeting Material	Net Benefits for Urban Roads ($)	Net Benefits for Rural Roads ($)
Super Engineering Grade	$10,950	($29,726)
High Intensity	($59,062)	($154,166)
High Intensity Prismatic	($80,340)	($209,708)

Table 9.8 Net Benefits of Warning Sign Sheeting Material for All Urban and Rural Roads

Type of Sign Sheeting Material	Net Benefits for Urban Roads ($)	Net Benefits for Rural Roads ($)
Super Engineering Grade	($81,853)	($213,658)
High Intensity	($423,649)	($1,105,833)
High Intensity Prismatic	($474,209)	($1,237,807)

Implications of the Sign Sheeting RAP

The RAP of reflective sign sheeting material using PEM revealed three main points:

1. On a strict benefit-cost basis, only super engineering regulatory sign sheeting yields positive net social benefits, as compared to the base case.

2. Switching to another type of sign sheeting material can be justified if ADOT believes accident cost savings will be achieved. Preventing just one fatal accident over the entire 30 year analysis period is enough to justify switching to any type of sign sheeting material. (While there is no conclusive evidence that sign sheeting material has any quantifiable impact on highway users, many panelists at the RAP session did feel strongly that sign sheeting materials did have an impact.)

3. Super engineering grade sign sheeting material is recommended as the best alternative sign sheeting material since it minimizes the risk of not achieving net social benefits, as compared to the base case.

Other Outcomes of the RAP Session

The analysis clearly highlights the need for further research in the area of sign sheeting. The RAP panelists felt strongly that sign sheeting can have significant impact on accident rates, and the over-all feeling of security of highway drivers, but they could not agree upon how much effect the sign sheeting would actually produce. Without research to back-up these claims, the panelists would not even venture a guess at the potential effects.

10.0 RESOURCE ALLOCATION PLAN

INTRODUCTION

Based on experience in evaluating the 1993 PRIDE products and the RAP session on sign sheeting materials, Hickling has developed a resource allocation plan for the ATRC to effectively use PEM. The core of the plan is a standard product evaluation process that is applied to each product. In terms of resource demand, the plan reflects the two central factors that affect the ATRC analyst's ability to perform a thorough product evaluation: the "class" of product and the ability to obtain useful product information for PEM. These factors are applied to the PEM process to determine an average amount of time required to complete each step. These estimates are then summed to provide a total average of time required to perform a basic PEM product analysis. Using the annual number of PRIDE product applications, the plan determines total time and personnel needed to perform the PEM product analyses on annual basis. The final plan also includes an estimate of the time and preparation required to perform a risk analysis process (RAP) session.

TIME REQUIREMENTS OF THE PEM PROCESS

This section estimates the average time required for a basic PEM product analysis. An estimate for each step of the PEM process is determined by considering the "class" of product and the availability of useful product data. The total average time for a PEM analysis is then presented as the sum of the time estimates for each step.

PEM Step 1

In this step of the PEM process, the analyst must input data concerning Roadway Characteristics and Highway User Cost and ADOT Policy Data. The most important part of this process lies in correctly defining the environment where the product will be implemented and used. Products such as concrete patching materials, for example, are used throughout Arizona on many miles of roadway. Depending on the application of the product, the analyst may need to make independent calculations to arrive at a reasonable estimate. This sub task can usually be accomplished with the aid of an ADOT District Engineer or by consultation with other sources.

The Highway User Cost Data used in PEM are normally default values that are seldom changed, except for a change in ADOT policy or other determinants. The Highway User Cost and ADOT policy default values used in this analysis are based on state of the art transportation research and correspond to values used in other economic analyses conducted for the ADOT Division of Transportation Planning. The analyst should refrain from changing these values, especially for products that are employed on a modest scale, since these variables significantly impact PEM's analysis.

Estimated Average Time for PEM Step 1: 2 hours

PEM Step 2

In step 2 of PEM, the user identifies common product attributes which refer to the standard qualities or features of a product that can be quantified and 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.

The factors affecting the time required by this step are the type of product and the availability of useful product data. New products that are improved versions of products already in use by ADOT are relatively easy to evaluate, since ADOT maintains records of product cost, productivity, and other common product attributes. Other products, which have limited field testing and no ADOT experience, are more difficult to evaluate and require more time to obtain useful data from vendors, federal research programs, etc. to construct the Base Case and New Product case scenarios. In some instances, a product evaluation can be held up several days before adequate productivity data, for example, is obtained. Based on these reasons, an average of two days, (16 hours) is assumed to collect and input all pertinent data for a PRIDE product evaluation.

Estimated Average Time for PEM Step 2: 16 hours

PEM Step 3

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 can be quantified and 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. Based on the review of 1993 PRIDE products, about 35% contain specific product attributes that can be used in PEM.

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 an important additional level of detail to PEM's cost-benefit analysis. Given the nature of product specific attributes, however, the analyst typically requires more time to obtain the information necessary for PEM.

The factors affecting the time required by this step are the type of product, the availability of useful product data, and the need for specific research. PEM is designed to address primarily the specific attributes associated with products that affect pavement condition. Obtaining the necessary information, such as the *PSI of Pavement with New Product* and *Resurfacing Costs associated with New Product*, depends largely on the technical knowledge of the product vendor or manufacturer or the estimates of ADOT personnel. Data for these products may be obtained immediately, or it may take several days for vendors to provide adequate information.

The ATRC analyst may need to conduct a literature review or limited research to determine the values for several of the non pavement-related specific product attributes. The *Percent Improvement in Speed/Flow with New Product*, for example, is largely debatable. Reference to specific research on the subject, however, can sometimes provide an important contribution to the PEM analysis.

Estimated Average Time for PEM Step 3: 40 hours

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 economic benefits through the use of risk analysis. To deal with the uncertainty surrounding new product performance, the analyst places probability ranges around each variable subject to real-world fluctuation, based on objective and subjective information obtained in the previous steps of the PEM process. This process leads to a more accurate forecast of the potential economic benefits stemming form the changes in product attributes.

As explained in the PEM Reference Manual and User's Guide, the user has can perform two variations of the risk analysis of the cost-benefit evaluation of a new product. Variation one assumes that the user self-generates a risk analysis based on the product information collected in previous steps. Variation two, however, involves the planning and conduct of a full risk analysis process (RAP) session and is discussed separately.

Based on experience evaluating the 1993 PRIDE products using PEM variation one, it is estimated that a user will need a day and a half per product to effectively enter and shape the input variables during this step of the PEM process.

Estimated Average Time for PEM Step 4: 12 hours

PEM Step 5

In Step 5, PEM 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.

Since this step of the PEM process is largely computer-generated, it does not require an extensive amount of time. The majority of time spent on this step involves selecting the appropriate options in the risk analysis software and in running the RAP simulations.

Estimated Average Time for PEM Step 5: 2 hours

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 probability distribution of net economic benefits derived in step 5 and "discounting" this value by five percent over a twenty five year period.[21] 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.

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 decumulative distribution option in the PEM RAP component.

Estimated Average Time for PEM Step 6: 4 hours

FULL RAP SESSION

As explained in PEM step 4, variation two of this step involves the preparation, planning and conduct of a RAP panel session. Depending on the complexity of the product, the time allotted for the preparation of the RAP session can vary significantly. The essential tasks lie in choosing the product attributes that will be discussed and conducting the necessary research on each variable. In some instances, such as with sign sheeting materials, specific product attributes, such as the impact of retroreflectivity, need additional research. The time required to plan, prepare, and write the RAP reference books and data sheets often takes an average of two-three days. Based on these factors, a minimum of one week (40 hours) is estimated to adequately prepare a RAP session. The Resource Allocation Plan assumes that four RAP sessions will be performed per year.

RESOURCE ALLOCATION PLAN

Based on the time estimates for each step of the PEM process, Hickling has developed the following Resource Allocation Plan for the ATRC's PRIDE program. Each step, as explained in the previous sections is listed in left-hand column with the estimated average hours required for each step. These values are then multiplied by the "Average Number of Cases," or number of product applications considered to determine an annual estimate of hours required for each task.

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[21] 5 percent is the discount rate recommended by the AASHTO Redbook (1977). The 25 year period of analysis is commonly used in the evaluation of transportation investments. Both values may be changed according to user requirements.

Table 10.1: PEM Annual Resource Allocation Plan for the PRIDE Program (hours)

Procedure	Average Required Hours	Annual Number of Cases	Annual Hours
PEM Step 1	2	25	50
PEM Step 2	16	25	400
PEM Step 3	40	9[22]	360
PEM Step 4	12	25	300
PEM Step 5	2	25	50
PEM Step 6	4	25	100
Full RAP Session	40	4	160
TOTAL			1,420

The total hours required to perform the PEM analysis on 25 PRIDE products, according to Table 10.1, is 1,420 hours or, 177.5 eight-hour work days. A program to fully implement the PEM process into the PRIDE program would require roughly half of one ATRC analyst's annual time to effectively evaluate 25 PRIDE products based on this plan. An alternative could be to hire a part-time intern or student to perform the first three steps of the PEM process involving data collection, and therefore leaving the essential analytical work for the ATRC staff.

The plan is based on estimated average time for each step as it was observed during the evaluation of the 1993 PRIDE products. As better and more reliable data sources are developed for using PEM, such as through the introduction of standard product information request sheets and a PEM database containing information used in previous analyses, the average time required for each step may decrease over time.

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[22] Based on Hickling experience in evaluating the 1993 PRIDE products, approximately 35% of all products have specific product attributes that can be used in the analysis. 35% of 25 annual cases, therefore, equals 9 products with specific attributes.

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12.0 TECHNICAL APPENDIX

PROPOSED PEM DATA REQUIREMENTS SHEET

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).

DOCUMENTATION OF ECONOMIC SCREENING OF 1993 PRIDE PRODUCTS

PEM Data Sheets

Eonite (Base Case)	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq ft)	$0.54	$0.25	$2.00
Useful Economic Life (Years)	50	49	51
Maximum Useful Life (Years)	100	99	101
Average Units of Material per Product (Units/Product)	1.0		
Current Products in Use (ft^2)	100,000	90,000	110,000
Annual Increase in Products (ft^2)	1,000	900	1,100
Products at First Year of Steady State (ft^2)	0	0	0
Years to Steady State (Years)	2	1.75	3
Steady State Product Growth (#)	0	0	0
Labor Productivity (#/HR/Person)	10,000	9,000	11,000
Labor Wage	$13.68		
Hourly Equipment Costs ($/HR)	$5.52	$4.97	$6.07
Failure Rate	4		

Permeon 501	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq ft)	$0.27	$0.15	$0.38
Useful Economic Life (Years)	50	49	51
Maximum Useful Life (Years)	100	99	101
Average Units of Material per Product (Units/Product)	1.0		
Products at First Year of Steady State (ft^2)	100,000	90,000	110,000
Years to Steady State (Years)	2	1.75	3
Steady State Product Growth (ft^2)	1,000	900	1,100
Labor Productivity (#/HR/Person)	5,000	4,500	5,500
Labor Wage	$13.68		
Hourly Equipment Costs ($/HR)	$5.52	$4.97	$6.07
Failure Rate	4		

Concrete Box (Base Case)	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq ft)	$54.42	$48.98	$59.86
Useful Economic Life (Years)	1.75	1.5	2.0
Maximum Useful Life (Years)	3.5	3.25	3.75
Average Units of Material per Product (Units/Product)	1.0		
Current Products in Use (#)	4,000	3,600	4,400
Annual Increase in Products (#)	40	36	44
Products at First Year of Steady State (#)	0	0	0
Years to Steady State (Years)	10	5	15
Steady State Product Growth (#)	0	0	0
Labor Productivity (#/HR/Person)	0.19	0.17	0.21
Labor Wage	$13.68		
Hourly Equipment Costs ($/HR)	$33.70	$30.33	$37.70
Failure Rate	1		

Polymer Concrete Handhole	**Median Value**	**10% Lower Limit**	**10% Upper Limit**
Material Unit Cost ($/Sq ft)	$70.00	$53.00	$77.00
Useful Economic Life (Years)	2.5	2.25	2.75
Maximum Useful Life (Years)	5.00	4.75	5.25
Average Units of Material per Product (Units/Product)	1.0		
Products at First Year of Steady State (#)	4,000	3,600	4,400
Years to Steady State (Years)	10	5	15
Steady State Product Growth (#)	40	36	44
Labor Productivity (Units/HR/Person)	0.31	0.27	0.35
Labor Wage	$13.68		
Hourly Equipment Costs ($/HR)	$33.70	$30.33	$37.07
Failure Rate Path	1		

Quazite Polymer Concrete Box	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq ft)	$152.00	$136.00	$167.20
Useful Economic Life (Years)	2.5	2.25	2.75
Maximum Useful Life (Years)	5.00	4.75	5.25
Average Units of Material per Product (Units/Product)	1.0		
Products at First Year of Steady State (#)	4,000	3,600	4,400
Years to Steady State (Years)	10	5	15
Steady State Product Growth (#)	40	36	44
Labor Productivity (Units/HR/Person)	0.19	0.17	0.21
Labor Wage	$13.68		
Hourly Equipment Costs ($/HR)	$33.70	$30.33	$37.07
Failure Rate Path	1		

UPM (Base Case)	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 Product (Units/Product)	3.0	2.5	3.5
Current Products in Use (#)	560	500	620
Annual Increase in Products (#)	56	50	62
Products 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
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 (Min)	5	3	7
Annual AADT Effected (%)	0.001	0.000	0.002
Failure Rate	1		

Rapid Set 3/8" Concrete Mix	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq Ft)	$5.68	$5.11	$6.25
Useful Economic Life (Years)	2.5	2.25	2.75
Maximum Useful Life (Years)	5.0	4.75	5.25
Average Units of Material per Product (Units/Product)	3	2.5	3.5
Products at First Year of Steady State (#)	560	500	620
Years to Steady State (Years)	2	1.75	3
Steady State Product Growth (#)	56	50	62
Labor Productivity (Units/Hr/Person)	5.0	4.5	5.5
Labor Wage ($/HR)	$13.68		
Hourly Equipment Costs ($/HR)	$84.56	$80.33	$88.79
Exp. Disruption Delay (Min)	20	15	25
Annual AADT Effected (%)	0.001	0.000	0.002
Failure Rate Path	1		

QPR 2000	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq Ft)	$1.93	$1.74	$3.00
Useful Economic Life (Years)	2.5	2.25	2.75
Maximum Useful Life (Years)	5.0	4.75	5.25
Average Units of Material per Product (Units/Product)	3	2.5	3.5
Products at First Year of Steady State (#)	560	500	620
Years to Steady State (Years)	2	1.75	3
Steady State Product Growth (#)	56	50	62
Labor Productivity (Units/Hr/Person)	5.0	4.5	5.5
Labor Wage ($/HR)	$13.68		
Hourly Equipment Costs ($/HR)	$74.12	$70.39	$77.79
Exp. Disruption Delay (Min)	5	3	7
Annual AADT Effected (%)	0.001	0.000	0.002
Failure Rate Path	1		

Slab Jacking (Base Case)	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq ft)	$1,600.00	$1,500.00	$1,700.00
Useful Economic Life (Years)	12.5	12.0	13.0
Maximum Useful Life (Years)	25.0	24.5	25.5
Average Units of Material per Product (Units/Product)	1.0		
Current Products in Use (#)	10	9	11
Annual Increase in Products (#)	1	0	2
Products 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
Labor Productivity (#/HR/Person)	0.005	0.004	0.006
Labor Wage	$16.27		
Hourly Equipment Costs ($/HR)	$1,000.00	$900.00	$1,100.00
Exp. Disruption Delay (Min)	60	50	70
Annual AADT Effected (%)	0.002	0.001	0.003
Failure Rate	1		

Uretek Method	**Median Value**	**10% Lower Limit**	**10% Upper Limit**
Material Unit Cost ($/Sq Ft)	$1,600.00	$1,500.00	$1,700.00
Useful Economic Life (Years)	12.5	12.0	13.0
Maximum Useful Life (Years)	25.0	24.0	26.0
Average Units of Material per Product (Units/Product)	1.0		
Products at First Year of Steady State (#)	10	9	11
Years to Steady State (Years)	2.0	1.75	3.0
Steady State Product Growth (#)	1	0	2
Labor Productivity (Units/Hr/Person)	0.42	0.038	0.046
Labor Wage ($/HR)	$16.27		
Hourly Equipment Costs ($/HR)	$1,000.00	$900.00	$1,100.00
Exp. Disruption Delay (Min)	60	50	70
Annual AADT Effected (%)	0.001	0.000	0.002
Failure Rate Path	1		

Wet Saw (Base Case)	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq ft)	$0.83	$0.75	$0.91
Useful Economic Life (Years)	12.5	12.0	13.0
Maximum Useful Life (Years)	25.0	24.0	26.0
Average Units of Material per Product (Units/Product)	1.0		
Current Products in Use (#)	25,000	20,000	30,000
Annual Increase in Products (#)	2,500	2,000	3,000
Products 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
Labor Productivity (#/HR/Person)	100	90	110
Labor Wage	$16.27		
Hourly Equipment Costs ($/HR)			
Exp. Disruption Delay (Min)	60	50	70
Annual AADT Effected (%)	0.001	0.000	0.002
Failure Rate	1		

Soft-Cut Dry Saw	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq Ft)	$0.60	$0.54	$0.66
Useful Economic Life (Years)	12.5	12.0	13.0
Maximum Useful Life (Years)	25.0	24.0	26.0
Average Units of Material per Product (Units/Product)	1.0		
Products at First Year of Steady State (#)	25,000	20,000	30,000
Years to Steady State (Years)	2.0	1.75	3.0
Steady State Product Growth (#)	2,500	2,000	3,000
Labor Productivity (Units/Hr/Person)	175	150	200
Labor Wage ($/HR)	$16.27		
Hourly Equipment Costs ($/HR)			
Exp. Disruption Delay (Min)			
Annual AADT Effected (%)			
Failure Rate Path	1		

Basic Paddle (Base Case)	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq ft)	$40.00	$36.00	$44.00
Useful Economic Life (Years)	5.0	4.5	5.5
Maximum Useful Life (Years)	10.0	9.5	10.5
Average Units of Material per Product (Units/Product)	1.0		
Current Products in Use (#)	1,000	900	1,100
Annual Increase in Products (#)	100	90	110
Products 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
Labor Productivity (#/HR/Person)	1.0	0.9	1.1
Labor Wage	$16.27		
Hourly Equipment Costs ($/HR)			
Failure Rate	1		

Pro Flag	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq Ft)	$150.00	$145.00	$155.00
Useful Economic Life (Years)	2.5	2.0	3.0
Maximum Useful Life (Years)	5.0	4.0	6.0
Average Units of Material per Product (Units/Product)	1.0		
Products at First Year of Steady State (#)	1,000	900	1,100
Years to Steady State (Years)	2.0	1.75	3.0
Steady State Product Growth (#)	100	90	110
Labor Productivity (Units/Hr/Person)	1.0	0.9	1.1
Labor Wage ($/HR)	$16.27		
Hourly Equipment Costs ($/HR)			
Failure Rate Path	1		

Standard Tape (Base Case)	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq ft)	$2.00	$1.80	$2.20
Useful Economic Life (Years)	1.5	1.25	1.75
Maximum Useful Life (Years)	3.0	2.75	3.25
Average Units of Material per Product (Units/Product)	2.5	2.0	3.0
Current Products in Use (#)	1,000	900	1,100
Annual Increase in Products (#)	100	90	110
Products 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
Labor Productivity (#/HR/Person)	4.01	3.60	4.40
Labor Wage	$16.27		
Hourly Equipment Costs ($/HR)	$39.35	$35.33	$43.18
Failure Rate	1		

HOTape	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq Ft)	$2.70	$2.43	$2.97
Useful Economic Life (Years)	1.5	1.25	1.75
Maximum Useful Life (Years)	3.0	2.75	3.25
Average Units of Material per Product (Units/Product)	2.5	2.0	3.0
Products at First Year of Steady State (#)	1,000	900	1,100
Years to Steady State (Years)	2.0	1.75	3.0
Steady State Product Growth (#)	100	90	110
Labor Productivity (Units/Hr/Person)	4.01	3.60	4.40
Labor Wage ($/HR)	$16.27		
Hourly Equipment Costs ($/HR)	$39.25	$35.33	$43.18
Failure Rate Path	1		

Stimsonite (Base Case)	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq ft)	$1.58	$1.42	$1.75
Useful Economic Life (Years)	2.0	1.75	2.25
Maximum Useful Life (Years)	4.5	4.25	4.75
Average Units of Material per Product (Units/Product)	1.0		
Current Products in Use (#)	1,000	900	1,100
Annual Increase in Products (#)	100	90	110
Products 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
Labor Productivity (#/HR/Person)	40	35	45
Labor Wage	$16.27		
Hourly Equipment Costs ($/HR)			
Exp. Disruption Delay (Min)	15	10	20
Annual AADT Effected (%)	0.001	0.000	0.002
Failure Rate	1		

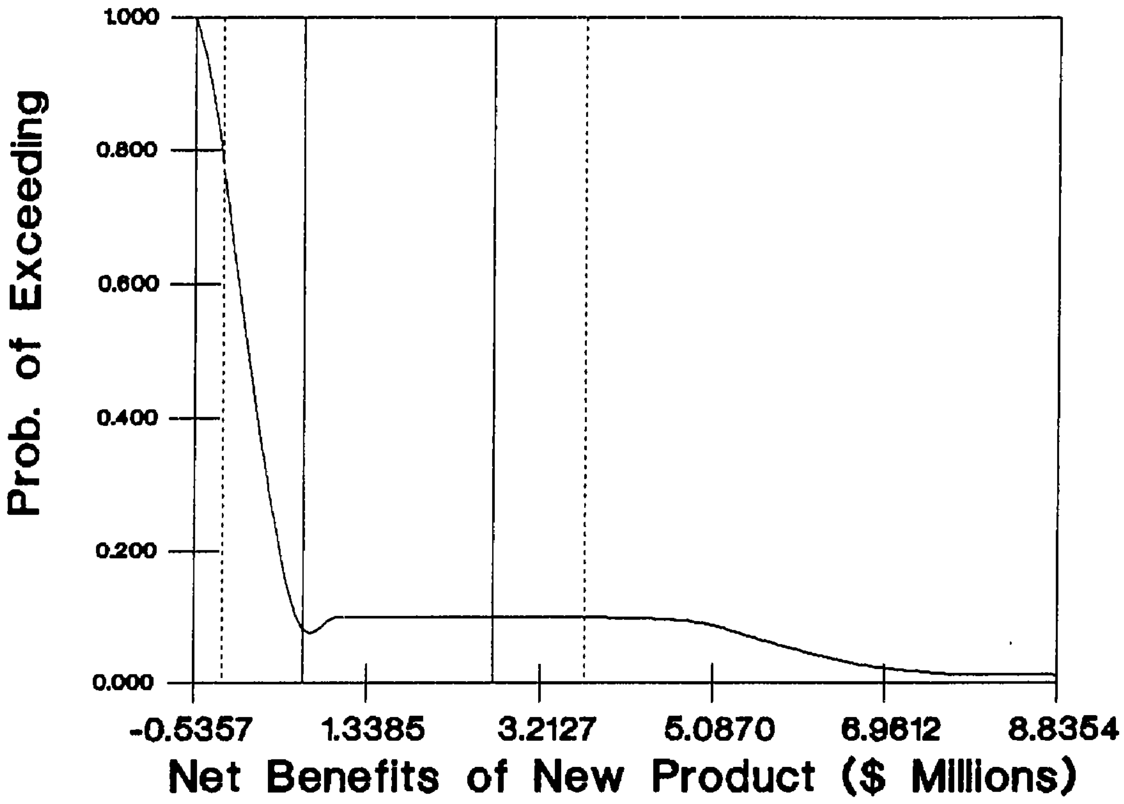
PCBM	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq Ft)	$2.00	$1.50	$2.50
Useful Economic Life (Years)	2.0	1.75	2.25
Maximum Useful Life (Years)	5.0	4.75	5.25
Average Units of Material per Product (Units/Product)	1.0		
Products at First Year of Steady State (#)	1,000	900	1,100
Years to Steady State (Years)	2.0	1.75	3.0
Steady State Product Growth (#)	100	90	110
Labor Productivity (Units/Hr/Person)	40	35	45
Labor Wage ($/HR)	$16.27		
Hourly Equipment Costs ($/HR)			
Exp. Disruption Delay (Min)	17	12	22
Annual AADT Effected (%)	0.001	0.000	0.002
Failure Rate Path	1		

Standard Bridge Joint (Base Case)	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq ft)	$68.00	$61.20	$74.8
Useful Economic Life (Years)	10.0	9.0	11.0
Maximum Useful Life (Years)	15.0	14.0	16.0
Average Units of Material per Product (Units/Product)	1.0		
Current Products in Use (#)	1,000	900	1,100
Annual Increase in Products (#)	100	90	110
Products 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
Labor Productivity (#/HR/Person)	2.1	1.9	2.3
Labor Wage	$16.27		
Hourly Equipment Costs ($/HR)			
Exp. Disruption Delay (Min)	5	0	10
Annual AADT Effected (%)	0.001	0.000	0.002
Failure Rate	1		

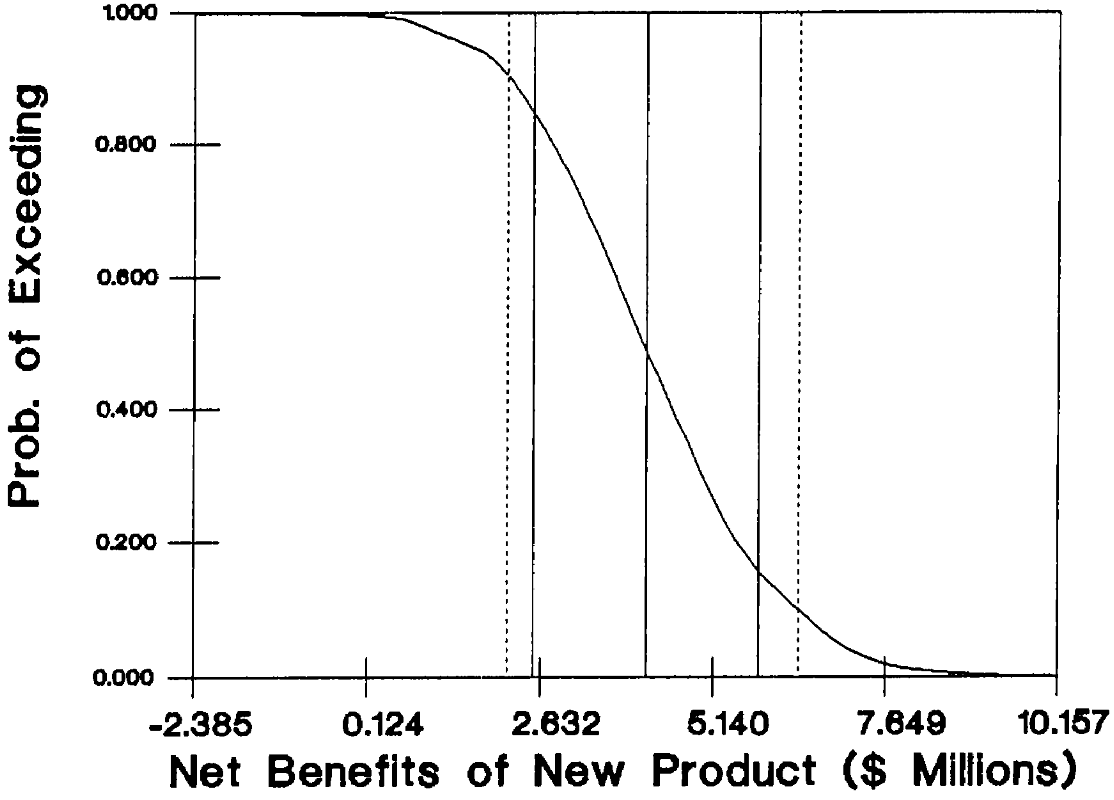
Koch BJS	Median Value	10% Lower Limit	10% Upper Limit
Material Unit Cost ($/Sq Ft)	$150.00	$100.00	$200.00
Useful Economic Life (Years)	10.0	9.0	11.0
Maximum Useful Life (Years)	15.0	14.0	16.0
Average Units of Material per Product (Units/Product)	1.0		
Products at First Year of Steady State (#)	1,000	900	1,100
Years to Steady State (Years)	2.0	1.75	3.0
Steady State Product Growth (#)	100	90	110
Labor Productivity (Units/Hr/Person)	2.1	1.9	2.3
Labor Wage ($/HR)	$16.27		
Hourly Equipment Costs ($/HR)			
Exp. Disruption Delay (Min)	5	0	10
Annual AADT Effected (%)	0.001	0.000	0.002
Failure Rate Path	1		

Probability Distribution Graphs for Economic Screening of 1993 PRIDE Products

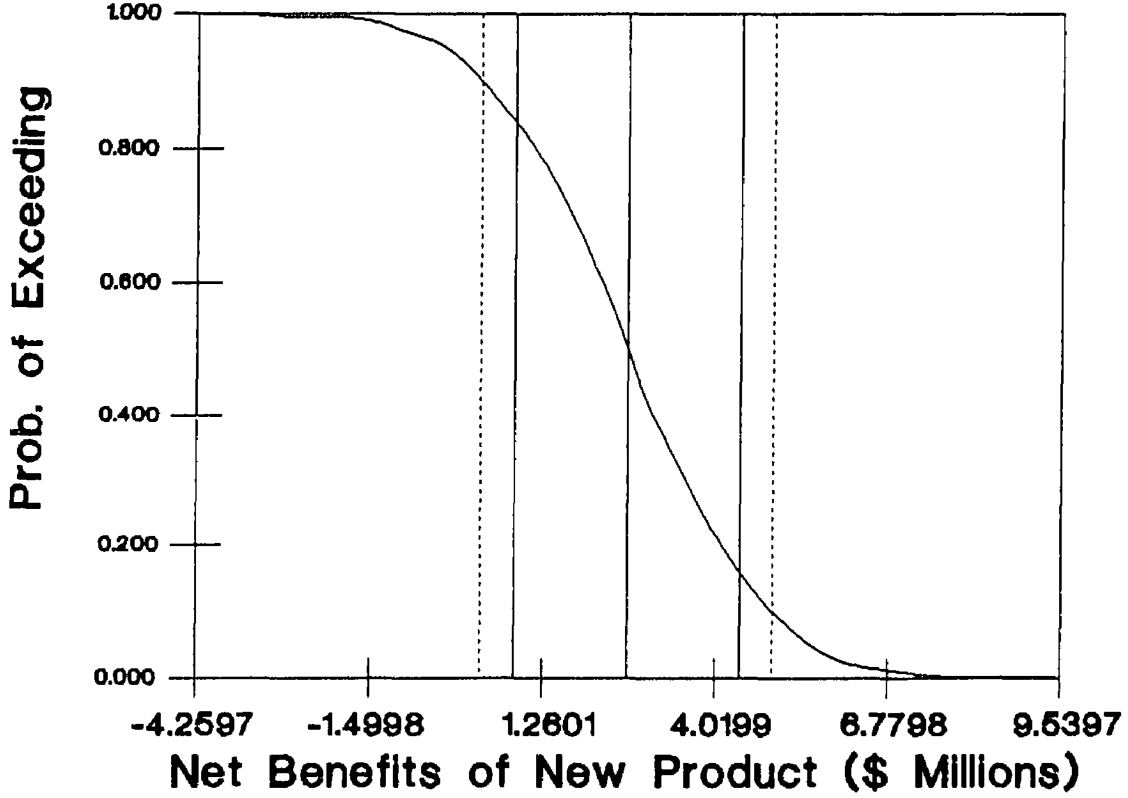
ATRC New Product Risk Analysis
Permeon 501

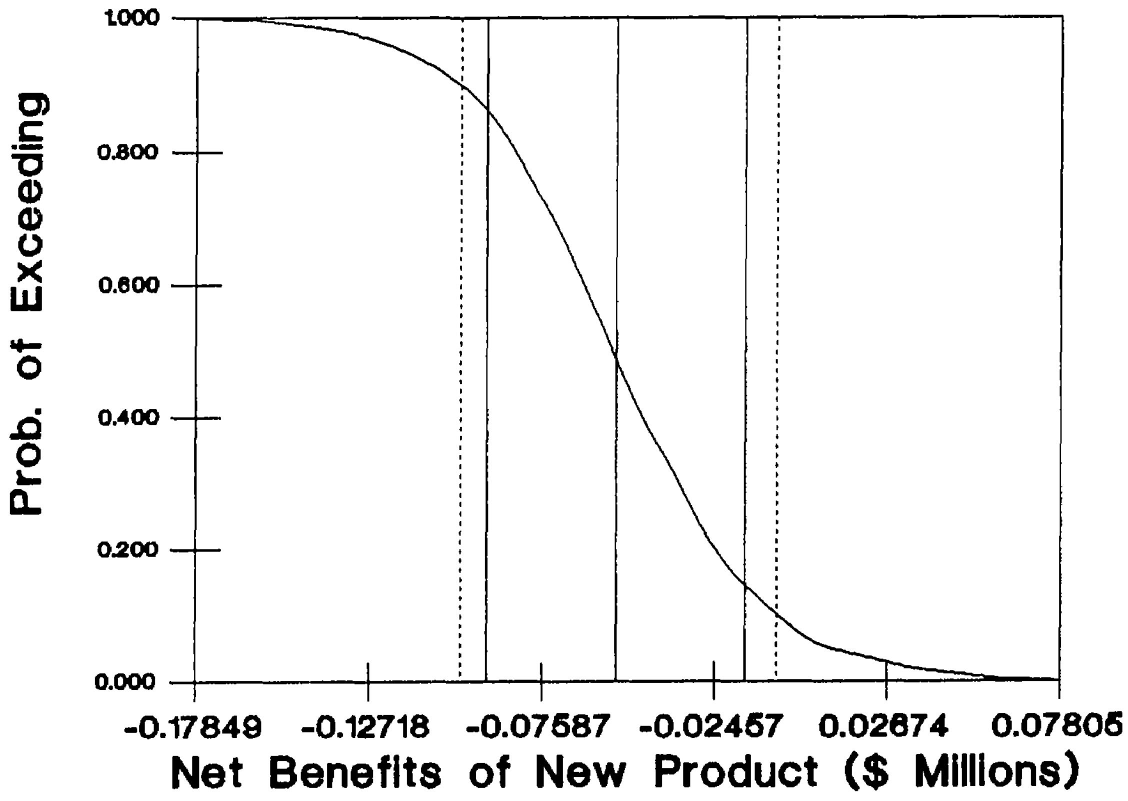


ATRC New Product Risk Analysis
Polymer Concrete Handhole

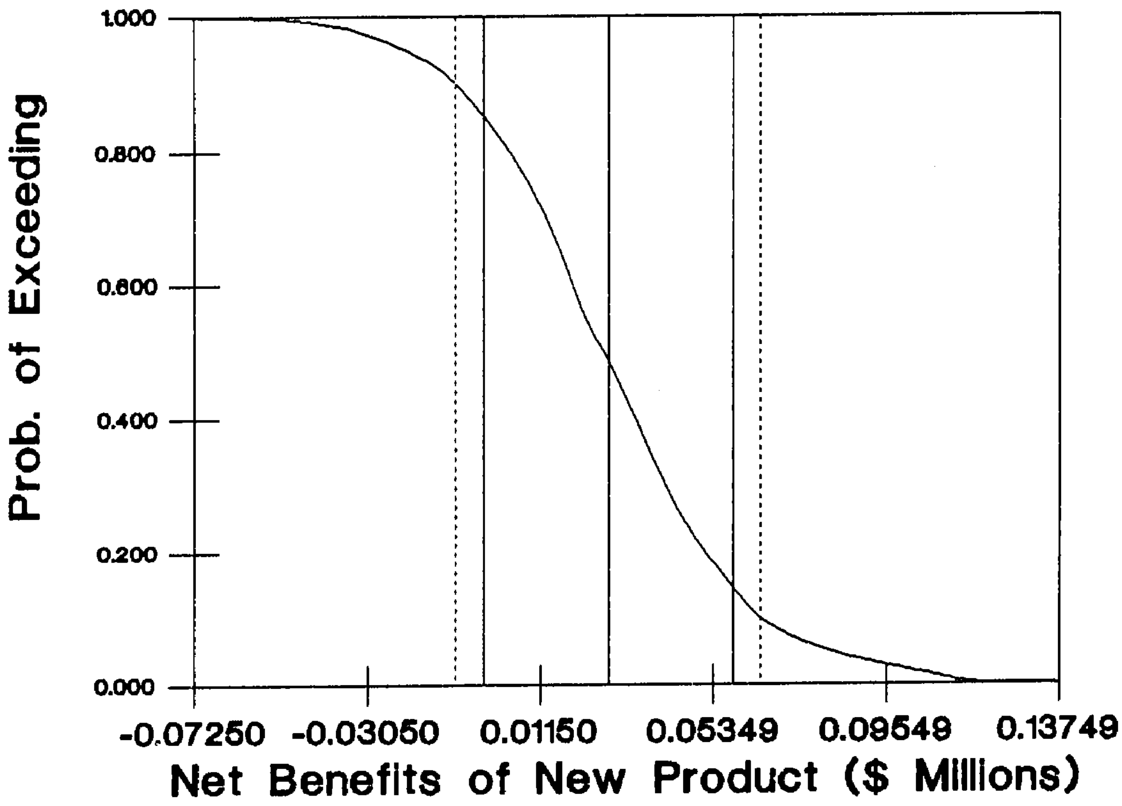


ATRC New Product Risk Analysis
Quazite Polymer Concrete Box

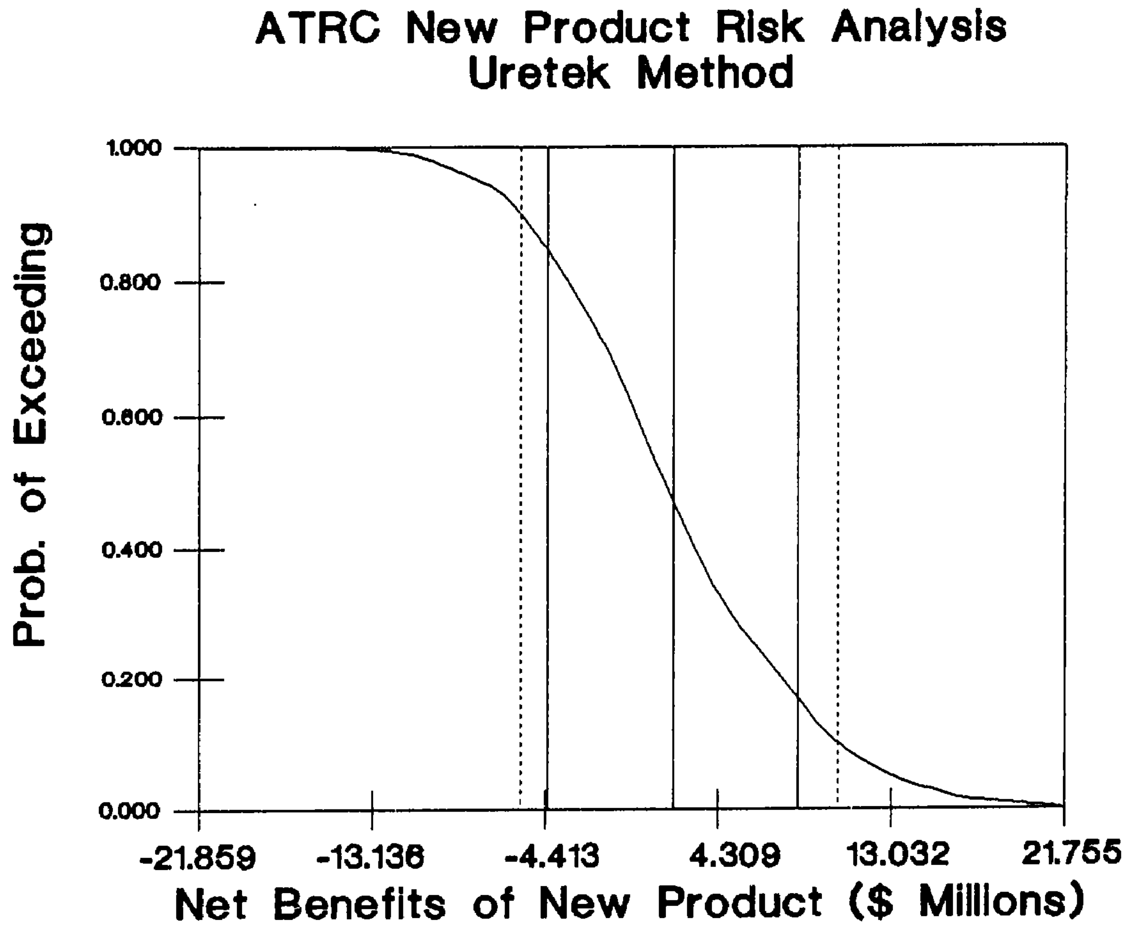




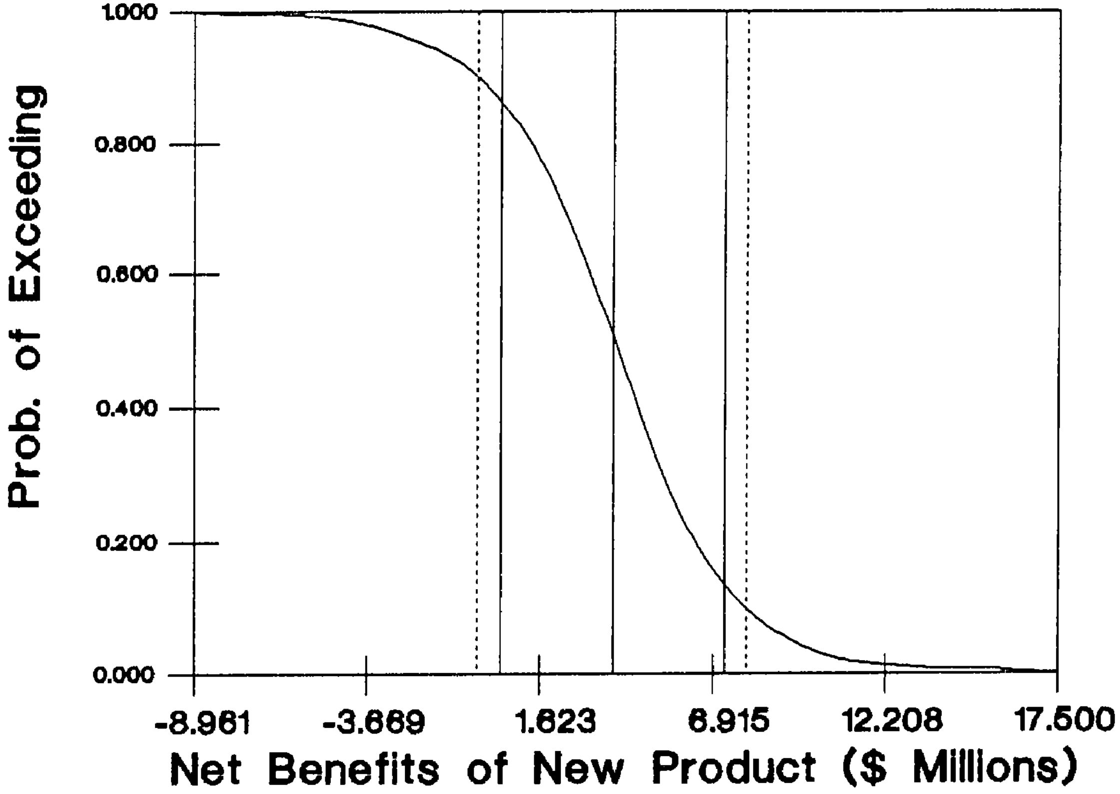
ATRC New Product Risk Analysis
Rapid Set 3/8 Concrete Mix

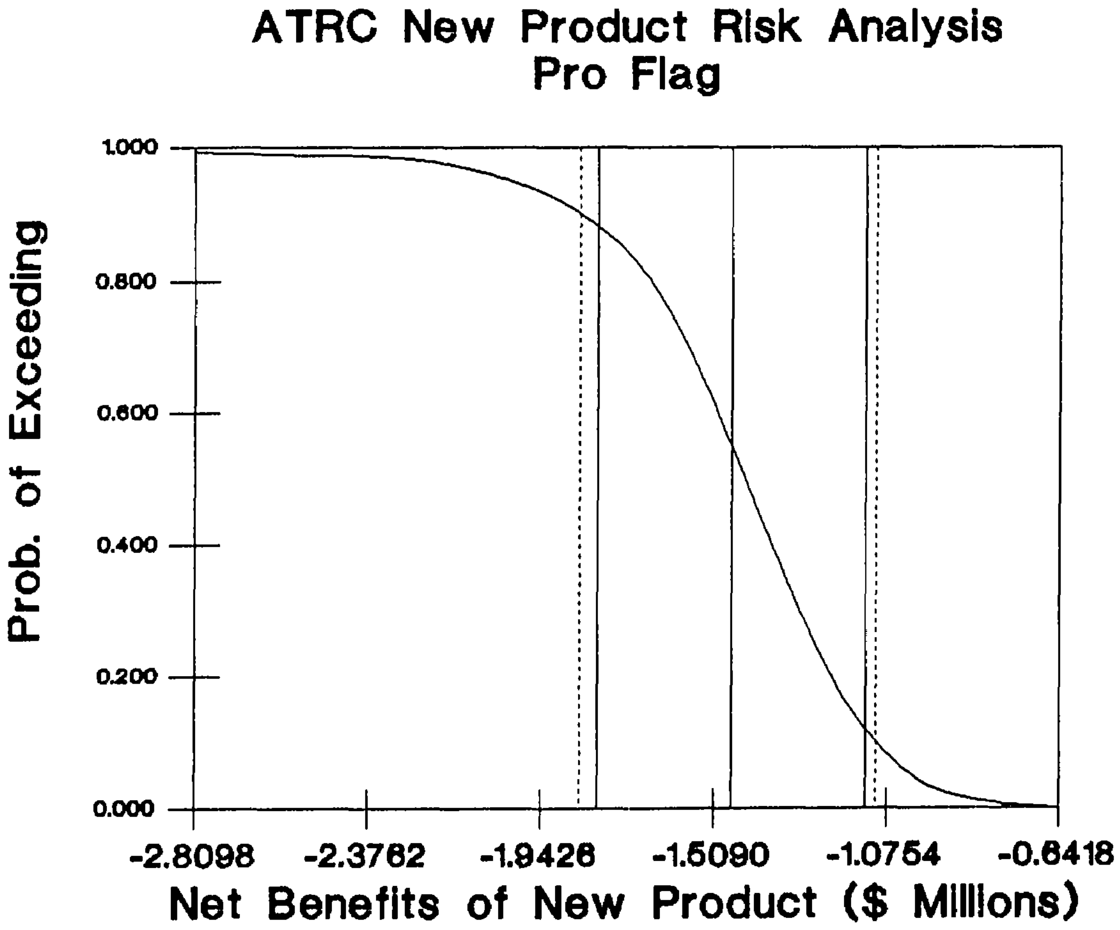


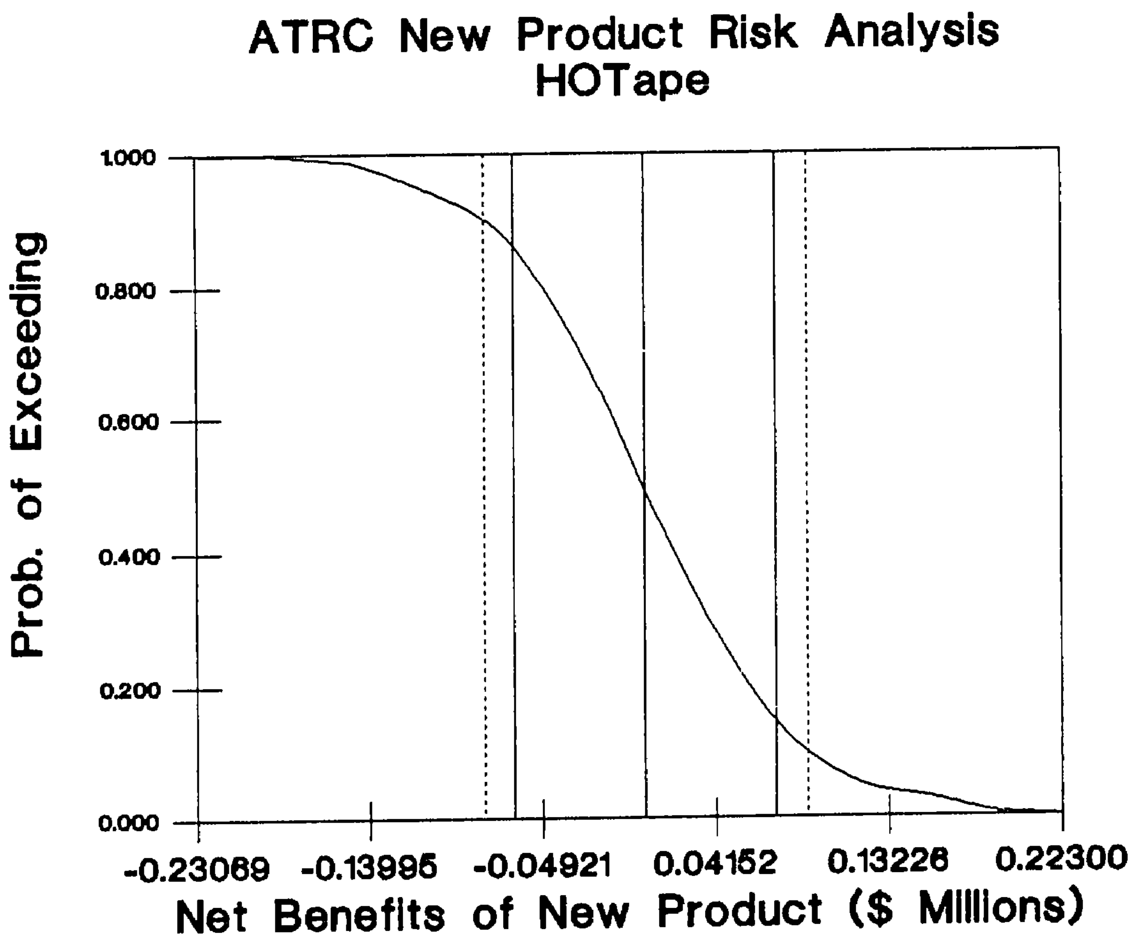
ATRC New Product Risk Analysis
QPR 2000

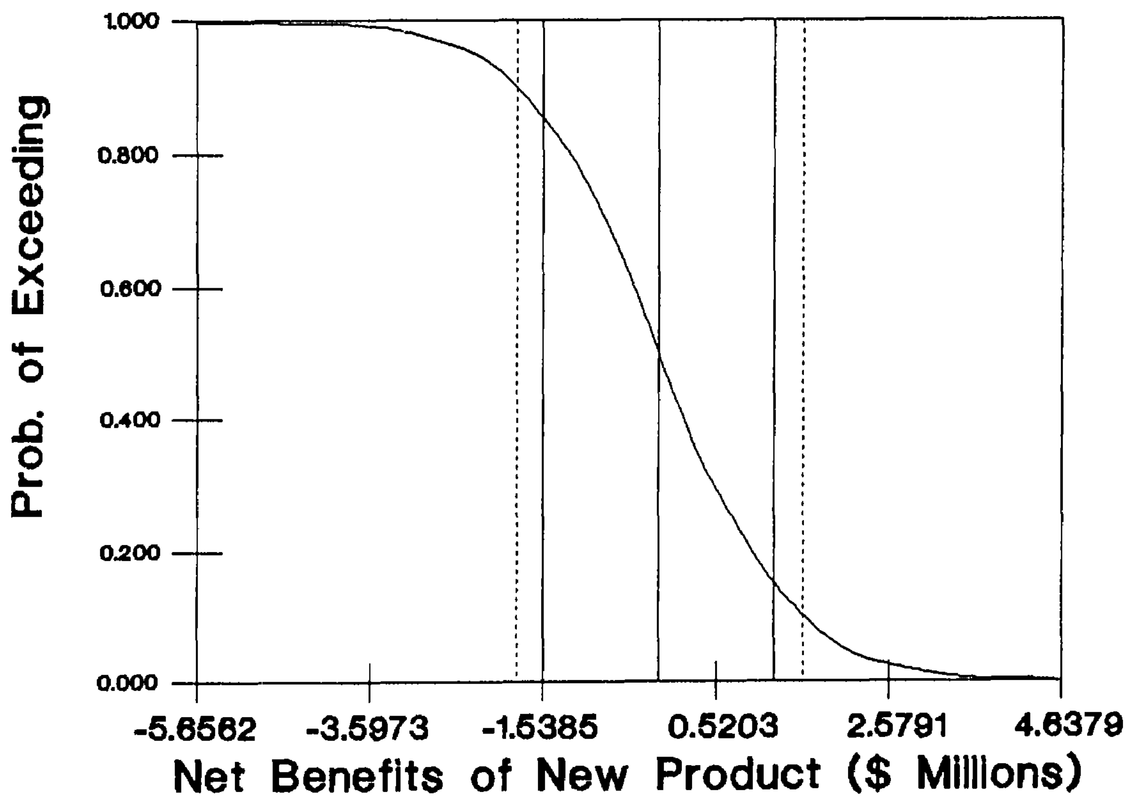

ATRC New Product Risk Analysis
Uretek Method
Prob. of Exceeding
1.000
0.800
0.600
0.400
0.200
0.000
-21.859
-13.136
-4.413
4.309
13.032
21.755
Net Benefits of New Product ($ Millions)

ATRC New Product Risk Analysis
Soft-Cut Dry Saw

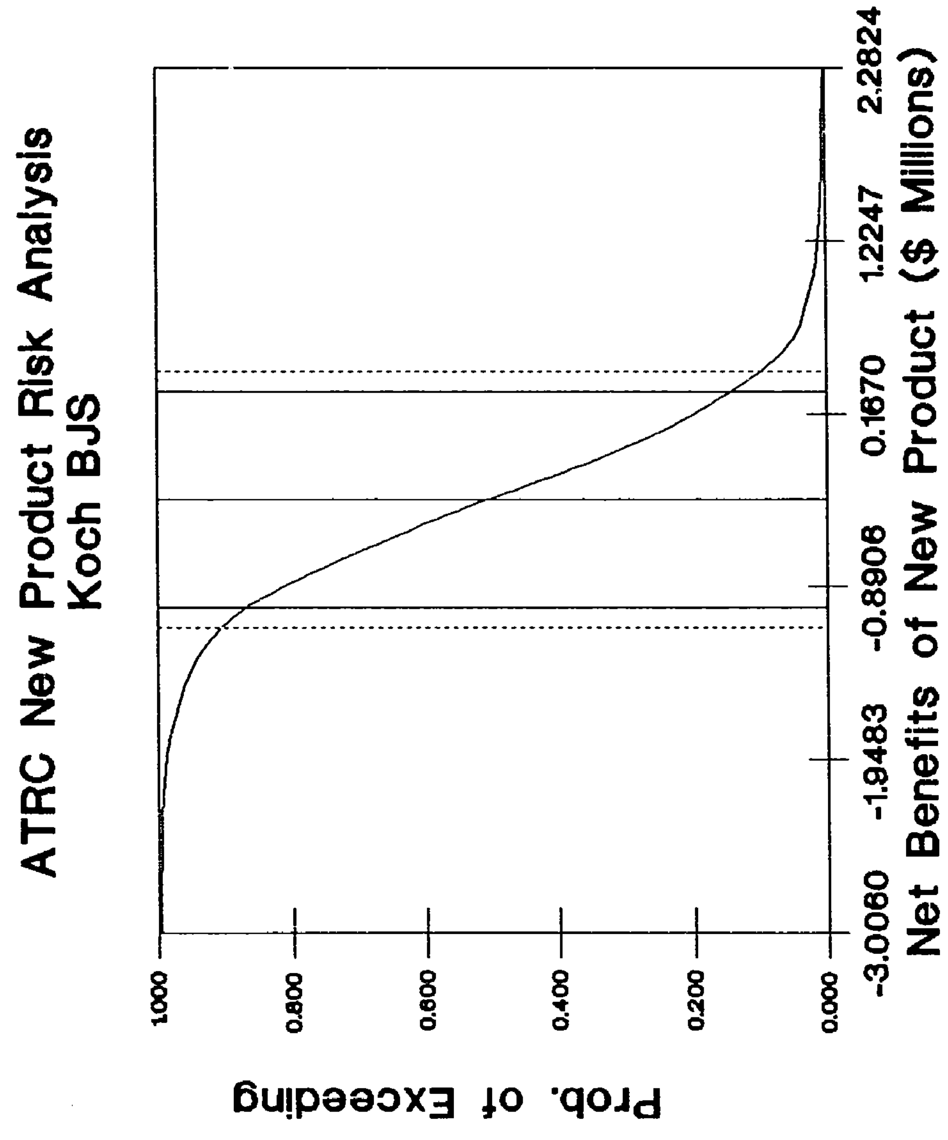



ATRC New Product Risk Analysis
Pro Flag
Prob. of Exceeding
1.000
0.800
0.600
0.400
0.200
0.000
-2.8098
-2.3762
-1.9426
-1.5090
-1.0754
-0.6418
Net Benefits of New Product ($ Millions)


ATRC New Product Risk Analysis
HOTape
Prob. of Exceeding
1.000
0.800
0.600
0.400
0.200
0.000
-0.23069
-0.13995
-0.04921
0.04152
0.13226
0.22300
Net Benefits of New Product ($ Millions)



ATRC New Product Risk Analysis
PCBM



ATRC New Product Risk Analysis
Koch BJS