Precursor Systems Analyses of Automated Highway Systems

RESOURCE MATERIALS

Preliminary Cost/Benefit Factors Analysis

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PRECURSOR SYSTEMS ANALYSES

OF

AUTOMATED HIGHWAY SYSTEMS

Activity Area P

Preliminary Cost/Benefit Factors Analysis

Results of Research

Conducted By

Delco Systems Operations

FOREWORD

This report was a product of the Federal Highway Administration's Automated Highway System (AHS) Precursor Systems Analyses (PSA) studies. The AHS Program is part of the larger Department of Transportation (DOT) Intelligent Transportation Systems (ITS) Program and is a multi-year, multi-phase effort to develop the next major upgrade of our nation's vehicle-highway system.

The PSA studies were part of an initial Analysis Phase of the AHS Program and were initiated to identify the high level issues and risks associated with automated highway systems. Fifteen interdisciplinary contractor teams were selected to conduct these studies. The studies were structured around the following 16 activity areas:

> (A) Urban and Rural AHS Comparison, (B) Automated Check-In, (C) Automated Check-Out, (D) Lateral and Longitudinal Control Analysis, (E) Malfunction Management and Analysis, (F) Commercial and Transit AHS Analysis, (G) Comparable Systems Analysis, (H) AHS Roadway Deployment Analysis, (I) Impact of AHS on Surrounding Non-AHS Roadways, (J) AHS Entry/Exit Implementation, (K) AHS Roadway Operational Analysis, (L) Vehicle Operational Analysis, (M) Alternative Propulsion Systems Impact, (N) AHS Safety Issues, (O) Institutional and Societal Aspects, and (P) Preliminary Cost/Benefit Factors Analysis.

To provide diverse perspectives, each of these 16 activity areas was studied by at least three of the contractor teams. Also, two of the contractor teams studied all 16 activity areas to provide a synergistic approach to their analyses. The combination of the individual activity studies and additional study topics resulted in a total of 69 studies. Individual reports, such as this one, have been prepared for each of these studies. In addition, each of the eight contractor teams that studied more than one activity area produced a report that summarized all their findings.

Original signed by:

Lyle Saxton
Director, Office of Safety and Traffic Operations Research and Development

NOTICE

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16. Abstract
A framework for the evaluation of benefits and costs of a hypothetical Automated Highway System (AHS) project is established. The support of Federal, State, and local agencies for AHS programs will depend on strong projected economic returns from the AHS. Analysis of a hypothetical AHS project examines the main risk elements as well as the principal sources of benefits. Guidelines for strategies of development and further research are provided. The cost / benefit analysis provides key findings in the following areas: travel time, improved convenience, economic activity benefits from congestion relief, urban form and livable communities, AHS and arterial congestion, operation thresholds, and vehicle cost.

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EXECUTIVE SUMMARY

The research in Activity P – Preliminary Cost/Benefit Factors Analysis establishes a framework (see figure 16) for the evaluation of benefits and costs of a hypothetical Automated Highway System (AHS). The willingness of State and local authorities to undertake AHS projects as well as the continuing Federal support for AHS will depend on the potential for strong economic returns from AHS. The analysis of a hypothetical AHS project will expose risk elements as well as the principal sources of benefits. In so doing, these can be used to provide guidelines for deployment strategies and identifying areas of further research.

The following presents a summary of the key findings of the analysis:

Travel Time

One of the principal AHS benefits categories is improved travel time. In the urban environment, the AHS will likely have a moderate impact on travel time during the peak hour of operation and a greater impact on travel times in the peak period outside the peak hours (the peak period margins).

Under normal operating conditions, with adequate penetration of AHS-equipped vehicles, there will likely be a phenomenon of temporal shifting of demand to the peak hour: Many of the AHS-equipped vehicles will travel in the peak hour while the additional capacity made available in the non-AHS lanes, through the diversion of AHS vehicles, will result in a greater number of trips by non-AHS vehicles being accommodated in the peak hour. Consequently, greater traffic volumes would flow in the peak hour. However, more substantial improvements in time savings per trip would occur in the peak period margins which will operate with lower volumes of traffic.

Improved Convenience

A greater number of trips being accommodated in the peak hour represents a significant benefit for many travelers. Urban congestion forces many commuters to travel at off-peak hours which results, sometimes, in lost economic opportunities as well as personal inconvenience (e.g., lost leisure opportunities, time spent with families, etc.)

Improved Safety

The AHS has the potential to significantly reduce accidents by assuming control of vehicles in the AHS lane, and by reducing congestion in conventional lanes and arterial streets. Benefits associated with improved safety include fewer fatalities, injuries, and property damage. It is estimated that the AHS could reduce accidents by around 70 percent for users of the AHS by assuming control of AHS vehicles removing driver error as the cause of many accidents.

Economic Activity Benefits From Congestion Relief

Urban traffic congestion represents a serious impediment to the development and retention of particular types of economic activity. Urban business centers grow and develop due to what has been called "economies of agglomeration." Many industries (e.g., wholesale and retail trade and business services) require that the majority of employees be on site during principal business hours in order to maintain smooth, profitable operations. Congestion frequently makes that difficult or costly resulting in businesses abandoning the urban centers. Relief of traffic congestion promotes conditions that enable cities to flourish as business centers.

AHS, insofar as it accommodates greater numbers of people being able to commute to business centers for principal business hours, will likely contribute to improved economic activity.

Urban Form And Livable Communities

The phenomenon of urban sprawl, low-density housing, and two-vehicle families have been facts of U.S. development for many decades. Many communities face the problem of growing congestion in daily commutes between suburbs and cities, contributing to both the decline of the cities as well as the quality of life in suburban communities. In the long run, rail and transit may represent a solution for some growing communities. However, achieving sufficient ridership thresholds to justify rail may be many years away. AHS may provide a lower cost and, overall, more acceptable solution for many communities.

AHS And Arterial Congestion

The highway and benefit-cost activities make clear that AHS represents a viable traffic alternative for regular commuting traffic only if congestion on surrounding arterial routes is relieved to an adequate degree. In the absence of arterial relief, AHS could be viable for periphery-to-periphery trips. An additional alternative might be a "many-to-few" AHS configuration where vehicles enter the AHS at many points but can only exit in the business district during rush hour at designated parking facilities. However, the many-on/many-off urban AHS would result in unacceptable ramp queuing if arterial congestion were allowed to exacerbate.

A conclusion to be drawn from the above is that AHS needs to be developed within the framework of multimodal regional planning.

Operation Thresholds

The benefit-cost analysis, which included an analysis of traffic distribution on a hypothetical AHS over the entire peak period (not just peak hours) reveals that a minimum penetration threshold for operating the AHS during the peak hour would be at about nine percent (assuming that most of the AHS vehicles will choose to travel in the peak hour). For levels of penetration below nine percent, AHS operations would actually reduce the total capacity of the highway system assuming that an existing lane is converted to AHS.

In order for AHS to improve overall highway operations in the off-peak hours, the estimated level of penetration would need to be 33 percent. Below this threshold, AHS operations would reduce total capacity in the peak period non-peak hour under the planning assumptions examined.

Vehicle Cost

From the point of view of a consumer, the willingness-to-pay for AHS equipment and service will be a function of how the individual values his own time. If, for instance, AHS results in a 15 minute time savings per day, and, supposing that the consumer makes 200 commutes per year and values his/her time at $10 per hour, then he/she would be willing to pay $500 per year for AHS. This, of course, assumes that the consumer derives no additional benefits (e.g., reduced stress, etc.) from AHS and that there are no other acceptance problems.

Vehicle cost will be a key component in the acceptability of AHS for all stakeholders concerned (travelers, public sector, vehicle manufacturers). In order to attain the relatively high thresholds of penetration required in a timely manner, the cost of equipment and services need to be maintained at sufficiently low levels.

INTRODUCTION

Description Of Activity Area

This report presents the research results for Activity P – Preliminary Cost/Benefit Factors Analysis. The terms of reference for the task objective were stated as:

> Identify the macro-economic cost and benefit factors to be considered in assessing overall AHS viability including economic externalities and efficiencies. Examine the factors using a sensitivity analysis, and provide preliminary, high-level metrics for each factor.

Assessing overall viability means that the benefits and costs need to be comprehensive and should contribute to an evaluation of the economic worth of AHS. This analysis, therefore, must not just delineate the components of benefit-cost, rather, it should develop an understanding of the components within a framework for conducting a benefit-cost evaluation of AHS.

Purpose And Focus Of This Effort

The focus of research for this activity area has been the development of an evaluation framework and preliminary quantification of social benefits and costs of AHS. This analysis was guided by the requirements of the recent Executive Order 12893 on "Principles for Federal Infrastructure Investment" which calls for the "systematic analysis of benefits and costs" including both quantitative and qualitative measures.[1] According to the Order, agencies responsible for infrastructure will develop and implement plans for infrastructure investment and management in which:

- Benefits and costs are to be measured and discounted over the life-cycle of an infrastructure investment project.
- Uncertainty relating to timing and the realization of benefits and costs are to be accounted for in the economic evaluation.
- Analyses should compare a comprehensive set of alternatives.

The Executive Order also discusses efficient management of infrastructure through private sector participation and market-based mechanisms (i.e., pricing). Insofar as AHS promotes the goal of greater operational efficiency, these too need to be considered in the analysis of benefits and costs.

The AHS program, as a recipient of significant Federal funding, will need to demonstrate that the benefits of AHS outweigh the costs. While the program is a national one, the implementation of AHS will be conducted by State and local authorities. These authorities will be the ones who will decide whether or not to construct AHS roadways. Consequently, the analyses presented here contribute to the analysis of benefits and costs when considering a particular AHS roadway project.

Overall Approach For This Activity Area

Our approach to the task has been to view AHS on a hypothetical project basis. The project-level analysis is a requirement for all transportation investments. Benefits and costs of AHS conceptually have many commonalities with other highway and transit projects. As such, this approach benefits from the methodological conventions and substantial data resources available.

Given the reality of tight budgets and deficit reduction, AHS will be competing for resources with other transportation and non-transportation uses of funds. If deployment of AHS is to proceed, it needs to be demonstrated that AHS projects have the potential to yield strong economic rates of return. This is accomplished in the research through the development of a parametric benefit-cost model and the evaluation of a hypothetical AHS project using probabilistic risk analysis.

The analysis of benefit and cost factors proceeds according to the following steps:

- The Methodology of Evaluation – The approach for evaluation.
- Benefit Metrics – Analysis of the prospective benefits from AHS and the affected stakeholder groups.
- The Base Case – The elements which comprise the baseline for analysis are presented.
- Alternatives for Evaluation – The AHS and non-AHS alternatives for evaluation.
- Logic Flows and Algorithms for Benefits and Costs – The logic flows, information requirements and algorithms for the evaluation of benefits and costs are presented.
- Risk Analysis – Major sources of uncertainty are identified and probability distributions are assigned to key factors of the analysis.

Guiding Assumptions

The guiding assumption here is that economic planning and evaluation matter. In the budgeting process a benefit-cost, risk-based analytic framework can indicate that AHS has potentially strong economic rates of return. Additionally, the framework can serve as a tool for the refinement of designs and concepts so as to direct the system development to its economically optimal configuration.

REPRESENTATIVE SYSTEM CONFIGURATIONS

The representative system configurations (RSC's) were generated very early in the Precursor Systems Analysis of AHS program. These RSC's are used throughout the various areas of analysis whenever a diversity of system attributes is required by the analysis at hand. The RSC's identify specific alternatives for 20 attributes within the context of three general RSC groups.

Since the RSC's have such general applicability to these precursor systems analyses, they are documented in the Contract Review Report.

TECHNICAL DISCUSSION

Task 1. Methodology Of Evaluation

This task provides a broad analytical framework for considering the potential benefits and costs of implementing an AHS system. By clearly defining the potential benefits and costs associated with the AHS in terms of metrics which are widely accessible to all activities in the AHS precursor systems analysis, the framework is capable of incorporating available data into a comprehensive evaluation of the proposed AHS.

The AHS benefit-cost analysis is conducted well into the future; 2010–2040. As a result, a characterization of the likely state of travel demand and relevant social and economic factors is required. This vision of the future helps ensure that the base case is as realistic a representation of the future as possible.

Five inter-related steps are followed in the economic evaluation of the AHS:

1. Specify the base case.

2. Specify the hypothetical AHS analysis and alternatives.

3. Forecast travel demand and market penetration of AHS vehicles.

4. Estimate roadway construction and other costs.

5. Conduct evaluation of benefits and costs.

These steps and methodological approach are detailed in Appendix 1.

In order to evaluate the benefits and costs of AHS and the available alternatives, traffic simulation models were used in combination with "off-line" analysis to generate metrics for the following:

- Congestion.
- Travel speed.
- Market penetration.
- Economic conditions.
- Travel demand.

Simulation results are generated for the years 2010 and 2017. These metrics are incorporated into a parametric risk based computer model for generating probability ranges for the benefits and costs of AHS implementation. A thirty year time stream of benefits and costs, which depend on the simulation results and off-line analysis, is extrapolated to derive metrics for Net Present Value, Rate of Return, and the Benefit-Cost Ratio over the thirty year life of the project.

Task 2. Benefit Metrics And Stakeholders

This section of the report describes in detail, the results metrics of the benefits estimation methodology. In addition, it provides a benefits accrual matrix, defining the stakeholder groups likely to accrue the various potential benefits associated with the AHS. The following sections establish the framework to evaluate benefits in the following categories:

- Travel Time – Time savings are expected from improved average speeds and reduced headways on AHS and the remaining conventional lanes.
- Temporal Travel Demand Shifting – Temporal demand shift benefits may result as more individuals are able to travel during the desired peak hour. These benefits are in essence a measure of the value of convenience associated with traveling at the desired times.
- Safety – It is expected that there will be a reduction in the number and severity of accidents with the advent of AHS technology. In addition improved emergency response time should reduce the number of secondary accidents. However, safety has an added cost, and therefore tradeoffs must be made with respect to the desired level of system safety.
- Vehicle Operating Costs – Savings in vehicle operating costs (VOC) are expected if AHS and associated technology is able to smooth traffic flows.
- Environmental – It is expected that with smoother traffic flows from AHS, fuel efficiency will improve, thereby reducing emissions.
- Productivity and Economic Benefits – Productivity benefits could be realized if roadway improvements result in more efficient distribution systems for firms with a significant transportation component. Economic benefits arise from the direct, indirect, and induced economic effects associated with major infrastructure investments.

Allocation Of Benefits To AHS Users And Non-Users

Table 1 summarizes the benefit areas and indicates their relation to broad strategic goals for AHS implementation. Although quantitative assessments of the degree to which benefits accrue to individual groups is not possible, qualitative statements are suggested.

The benefits accrual matrix, presented in table 2, is divided into road system users and non-road system users in order to isolate direct benefits from indirect benefits and externalities. Non-system users are further divided into public transit users and operators, AHS manufacturers, and Government agencies that are responsible for system construction, monitoring and other related functions. System users are divided into users who purchase AHS technology, and other highway users who do not purchase AHS technology but benefit in time, convenience, and safety savings resulting from less congestion as more drivers utilize AHS.

Table 1. AHS Strategic Goals And Benefits Categories

Strategic Goal	Benefits Area
Operating Efficiency	Time Savings Added Convenience Vehicle Operating Cost Savings Reduced Infrastructure Costs
Improved Safety	Lives Saved Reduced Number and Severity of Accidents Reduced Property Damage
Reduced Energy Use & Improved Environmental Quality	Improved Health and Environmental Quality Reduced Fuel Use Reduced Emissions
Increased Productivity and Economic Growth	Increased GDP Economic Impacts Productivity
Multimodal Planning	More Optimal Use of Complimentary Modes (Highways & Transit)
Improved Travel	Added Driver Amenities Driver Comfort Improved Mobility for Elderly/Disabled
Urban Form	Less Urban Sprawl Shorter Work/Shopping Trips Promote Livable Communities

As with most transportation infrastructure projects, time savings will likely be the largest single benefit derived from AHS implementation. Time savings are derived from reduced congestion and increased traffic flow under AHS. Less stop and go traffic and better flow also reduces vehicle operating costs for all highway users as automobiles maintain a more constant speed. Time savings and reduced transportation operation and maintenance costs will likely be captured by road system users with those who adopt AHS technology capturing greater benefits than those who do not adopt AHS technology.[2] Users must derive greater benefits than non-users or nobody would adopt AHS technology.

Temporal demand shift benefits refer to savings from allowing more vehicles to travel in the peak hour. The benefits will accrue as added convenience to people who can travel when they want.

Table 2. Benefits Accrual Matrix

	Stakeholders	Time Save	Safety Ben.	VOC Save	Env. Ben.	Incr. Mobility	Prod. Ben.	Econ. Ben.
Road System Users	AHS Users	√	√	√	√	√		
	Non-AHS Users	√	√	√	√	√		
	Commercial Vehicle Operators	√	√	√	√	√		
	Public Transit Users	√	√		√	√	√	
Non-Road System	Public Transit Operators	√		√		√		
	AHS Manufacturers							√
	Government Agencies		√		√	√		√
Society			√		√		√	√

Safety benefits include lives saved, reduced injuries, and other metrics related to accident reduction. Road systems users, both AHS users and non-users, are the largest stakeholders in benefits from increased safety, directly benefiting from the reduction in accidents. Government agencies also capture benefits related to lives saved, reduced injuries, and reduced property damage through less emergency management costs.

Reduced energy use and improved environmental quality, expected from AHS technology, benefits all of society. In the case of reduced fuel consumption, system users also benefit due to reduced operating costs associated with fuel consumption. Increased productivity and economic growth as well as improved mobility benefits are realized by highway system users and non-users alike. These secondary benefits are realized in terms of faster arrival of goods and services and through better maintenance of pre-scheduled activities such as meetings. Over time, as mobility increases, those who previously were unable to access the system will share in the benefits of users.

Benefits will accrue to AHS users and non-users alike, but will provide different levels of benefit to users and non-users. AHS users will receive the benefits of the system directly while non-users will derive benefits because AHS siphons off current highway users to the AHS system. This reduces congestion for non-users providing them with similar, though smaller, benefit flows from

AHS implementation. In addition, non-users as part of society in general will benefit from the economic, productivity, and environmental impacts that are expected to result from the implementation of AHS.

Task 3. Base Case And Alternatives

In order to evaluate the benefits of an AHS project or an alternative project, the net benefits of the proposed project must be evaluated against a consistent basis of comparison or base case. Investment decisions should be based on the expected net benefits of a given project compared to a realistic view of the world in the absence of the proposed project. It is possible that the best course of action is to continue to use the existing highway infrastructure, thereby freeing scarce resources for use in other more productive transportation projects. The following sections provide a detailed specification of the base case in terms of the outlook for highway infrastructure that can be expected in the absence of AHS. In addition, the alternative scenarios are specified and will be compared to AHS using net present value (NPV) criteria.

AHS Evolutionary Process

The base case and alternative visions of the highway infrastructure, including AHS, are not anticipated to develop in discrete moments in time. The process by which AHS is likely to become operational is one in which current vehicle and infrastructure technologies become more sophisticated over time. The implementation of AHS is assumed to be evolutionary, building on ITS technology assumed to be in place at the time. This is opposed to revolutionary AHS implementation which would require building an AHS system from scratch. The evolutionary process, as well as being the most likely course of AHS implementation, will help restrain the costs of AHS since evolutionary deployment makes use of existing infrastructure. Table 3 describes the evolutionary framework that forms the basis of much of the analysis which follows.

AHS Vision

The vision for AHS in this task is of a full implementation of AHS on an 12.8 km segment of I-17 in Phoenix, Arizona. AHS is assumed to result from an evolutionary process, built on existing Intelligent Transportation System (ITS) technology. The conception of AHS includes:

- Fully automated driving.
- Fully segregated AHS lane.
- Built on existing right-of-way.

In many areas AHS will build on ITS technology which is currently being developed and is expected to be functional by the turn of the century. In table 3, this includes elements within the PREBASE and BASE elements of the evolutionary process. If there are delays in the implementation of pre-AHS technologies then AHS costs would be expected to increase and the net benefits to society reduced. Similarly, if ITS and associated technologies are further advanced than expected this will have a positive impact on costs and net benefits.

Table 3. AHS Evolutionary Process

AHS EVOLUTIONARY PROCESS - LIMITED ACCESS HIGHWAYS (FREEWAYS) AUTO EQUIVALENT ONLY EQUIPPED TO PERFORM OPERATIONS, SELF DIAGNOSTICS AND FAIL SAFE

	PREBASE	BASE	AHS I	AHS II	AHS III
INFRASTRUCTURE					
I1	Existing Freeway, Mixed Intelligence and Types of Vehicles				
	Manual Entry/Exit to Freeway		To AHS Within Left Lane		
I2			Separated Lane	Separated Lane W Transition Breakdown Lane	
			To AHS Within Lane	To AHS Transition Lane Automatic to Cruise Lane	
I3			Dedicated Lane With Breakdown or Multiple Lanes		
			Direct Entry/Exit to Dedicated Lanes, To AHS on Access Ramp		
OPERATION	Manual Control	Intelligent Cruise Control (Longitudanal)	Automatic Cruise Control (Longitudanal/Lateral)	Auto Cruise/Mgmt Control (Lat/Long/Lane Changing)	Automatic Mgmt Control (Fully Automatic)
Command	Nil	Advisory	Commands Speed	Command Speed & Spacing	Command all Veh'l Actions
C3 Control	Driver	Driver/Vehicle	Driver/Vehicle	Driver/Vehicle	Managment/Vehicle
Communications		Management Advisory (Radio)	Managment Command (Data Link)	Mgmt Command Veh to Veh (Data Links)	Management to Vehicle (Two Way Data Links)
SUPPORT					
Roadway Devices		HAR/Fixed Signing	HAR, Fixed, Variable Signing, CCTV, Centre Lane Tracking, and Vehicle Detectors	HAR, Full, TSCS, MIS, Redundant, Tracking	Full Visual and Electronic Surveillance
Control Centers		Regional (Low)	Regional (Medium)	Regional/Local (High)	National/Regional/Local (Extensive)
Enforcement		Conventional	Part Time	Full Time	Minimal
Emergency Response		Conventional	On Call	Dedicated	Dedicated
Road Pricing		No	No	Required	Required
Maintenance		Conventional	Conventional	Extra	Extraordinary
Cost Mileposts		*	*	*	*
MARKET		0 to 30%		30 to 65%	85%

Source: Parsons Brinkerhoff Quade & Douglas, Inc.

There are also several stages through which the path of full implementation of AHS will pass. For instance, AHS I in table 3 contains only automatic cruise control but AHS III includes Automatic Management Control. The current analysis is based on a AHS system which closely resembles AHS III; a full blown implementation of AHS technology. However, it is necessary to realize that cost effective implementation of this system relies heavily on the timely completion of all the previous stages.

The base case is conceived of as a stage of ITS deployment. The base case will be part of the evolutionary process for implementing AHS. Since AHS will take advantage of all of the existing ITS infrastructure, the costs will be much lower than if AHS were built from scratch.

Base Case Specification

The base case specification considers actions that can be expected to be taken to make the most efficient use of existing transportation infrastructure in the context of a reasoned "vision of the future". The base case is therefore not a "do nothing" or status quo scenario, but takes into account all of the expected changes in technology, demand management, public policy, the economy, ITS deployment, and other social trends that are likely to occur in lieu of implementation of the other investment alternatives.

For the purposes of this analysis, the hypothetical urban freeway to be modeled is based upon a 12.8 km section of I-17 in Phoenix, Arizona between the I-10 interchange and Peoria Avenue (see figure 1). Factors specific to the Phoenix metropolitan area relative to national trends will be used to specify the base case and alternatives. Transportation factors include congestion, travel demand, demand management, environmental initiatives, and more general factors include personal income, economic and population growth.

The base case assumes that I-17 will have four general purpose freeway lanes in the absence of AHS development. Currently, there are three lanes with a fourth planned for construction. Characteristics of the base case, such as vehicle hours traveled, safety measures, and environmental conditions (e.g. vehicle emissions) are generated using simulation models.

Alternative Cases

Alternative cases include the main object of study, implementation of AHS, as well as an HOV lane case, and the construction of an additional lane. The chosen alternatives would result in the same highway user benefits, although the level of benefits will be different in each case. A variety of possible alternatives are specified so that net benefits of AHS can be compared, not only to the base case, but to a range of possible projects to determine whether there are any alternatives with a greater expected present value of net benefits than the AHS project.

The cost of an alternative needs to include the cost of all transportation system improvements which the alternative necessitates. For instance, surrounding streets and arterials may need to upgraded, increasing the costs of the project.

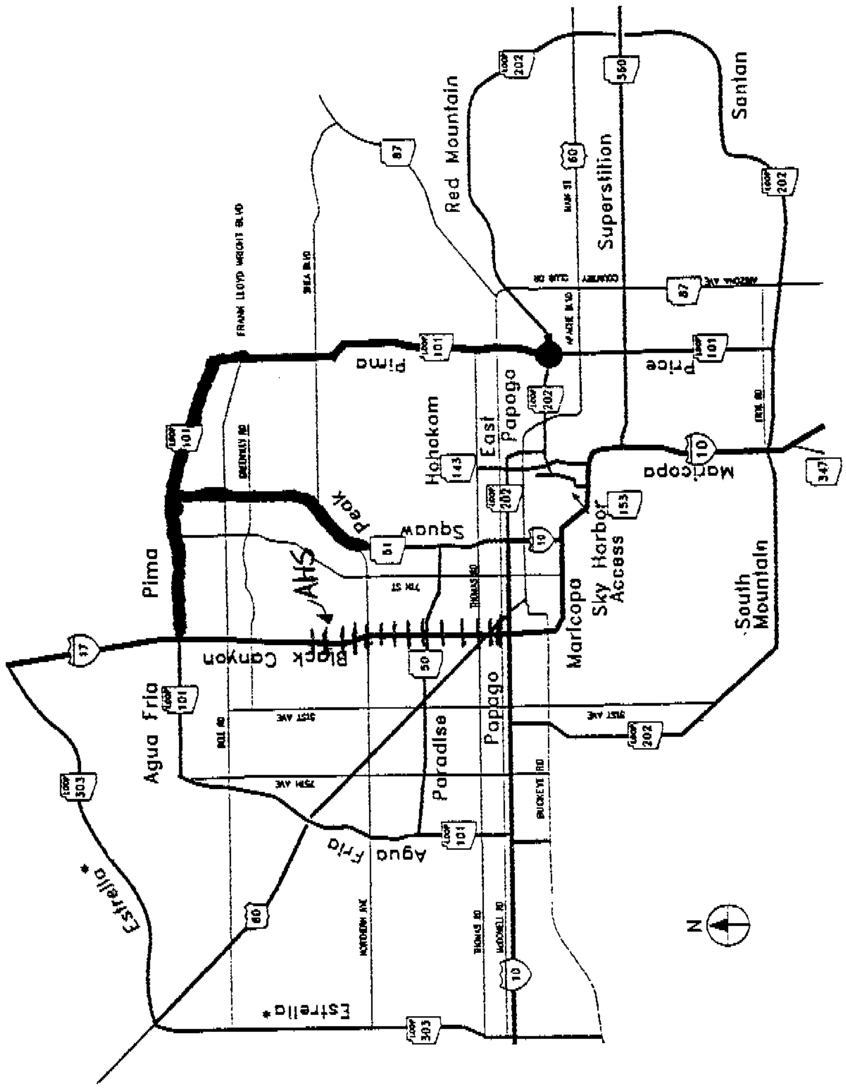

Figure 1. Map Of Phoenix Area Transportation System & Plans

Alternative 1 – HOV Lane And Three General Purpose Freeway Lanes

This alternative specifies that one high occupancy vehicle (HOV) lane be built from one of the base case lanes. This option should encourage car pooling to reduce the number of vehicles using the highway. The HOV lane project would mitigate the need to widen the freeway, increase the number of trips on the freeway, and provide benefits to HOV users and non-users by reducing congestion. This alternative uses simple, existing technologies and requires no vehicle upgrades.

Alternative 2 – AHS Lane And Three General Purpose Freeway Lanes

In this case, one AHS lane is to be built out of one of the general purpose base case lanes, increasing the capacity and efficiency of the freeway under study.

The AHS alternative is modeled using two different configurations. RSC 1, the infrastructure centered configuration, and RSC 2, the vehicle centered configuration will be modeled as an urban freeway. These configurations differ with regard to cost. RSC 1 is more expensive, but generates higher AHS travel demand because the Government assumes a greater share of the total costs of implementation. RSC 2 is the less expensive option for the Government, but the vehicles are more costly due to the higher functionality of AHS equipment built into vehicles. For both of these configurations, the number of check in/check out terminals is assumed to be one every 1.6 km.

Alternative 3 – Widen Freeway To Five General Purpose Freeway Lanes

This alternative is an expansion of freeway capacity through the construction of an additional lane. This option is the same as the base case, only with one added lane. This alternative continues the traditional method of expanding freeway capacity with the construction of additional lanes. Widening freeways is becoming more expensive, especially in urban areas, as development clusters around urban highways, limiting the ability to use more land, or, to make right-of-way acquisition prohibitively expensive. Expanding the freeway to five lanes will have high costs in terms of land use, noise, and increased pollution.

Task 4. Logic Flows And Algorithms For Benefits And Costs

Vehicle Cost, Deployment, And Penetration

Base Case Assumptions

The first year of the cost benefit analysis of AHS is 2010. In order to conduct an analysis this far in the future, several assumptions are required. A summary of the assumptions which characterize the transportation and public policy environment, expected in the year 2010, is given below.

One of the key assumptions which will impact AHS deployment is the evolution of ITS technology. The extent to which ITS technology continues to develop will, in part, determine the additional costs associated with AHS vehicles. It is anticipated that the current development path of ITS and related technology will proceed according to accepted deployment scenarios (see, for instance, Activity K - AHS Roadway Operational Analysis). Specifically, adaptive cruise control/collision avoidance capability will be introduced by manufacturers as technology and cost converge with consumer demand. Manufacturers will progress to throttle by wire and brake by wire as part of projected vehicle development. Steer by wire, although not as clearly driven by market forces will also need to be introduced by the first year AHS is introduced.

In terms of the public policy environment, it is assumed that the AHS consortium is successful in coordinating Government, academia, and several automotive manufacturers in developing AHS specifications and demonstrating feasible technology. In addition, initiating AHS in 2010 will continue to require substantial Federal Government support both in terms of support for the AHS consortium and in terms of investment dollars to deploy AHS technology in a dozen urban areas. This funding will be in the order of $100 billion in 2003. The Federal funding in 2003 must also allow for the construction and conversion to AHS to proceed in about 12 major cities leading to modest networks of AHS roads being operational by 2010.

Continued Government support will allow vehicle manufacturers to immediately begin production planning leading to initial production of at least one vehicle platform from each of the three domestic vehicle manufacturers fully compatible with AHS by 2007. This vehicle will need to be available either fully AHS equipped or equipped with all of the necessary actuators, communications, and computation equipment such that it can be retrofitted at a late date. After 2007, most new vehicle platforms will be available with AHS equipment. It is also assumed that vehicle platforms will be replaced or significantly refurbished between six to eight years after the initial year of deployment. By 2013, AHS should be available on several passenger and light truck platforms offered by each manufacturer, with particular emphasis on the high end vehicles.

Recovery Of Development Costs

In order to conduct the benefit cost analysis of the AHS in 2010 it is also necessary to specify the assumptions relating to the recovery of AHS development costs. Ultimately, the nature of cost recovery will help determine the cost to the consumer of AHS vehicles and in turn have an impact on the level of AHS demand.

For this analysis it is assumed that the manufacturer does not directly recover the explicit costs of AHS development through the sale of vehicles to consumers. The basis for this assumption is that AHS is expected to be the next major automotive engineering development effort. Within ten years the traditional efforts to enhance automotive safety, economy, and harmful emissions will have achieved all mandated results and will be totally integrated into all aspects of automotive design to the point where directly identifiable engineering development can significantly decline. The available engineering staff will be available for AHS development. AHS will also significantly contribute to continued advancements in the areas of safety, economy, and emissions while also enhancing other attributes of automotive design. Thus, the development of AHS will be budgeted by the manufacturers as just the normal engineering effort required to remain progressive and viable manufacturers of automobiles. In the event that the development costs are partially or fully recovered, it is assumed that the time period for this recovery is five to seven years.

Projection Of AHS Sales

Projections of AHS sales, given in table 4, are used in the 2010 benefit cost analysis. These estimates were developed in the context of an assumed average annual sales of 15 million passenger and light duty vehicles. As described in the summary of the introduction scenario above, some of these vehicles will not be fully AHS equipped until a communications, actuator, and computation capability is retrofitted. This is assumed to be possible, at the owners' option, for essentially no difference in total price as compared to factory equipped AHS vehicle. The sales of AHS vehicles correspond to the baseline assumption of cost and deployment.

Table 4. Projected Sales Of AHS Vehicles, 2007–2016

Year	**Vehicles Sold**('000)
2007	25
2008	50
2009	100
2010	200
2011	300
2012	500
2013	700
2014	900
2015	1200
2016	1500

Source: Planning Assumptions of AHS Team Members

Development Cost Estimates

The development cost estimates were derived from project team planning assumptions commensurate with developing and implementing an AHS. These cost estimates were provided by fellow research team members. The Government's estimated development costs are summarized in table 5.

Table 5. Government Development Cost Estimates (1994 Dollars)

Development Area	**Cost** ($)
Initial Technology Selection and Demonstration, 1994-98	$300 Million
Alternative Testing and Specification, 1998-2002	$3.0 Billion
Vehicles	$500 Million
Test Highway	$1.5 Billion
Staffing	$1.0 Billion
Operational Testing at Two Modest Deployments, 2002-2006	$6.0 Billion
Vehicles	$1.5 Billion
Test Highway	$3.0 Billion
Staffing	$1.5 Billion

Source: Planning Assumptions of AHS Team Members

Team members also estimated the manufacturer's costs commensurate with developing AHS and associated vehicles. The manufacturer's cost estimates associated with taking detailed specifications through the product development stages, ultimately culminating in production, is summarized below for the years 2003-2007:

- Interface development by each of the three manufacturers – $500 million each.
- Equipment development shared – $1.5B total.
- Continuing manufacturer cost for new platforms – $300M per year per manufacturer.

Estimated Component Costs Per Vehicle

The costs described in table 6 are based on the projections of vehicle demand in table 4. The costs are for equipment in addition to ITS equipment. The costs are in 1994 dollars but also recognize, to the extent possible, the positive price implications associated with rapidly improved AHS technology.

Table 6. Component Cost Per Vehicle (1994 Dollars)

Vehicle Subsystem	**RSC 1** ($ per vehicle)	**RSC 2** ($ per vehicle)
Sensing	200	800
Communication	500	700
Computation	500	1000
Actuation	600	600
Driver Interface	150	150
Total (midpoint)	1950	3250
Total (low)	1500	2500
Total (high)	5000	7500

Source: Planning Assumptions of AHS Team Members

Highway Operations

The estimation of benefits from AHS requires an analysis of the integration of the AHS lane into the overall highway operations. One of the operational assumptions is that an AHS lane could be operated as a conventional lane during specified hours of the day. This assumption implies that there will be some kind of movable barrier which will allow entrance to the AHS lane and exit from it.

A simplifying assumption of the analysis is that benefits from AHS will be realized in the peak period. There will, of course, be benefits from AHS outside the peak period. Reduced stress and increased mobility to elderly drivers will be among the benefits realized outside the peak hour. However, the principal transportation benefits will be realized under peak conditions while the values for key benefit metrics in the off-peak period will be unchanged (or negligibly changed) under the base case and alternatives.

Another simplifying assumption is that the peak period is the same length every day. While this assumption is reasonable on normal days, events such as festival, sporting events, or other special events can cause more than two peak periods per day, and can extend normal peak periods when they coincide. It is assumed that these events are infrequent enough to make negligible difference to the analysis.

The AHS lane being considered in the evaluation was assumed to have capacity of 4000 vehicles per hour per lane with average speed of 96 km/h.

The analysis of the peak period is broken into a peak hour and peak period non-peak hour. The benefit metrics are calculated in each of the sub-periods of the peak period and, for AHS-equipped and non-equipped vehicles.

Penetration And Capacity-Increasing Thresholds

An important operational issue will be when to operate the AHS lane for its dedicated purpose and when to use the lane for conventional traffic. The percentage of AHS vehicles which will be used in the peak hour will determine rates of utilization of the AHS lanes. If the AHS lane does not attain minimal utilization then it will not contribute to the overall capacity of the roadways.

Our analysis indicates that if 80 percent of AHS-equipped vehicles will be used in the peak hour, then the following table 7 shows the thresholds of AHS penetration beyond which operating the AHS lane will contribute to capacity.

Table 7. Threshold Of AHS Penetration

Thresholds of AHS Penetration (Percent)	
Peak Hour	Non-Peak Hour, Peak Period
9	31

If AHS is operated below these thresholds, there will be net time savings. However, AHS users will be large winners in this instance with non-AHS traffic being losers. 8 shows time savings improvements with increased penetration of AHS-equipped vehicles, including a breakdown of time savings between the peak hour and peak period margins.

When penetration is below 9 percent, the peak-hour capacity increasing threshold, fewer vehicles can travel in the peak hour. In this case, total VHT in the peak period is less than in the base case. However, this situation corresponds to constrained capacity and an underutilized AHS lane. At 20 percent penetration, AHS utilization in the peak hour is maximized, (see figure 2). Time savings remain flat when penetration is between 20 percent and 33 percent and continues to grow when AHS penetration exceeds 33 percent and the AHS lane can be effectively utilized in the peak period margin, (see figure 3).

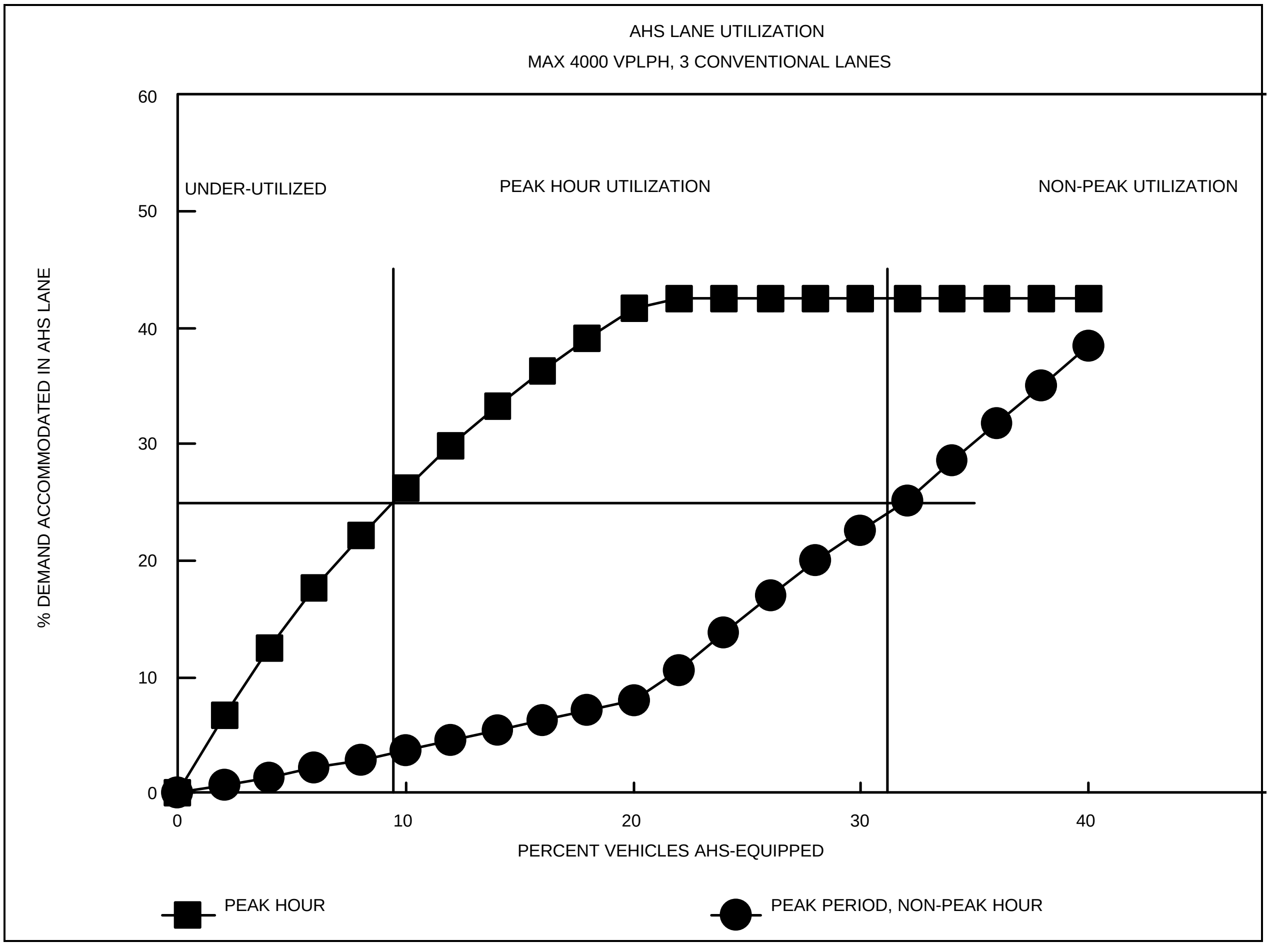

Figure 2. Utilization Of AHS Lanes

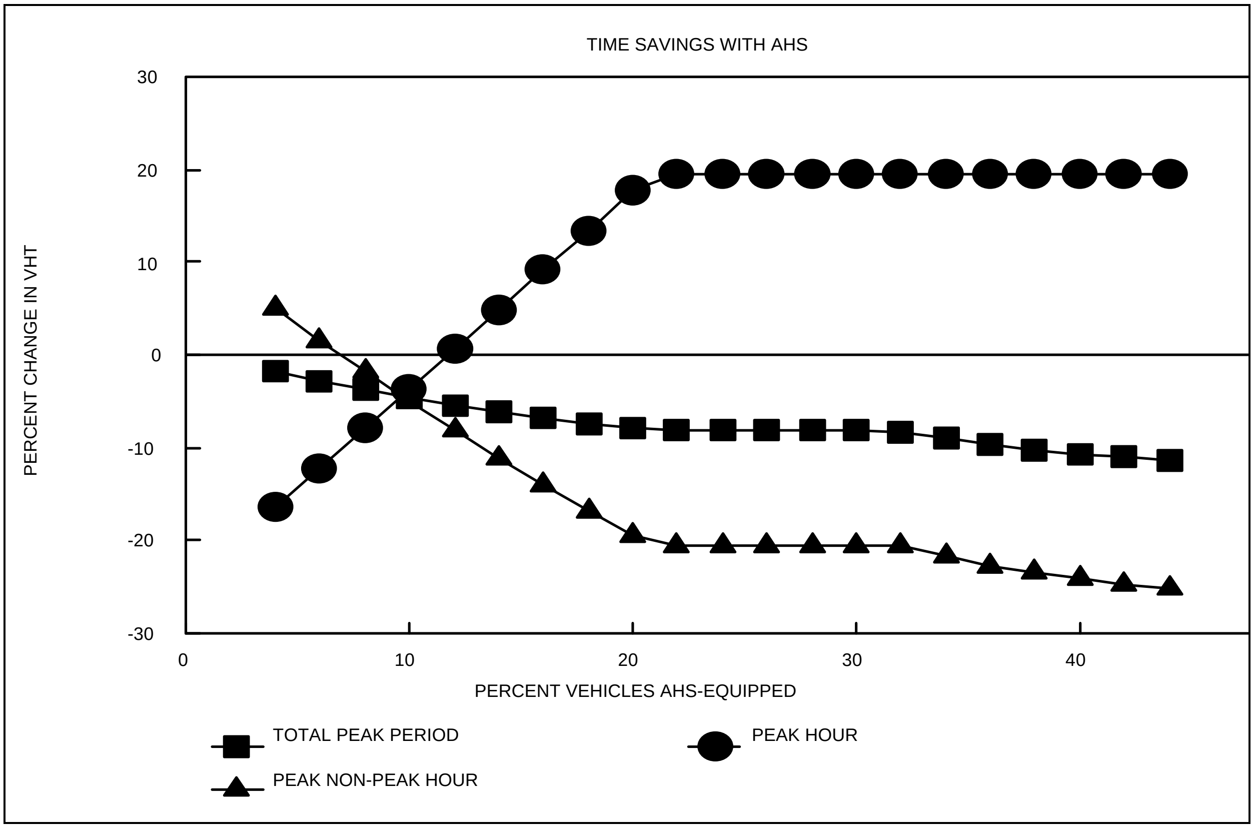

Figure 3. Time Savings And AHS Penetration

Analysis Of Time Savings

A parametric equation for computing travel time was estimated from traffic simulation outputs where travel time is a function of travel demand and market penetration. Simulation results provide vehicle kilometers traveled (VKT) and vehicle hours traveled (VHT) for only peak hour travel. Additional analysis was conducted to determine the time savings benefits for the entire peak period. It is assumed that travel time savings benefits will be negligible in non-peak travel. The structure and logic diagram is presented in figure 4.

Analysis Of Temporal Demand Shift Benefits

Temporal demand shift benefits refers to the potential value associated with travelers being able to travel at their desired time as a result of AHS. That is more travelers will be accommodated during the peak hour with AHS as a result of reduced headways and increased average speeds.

As highways reach traffic volumes that exceed capacity, congestion occurs and travel time increases. As congestion increases, travelers begin rearranging their schedules to avoid delays, increasing the length of the peak travel period. If a highway project such as the proposed AHS allows the peak period to shorten, and hence, more traffic is accommodated in free flow conditions during peak times than previously, then demand shift benefits result in addition to pure travel time savings. These types of benefits have just recently become a part of the traditional benefits evaluation framework of highway projects and as such rely on new methodologies which are still in the development stages.[3]

Figure 5 shows the distributional effect of demand under some of the hypothetical highway projects in this benefit-cost analysis. In each case, the actual level of daily traffic, as measured by average annual daily traffic (AADT), is assumed to be the same. Only the distribution of that traffic over peak and non-peak periods changes.

In order to quantify these benefits assumptions regarding the unconstrained percentage of peak demand which would travel in the peak hour are required (i.e., the percentage of peak demand traveling in the peak hour assuming no congestion). In addition, the volume of traffic that can shift from the base case distribution to the distribution made possible by the project must be parameterized. This parameterization allows the calculation of the volume of shifted traffic. The shifted traffic represents those people who now drive during the peak hour instead of being pushed in to the peak period non-peak hour.

Assuming, as above, a uniform temporal distribution in peak period non-peak hour traffic, and further, that shifted hours are likewise distributed uniformly over the peak period, the average time shift per shifted hour can be calculated. From this result, the total number of shifted hours can be calculated using simulation model results. Once this is complete a value is placed on the number of shifted hours to produce these estimates in monetary terms. Figure 6 shows the structure and logic representation of this estimation methodology.

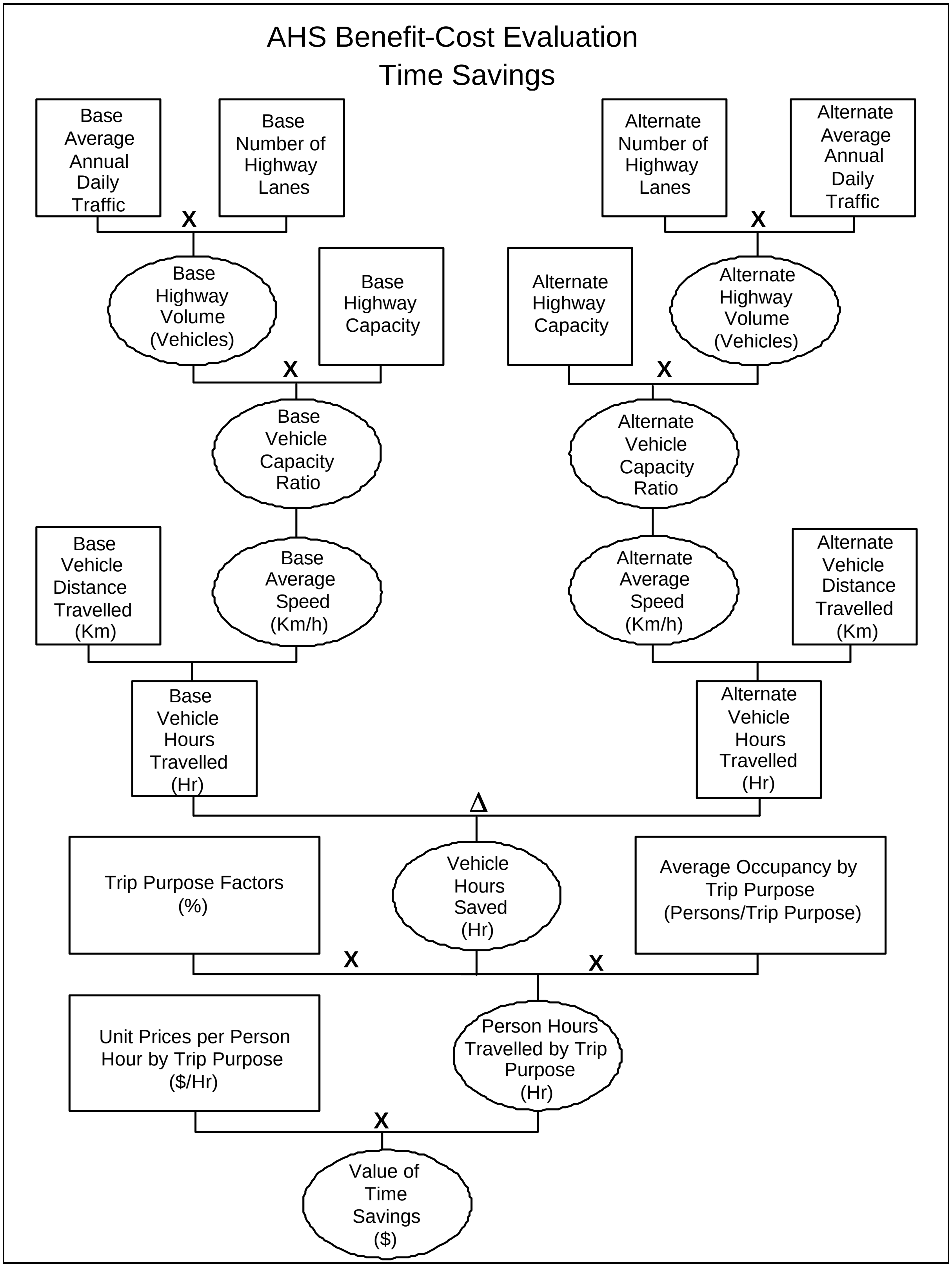

Figure 4. AHS Time Savings

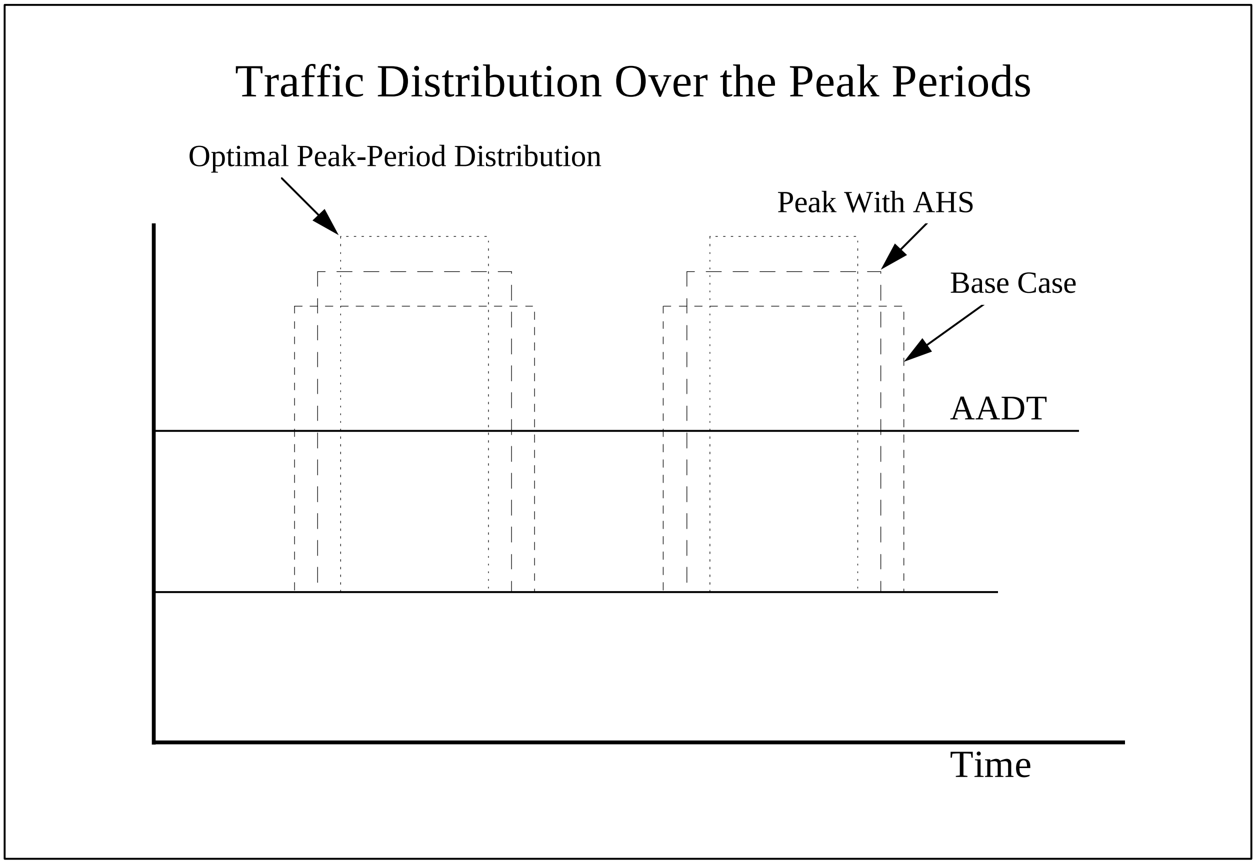

Figure 5. Temporal Demand Shift Benefits

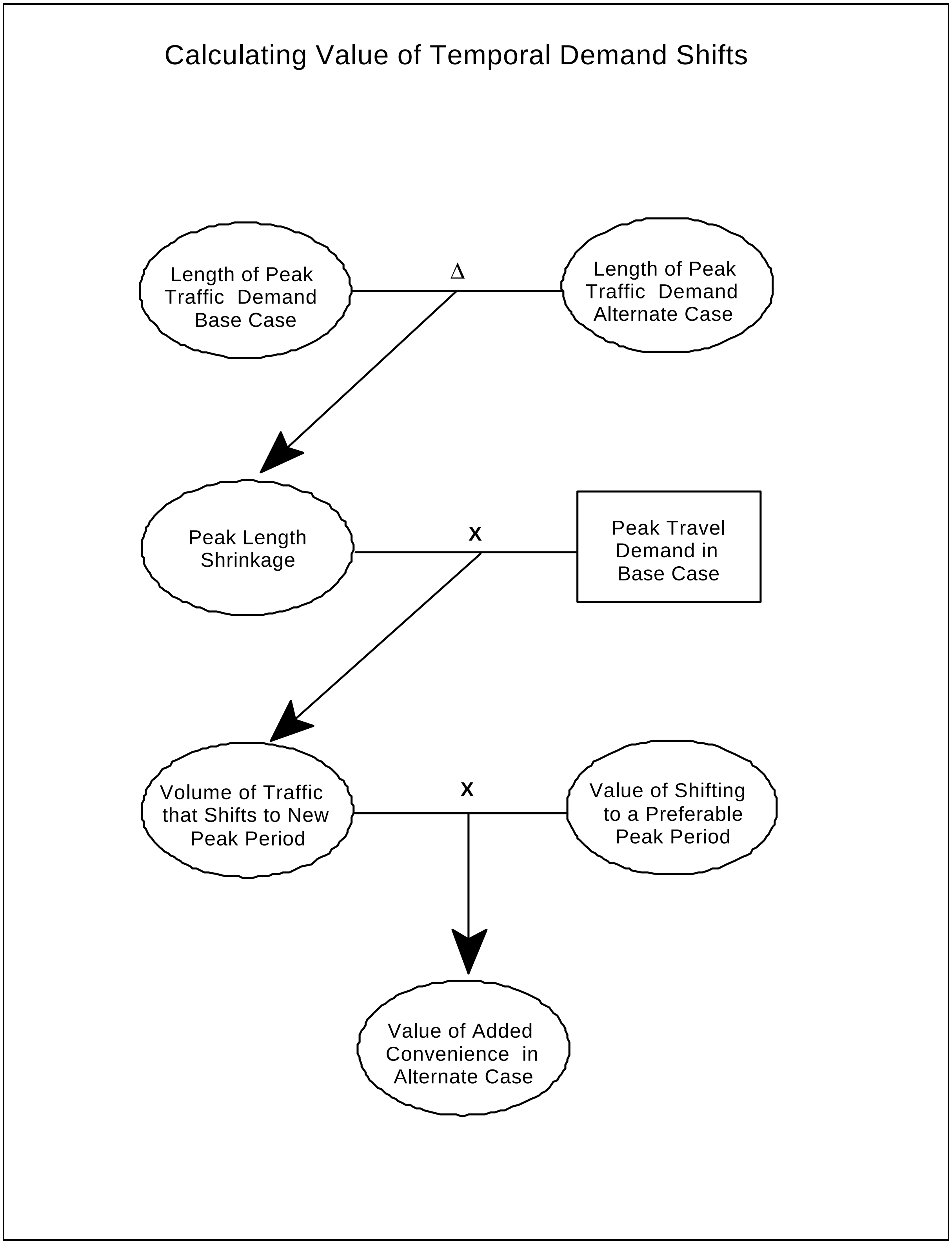

Figure 6. Temporal Demand Shift Valuation

Analysis of Vehicle Operating Cost Savings

Vehicle operating costs include the following: fuel, oil, tires, maintenance and repair, and depreciation. Vehicle operating costs are a function of two variables which are determined by simulation output of average speed and standard deviation of speed. The structure and logic model of vehicle operating cost savings is given in figure 7.

Using widely accepted look-up tables that parameterize vehicle consumption equations, vehicle operating costs will be calculated for the base case AHS and alternative projects.[4] The difference between base case and AHS vehicle operating costs represents the benefit associated with AHS.

Analysis of Safety Benefits

Safety benefits, like vehicle operating costs benefits, are estimated using off-line analysis. Using simulation model VKT results, base case accident rates,[5] costs of accidents,[6] and assumptions relating to AHS accident rates, the difference between the cost of accidents in the base case and the AHS case represents the benefits. The associated structure and logic model is given in figure 8.

This analysis considers three accident types: property damage only, injury accidents and fatality accidents. AHS is assumed to reduce the number of accidents of all types uniformly by approximately 80 percent.

Analysis of Environmental Benefits

Environmental benefits are calculated using interpolated VKT simulation model results which give the quantity of emissions by type. The structure and logic model for this calculation is shown in figure 9.

Each emission type is assigned a value, based on secondary sources, with the reduction in emissions under AHS representing the environmental benefits.

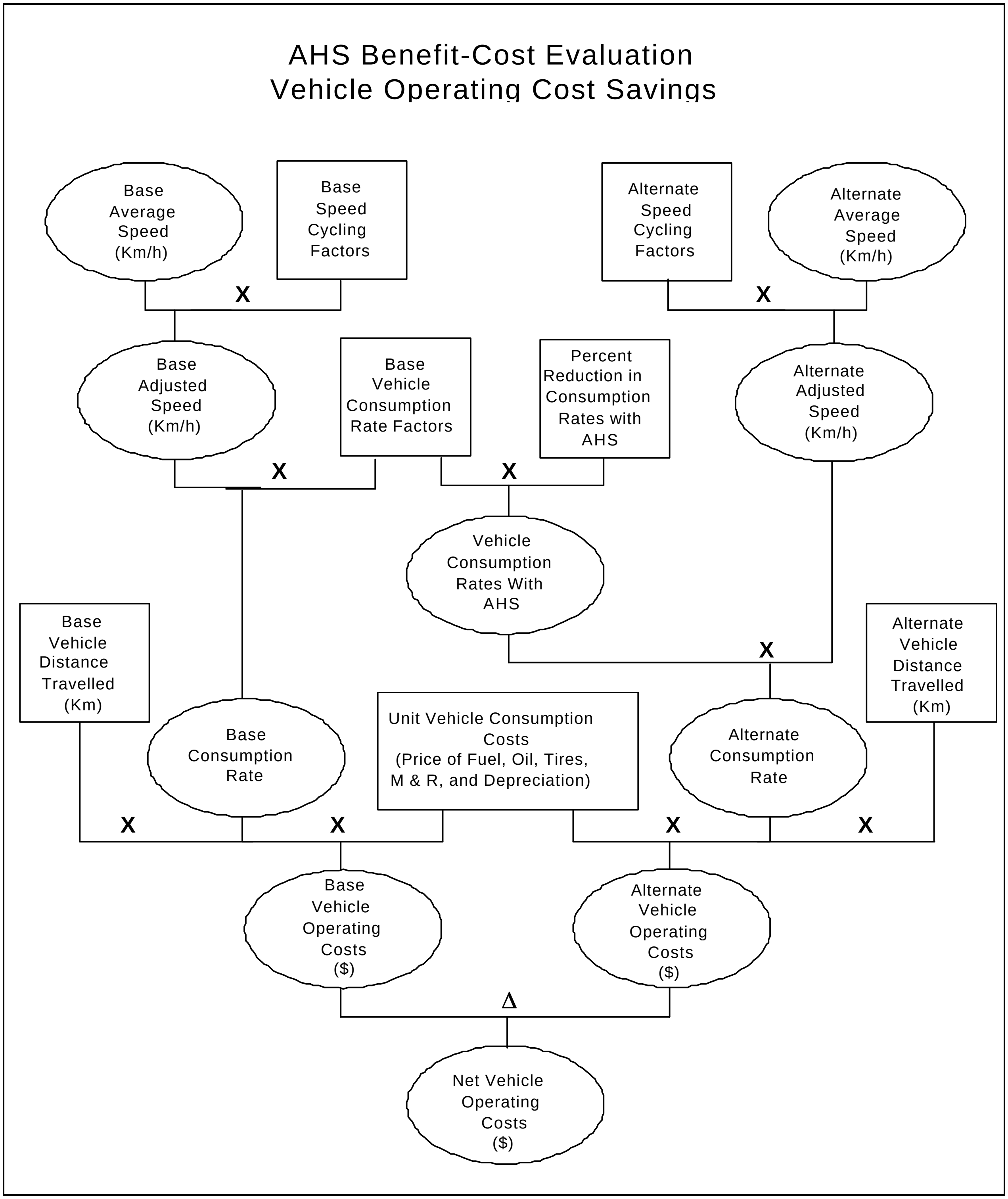

Figure 7. Vehicle Operating Cost Savings

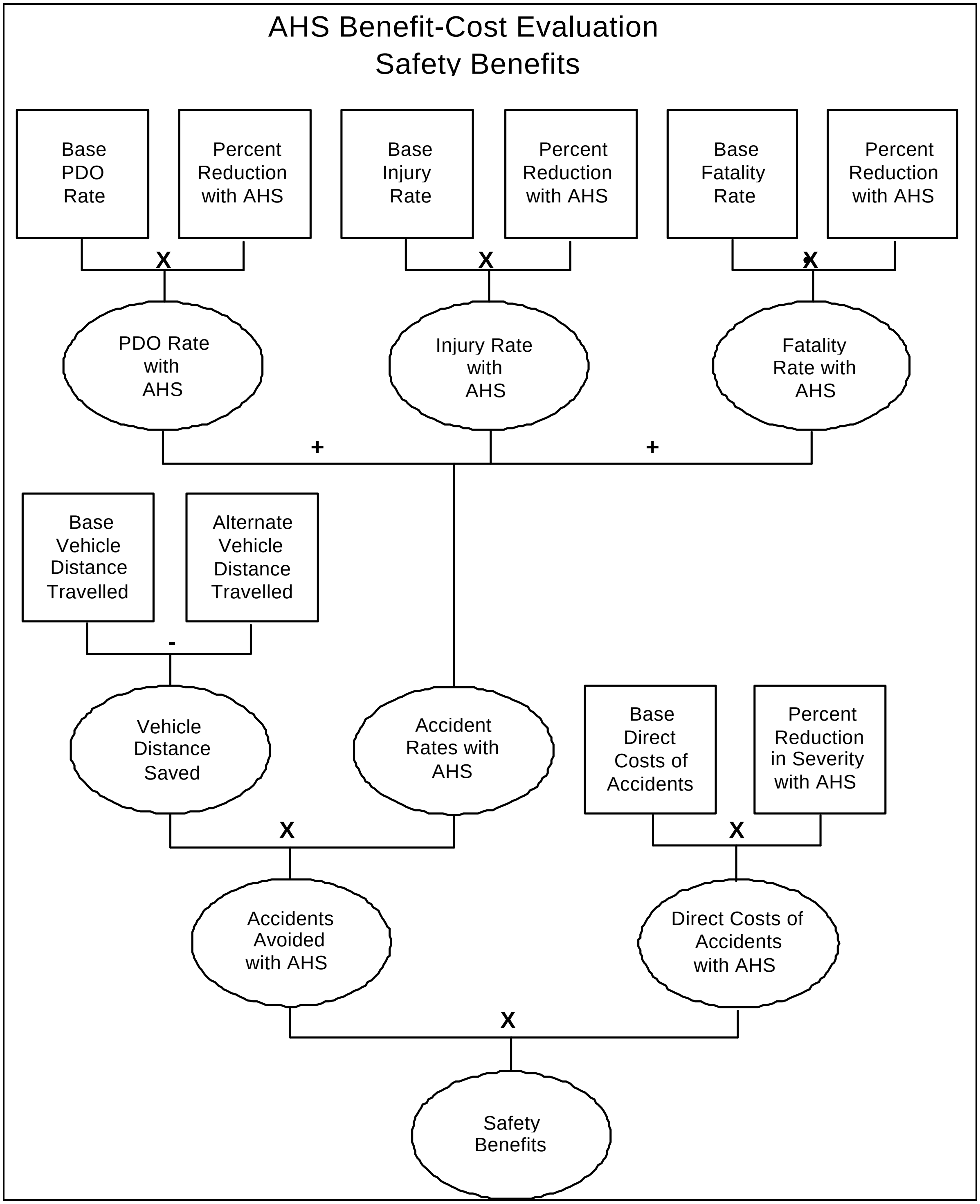

Figure 8. Calculating Safety Benefits

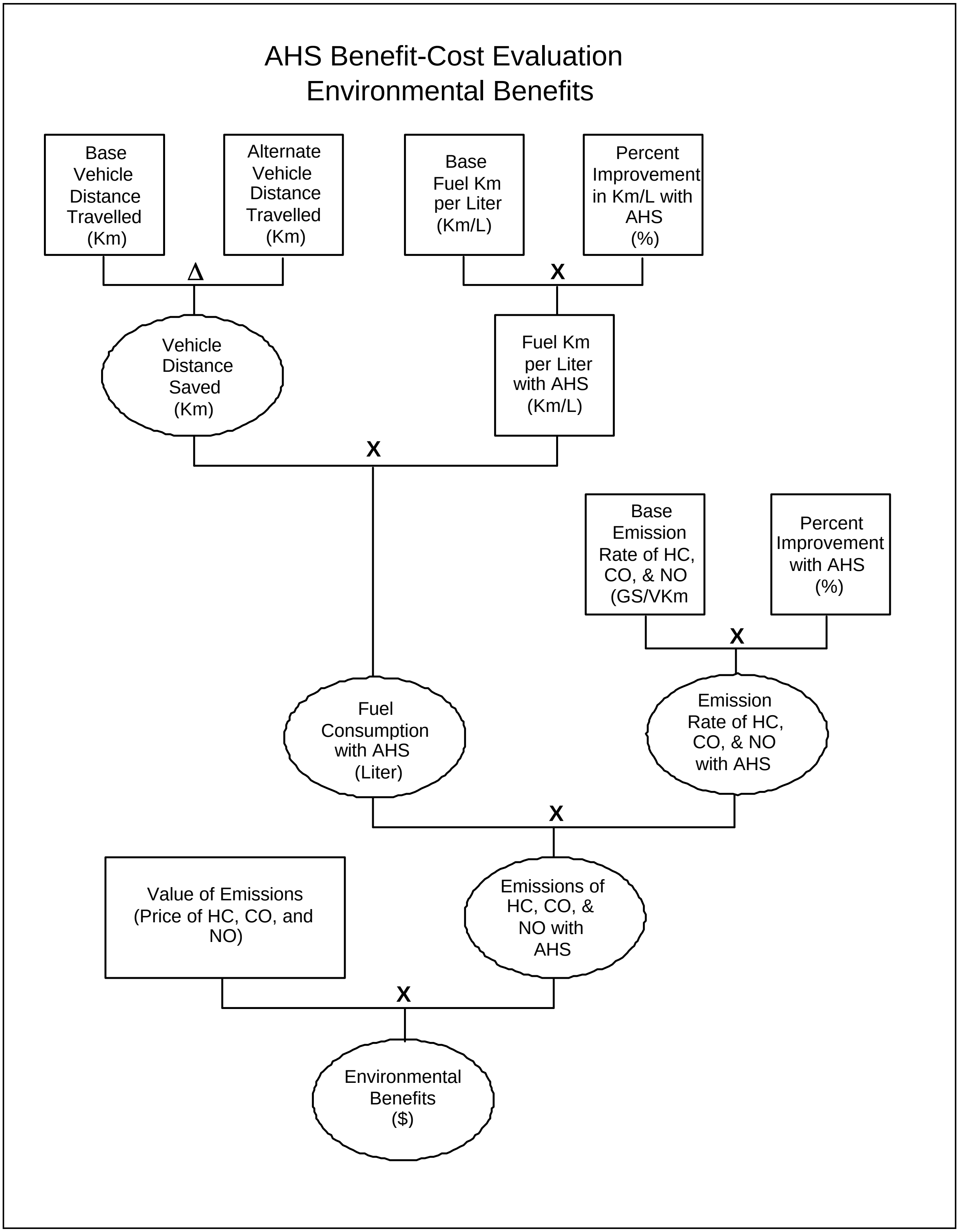

Figure 9. Calculating Environmental Benefits

Analysis Of Infrastructure Costs

There are two main components of AHS costs: construction costs and operation and maintenance costs. AHS costs will be largely dependent on the evolutionary process described in task 3. The extent to which AHS can map into existing, highly sophisticated physical and technological infrastructure will play a large part in determining the level of additional costs required to meet AHS needs. The same holds true for operation and maintenance costs which will depend in part on the level of technological skills available in the workforce.

Construction Costs

For the base case and each AHS configuration the following construction costs are estimated:

- Right-of-Way – Costs of land acquisition.
- Base Construction – Costs of AHS physical roadway infrastructure.
- AHS Infrastructure – Costs of AHS technological infrastructure.
- Traffic Management Center Construction.
- Disruption – Costs of construction disruption (i.e., re-routing of traffic during construction phase of project).

Right-of-way costs and base construction costs are subject to traditional forms of uncertainty including delays caused by legal complications, labor disputes and poor weather. AHS infrastructure and traffic management center construction are subject to technological uncertainties which can also cause delays and increase costs. Figure 10 shows the structure and logic representation of the construction cost model.

Analysis Of Maintenance And Other Costs

Operation, maintenance, and repair costs occur once the project is operational. These include: labor and materials costs that are expended during the normal operation of the system. Life cycle costs, by definition, occur at irregular intervals throughout the usable life of the project. These include the following: repaving, worker training, and disposal and salvage costs. Maintenance and operating costs are both subject to technology and price uncertainty while life-cycle costs will be subject to engineering uncertainty. Figure 11 illustrates the structure and logic for the estimation of operating, maintenance and life cycle costs.

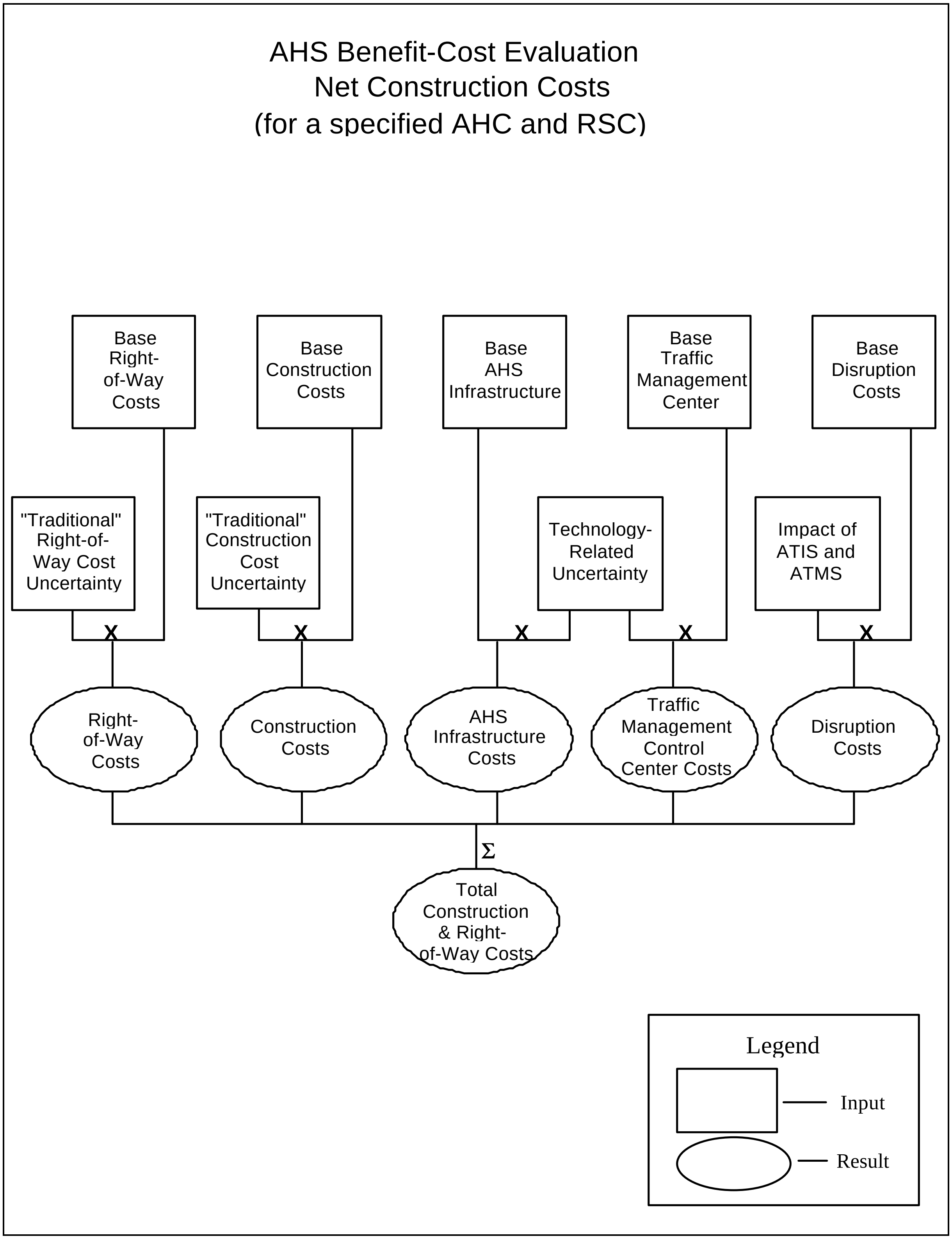

Figure 10. Construction Cost Model

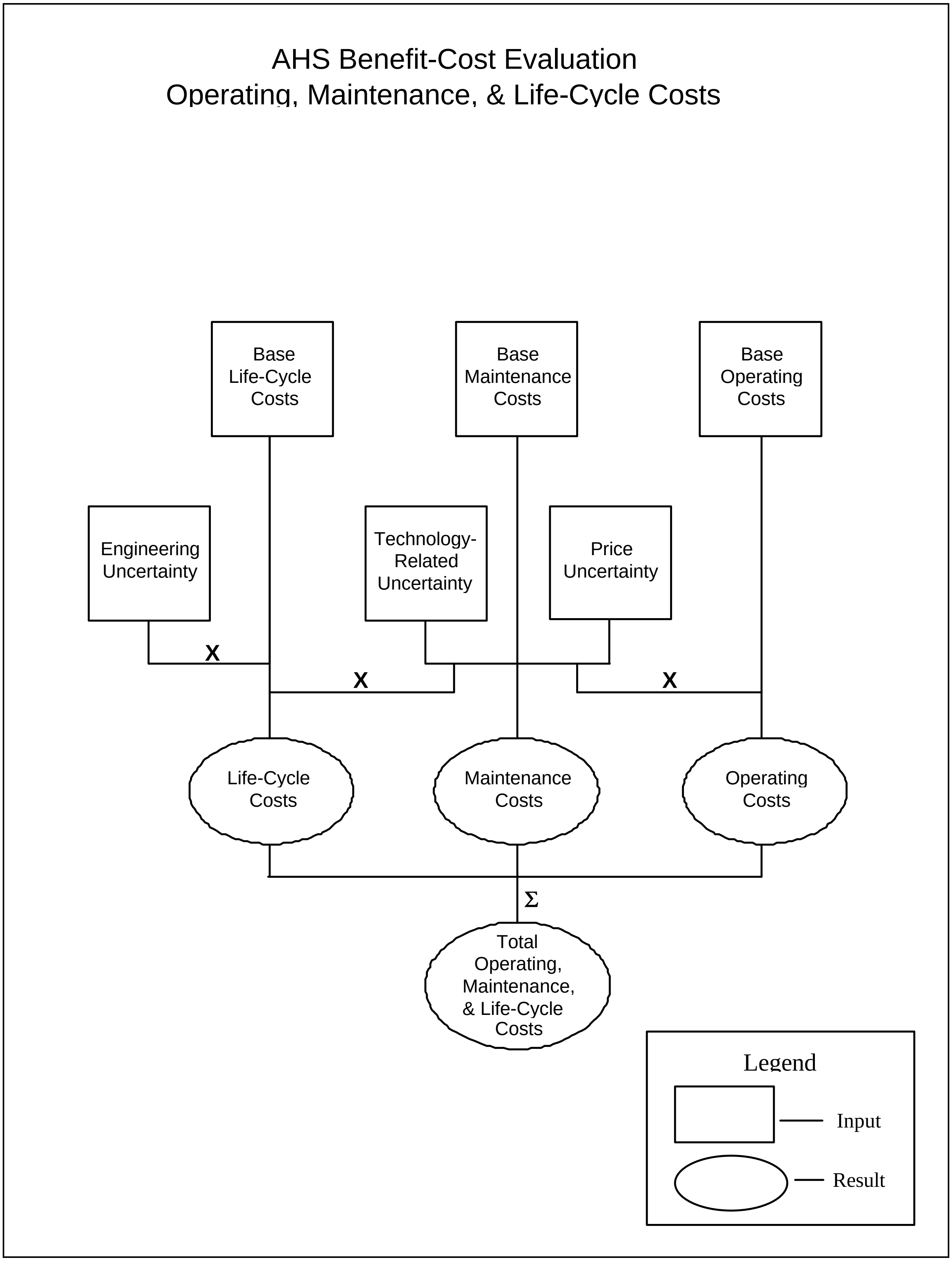

Figure 11. Operation Maintenance & Repair

Task 5. Risk Analysis Parametric Model Of Benefits And Costs

To improve confidence in the forecasts, the Risk Analysis Process involves outside expert evaluation of the forecasting assumptions and the estimated probabilities associated with their accuracy.

The Risk Analysis component of the AHS benefit-cost analysis involves four steps:

1. Adapt benefit-cost models and estimation procedures into the Risk Analysis Framework.

2. Assign estimates and ranges (probability distributions) to each variable and assumption in the forecasting process.

3. Expert evaluation, including revision of estimates and ranges developed in step 2.

4. Risk Analysis.

The process begins with the development of “structure and logic models” depicting the methodology, non mathematically, of all the interrelationships between input variables and exogenous assumptions used to estimate the potential benefits associated with the AHS project. Once the structure and logic of the model is accurately represented in the Risk Analysis framework, it is programmed into the Risk Analysis software.

Step 2 assigns each variable a central (median) estimate and a range (probability distribution) to represent the degree of uncertainty. Specially designed data sheets are used to present the data and to solicit expert opinion where secondary data is unavailable or unreliable. The upper and lower 10 percent limit define a range which represents “an 80 percent confidence interval” – the range within which we can be 80 percent confident of finding the actual outcome. The greater the range of uncertainty associated with a variable the wider the range will be (and vice versa). This process considers all of the relevant risks associated with the input variables and allows for stakeholders’ views to be reflected in the probability ranges.

Probability ranges for the variables are generated on the basis of both statistical analysis and subjective input. Ranges need not be normal or symmetrical – that is, there is no reason to assume a bell shaped normal probability curve. The Risk Analysis Process places no restrictions on the degree of skew and is therefore flexible to consider situations where there is much greater upside rather than downside risk.

The third step is closely related to the first two steps in that it consists of incorporating the advice of experts in the many task areas of the AHS evaluation to scrutinize the modeling framework and provide input into the determination of central estimates and probability ranges. In the AHS evaluation steps 1 and 2 have been conducted simultaneously with the methodology benefiting from the comments of team members on a regular and ongoing basis.

The final step, undertaken when the data sheets are finalized, involves using the RAP software to transform ranges given in the data sheets into statistical probability distributions as illustrated in figure 12. These distributions are combined using simulation techniques that allow all variables to vary simultaneously from their expected values as illustrated in figure 13. The result is a forecast of benefits, costs or the appropriate result metric together with the estimates of the probability of achieving alternative outcomes given the uncertainty in the underlying assumptions.

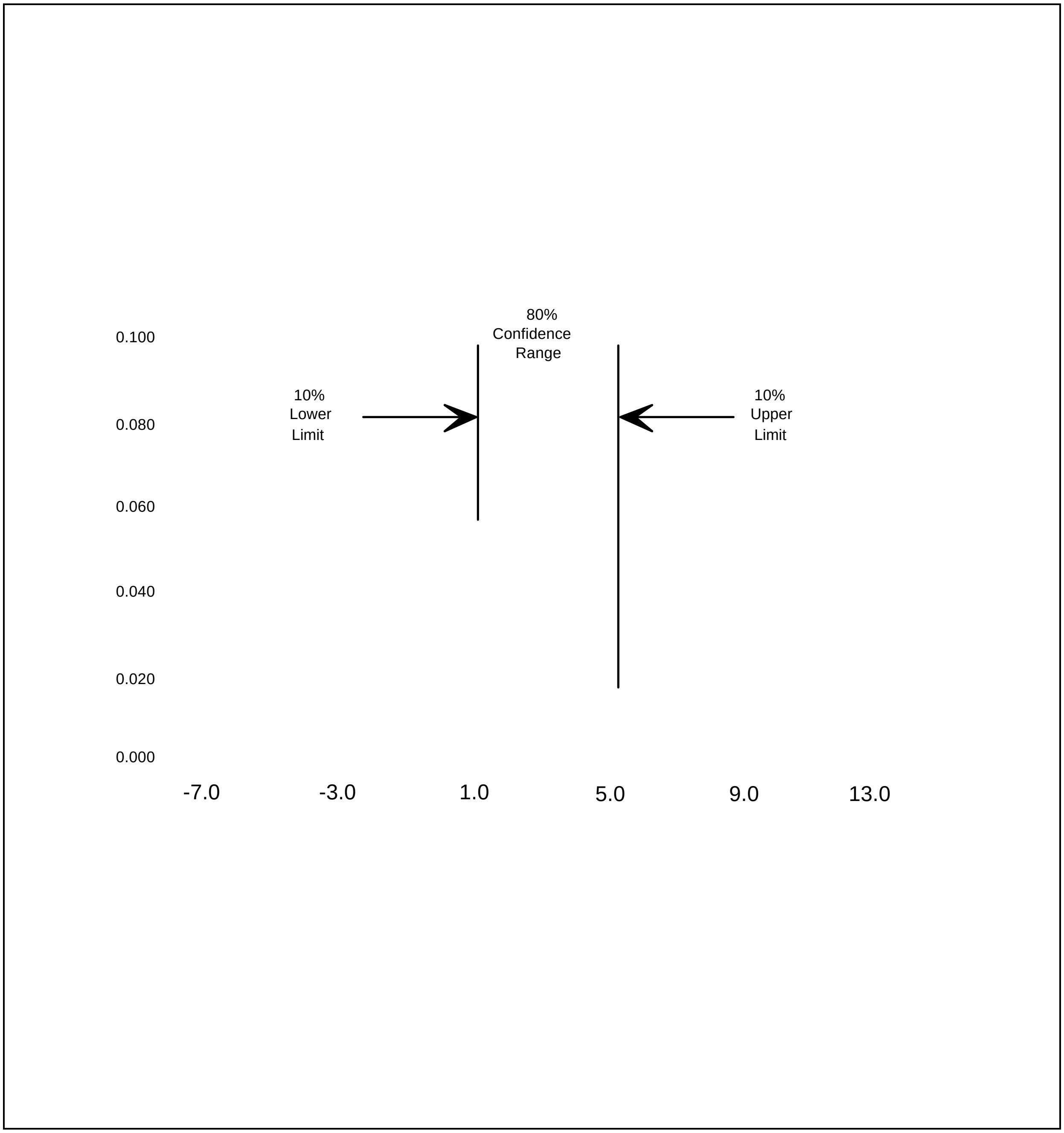

Figure 12. Probability Density Function For Input Variable

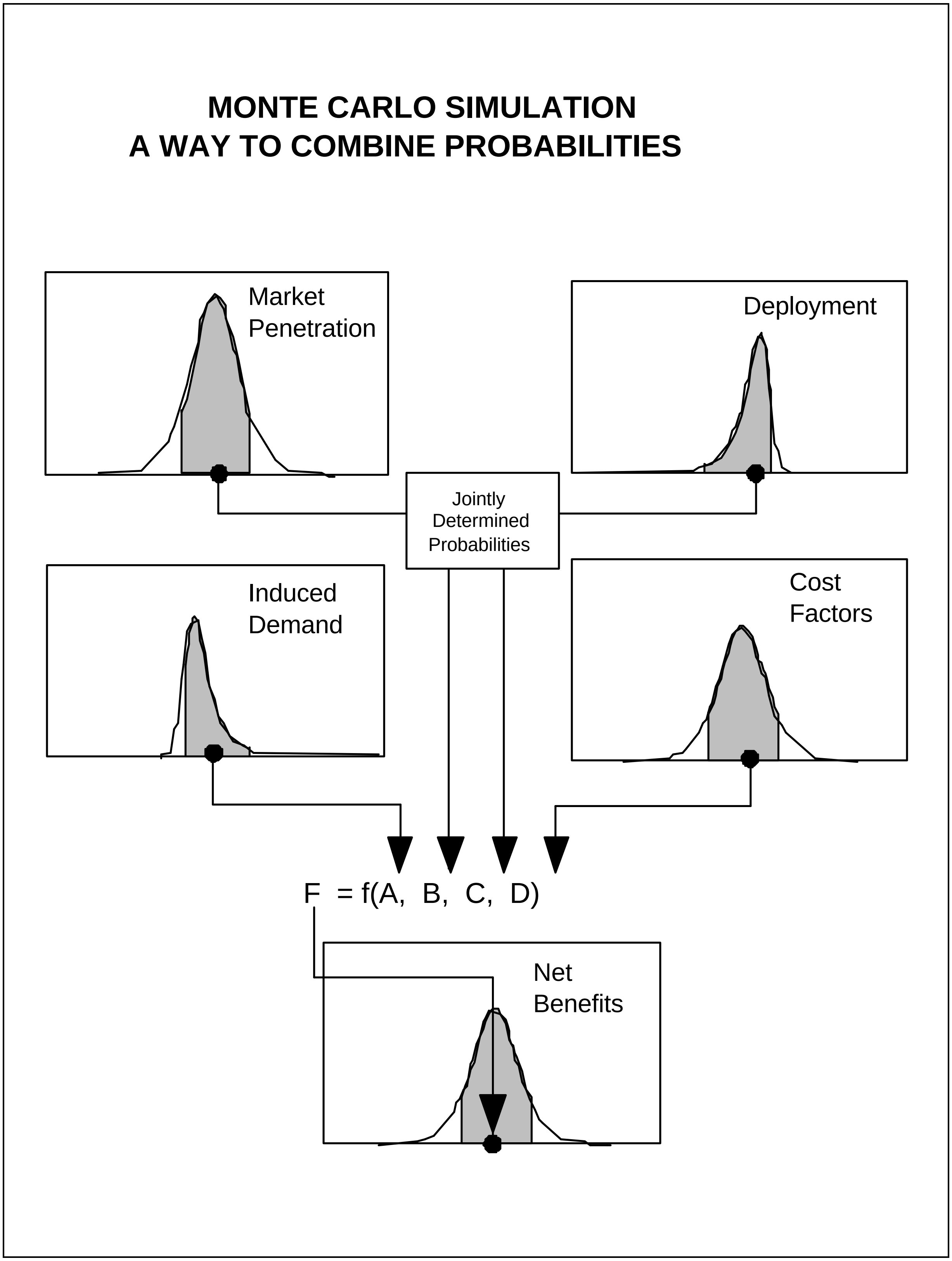

Figure 13. Monte Carlo Simulation

Task 6. Scenario Analyses

The analysis of benefits and costs focuses on the hypothetical AHS proposed for a 12.8 km stretch of I-17 in metropolitan Phoenix. The alternative scenarios which were considered for evaluation were:

- Base case – Four lanes each direction of conventional highways with ITS improvements.
- AHS RSC 1 – Characterized by "smart" infrastructure and less expensive in-vehicle equipment.
- AHS RSC 2 – Characterized by more expensive vehicles and less expensive infrastructure.
- Expand highway to five lanes.
- HOV lane instead of AHS lane.

The full analysis was conducted for the base case and for the AHS RSC 1 alternative. The complete sets of inputs and results are presented in Appendix 4.

In the analysis of AHS demand, national sales of AHS-equipped vehicles were assumed to reach three percent of total vehicle sales in 2013 and 14 percent in 2017. The Phoenix region local council of governments was assumed to pursue a policy of aggressive AHS deployment resulting in AHS-equipped vehicle penetration of 30 and 40 percent in each of the above years. Assuming fleet growth and vehicle retirement rates, levels of penetration of AHS vehicles in the regional fleet reach about 8 percent in 2010 rising to 30 percent in the year 2020. This baseline demand was allowed to fluctuate subject to uncertainty in underlying factors related to vehicle cost, i.e., if national sales were slower than expected then vehicle prices would increase resulting in lower demand. Demand was also assumed to respond to the pace of deployment of AHS in the region.

Capital and life-cycle costs were calculated based upon information surveyed from within the research team.

The principal benefits categories that were considered were: time savings, vehicle operating cost savings, safety and temporal demand shifts (i.e., the benefit from increased capacity). It is recognized that there are additional benefits from AHS which are less readily quantified.

Results

The expected net present value of the project, discounted at five percent to the beginning of the year 2008 when construction is assumed to begin is negative $2.5 million. There is a 25 percent probability that the project will break even and 10 percent probability of achieving a surplus of $4.9 million.

The expected benefit-cost ratio is 0.945 and present value of benefits is estimated at $42.3 million while costs are estimated at $44.9 million.

The largest prospective benefits are anticipated to be from the convenience afforded to more travel in the peak hour.

CONCLUSIONS

This research provides a framework and preliminary estimates of the benefit-cost of a hypothetical AHS project. The result of the analysis are attached in Appendix 4.

Key Assumptions Of The Analysis

The results show that given the assumptions of the analysis, a hypothetical AHS project has a high likelihood of providing a strong economic rate of return. Key assumptions which are crucial to the analysis include the following:

- A successful evolutionary deployment of AHS and ITS systems and products.
- The ongoing development of an AHS roadway network in Phoenix and other metropolitan areas.
- Continued public funding of AHS development.
- Implementation of multimodal planning and investment to relieve arterial congestion.
- Technological development and market acceptance keeps pace with scheduled deployment.

Operation Thresholds

AHS will not enhance capacity if penetration is below nine percent assuming that 80 percent of AHS-equipped vehicles will travel in the peak hour. At 20 percent penetration AHS is fully utilized in the peak hour. However, AHS will enhance capacity in the peak period margin only when the 33 percent of vehicles are AHS equipped. More detailed analysis of traffic flows and temporal distribution of traffic can determine what hours of operation will be optimal.

Benefits

Highway projects, in general, generate most of their benefits through time savings and convenience benefits, with safety and other benefits a much smaller proportion of the total. The principal benefits which are expected to be derived from the AHS project are time savings and convenience made possible through added capacity in the peak hour. The benefits to non-AHS users are projected to comprise the majority of benefits even for levels of AHS penetration as low as 20 percent.

Other Conclusions

It was apparent from the highway operations analysis that AHS would be clearly not viable unless implemented within a multimodal planning context. Without complementary planning and improvements to supporting roadways, ramp queuing on the AHS would rapidly make any prospective urban AHS a non-starter.

Within a multimodal planning context, AHS could potentially relieve congestion in crowded corridors. While not captured in direct benefits, the relief of congestion from AHS could contribute to the preservation of business districts and prevent continuing urban sprawl. This could be the case in areas with relatively low housing densities which could not support a rail project yet still need a cost-effective solution to congestion.

Further Research

Further clarification of the deployment scenario will be crucial to firming up estimates for economic benefit-cost and rates of return. The benefits from added convenience and AHS benefits which are less readily quantified (i.e., reduced stress, mobility for the elderly) still require research to determine the value of these benefits.

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APPENDIX 1. METHODOLOGICAL APPROACH

Specify The Base Case

The base case represents the baseline against which all major investment strategies are compared. The base case is distinct from a "do nothing" or status quo scenario in that it accounts for expected changes in technology, demand management, public policy, the economy, ITS deployment, and other social trends that may occur in the absence of an AHS system.

The base case specification involves projecting the impact of future travel, social and economic trends on travel demand. While these projections are difficult to develop far into the future, failing to account for them may result in the overestimation of benefits attributable to a given project.

For the current analysis the base case is considered in the context of a continuing ITS evolutionary process into the next century. In terms of vehicle technology this means that vehicles will continue to show advances in electronic capabilities, e.g., speed control, availability of information. ITS infrastructure will also progress steadily into the next century, providing advanced traffic management and information systems.

Specify The Hypothetical AHS Project And Alternatives

In order to evaluate the benefits and costs of AHS and available alternatives, traffic simulation models are used in combination with off-line analyses to depict the state of the roadways affected by AHS implementation, as illustrated in figure 14. This involves the assignment of traffic demand to AHS, base case and other alternative roadway configurations. All of the alternatives are characterized differently in terms of the engineering specifications of traffic capacity.

Traffic simulation models represent expected congestion levels, and associated travel speeds, both with and without AHS and produce the following outputs for the hypothetical AHS project and alternatives:

- Total travel time (Vehicle Hours Traveled, VHT).
- Ramp/Freeway delay (Vehicle Hours, VH).
- Total travel distance (Vehicle Kilometers Traveled, VKT).
- Average speed (km/h).
- Gasoline consumption.
- Hydrocarbon, carbon monoxide, and nitrous oxide emissions.

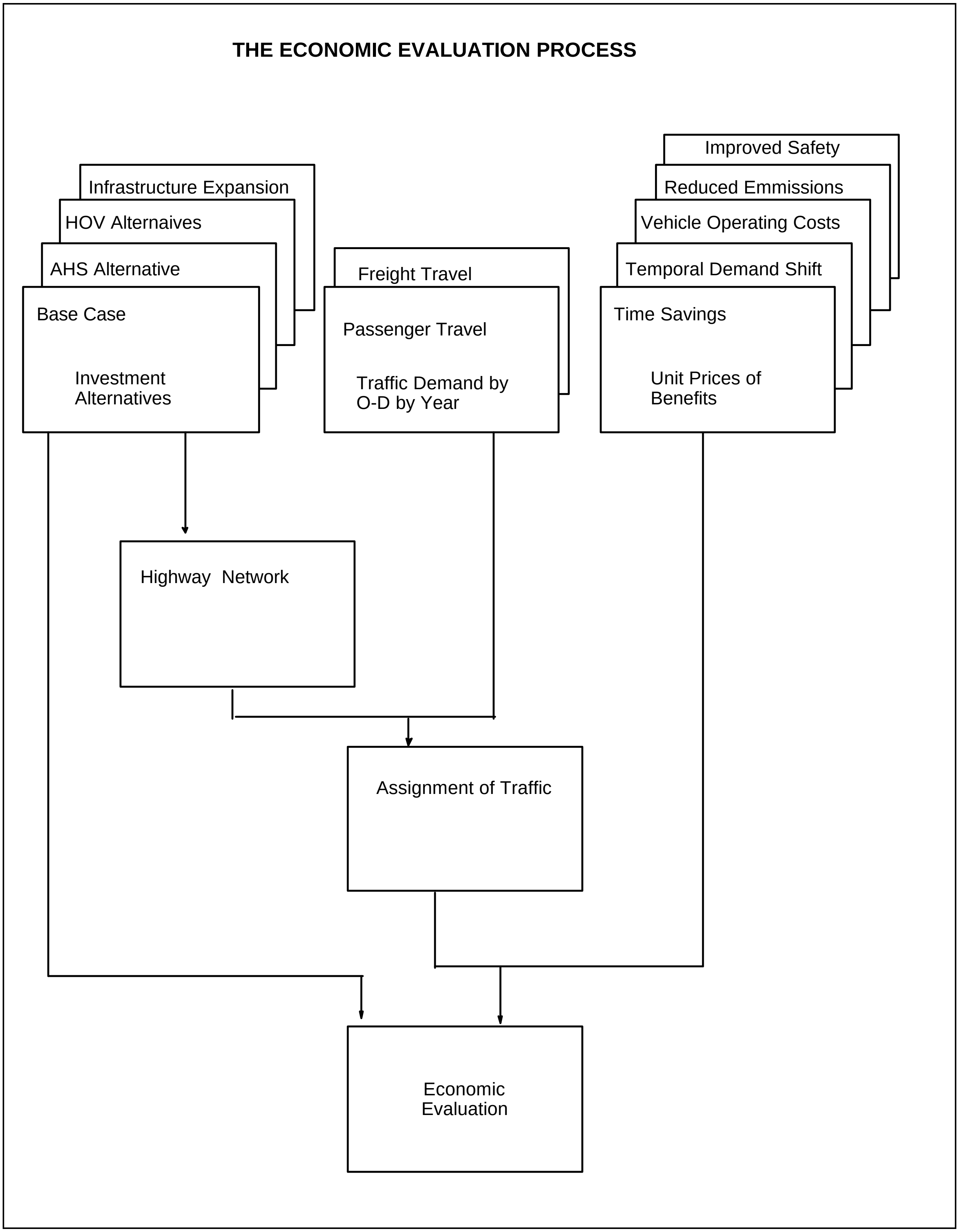

Figure 14. Economic Evaluation Process

These outputs are produced for peak hour traffic for freeways, arterials, and ramps. In the peak hour it is assumed that the maximum volume over capacity ratio is one. With the addition of volume to this maximum, ramp/freeway delay increases, thus increasing travel time. Simulation results are available for the years 2010 and 2017. Flows of benefits and costs which are dependent on simulation model results are extrapolated to generate a thirty year stream of benefits.

Off-line analysis are conducted to estimate time savings benefits in the peak period (including peak hour outputs from the simulation) and to estimate benefits such as reduced vehicle operating costs and improved safety. Task 4 presents a full description of these analyses.

Forecast Travel Demand And Market Penetration Of AHS Vehicles

AHS is likely to be introduced in a marketplace which differs greatly from today's, with different consumer tastes and a far different regulatory environment. This requires a detailed articulation of a "vision of the future" which will influence many of the factors affecting AHS demand and the associated benefits and costs. Figure 15 illustrates the interrelationships between the factors driving AHS demand and, ultimately, the benefits and costs associated with the project.

Market Penetration And Vehicle Costs

Market penetration, measured as the percentage of vehicles which are AHS equipped, is dependent, in part, on the key relationship between vehicle cost and vehicle demand. Cost-per-vehicle of AHS equipment varies under each system configuration. Lower costs per vehicle, are likely to generate higher levels of market penetration. Cost per vehicle will decline as economies of scale are achieved and development and other fixed costs are spread over a larger number of vehicles. Market penetration and vehicle costs are therefore determined simultaneously. The simultaneous determination of these variables is reflected in the structure and logic models presented in task 4.

Other Factors Influencing AHS Demand

The operating characteristics of the AHS system will be an important element in determining AHS demand. Operating characteristics such as average speed and headways which determine the average time per trip, the safety of the system, and the level of driver involvement, (e.g., hands off, feet off) will be the basis of comparison when consumers are making choices between conventional and AHS equipped vehicles. Operating characteristics combined with the relative cost of alternative technologies will be two of the key factors determining AHS demand.

The level of AHS deployment will also play a role in determining AHS demand. Travelers willingness to pay for AHS technology is expected to increase with the number of urban and rural areas equipped with the supporting technology. If AHS is available in only a localized setting then the likelihood of high market penetration diminishes.

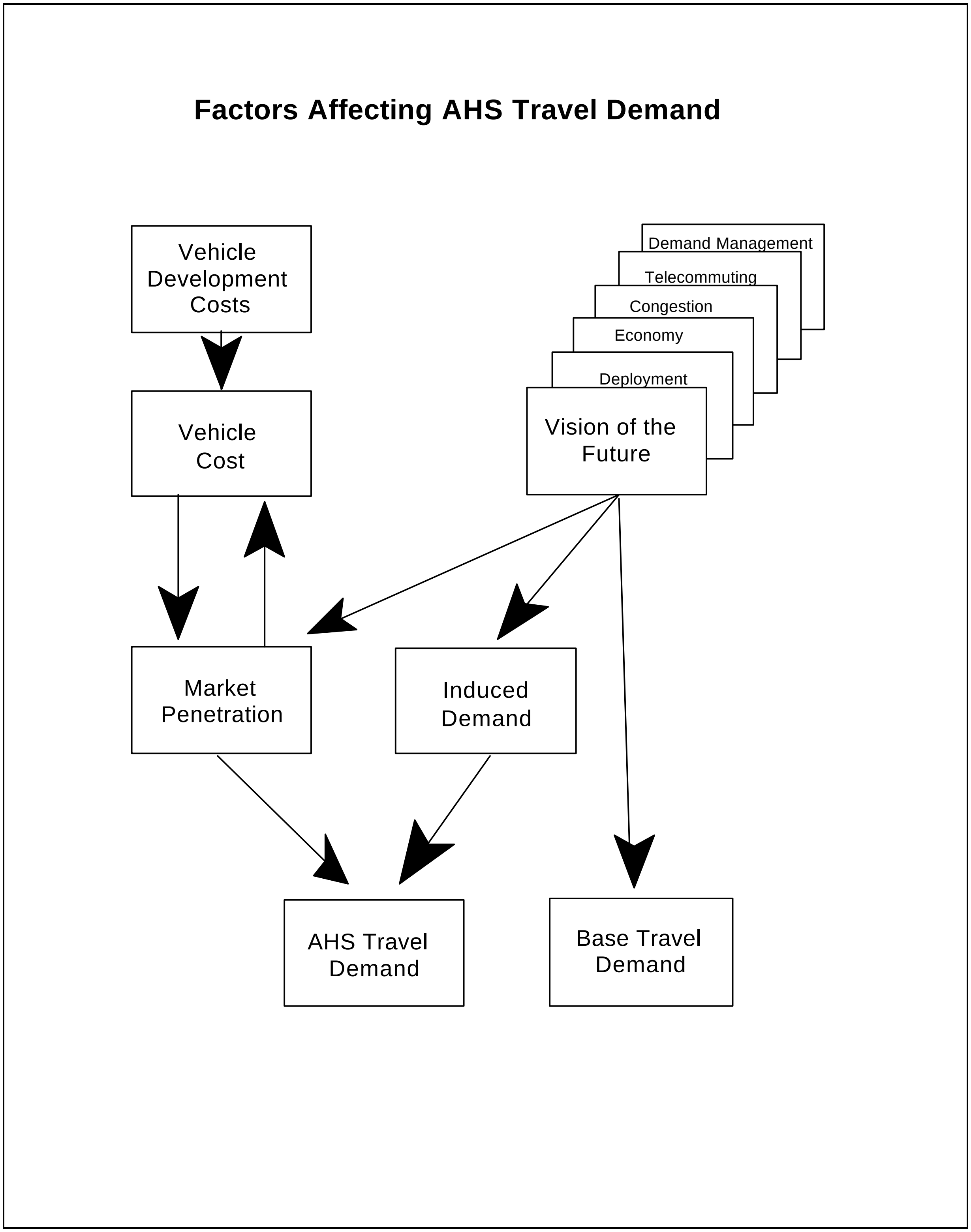

Figure 15. Factors Affecting Travel Demand

Underlying all of the above factors which are thought to affect AHS demand are the general economic, demographic and travel related trends. Prevailing economic conditions at the time of implementation in terms of GDP, personal income, and employment will determine the ability of the economy to support major infrastructure investments and the ability of individuals to pay for more expensive AHS equipped vehicles. Key demographics affecting AHS will be population growth, population density, and population distribution, in terms of age and sex. Travel related trends refers to things like working at home, increased propensity to use public transit due to environmental concerns, or flexible work weeks which could spread the flow of daily traffic thereby decreasing traditional peak delays. The above factors contribute significantly to the overall size of the road travel market and are considered in the demand estimations used in this analysis.

Estimate Infrastructure Costs

Their are three broad categories under which AHS costs will fall: capital, operation and maintenance, and life-cycle costs. Capital costs include financing costs as well as the following construction related costs:

- Right-of-Way – Costs of land acquisition.
- Base Construction – Costs of AHS physical roadway infrastructure.
- AHS Infrastructure – Costs of AHS technological infrastructure.
- Traffic Management Center Construction.
- Disruption – Costs of construction disruption (i.e., re-routing of traffic during construction phase of project).

Operation, maintenance, and repair costs occur once the project is operational. These include: labor and materials costs that are expended during the normal operation of the system. In addition to yearly operation costs, life cycle costs occur at irregular intervals throughout the usable life of the project. These include: repaving, worker training, and disposal and salvage costs.

Economic Evaluation

To conduct the economic evaluation, projected AHS costs are compared to projected benefits of AHS. This requires the definition of unit prices for all benefits and costs, including externalities, and the selection of appropriate result metrics which will in the end be used to judge the relative efficiency of alternative projects.

Potential AHS Benefits

The implementation of AHS is expected to generate benefits which can be divided into the following categories:

- Travel time.
- Temporal travel demand shifting.

- Safety.
- Vehicle operating costs.
- Environmental.
- Productivity and economic benefits.

The development of estimates for the above categories is described in detail in the technical discussion of task 4 with the accompanying structure and logic flows and algorithms. Figure 16 summarizes the interrelationships between AHS benefits and costs in the determination of net benefits.

The vast majority of AHS benefits are expected to accrue to road users, however, some of the benefits from AHS will “spillover” to non-users of the system. These benefits are often referred to as positive externalities and are attributable to society as a whole. Environmental benefits, productivity benefits, and economic benefits are three examples. A full discussion of the allocation of benefits amongst AHS users and non-users is provided in the detailed discussion of benefits estimation.

Result Metrics

The result metrics used in the analysis measure the economic worth of the AHS project and allow for the ranking of alternatives. The primary metric used in this analysis is Net Present Value (NPV). Economic Rate of Return (ERR) will also be used as a result metric for the analysis.

- Net Present Value – Measures how people value future benefits and costs in the present. The present day value of benefits minus present day value of costs yields the NPV. An NPV greater than zero means that a project is economically efficient. NPV is also the basis for comparing alternative projects.

- Economic Rate of Return – Represents the discount rate at which the NPV equals zero. This metric compares projects on the basis of a minimum required rate of return. If the project rate of return exceeds the minimum required rate of return, the project qualifies for consideration.

A series of intermediate metrics for costs and benefits and their interrelationships are developed to estimate NPV and ERR. All costs and benefits are estimated in present value terms using standard discounting procedures. The present value of total benefits minus the present value of total costs yields the NPV of AHS and alternatives.

Calculation of Net Benefits from AHS

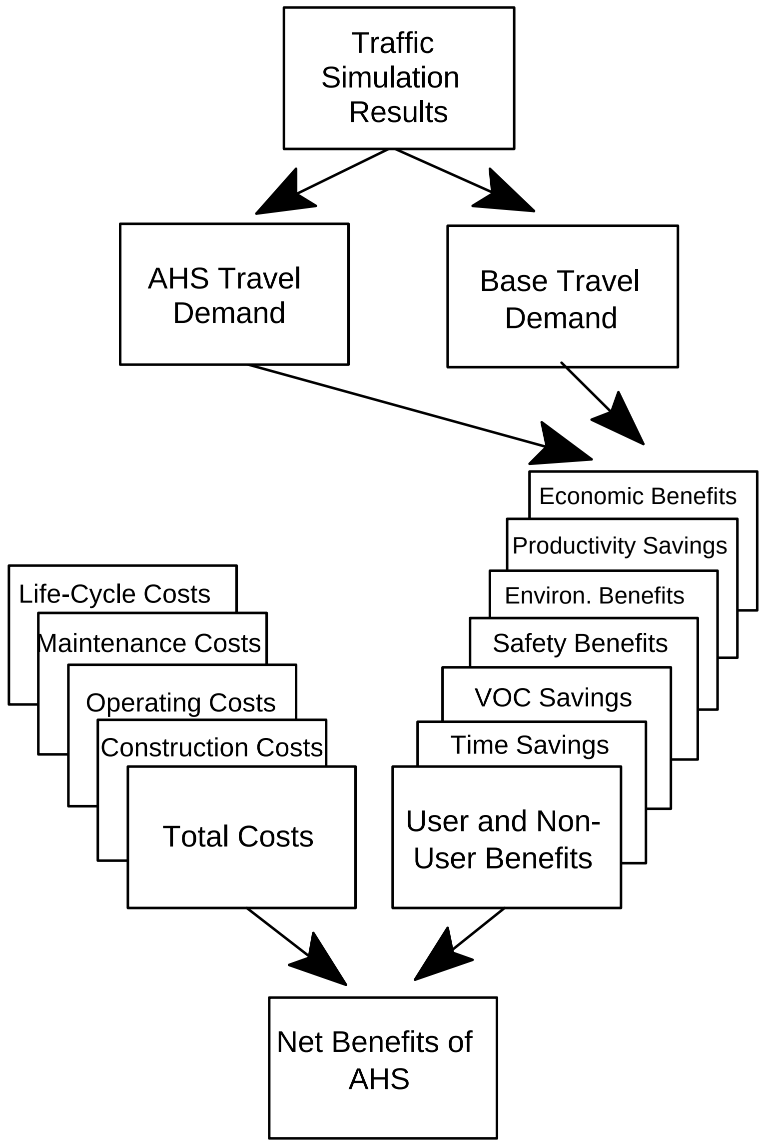

Figure 16. Calculating Net Benefits Of AHS

APPENDIX 2. RISK ANALYSIS APPROACH

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

In the case of AHS, some risks are technical and involve forecasts of the future, while others involve value judgments about the willingness of highway users to accept delays, increased congestion, and certain levels of safety and vehicle functionality. All of the above costs are subject to uncertainty due to technological, traditional, and unforeseen environmental factors. In addition, AHS capital costs will be dependent on the economic “vision of the future,” specifically relating to prevailing labor and capital market conditions.

When evaluating public infrastructure investments that are characterized by high levels of uncertainty traditional forecasts which generate a single “expected outcome” are often of limited usefulness. While these forecasts may provide the single “best guess” they offer no insight into the range of probable outcomes. The problem becomes acute when uncertainty surrounding the underlying assumptions of the forecast is especially high.

A common approach to enrich the perspective of forecasts is sensitivity analysis, whereby key forecast assumptions are varied one at a time in order to assess their relative impact on the outcome. Problems arise because often the variations are arbitrary and there is no accounting for the simultaneous nature of uncertainty that exists in long range forecasts. To correct for these deficiencies, this methodology adopts Hickling’s Risk Analysis Process to add perspective to the analysis. The process allows all inputs to be varied simultaneously, within a probability distribution, and avoids the problems inherent in conventional sensitivity analysis. The result of the risk analysis is both a “best guess” forecast and a quantification of the probability that the forecast will be achieved.

Risk Analysis provides a solution to the problems outlined above. It helps avoid the lack of perspective in the “high” and “low” cases by measuring the probability that an outcome will actually materialize. This is accomplished by attaching ranges (probability distributions) to the forecasts of each input variable. The approach allows all inputs to be varied simultaneously within their distributions, thus avoiding the problems inherent in conventional sensitivity analysis. The approach also recognizes interrelationships between variables and their associated probability distributions.

APPENDIX 3. INFRASTRUCTURE ELECTRONICS COSTS

Infrastructure electronics costs refer to costs for hardware that is installed in the physical infrastructure to communicate with and control AHS equipped vehicles. Two options are considered. First is RSC 1, the infrastructure centered platoon control configuration. This option uses infrastructure intensive technology. Second is RSC 2, the vehicle centered platoon control configuration which uses more vehicle based control. Both systems would derive the same effect, but the Government bears a greater burden of the costs in RSC 1, while the consumer bears more costs under RSC 2.

The following tables show the component costs for infrastructure electronics and communications equipment as estimated by team members most knowledgeable in this area.

Table 8. RSC 1 Infrastructure Electronics Costs

Component	Units/Km	Unit Price	Kilometers	Cost
Road Condition Sensors	0.1563	$31,000	12.8	$62,000
Check-In Controller	0.625	$3,000	12.8	$24,000
Check-Out Controller	0.625		12.8	-
Communications Controller	2.50	$3,000	12.8	$96,000
Traffic Processor	0.125	$4,000	12.8	$6,400
Lateral/Longitudinal Measurement	2.50	$4,000	12.8	$128,000
TOTAL				$316,400

Source: Planning Assumptions of AHS Team Members

Table 9. RSC 2 Infrastructure Electronics Costs

Component	Units/Km	Unit Price	Kilometers	Cost
Road Condition Sensors	0.1563	$31,000	12.8	$62,000
Check-In Controller	0.0	$3,000	12.8	-
Check-Out Controller	0.625		12.8	-
Communications Controller	0.0	$3,000	12.8	-
Traffic Processor	0.125	$6,000	12.8	$9,600
Lateral/Longitudinal Measurement	0.0	$4,000	12.8	-
TOTAL				$71,600

Source: Planning Assumptions of AHS Team Members

APPENDIX 4. RESULTS

This appendix summarizes the results of applying the benefit-cost risk analysis model to the base case and the AHS RSC 1 alternative. Table 10 presents the risk analysis results in terms of the estimated benefit-cost metrics; the net present value, present value of costs and benefits, the benefit cost ratio, and the actual savings metrics at five year intervals.

Table 11 presents all input variables used to estimate the model. This table lists all variables along with any levels of uncertainty attached to them. The 10 percent lower limit is the value that the input has a 90 percent chance of exceeding while the 10 percent upper limit is the value that the input has a 90 percent chance of falling below. This range provides an 80 percent confidence interval for the input variables.

The benefit-cost risk analysis results can also be seen in the graph section. Figure 17 through Figure 51 present in graphic form the results summarized in table 10. The graphs are de-cumulative distribution functions that show the expected values of the results as well as the 80 percent confidence interval for the result variable.

Table 10. Risk Analysis Results

AHS BENEFIT-COST

Results, RSC 1 Name of datafile: sceng1	Mean	Lower 10%	Upper 10%
NET PRESENT VALUE OF PROJECT (MIL. 1994$)	-1.089	-11.354	9.633
PRESENT VALUE OF COSTS (MIL. 1994 $)	42.567	40.674	44.717
PRESENT VALUE OF BENEFITS (MIL. 1994 $)	41.499	31.049	51.807
BENEFIT-COST RATIO	0.973	0.738	1.225
TIME SAVINGS, 2010, 1994 $	0	0	0
TIME SAVINGS, 2014, 1994 $	425127	288426	561338
TIME SAVINGS, 2019, 1994 $	476254	363818	604424
TIME SAVINGS, 2024, 1994 $	509819	382924	641056
TIME SAVINGS, 2029, 1994 $	505827	385267	632950
TIME SAVINGS, 2034, 1994 $	506102	377479	622269
TIME SAVINGS, 2039, 1994 $	497805	365961	635750
SAFETY BENEFITS, 2010, 1994 $	0	0	0
SAFETY BENEFITS, 2014, 1994 $	41915	31072	54841
SAFETY BENEFITS, 2019, 1994 $	84131	57354	120360
SAFETY BENEFITS, 2024, 1994 $	154605	123161	184885
SAFETY BENEFITS, 2029, 1994 $	172639	142055	205567
SAFETY BENEFITS, 2034, 1994 $	188527	149344	228510
SAFETY BENEFITS, 2039, 1994 $	203406	160661	252956
VOC SAVINGS BENEFITS, 2010, 1994 $	0.00	0.00	0.00
VOC SAVINGS BENEFITS, 2014, 1994 $	25389	-17794	71332
VOC SAVINGS BENEFITS, 2019, 1994 $	181426	69342	378855
VOC SAVINGS BENEFITS, 2024, 1994 $	528936	381765	678296
VOC SAVINGS BENEFITS, 2029, 1994 $	650878	493544	814367
VOC SAVINGS BENEFITS, 2034, 1994 $	736508	554981	931792
VOC SAVINGS BENEFITS, 2039, 1994 $	799068	595412	1002829
TEMPORAL SHIFT BENEFITS, 2010, 1994 $	0	0	0
TEMPORAL SHIFT BENEFITS, 2014, 1994 $	17921	-706489	769241
TEMPORAL SHIFT BENEFITS, 2019, 1994 $	2106120	729085	3573002
TEMPORAL SHIFT BENEFITS, 2024, 1994 $	4039738	2446893	5515705
TEMPORAL SHIFT BENEFITS, 2029, 1994 $	4623910	3496692	5791407
TEMPORAL SHIFT BENEFITS, 2034, 1994 $	4670222	3550441	5786497
TEMPORAL SHIFT BENEFITS, 2039, 1994 $	4671274	3541007	5798666
AHS SHARE OF VEH. IN REG. FLEET, 2010, %	8.0	6.7	9.2
AHS SHARE OF VEH. IN REG. FLEET, 2014, %	17.2	14.4	19.7
AHS SHARE OF VEH. IN REG. FLEET, 2019, %	27.6	23.1	31.5
AHS SHARE OF VEH. IN REG. FLEET, 2024, %	38.4	32.1	43.8
AHS SHARE OF VEH. IN REG. FLEET, 2029, %	49.1	41.0	56.0
AHS SHARE OF VEH. IN REG. FLEET, 2034, %	58.3	48.8	66.5
AHS SHARE OF VEH. IN REG. FLEET, 2039, %	65.6	54.9	74.9

Table 11. Risk Analysis Inputs

AHS BENEFIT-COST

Inputs,
RSC 1

Year	Var Name	Description	Median	Lower 10%	Upper 10%
====	========	===================================	=======	========	========
	VFLAG	VARIABLE FLAG	5.00	0.00	0.00
	BFLT	BASE YEAR NATIONAL PAX CAR FLEET	144.22	0.00	0.00
	FLTR	PAX CAR FLEET GROWTH RATE	0.50	0.40	0.70
	VRTR	VEHICLE RETIREMENT RATE	10.00	8.00	11.00
	NTP1	1ST AHS NATIONAL SALES PEN. TARGET	3.00	0.00	0.00
	NTP2	2ND AHS NATIONAL SALES PEN. TARGET	14.00	12.00	16.00
	RTP1	1ST AHS REGIONAL SALES PEN. TARGET	30.00	0.00	0.00
	RTP2	2ND AHS REGIONAL SALES PEN. TARGET	40.00	0.00	0.00
	YRP1	YEAR IN WHICH AHS TARGET ACHIEVED	2013.00	0.00	0.00
	YRP2	YEAR IN WHICH AHS TARGET ACHIEVED	2017.00	0.00	0.00
	CAPN	NATIONAL AHS PENETRATION CAP	0.80	0.00	0.00
	CAPR	REGIONAL AHS PENETRATION CAP	0.80	0.00	0.00
	ELASP	ELASTICITY OF REGIONAL SALES WRT COST	0.00	0.00	0.00
	ELASD	ELASTICITY OF REG SALES WRT DEPLOYMENT	0.00	0.00	0.00
	CLC	CONVENTIONAL LANE CAPACITY (VPHPL)	2000.00	0.00	0.00
	ALC	AHS LANE CAPACITY (VPHPL)	4000.00	0.00	0.00
	LENF	LENGTH OF FACILITY (KM)	12.20	0.00	0.00
	PHTHL	PEAK HOUR AHS OPERATING THRESHOLD	14.00	0.00	0.00
	PMTHL	PEAK MARGIN AHS OPERATING THRESHOLD	31.00	0.00	0.00
	DRATE	DISCOUNT RATE	5.00	0.00	0.00
	VTIME	VALUE OF TIME, $/HR	12.50	10.00	15.00
	PVMTHS	VALUE OF TEMPORAL SHIFT, $/KMT-HR	0.25	0.20	0.30
	LENGTH	LENGTH OF FACILITY	12.17	0.00	0.00
	VLIFE	COST OF A STATISTICAL LIFE, MIL. 1994 $	2.50	2.00	3.00
	VPDO	COST OF PDO ACCIDENT, 1994 $	500.00	400.00	600.00
	VINJ	COST OF INJURY, 1994 $	50000.00	45000.00	55000.00
	PFUEL	PRICE OF FUEL, ($/L) 1994 $	0.45	0.40	0.50
	POIL	PRICE OF OIL, ($/L) 1994 $	0.55	0.50	0.60
	PTIRE	TIRE PRICE, ($/UNIT) 1994 $	50.00	0.00	0.00
	PMAR	PRICE OF MAINTENANCE & REPAIR	67.00	0.00	0.00
	PDEPR	DEPRECIABLE AMOUNT OF VEHICLE	1000.00	0.00	0.00
	AVGOCCB	AVERAGE OCCUPANCY IN BASE CASE	1.40	0.00	0.00
	AVGOCCA	AVERAGE OCCUPANCY IN ALT. CASE	1.40	0.00	0.00
	AVGSHFT	AVERAGE TEMPORAL SHIFT, HR	1.50	0.00	0.00
	ACCPCT	% ACCIDENT INCIDENCE REDUCTION W/AHS	95.00	0.00	0.00
	VOCPCT	% REDUCTION OF VOC W/AHS	20.00	0.00	0.00
2007	AHSRR	AHS VEHICLE RETIREMENT RATE	0.00	0.00	0.00
2008			1.00	0.00	0.00
2009			2.00	0.00	0.00

2010			3.00	0.00	0.00
2011			4.00	0.00	0.00
2012			5.00	0.00	0.00
2013			6.00	0.00	0.00
2014			7.00	0.00	0.00
2015			8.00	0.00	0.00
2016			9.00	0.00	0.00
2017			10.00	0.00	0.00
2018			10.00	0.00	0.00
2019			10.00	0.00	0.00
2020			10.00	0.00	0.00
2021			10.00	0.00	0.00
2022			10.00	0.00	0.00
2023			10.00	0.00	0.00
2024			10.00	0.00	0.00
2025			10.00	0.00	0.00
2026			10.00	0.00	0.00
2027			10.00	0.00	0.00
2028			10.00	0.00	0.00
2029			10.00	0.00	0.00
2030			10.00	0.00	0.00
2031			10.00	0.00	0.00
2032			10.00	0.00	0.00
2033			10.00	0.00	0.00
2034			10.00	0.00	0.00
2035			10.00	0.00	0.00
2036			10.00	0.00	0.00
2037			10.00	0.00	0.00
2038			10.00	0.00	0.00
2039			10	0	0
2007	AHSIC	AHS INCREMENTAL VEHICLE COST, BASE	1950	0	0
2008			1852.5	0	0
2009			1759.88	0	0
2010			1671.88	0	0
2011			1588.29	0	0
2012			1508.87	0	0
2013			1433.43	0	0
2014			1361.76	0	0
2015			1293.67	0	0
2016			1228.99	0	0
2017			1167.54	0	0
2018			1109.16	0	0
2019			1053.7	0	0
2020			1001.02	0	0
2021			950.97	0	0
2022			903.42	0	0
2023			858.25	0	0
2024			815.33	0	0
2025			774.57	0	0
2026			735.84	0	0

2027			699.05	0	0
2028			664.1	0	0
2029			630.89	0	0
2030			599.35	0	0
2031			569.38	0	0
2032			540.91	0	0
2033			513.86	0	0
2034			488.17	0	0
2035			463.76	0	0
2036			440.57	0	0
2037			418.55	0	0
2038			397.62	0	0
2039			377.74	0	0
2007	AHSICD	$ DEVIATION FROM VEHICLE COST, BASE	390	0	0
2008			370.5	0	0
2009			351.98	0	0
2010			334.38	0	0
2011			317.66	0	0
2012			301.77	0	0
2013			286.69	0	0
2014			272.35	0	0
2015			258.73	0	0
2016			245.8	0	0
2017			233.51	0	0
2018			221.83	0	0
2019			210.74	0	0
2020			200.2	0	0
2021			190.19	0	0
2022			180.68	0	0
2023			171.65	0	0
2024			163.07	0	0
2025			154.91	0	0
2026			147.17	0	0
2027			139.81	0	0
2028			132.82	0	0
2029			126.18	0	0
2030			119.87	0	0
2031			113.88	0	0
2032			108.18	0	0
2033			102.77	0	0
2034			97.63	0	0
2035			92.75	0	0
2036			88.11	0	0
2037			83.7	0	0
2038			79.52	0	0
2039			75.54	0	0
2007	AHSDEI	AHS DEPLOYMENT INDEX	100	0	0
2008			100	0	0
2009			100	0	0
2010			100	0	0

2011			100	0	0
2012			100	0	0
2013			100	0	0
2014			100	0	0
2015			100	0	0
2016			100	0	0
2017			100	0	0
2018			100	0	0
2019			100	0	0
2020			100	0	0
2021			100	0	0
2022			100	0	0
2023			100	0	0
2024			100	0	0
2025			100	0	0
2026			100	0	0
2027			100	0	0
2028			100	0	0
2029			100	0	0
2030			100	0	0
2031			100	0	0
2032			100	0	0
2033			100	0	0
2034			100	0	0
2035			100	0	0
2036			100	0	0
2037			100	0	0
2038			100	0	0
2039			100	0	0
2007	MAXA	PERCENT OF AHS FLEET TRAVELING IN PKHR	0	0	0
2008			0	0	0
2009			0	0	0
2010			0.7	0.6	0.8
2011			0.7	0.6	0.8
2012			0.7	0.6	0.8
2013			0.7	0.6	0.8
2014			0.7	0.6	0.8
2015			0.7	0.6	0.8
2016			0.7	0.6	0.8
2017			0.7	0.6	0.8
2018			0.7	0.6	0.8
2019			0.7	0.6	0.8
2020			0.7	0.6	0.8
2021			0.7	0.6	0.8
2022			0.7	0.6	0.8
2023			0.7	0.6	0.8
2024			0.7	0.6	0.8
2025			0.7	0.6	0.8
2026			0.7	0.6	0.8
2027			0.7	0.6	0.8

2028			0.7	0.6	0.8
2029			0.7	0.6	0.8
2030			0.7	0.6	0.8
2031			0.7	0.6	0.8
2032			0.7	0.6	0.8
2033			0.7	0.6	0.8
2034			0.7	0.6	0.8
2035			0.7	0.6	0.8
2036			0.7	0.6	0.8
2037			0.7	0.6	0.8
2038			0.7	0.6	0.8
2039			0.7	0.6	0.8
2007	RPPHB	% PEAK HOUR VMT IN PEAK HOUR BASE	0	0	0
2008			0	0	0
2009			0	0	0
2010			50	47	52
2011			50	47	52
2012			50	47	52
2013			50	47	52
2014			50	47	52
2015			50	47	52
2016			50	47	52
2017			50	47	52
2018			50	47	52
2019			50	47	52
2020			50	47	52
2021			50	47	52
2022			50	47	52
2023			50	47	52
2024			50	47	52
2025			50	47	52
2026			50	47	52
2027			50	47	52
2028			50	47	52
2029			50	47	52
2030			50	47	52
2031			50	47	52
2032			50	47	52
2033			50	47	52
2034			50	47	52
2035			50	47	52
2036			50	47	52
2037			50	47	52
2038			50	47	52
2039			50	47	52
2007	VCPHB	VEHICLE/CAPACITY RATIO IN PEAK HOUR, BASE	0	0	0
2008			0	0	0
2009			0	0	0
2010			0.9	0.87	0.92
2011			0.9	0.87	0.92

2012			0.9	0.87	0.92
2013			0.9	0.87	0.92
2014			0.9	0.87	0.92
2015			0.9	0.87	0.92
2016			0.9	0.87	0.92
2017			0.9	0.87	0.92
2018			0.9	0.87	0.92
2019			0.9	0.87	0.92
2020			0.9	0.87	0.92
2021			0.9	0.87	0.92
2022			0.9	0.87	0.92
2023			0.9	0.87	0.92
2024			0.9	0.87	0.92
2025			0.9	0.87	0.92
2026			0.9	0.87	0.92
2027			0.9	0.87	0.92
2028			0.9	0.87	0.92
2029			0.9	0.87	0.92
2030			0.9	0.87	0.92
2031			0.9	0.87	0.92
2032			0.9	0.87	0.92
2033			0.9	0.87	0.92
2034			0.9	0.87	0.92
2035			0.9	0.87	0.92
2036			0.9	0.87	0.92
2037			0.9	0.87	0.92
2038			0.9	0.87	0.92
2039			0.9	0.87	0.92
2007	LENP	LENGTH OF PEAK PERIOD (HRS)	0	0	0
2008			0	0	0
2009			0	0	0
2010			4	0	0
2011			4.04	0	0
2012			4.08	0	0
2013			4.12	0	0
2014			4.16	0	0
2015			4.2	0	0
2016			4.25	0	0
2017			4.29	0	0
2018			4.33	0	0
2019			4.38	0	0
2020			4.42	0	0
2021			4.46	0	0
2022			4.51	0	0
2023			4.55	0	0
2024			4.6	0	0
2025			4.64	0	0
2026			4.69	0	0
2027			4.74	0	0
2028			4.79	0	0

2029			4.83	0	0
2030			4.88	0	0
2031			4.93	0	0
2032			4.98	0	0
2033			5.03	0	0
2034			5.08	0	0
2035			5.13	0	0
2036			5.18	0	0
2037			5.23	0	0
2038			5.29	0	0
2039			5.34	0	0
2007	CONST	CONSTRUCTION COST OF PROJECT	0	0	0
2008			15	14	17
2009			15	14	17
2010			0	0	0
2011			0	0	0
2012			0	0	0
2013			0	0	0
2014			0	0	0
2015			0	0	0
2016			0	0	0
2017			0	0	0
2018			0	0	0
2019			0	0	0
2020			0	0	0
2021			0	0	0
2022			0	0	0
2023			0	0	0
2024			0	0	0
2025			0	0	0
2026			0	0	0
2027			0	0	0
2028			0	0	0
2029			0	0	0
2030			0	0	0
2031			0	0	0
2032			0	0	0
2033			0	0	0
2034			0	0	0
2035			0	0	0
2036			0	0	0
2037			0	0	0
2038			0	0	0
2039			0	0	0
2007	ROWCOST	RIGHT OF WAY COST OF PROJECT	0	0	0
2008			0	0	0
2009			0	0	0
2010			0	0	0
2011			0	0	0
2012			0	0	0

2013			0	0	0
2014			0	0	0
2015			0	0	0
2016			0	0	0
2017			0	0	0
2018			0	0	0
2019			0	0	0
2020			0	0	0
2021			0	0	0
2022			0	0	0
2023			0	0	0
2024			0	0	0
2025			0	0	0
2026			0	0	0
2027			0	0	0
2028			0	0	0
2029			0	0	0
2030			0	0	0
2031			0	0	0
2032			0	0	0
2033			0	0	0
2034			0	0	0
2035			0	0	0
2036			0	0	0
2037			0	0	0
2038			0	0	0
2039			0	0	0
2007	MAINT	MAINTENANCE COST OF PROJECT	0	0	0
2008			0	0	0
2009			0	0	0
2010			1	0	0
2011			1	0	0
2012			1	0	0
2013			1.085	0	0
2014			1	0	0
2015			1	0	0
2016			1	0	0
2017			1	0	0
2018			1	0	0
2019			1.085	0	0
2020			1	0	0
2021			1	0	0
2022			1	0	0
2023			1	0	0
2024			1	0	0
2025			1	0	0
2026			1	0	0
2027			1	0	0
2028			1	0	0
2029			2.75	0	0

2030			1.665	0	0
2031			1.665	0	0
2032			1.665	0	0
2033			1.665	0	0
2034			1.665	0	0
2035			1.665	0	0
2036			1.665	0	0
2037			1.665	0	0
2038			1.665	0	0
2039			1.665	0	0
2007	LIFECYC	LIFE-CYCLE COSTS OF PROJECT	0	0	0
2008			0	0	0
2009			0	0	0
2010			0	0	0
2011			0	0	0
2012			0	0	0
2013			0	0	0
2014			0	0	0
2015			0	0	0
2016			0	0	0
2017			0	0	0
2018			0	0	0
2019			0	0	0
2020			0	0	0
2021			0	0	0
2022			0	0	0
2023			0	0	0
2024			0	0	0
2025			0	0	0
2026			0	0	0
2027			0	0	0
2028			0	0	0
2029			0	0	0
2030			0	0	0
2031			0	0	0
2032			0	0	0
2033			0	0	0
2034			0	0	0
2035			0	0	0
2036			0	0	0
2037			0	0	0
2038			0	0	0
2039			0	0	0

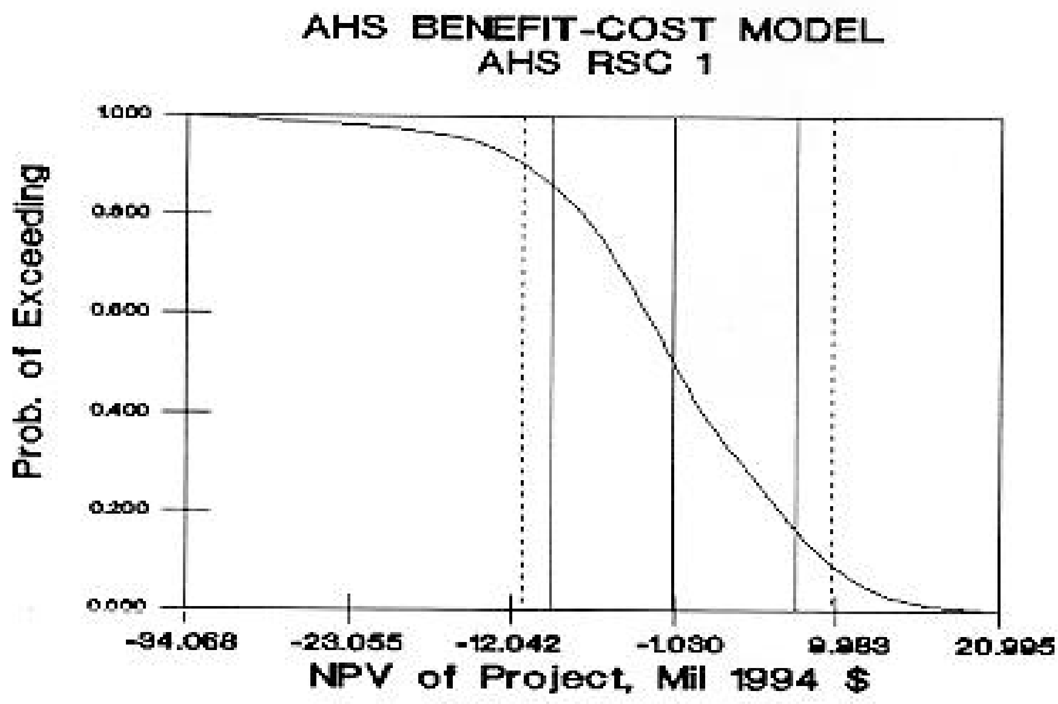

Figure 17. Distribution Function Of Project Net Present Value

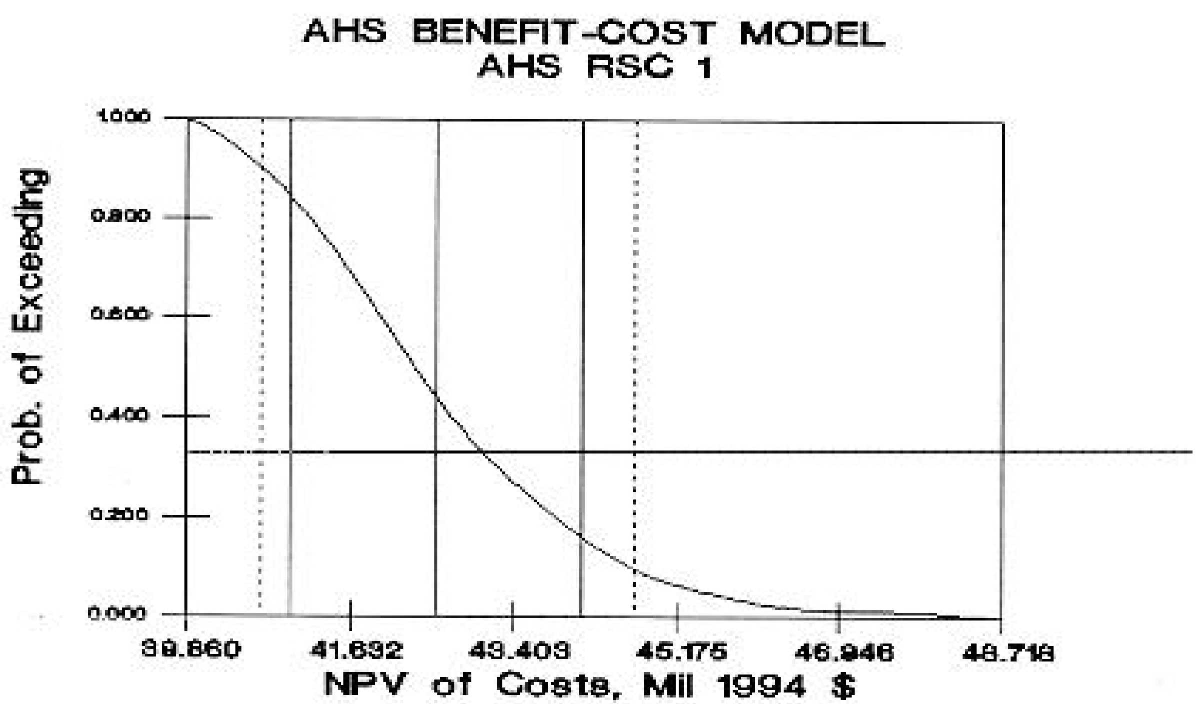

Figure 18. Distribution Function Of Cost Net Present Value

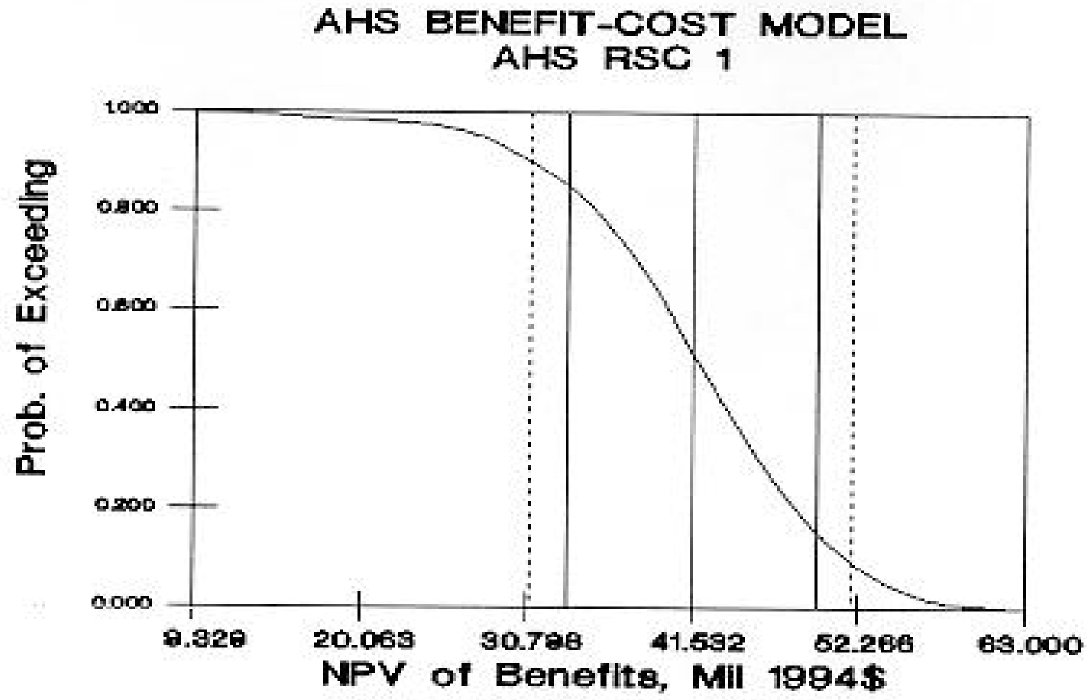

Figure 19. Distribution Function Of Benefits Net Present Value

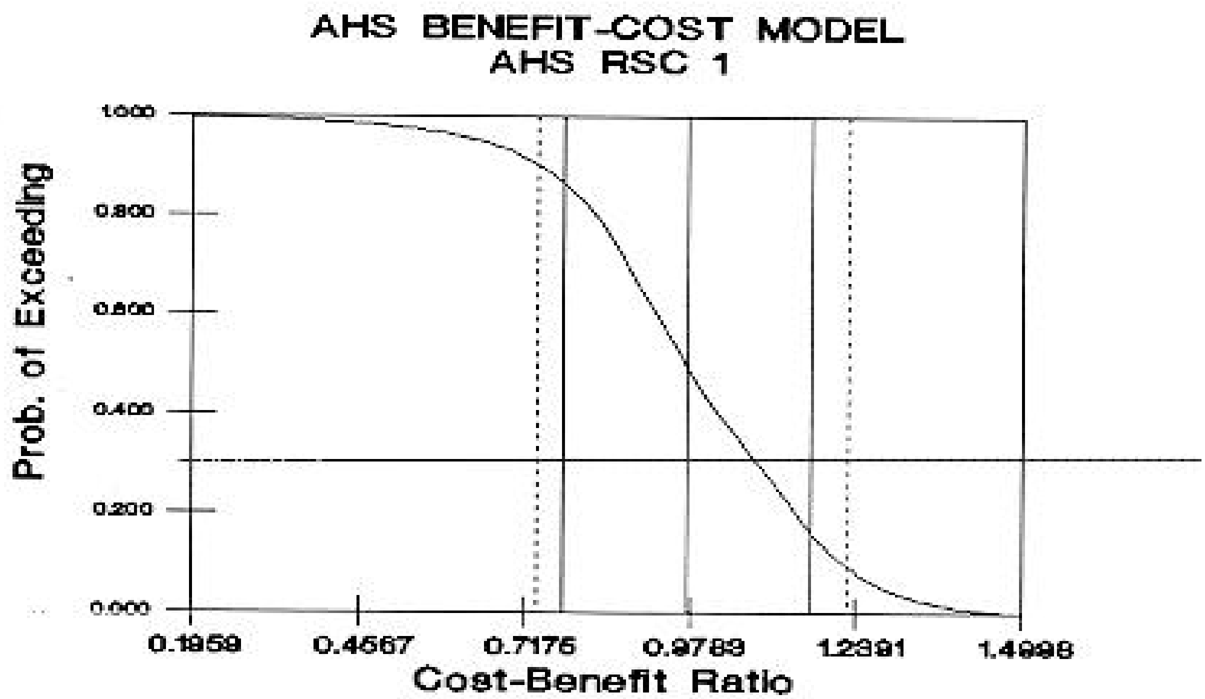

Figure 20. Distribution Function Of Cost-Benefit Ratio

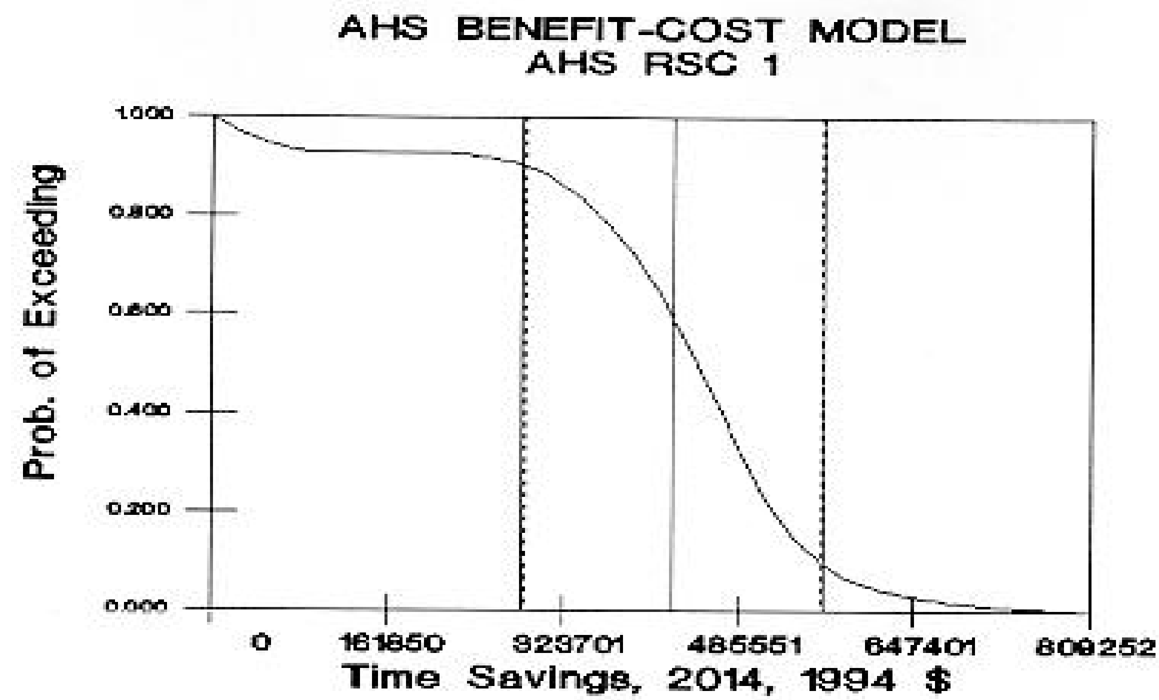

Figure 21. Distribution Function Of Year 2014 Time Savings

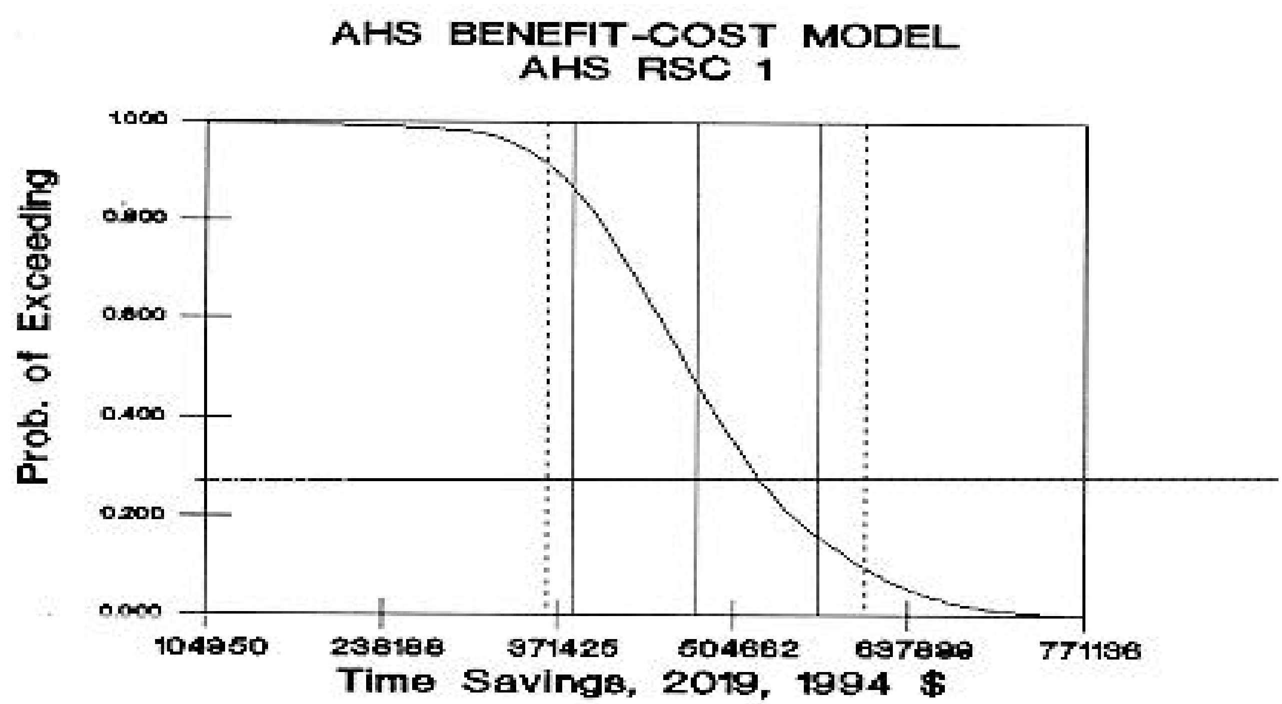

Figure 22. Distribution Function Of Year 2019 Time Savings

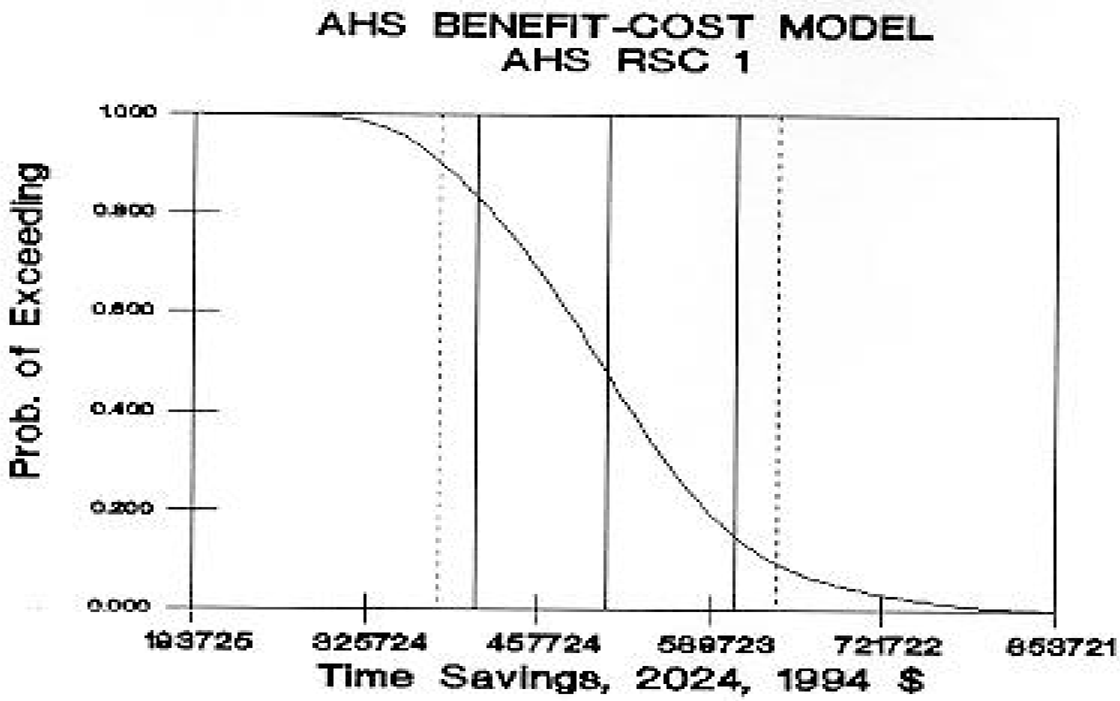

Figure 23. Distribution Function Of Year 2024 Time Savings

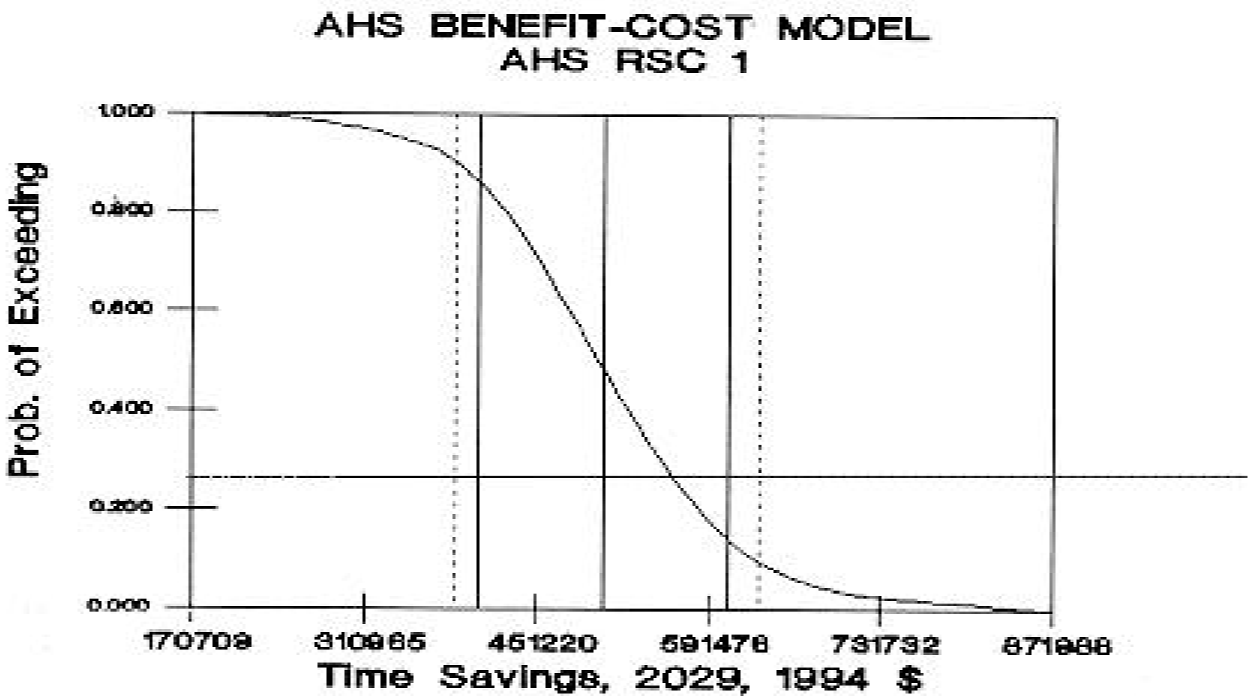

Figure 24. Distribution Function Of Year 2029 Time Savings

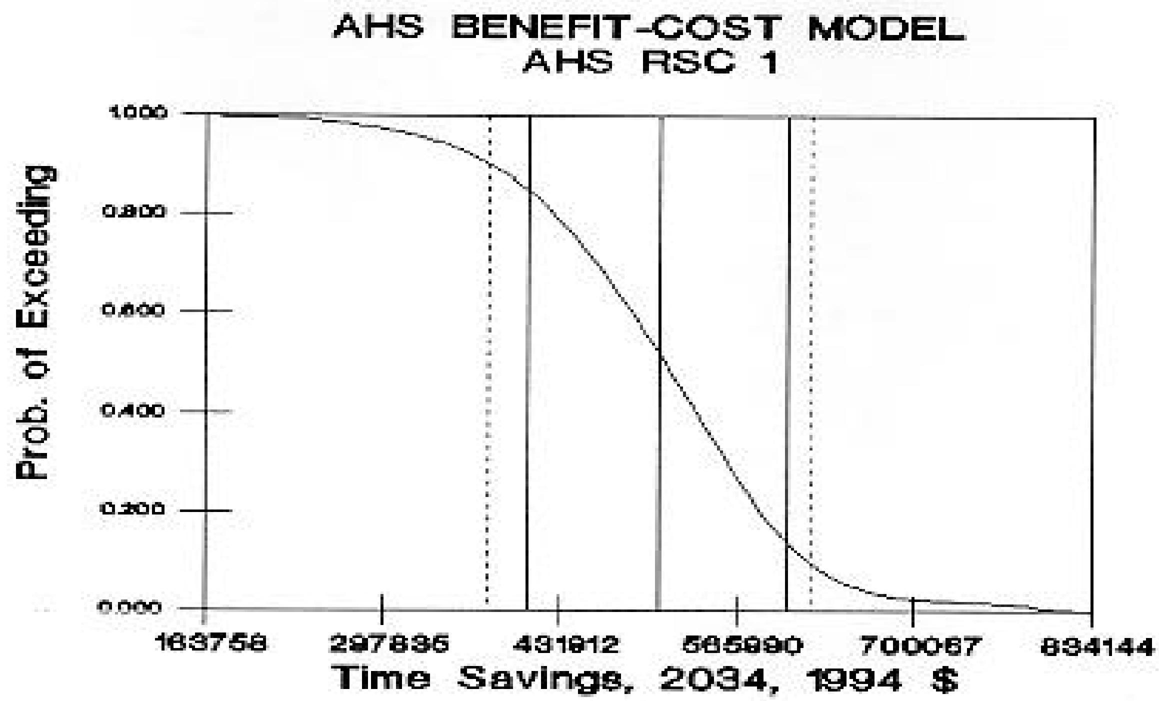

Figure 25. Distribution Function Of Year 2034 Time Savings

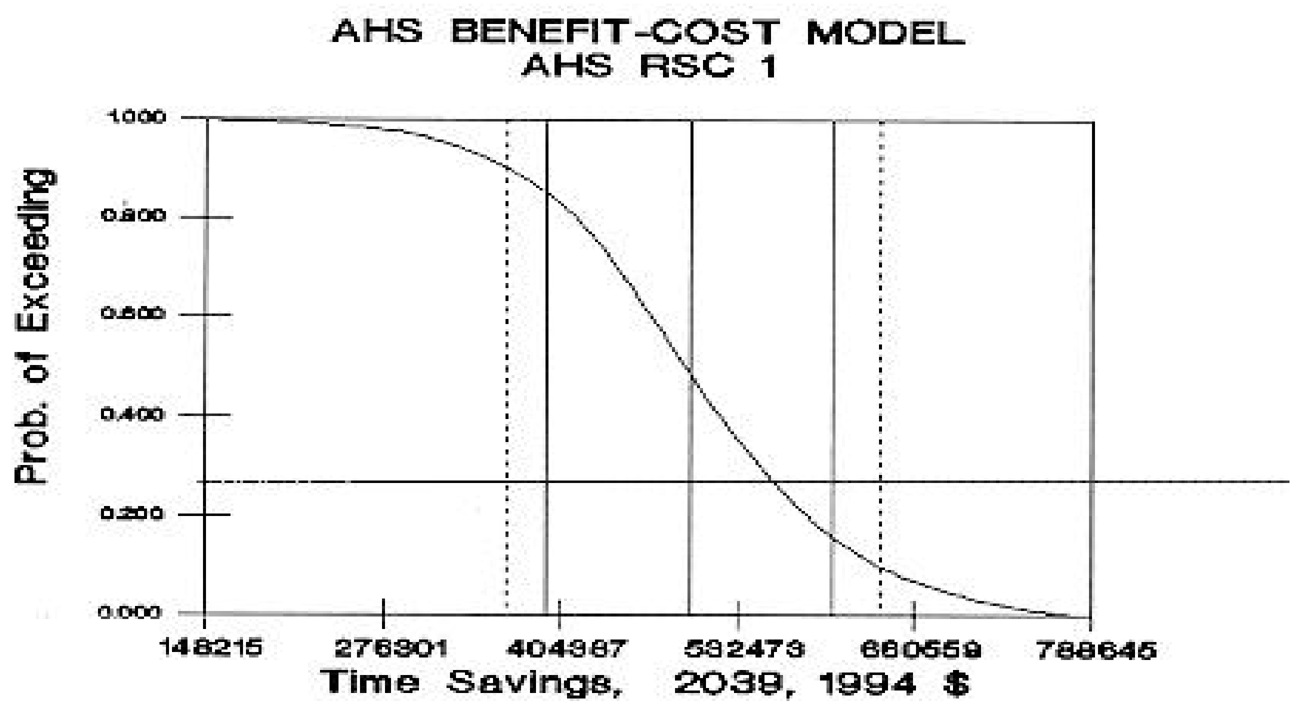

Figure 26. Distribution Function Of Year 2039 Time Savings

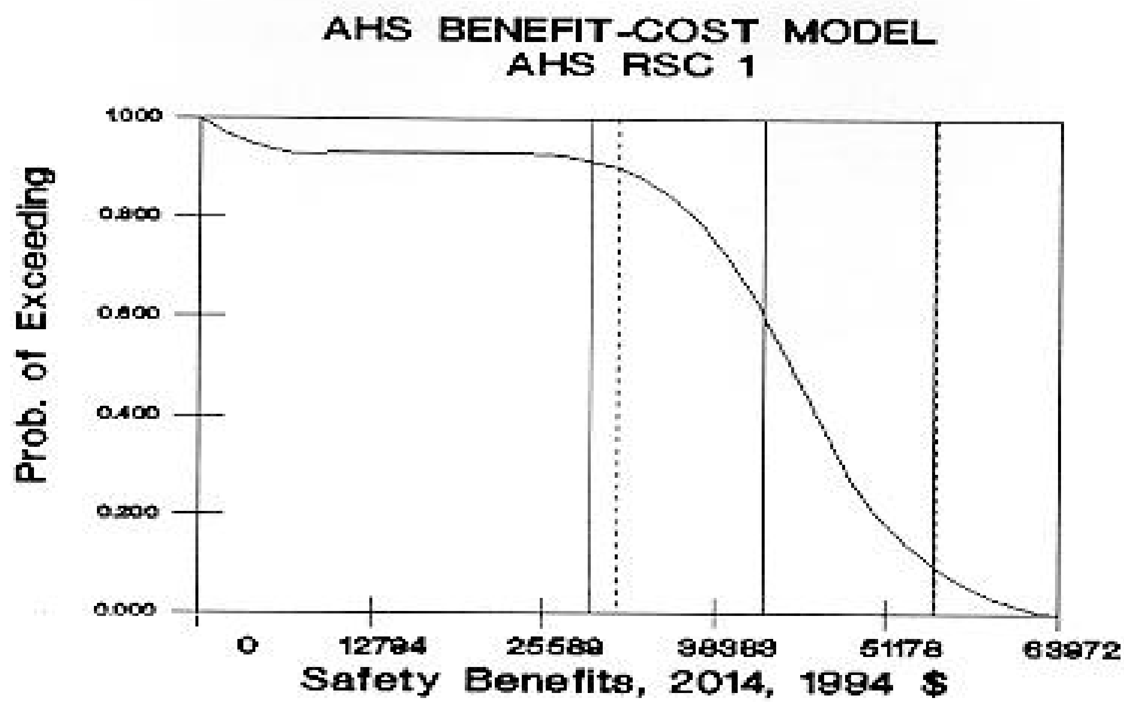

Figure 27. Distribution Function Of Year 2014 Safety Benefits

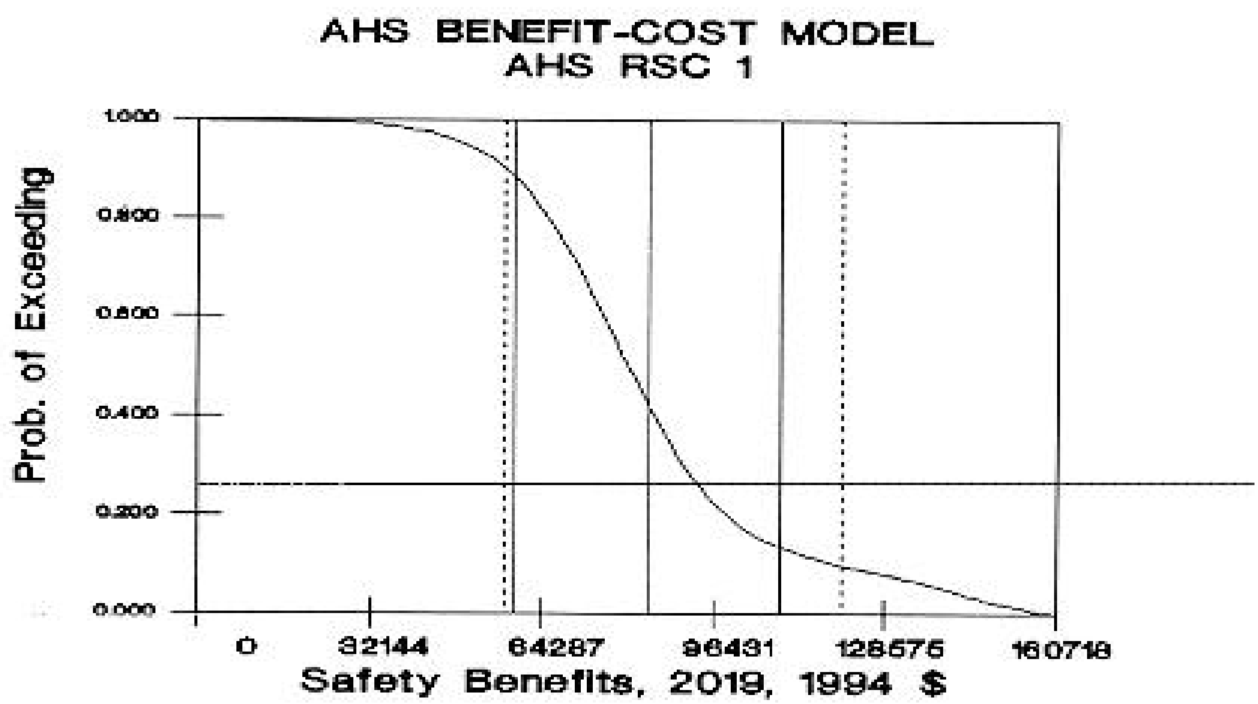

Figure 28. Distribution Function Of Year 2019 Safety Benefits

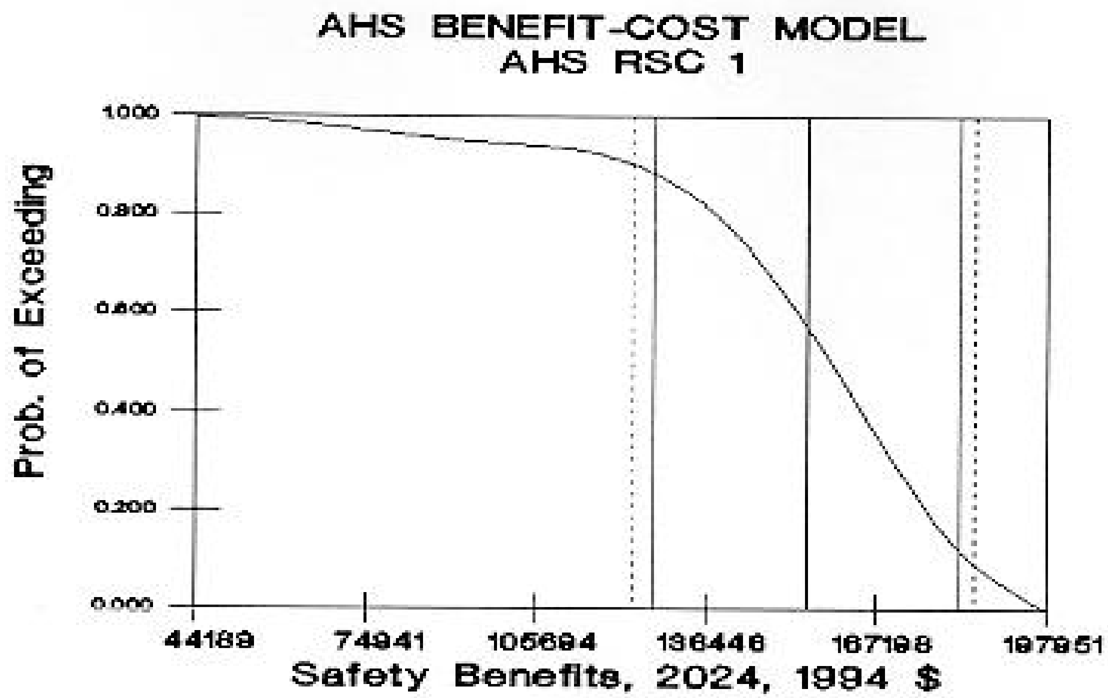

Figure 29. Distribution Function Of Year 2024 Safety Benefits

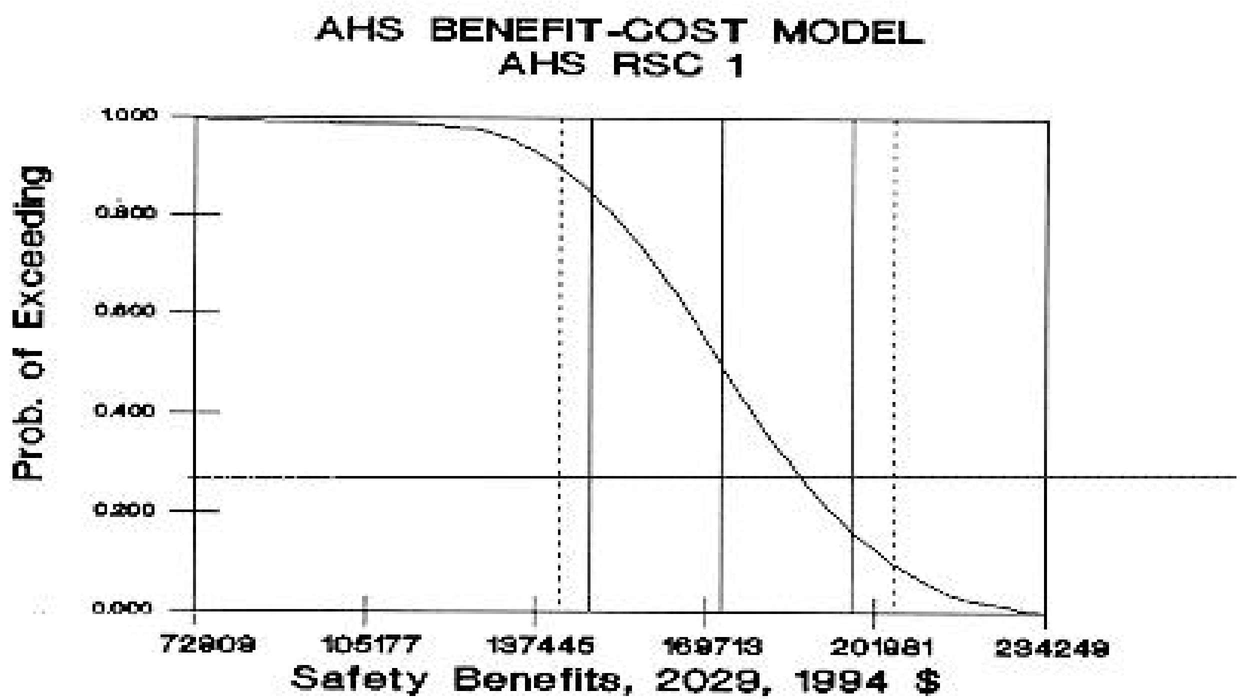

Figure 30. Distribution Function Of Year 2029 Safety Benefits

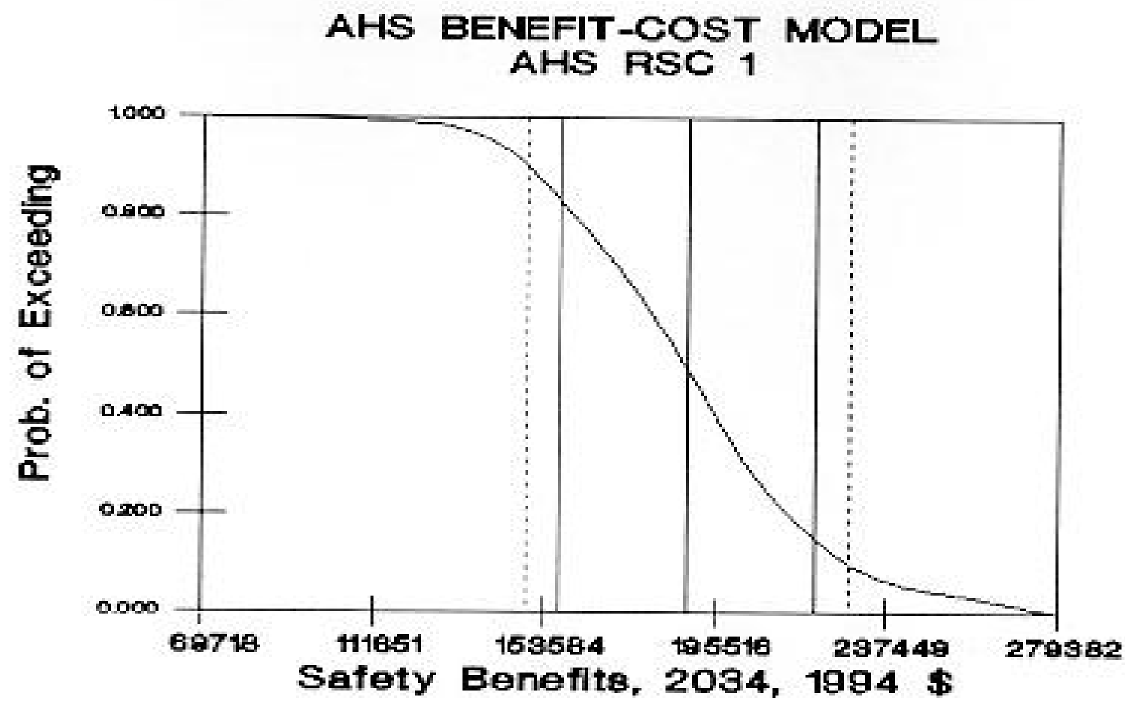

Figure 31. Distribution Function Of Year 2034 Safety Benefits

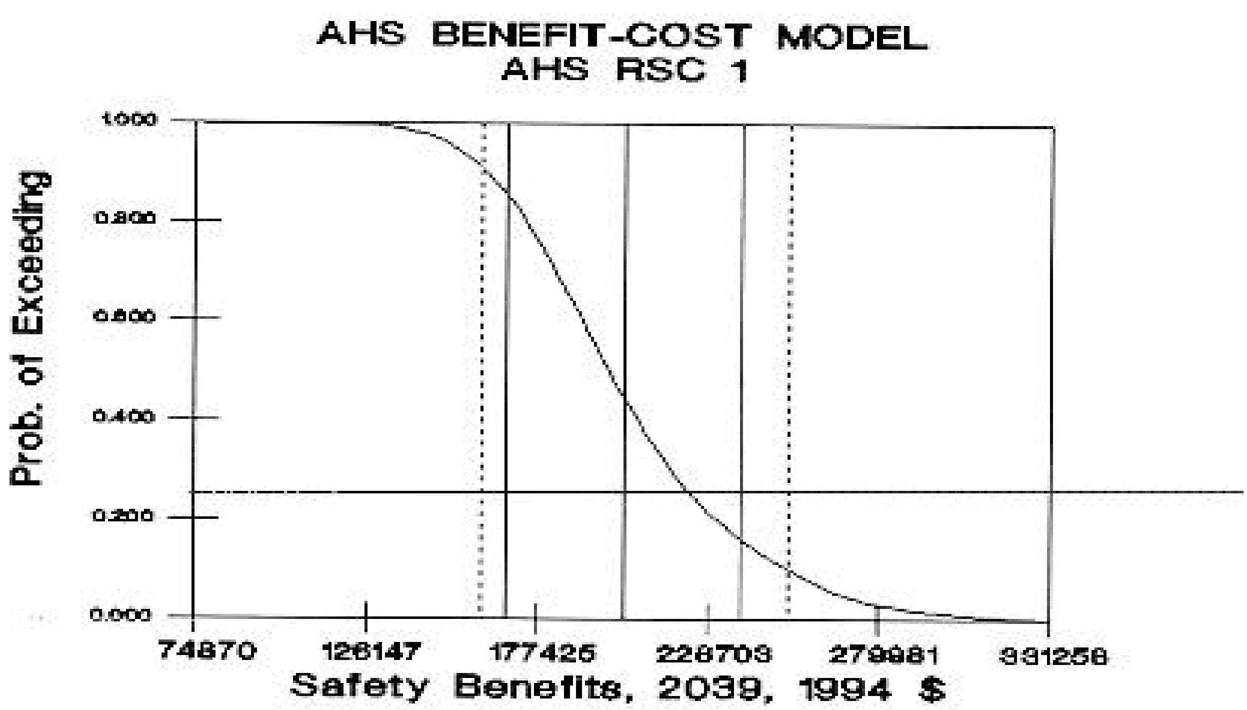

Figure 32. Distribution Function Of Year 2039 Safety Benefits

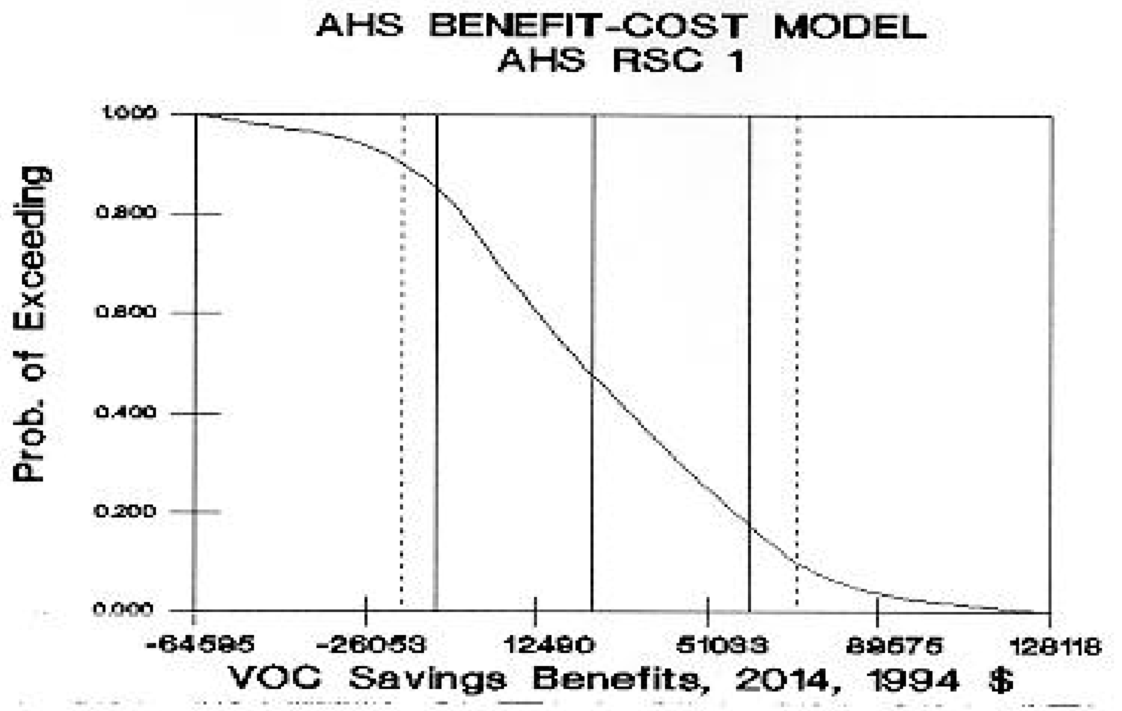

Figure 33. Distribution Function Of Year 2014 VOC Savings

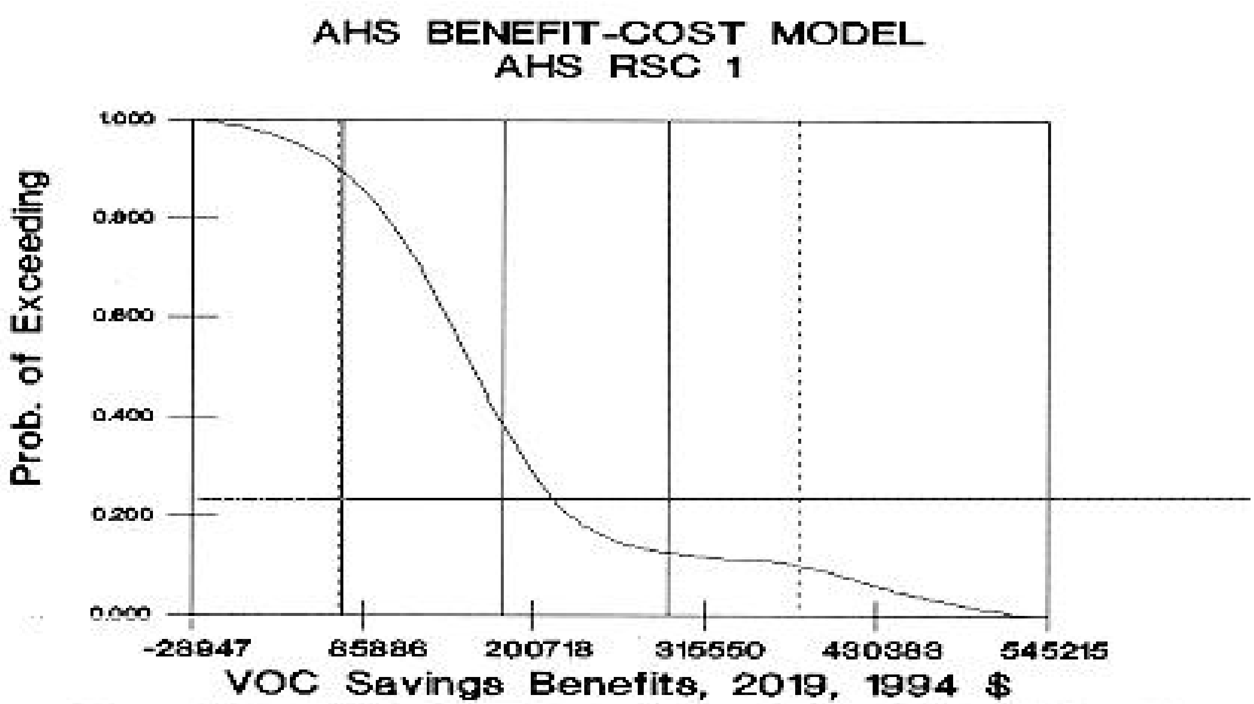

Figure 34. Distribution Function Of Year 2019 VOC Savings

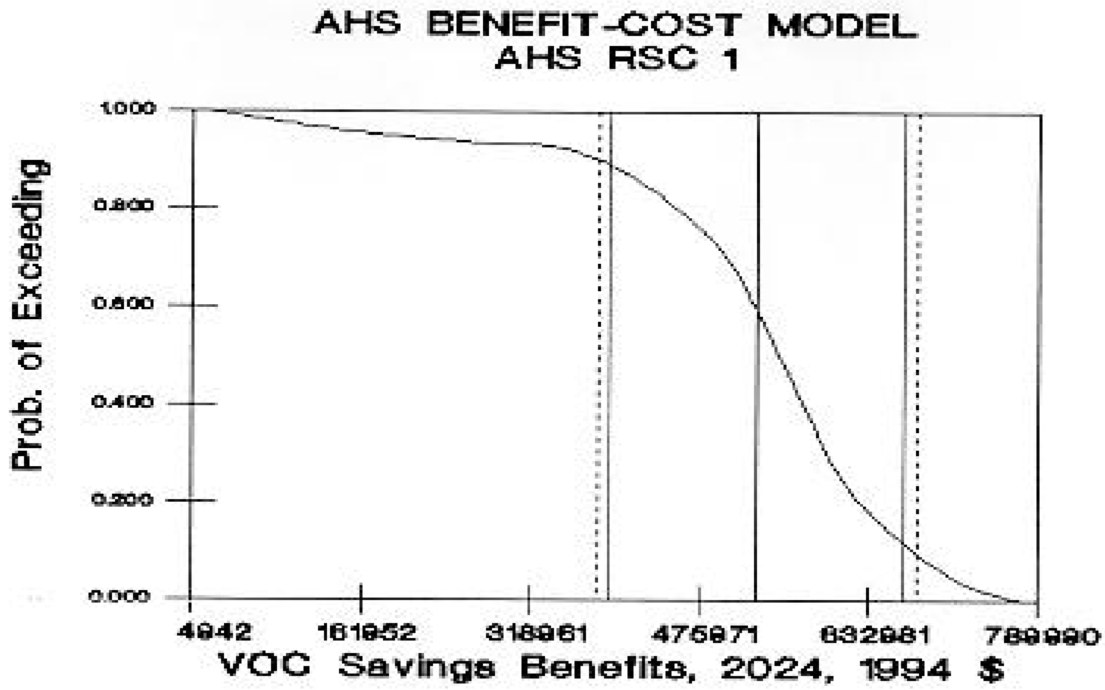

Figure 35. Distribution Function Of Year 2024 VOC Savings

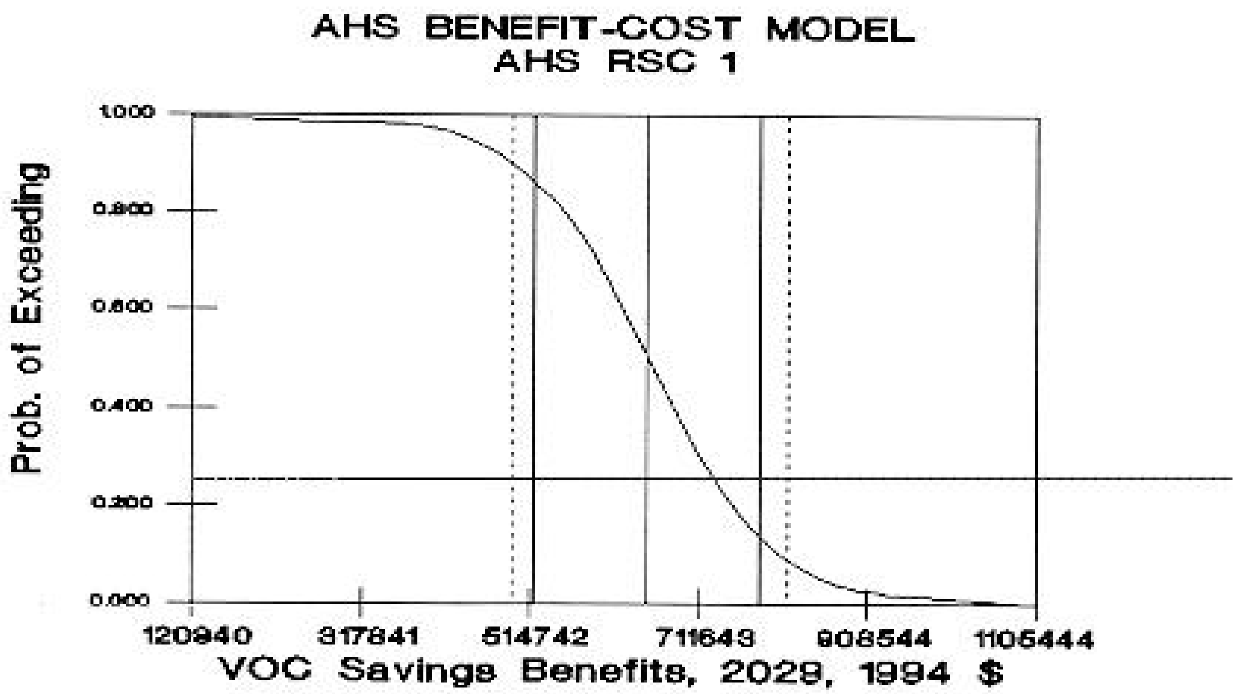

Figure 36. Distribution Function Of Year 2029 VOC Savings

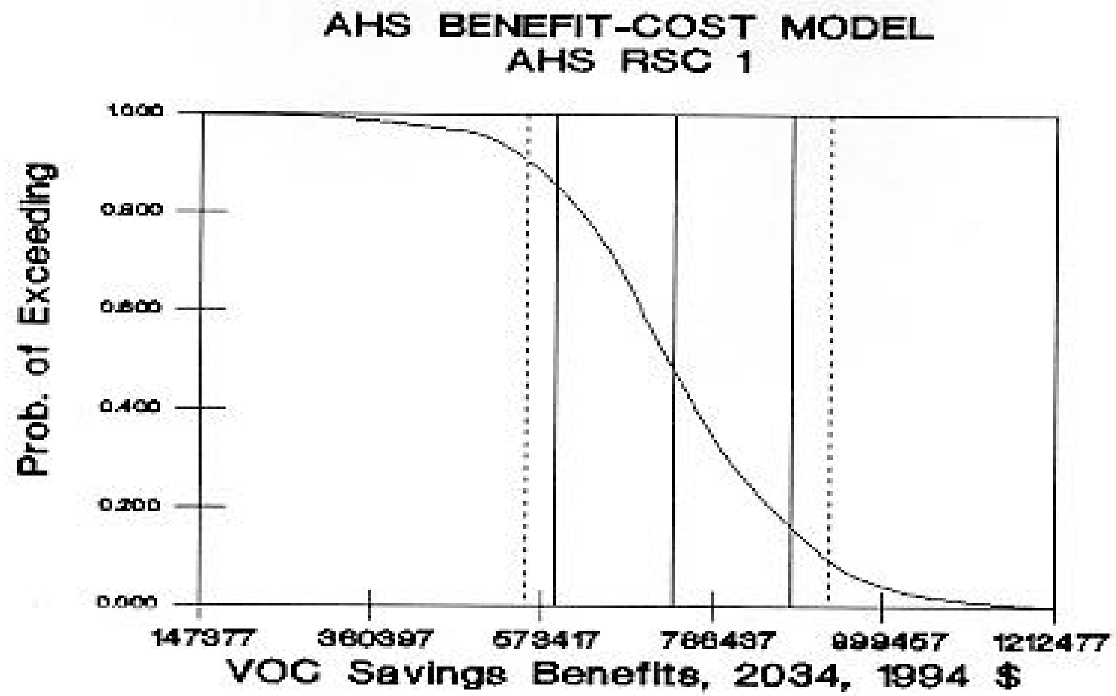

Figure 37. Distribution Function Of Year 2034 VOC Savings

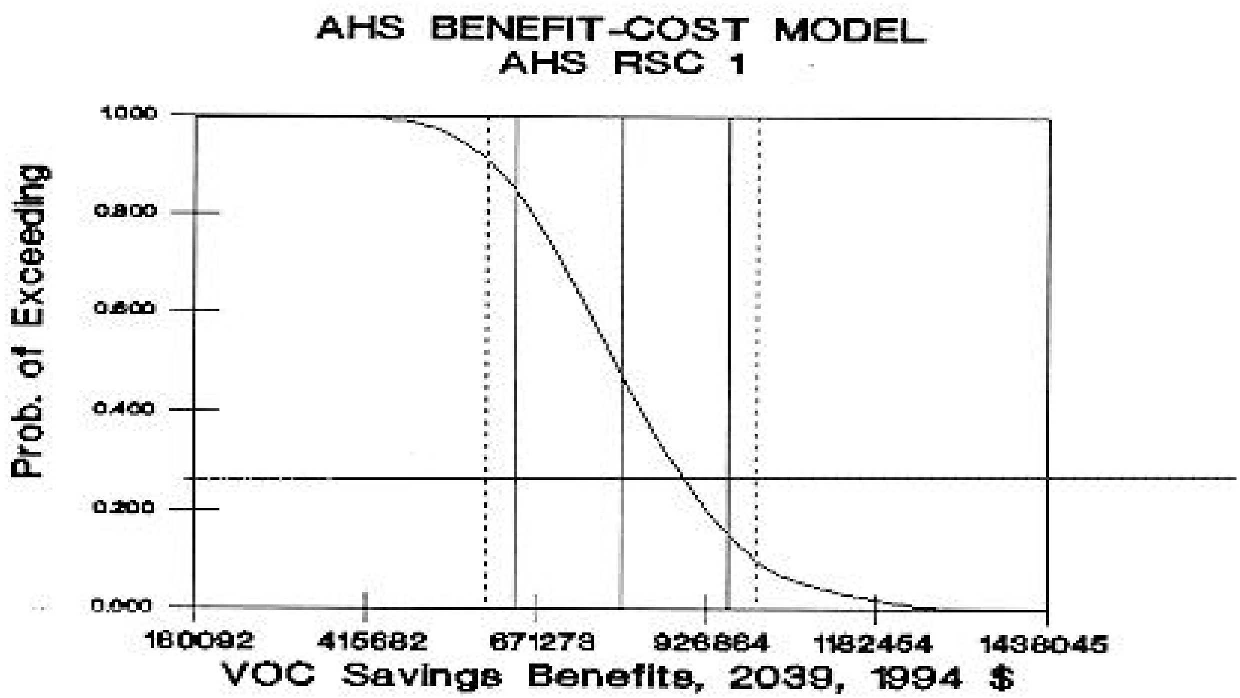

Figure 38. Distribution Function Of Year 2039 VOC Savings

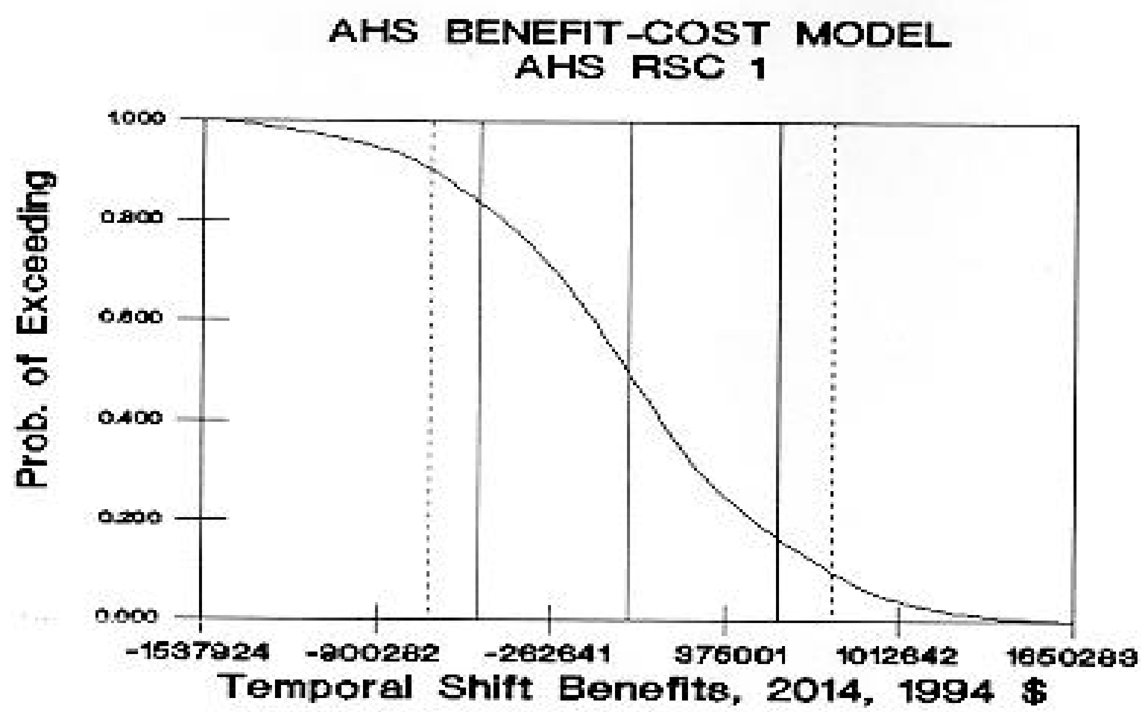

Figure 39. Distribution Function Of Year 2014 Temporal Shift Benefits

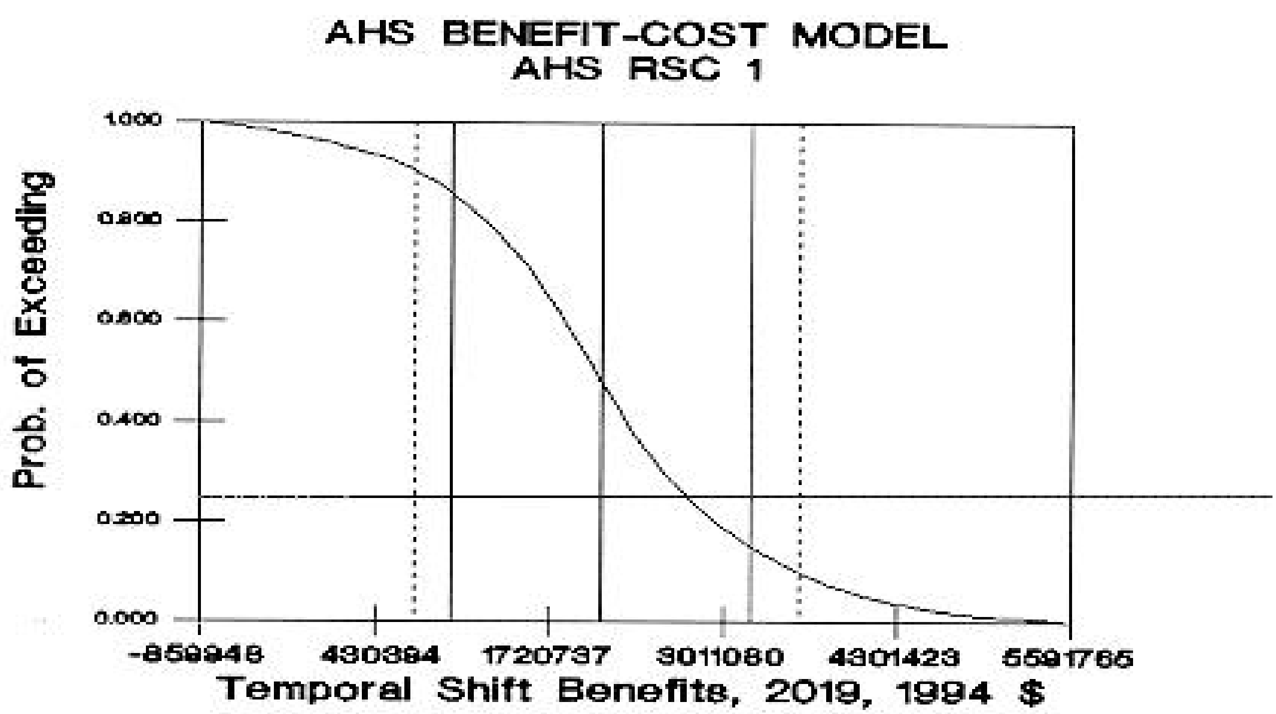

Figure 40. Distribution Function Of Year 2019 Temporal Shift Benefits

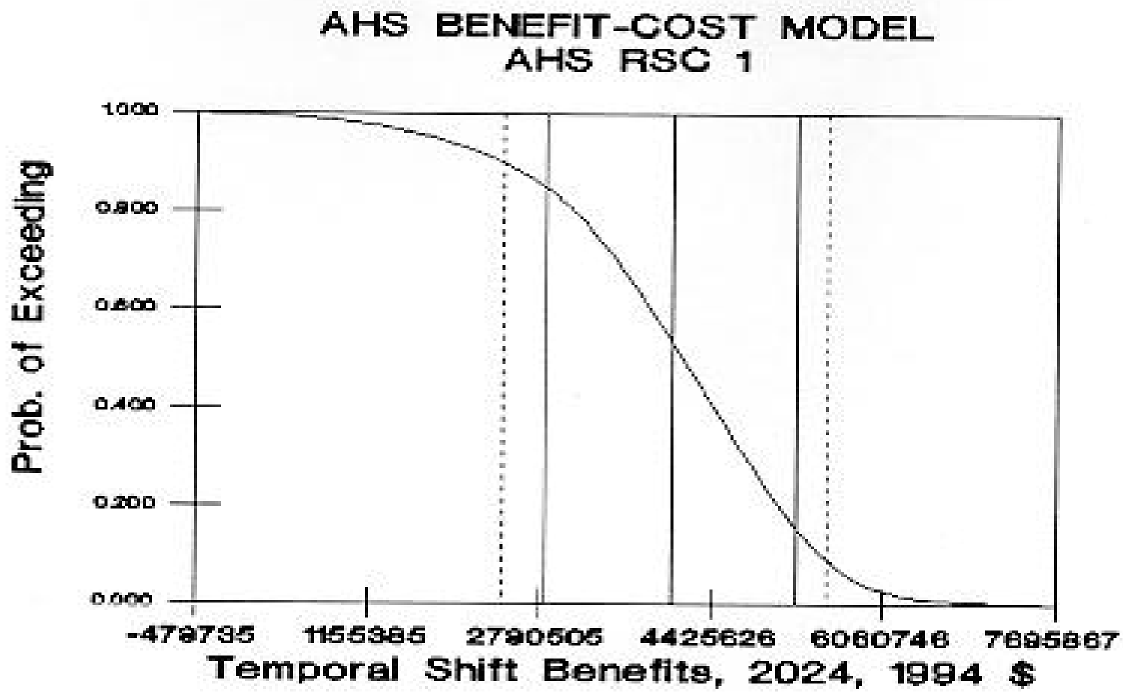

Figure 41. Distribution Function Of Year 2024 Temporal Shift Benefits

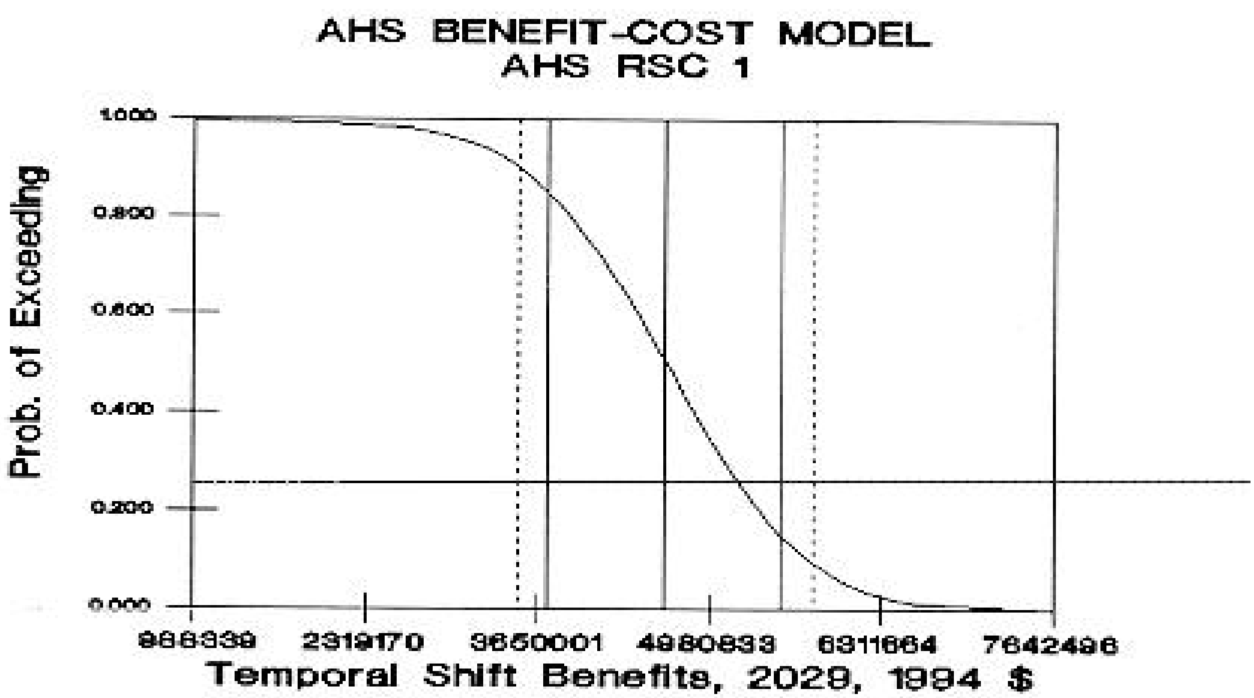

Figure 42. Distribution Function Of Year 2029 Temporal Shift Benefits

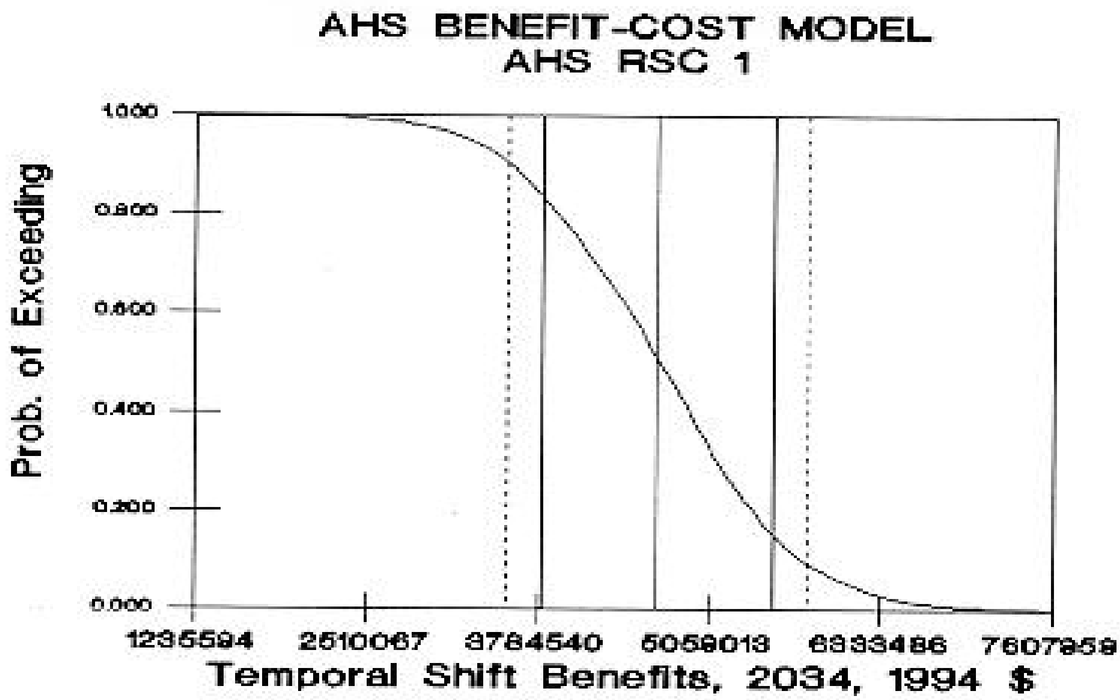

Figure 43. Distribution Function Of Year 2034 Temporal Shift Benefits

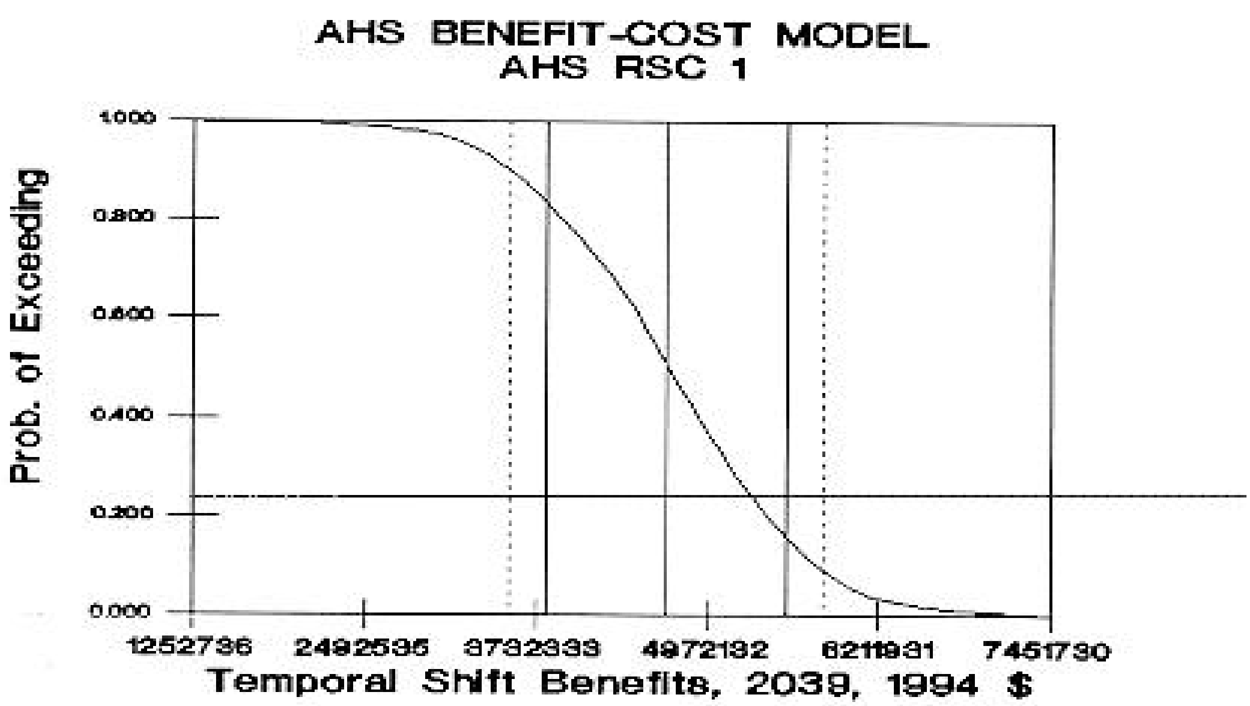

Figure 44. Distribution Function Of Year 2039 Temporal Shift Benefits

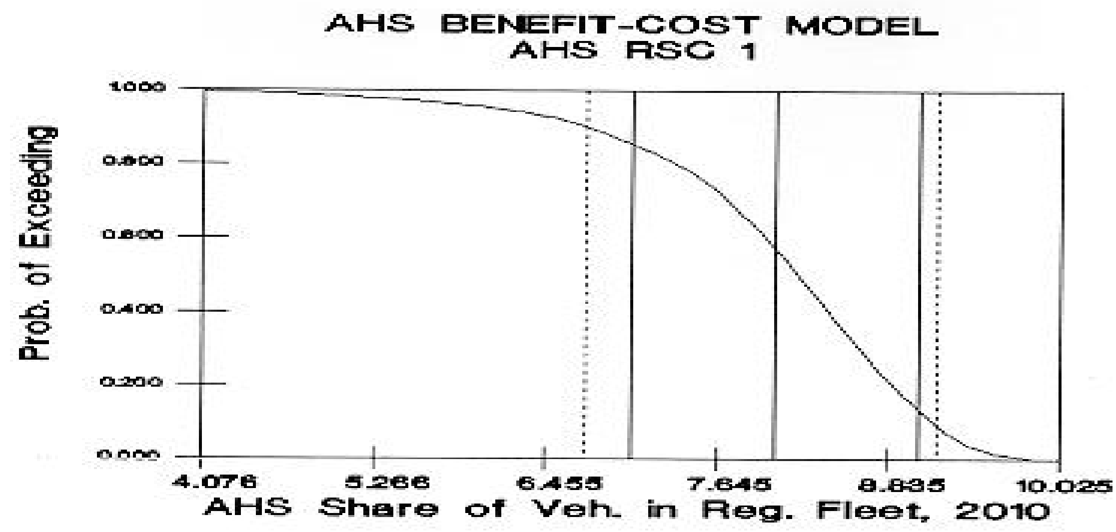

Figure 45. Distribution Function Of Year 2010 AHS Percent Of Fleet

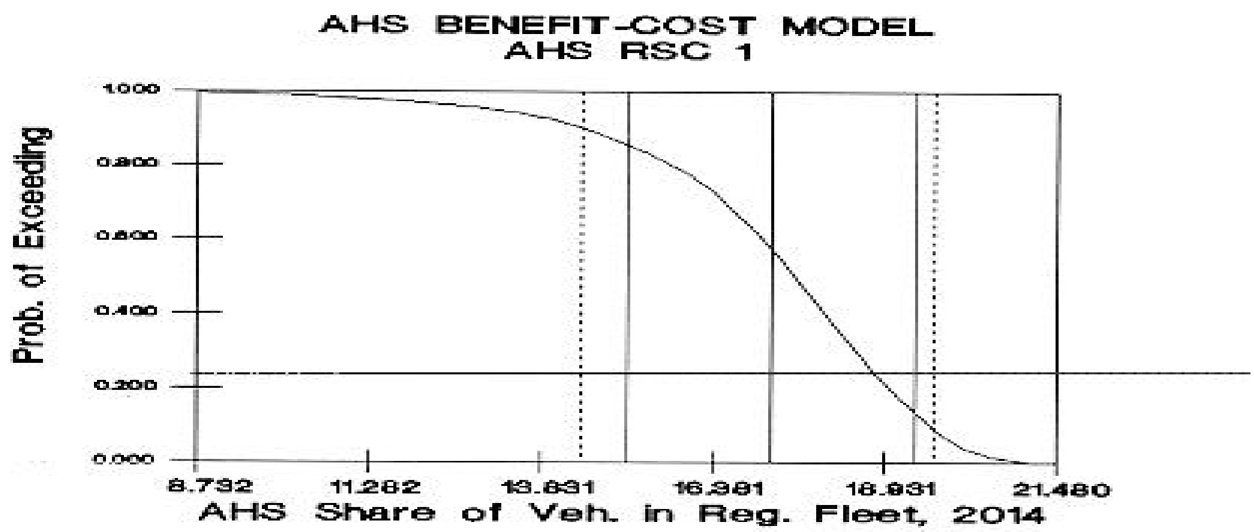

Figure 46. Distribution Function Of Year 2014 AHS Percent Of Fleet

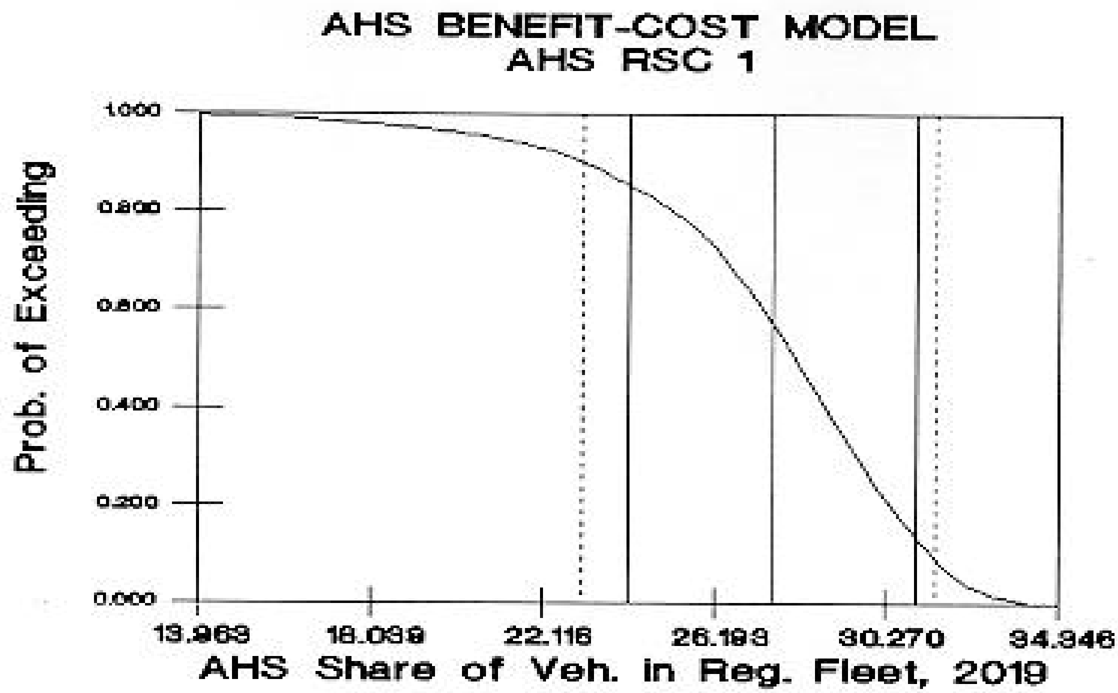

Figure 47. Distribution Function Of Year 2019 AHS Percent Of Fleet

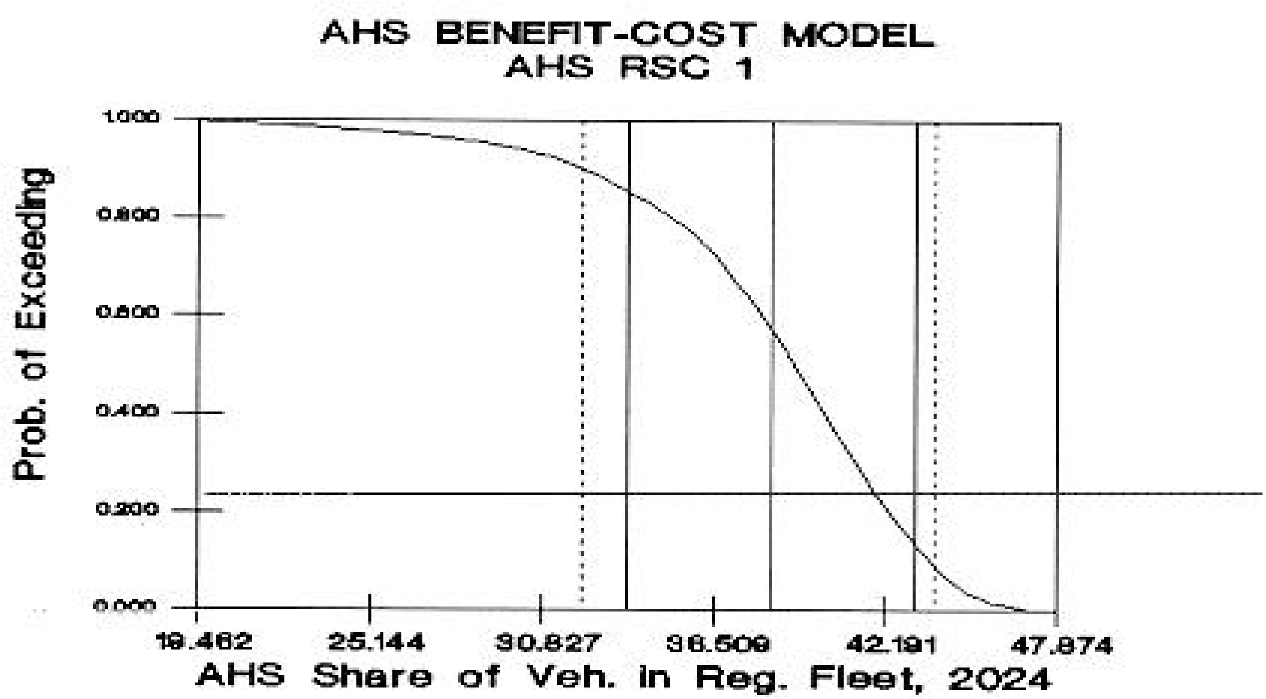

Figure 48. Distribution Function Of Year 2024 AHS Percent Of Fleet

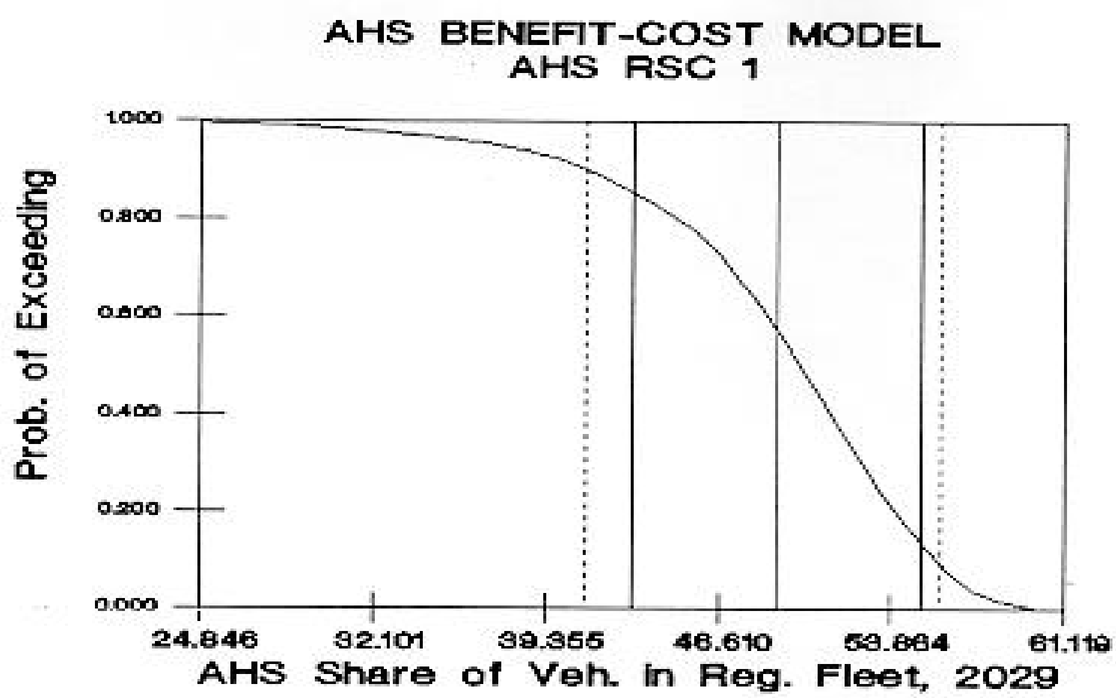

Figure 49. Distribution Function Of Year 2029 AHS Percent Of Fleet

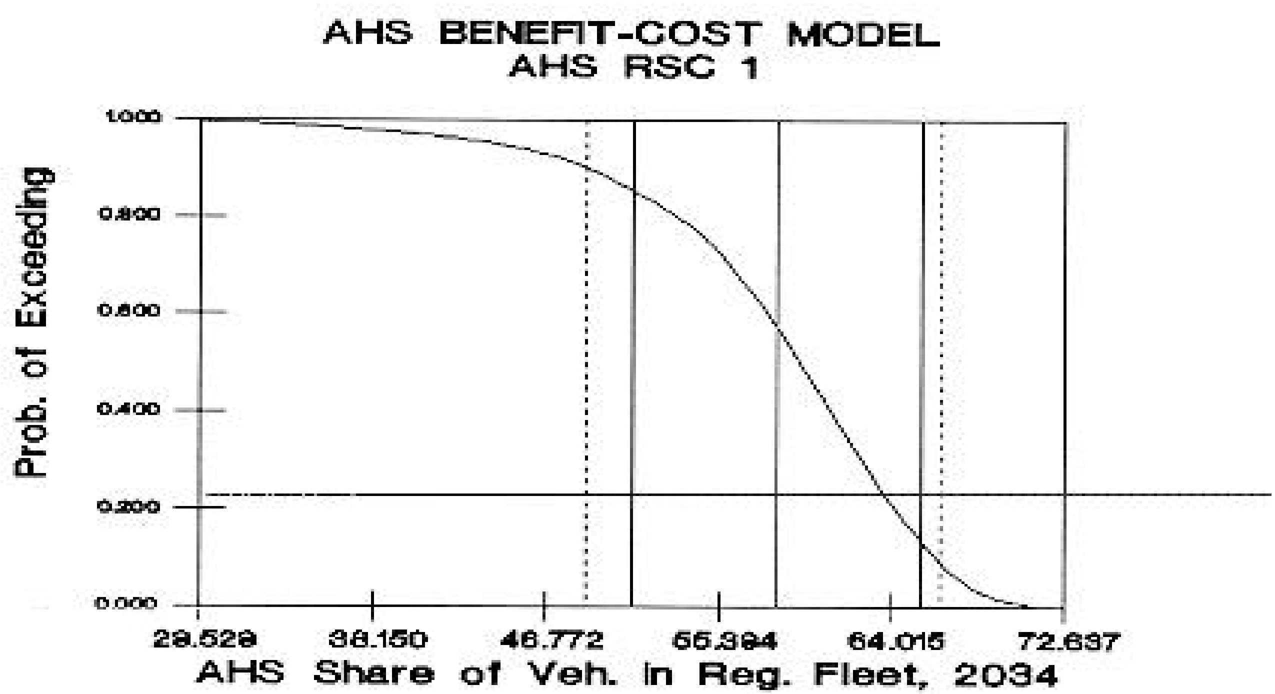

Figure 50. Distribution Function Of Year 2034 AHS Percent Of Fleet

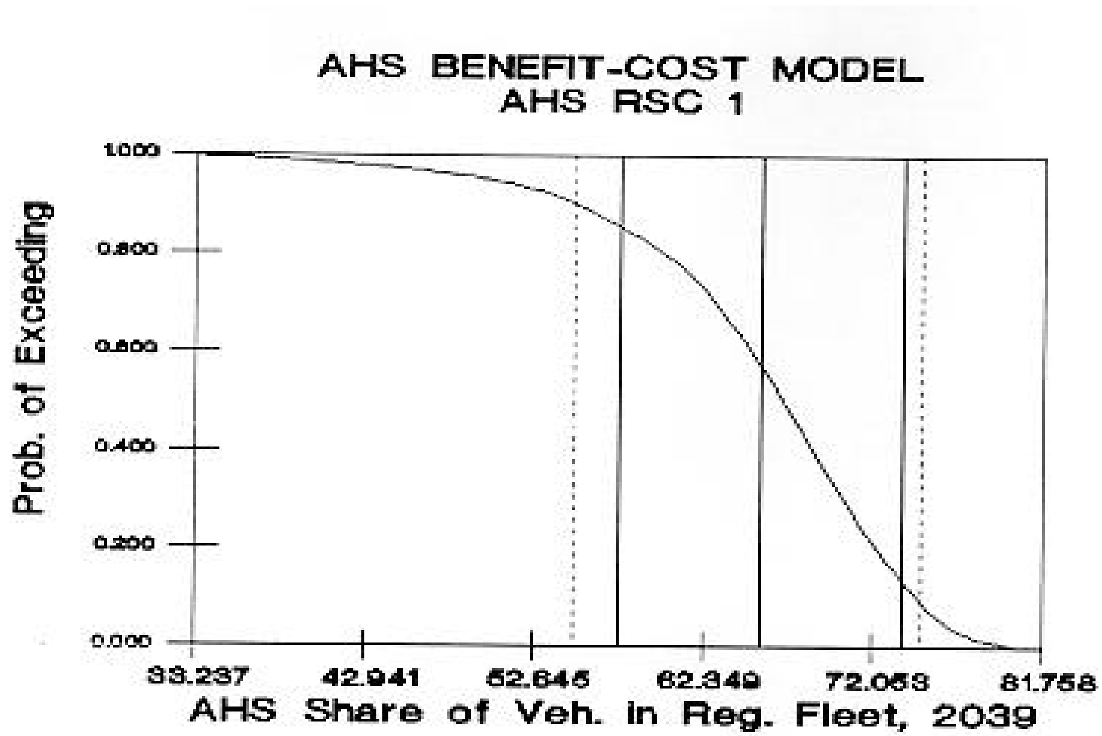

Figure 51. Distribution Function Of Year 2039 AHS Percent Of Fleet