# Precursor Systems Analyses of Automated Highway Systems

RESOURCE MATERIALS

## Preliminary Costs/Benefit Factors Analysis

U.S. Department of Transportation
Federal Highway Administration

Publication No. FHWA-RD-95-135
November 1995

## 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.

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## NOTICE

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# VOLUME VIII — INSTITUTIONAL, SOCIETAL, AND COST-BENEFIT ANALYSIS

## CHAPTER 2: Preliminary Costs/Benefit Factors Analysis (Task P)

## 1.0 EXECUTIVE SUMMARY

### 1.1 Overview

Formulating the expected costs and benefits of an automated highway system requires the use of a conceptual framework for determining types of costs and benefits, measures of cost and benefits, and an understanding of the uncertainty involved in the range of estimates derived as a result of the framework. We have developed an analytical matrix that accomplishes this task. We have also evaluated the major factors affecting the incremental costs of an AHS system, from initial research, to early deployment, through ongoing operations. Similarly, we have identified the most important benefit measures to be travel time savings, from the point of view of AHS road users themselves; accident avoidance and congestion avoidance benefits, from the societal point of view; and traffic throughput from the road operator's point of view. In addition, there are significant construction and ongoing operations and maintenance benefits to be gained as a result of secondary or "multiplier" effects of spending resources in deploying such systems regionally, or even nationally. Other benefits, such as productivity improvements at the workplace, will have to be an area for further research. It is conceivable that these may be significant, but quantifying such benefits, when little is known or predicted about the share of (say) commuting trips that are taken on AHS roadways the produce travel time savings or other user comforts/conveniences, is difficult if at all possible.

On the cost side, AHS roadways will incur substantial infrastructure construction, operating and maintenance costs. In addition, there are the costs of on-board electronics, as well as the added costs of the system infrastructure. A proper evaluation of AHS systems will thus have to consider these cost components.

We also examined traffic data for several actual roadways that could implement candidate AHS systems. Considering estimates of both benefits and incremental costs for these actual roadway scenarios, we found that, on the whole, AHS roadways do not produce sufficient economic gains to outweigh potential costs. Only in one of our roadway scenarios did we find that AHS roadways would pass a numerical cost-benefit test. However, we cautioned against over-interpreting these results. Our estimated performance gains were just that: estimated. Our cost estimates could be subject to wide variation when real systems would be actually deployed. But this exercise provided us with some useful insights into some of the more prominent relationships between benefits and costs when considering AHS.

Our research focused on the major benefit and cost factors that should enter into proper evaluations of candidate AHS systems. We first defined the economic rationale behind cost-benefit analysis. The strongest principle of a sound investment in a project is its internal rate of return, which is the discounted present value of its projected income stream net of its initial investment and all other costs to be incurred during its projected lifetime. A project with a projected rate of return that is both large and positive is indeed a project that should be undertaken. Alternatively, we reviewed the net present value appraisal method. A project should be undertaken if its net present value, or its net discounted stream of future income minus costs, is positive. For example, we found that travel time savings will accrue to some roadway users after implementing an AHS system. These savings, expressed in dollars, constitute one component of the annual stream of expected benefits. On the other hand, annual periodic payments need to be made for the upkeep of the roadway, to take another example. These payments are counted in the future stream of costs.

Following our discussion of cost-benefit principles, we discussed the importance of considering cost-benefit analysis for the policy context. There will be many goals expected from future AHS systems. Roadway operators will be concerned with performance gains, such as increased vehicular throughput and gains in operational efficiency, particularly in inclement conditions. Users will be concerned with increased in comfort and convenience and reductions in operating costs, delay and congestion, as well as better schedule reliability. To society as a whole, AHS roadways will have to deal with the roadway safety issue, with traffic congestion, with better personal mobility, with trip and schedule reliability, and so on. Concurrent with such benefit categories, AHS roadways will have to accomplish such gains while keeping deployment, operation, maintenance and renewal costs to a minimum. The importance of cost-benefit analysis, then, in this policy context, is to outline these categories of expected system benefits and costs so that AHS can be evaluated effectively, or even tailored so that it can achieve the maximum gain for the least amount of cost in general.

Our next objective was to ensure that we could capture the major components of system benefits and costs. To do this, we research several possible evolutionary deployment scenarios for representative AHS roadways. At each step in the evolutionary process, the costs of deploying systems would generally increase, with often either a corresponding or a less than corresponding increase in expected benefits. We took care in distinguishing between performance gains themselves, and the perceived value to users or others of such gains. We included at first all of the major components of benefits and costs, and then judged several distinct components to be more than significant than the others using currently accepted standards of evaluation.

In particular, we judged travel time savings, accident cost savings, and the secondary economic effects of ongoing operations and maintenance activities on societal output and employment to be among the most important categories of economic benefits that are the most easily quantifiable. Other benefit measures, such as general increases in workplace productivity or better schedule reliability are certainly important, but do not readily lend themselves to reasonable quantification. On the cost side, we found that the major component of system costs is the actual construction cost of the AHS roadway. Other important costs include system infrastructure costs, vehicle electronic costs, and the costs of ongoing operations and maintenance.

To apply our general principles, we then considered four candidate real roadways where deploying some form of AHS would be possible and even desirable. We looked at New York's Long Island Expressway and the New York State Thruway, Baltimore's section of Interstate 495 and Boston's Interstate 93. Our analysis of these roadways suggested that, at least conceptually, AHS deployment would pass a numerical cost-benefit test on only one roadway scenario, New York's Long Island Expressway, a particularly congested roadway with parked peak hours of congestion, and a roadway with significant commercial vehicle access as well as transit (bus) use. However, that is not to suggest that AHS as currently configured does not make economic sense anywhere else. There are several reasons for this. One, our current evaluation methods are relatively crude, and cannot capture the major societal effects of general improvements in living standards or in workplace productivity as a result of reducing the stress, fatigue and accidents involved with major commuting patterns. Two, our analysis is preliminary and is entirely limited by the many assumptions used in our traffic analysis, cost estimates, and roadway deployment scenarios. It is entirely possible that as we refine our work in these and other areas, we will derive performance gains that are much more substantive. Three, there are too many uncertainties with regards to the possible makeup of future AHS systems that concluding at this stage that AHS has only limited economic applicability would be too premature. Clearly, AHS displays a considerable amount of promise with regards to potential economic gain, and this needs to be carefully developed further. Particularly since AHS will undoubtedly involve a significant commitment of public resources, its justification will hinge on the ability to develop and achieve such gains.

## 1.2 Key Findings

Much analysis needs to be done in the proper evaluation of potential AHS corridors. The tools currently available with conventional cost-benefit analysis may be sufficient to do so, but considerable uncertainty lies with projected operational savings, cost magnitudes, scope, on-board electronics components costs and the potential for passing through costs to users, as well as the overall market penetration of such systems. A socially useful cost-benefit analysis is only as good as the underlying analysis that will come up with values for such parameters. In the experimental stage that AHS seems to be in at the moment, there is sufficient uncertainty with regard to such parameters that a good judgment on the adequacy of the cost-benefit analytical framework needs to be deferred until a later date.

In the interim, our research suggests that AHS corridors can be sufficiently evaluated on the basis of their potential to generate the following principal components of benefits: travel time savings, roadway safety improvements, and secondary or multiplier effects of ongoing system operational and maintenance activities. Considerable research should be focused on the safety improvements component.

On the cost side, our research suggests that roadway and system infrastructure costs seem to be more readily accessible and easy to quantify than the other cost components. More uncertainty exists with regards to ongoing operating and maintenance costs, over and above costs incurred on current roadways. The greatest uncertainty exists with respect to on-board vehicle electronics costs. The more advanced we are in the AHS planning process, the closer we will be towards reducing these uncertainties.

## 1.3 Recommendations for Future Research

The most critical path for future research on the costs and benefit factors in evaluating proposed AHS systems is to investigate, develop and refine work on its performance gains as well as its incremental cost components. The state of the art in traffic engineering needs to be brought to bear on systems that have yet to see operational testing. Much needs to be accomplished in the area of on-board system configurations to enable some form of costing analysis to be done with greater precision than is currently achievable. Much more detailed research needs to be accomplished on the safety improvements promised by AHS. Stakeholders in the systems community need to be better integrated in systems definition to enable more accurate market definition, as well as to achieve a better sense of the ultimate consumer cost parameters. This is perhaps the most fertile area for future research, since cost-benefit analysis of tomorrow's AHS roadways depends crucially on the quality of the inputs from work on roadway deployment and operations, safety analysis, roadway configurations and systems infrastructure, and so on.

# 2.0 INTRODUCTION

## 2.1 Description of Cost-Benefit Analysis

Cost-benefit analysis was first practiced in the United States by the federal water agencies, primarily the Bureau of Land Reclamation and the U.S. Army Corps of Engineers. Indeed, a U.S. Secretary of the Treasury (Albert Gallatin) was recommending the comparison of costs and benefits in water-related projects as early as 35 years before (1808) the recognized economic theorists expounded on the subject in France. It can be described simply as the monetary valuation of the physical measures of impacts, and is the most common technique for evaluating public and private sector projects.

Specifically in transportation, cost-benefit analysis involves examining the advantages, privileges and/or cost reductions or value enhancements that do or will accrue to transportation facility users, and comparing those to the net change in dollar costs directly attributable to certain given decisions or changes or proposals compared to some other alternative. Because the benefits of a transportation facility are often not confined to direct users themselves, cost-benefit analysis calls for the examination of the accrued benefits and costs to non-users or other ancillary effects of proposed changes in policy.

The importance of sound project evaluation can be illustrated by realizing the consequences of failing to carry out such evaluation adequately. A project may fail to generate a positive return on its invested capital dollars, measured by appropriate criteria, that is sufficient to make the project worthwhile. The failure of many public sector projects such as the Concorde and (arguably) the lunar program to yield a positive return despite their technical engineering success can be viewed as resulting largely from a failure to apply sound economic and financial analysis throughout initial conception and evaluation. Concorde was a failure of conception, a product of a forecast of aviation trends in the incorrect direction (faster travel at ever increasing cost for an ever shrinking base of clientele). The investment was further compromised by higher than expected fuel usage levels per passenger mile, its subsequent sensitivity to fuel price increases, the unknown development costs for a new technology that needed to be developed, and its increased unreliability for mass travel despite the advantages of increased speed. In contrast, Boeing successfully developed the 747 Jumbo jet, a widebodied extrapolation of existing technology. The aircraft featured greater carrying capacity at decreasing average cost per passenger mile, and was a commercial success story to this day, appealing to an ever increasing market. Many economists have also pointed out the obvious contrast in that while Boeing was a private sector producer of the widebody aircraft, the Concorde was a joint sponsorship of the British and French governments.

Cost-benefit analysis is not simply an application of economic theory. It is the application of market principles to the development, in this case, of an unproven new technology seeking to address numerous transportation problems with today's conventional highways: congestion, travel time delays and uncertainty, trip and scheduling unreliability, a poor safety record relative to other modes, inconvenience and discomfort with respect to in-vehicle idle time, and so on. An AHS program, in almost any guise, will no doubt require a significant expense of time and other valuable resources to carry out. Since society can ill afford a wasteful expenditure of such resources, and since resources are scarce and compete to fund an ever increasing share of public needs, the successful selling of an AHS roadway will be done only with the market in mind.

## 2.2 Cost-Benefit Factors

Cost-benefit analysis is the economic rationale for societal and private sector investment in an AHS system, of whatever configuration. The strongest underlying principle of a sound investment is the project's internal rate of return (IRR), which is the discounted present value of the annual income generated by the project net of its initial investment and other costs over a projected lifetime. Simply, a project's IRR can be expressed as the value of the rate of interest, "r" that will equate the net discounted cash flow or net present value (NPV):

$$NPV = A_1/(1+r) + A_2/(1+r)^2 + A_3/(1+r)^3 + \ldots\ldots. - I_o$$

to zero. Here, "A" refers to the project's annual income or revenues, or to the monetized value of benefits, with subscripts denoting the year (years 1,2,3 and so on), and "I" denotes the initial investment cost of the projects, usually expressed as the capital cost.

The net present value (NPV) calculation above reflects that there is a time value to money; that is, income received tomorrow or later in the project life cycle is worth less, and hence discounted by a larger factor, than the same amount of income received earlier. Having to wait longer for income or benefits means a loss of additional interest that could have been obtained if that income had been received earlier and invested in interest-bearing uses in the intervening years.

The net present value rule of appraising an investment of public or private resources is thus:

UNDERTAKE the project if NPV > 0;

REJECT the project if NPV = 0 or NPV < 0.

That is, a given AHS project should be undertaken if its net present value is positive, and rejected if it is negative or zero.

It is up to the cost-benefit task of this report to define, outline and include the proper factors that will enter such a calculation. In particular, annual income (referred to as "A" above) during any given year of a project's expected life cycle, is given by the residual of benefits minus costs. For example, the time savings attributable to an AHS corridor will be counted as benefits. Net of these benefits are the costs of maintaining or operating the corridor. The project should be undertaken if its net present value is positive and rejected if it is negative or zero. Similarly, if the project's internal rate of return exceeds the prevailing rate of interest (on, say, riskless government bonds), then the IRR criterion recommends that the project be undertaken, but not otherwise.

## 2.3 Purpose of Effort

There will be many economic goals and costs of an AHS program. To roadway operators who are concerned with operational parameters, AHS should increase vehicular throughput and operational efficiency, particularly in inclement conditions such as adverse weather. To society as a whole, an AHS corridor should reduce trip times, improve trip and schedule reliability, improve safety, and enhance personal mobility. At the same time, the program should accomplish these and other goals while reducing vehicle operating costs, reducing societal insurance costs, and perhaps reducing the cost of making an individual trip by automobile. Achieving these goals will be challenging for any program. It is the task of the cost-benefit portion of the conceptual planning for an AHS system that will seek to provide guidance in this regard.

The purpose of the cost-benefit task is to outline the major categories of benefits and costs that are to be considered in a typical project evaluation and appraisal. Clearly, a particular AHS corridor or program should be undertaken if it can be shown that the project has the potential of generating a positive net present value. The problem, of course, presents itself in that little is known regarding the potential development costs of such a new technology. There could be many pitfalls in its implementation. Indeed, a pilot AHS roadway may bear little resemblance to the one envisioned in these pages. Much can be foreseen, but at great uncertainty, regarding potential benefits or performance measures. This task, therefore, is not designed as a final say in whether to go on ahead with any particular AHS program. Rather, as we see it, it should shed light on the discussion of how to properly evaluate and appraise such a new system as we proceed to the next stage of initial planning.

The purpose of this task will also be to discuss the uncertainty regarding the cost-benefit factors themselves, uncertainty with regards to timing, magnitude, impact, valuation of impacts, and so on. Rather than attempting to become too precise regarding factors that are too speculative, the task will outline the major items that will need to be considered and evaluated. It will also propose an evaluation method framework that can and will evolve as needs change, but should for the moment provide the basis for a societal consideration of project worthiness.

## 2.4 Overall Approach

This task required an examination of the costs and benefits of an AHS roadway. Our specific charge was to develop a conceptual framework for analyzing costs and benefits; determine cost and benefit measures; list and rank by importance of impact such measures; examine how such measures are affected by the evolutionary deployment of AHS systems; and, finally, examine the critical threshold points of incremental costs and benefits across various system configurations. Also, we were to examine four specific roadway deployment scenarios and report on benefit and cost measures.

Our approach was to first list all the possible categories of costs that are incurred when deploying an automated highway system. These include capital costs, such as construction of roadways, or installation of on-board vehicle intelligence; and, the ongoing costs of operations and maintenance, including staff time, or system processing costs of all the data and information received by central control stations. Next, we listed all the various types of benefit evaluation measures that are typically considered when evaluating proposed transportation policies or projects. These included typical performance measures such as vehicular throughput, passenger throughout, or time taken to process a certain number of vehicles through a bottleneck point at a roadway. Also included were travel time values, in dollars terms at rates roughly corresponding to the rate of take home pay, to value travel time savings (or decreases in travel costs) as well as the economic value of lives saved, accidents prevented, property damage averted or hospitalizations avoided by the use of an improved highway transportation system as a result of AHS.

We then ranked these measures by importance, and differentiated them by road user perspective, societal perspective, and road authority perspective. We then examined how these measures were affected by the evolutionary deployment of AHS scenarios. Certain cost categories would undergo threshold changes in values at certain evolutionary stages; similarly, users benefits would undergo significant changes in values at certain market penetration levels, and so on.

Finally, we tailored our discussion of factors to consider actual examples of configured AHS roadways as if they were to be deployed today. What would be the construction costs of implementing such a roadway on four existing roadways throughout the United States: the Long Island Expressway (I-495) and the New York State Thruway (I-87), both in New York State; a section of the Capital Beltway (I-495) in Maryland; and a section of I-93 in the Boston area? What would reasonable estimates on ongoing costs of operating and maintaining such a roadway be, together with the associated systems electronics costs, and so on? Compared to such costs, what reasonable benefits measures can be expected and calculated with respect to the use of such AHS roadways? Taken as a whole, then, what would be the individual project net present values, and should such projects be undertaken given our assumptions of AHS configurations? In all cases, we took care in considering indirect or non-AHS-road-user costs and benefits so as not to understate the net benefits of such systems.

## 2.5 Guiding Assumptions

Our guiding assumptions used throughout the analysis will be outlined in the context of the technical discussion below.

# 3.0 Technical Discussion

## 3.1 Cost-Benefit Analytical Framework

### 3.1.1 List of Benefit Categories

As a natural starting point in setting up an analytical framework for performing future cost-benefit analyses, we determined the typical categories and types of benefits and costs that should enter into the appraisal calculations. There is also a distinction between benefit measures per se, such as the value of reduced travel time, and typical measures of effectiveness or performance, such as increases in traffic throughout. The latter is simply a physical measure of the impact of an AHS scenario. Although performance measures are crucial to potential and current roadway operators, departments of transportation, highway planning agencies and others, they are quite different from what economists and financial planners consider in cost-benefit analysis. As explained earlier, in cost-benefit analysis, economists attempt to put a value on such performance measures, value in terms of the usefulness of a certain measure to a human. In and of themselves, performance measures may indeed have some intrinsic value, but the distinction stands. We list BOTH benefit categories and performance measures, and intend for these lists to be non-exhaustive.

The following lists the typical performance measures typically considered by planning agencies and endemic to AHS roadways, according to the perspective of motorists themselves, road operators and society as a whole:

MEASURES OF EFFECTIVENESS - QUANTITATIVE

1. MOTORISTS: AHS & NON-AHS USERS
   - Travel Time - Increased average speed, uniform flow,etc.
   - Trip Reliability - Less congestion/incidents, schedule assurance, etc.
   - Reduced Pollution - Minimize stop & go, etc.
   - Safety - Minimize incidents, accidents, property damage, etc.
   - Vehicle Operation - Reduce wear, energy, insurance, etc.

2. ROAD OPERATORS
   - Revenue Source - Tolls, fees, etc.

Capacity - Increased throughput, etc.

3. SOCIETY IN GENERAL
Road Construction - Labor, supplies, materials, etc.
Vehicle Devices - Development, fabrication, installation, etc.
Operation & Maintenance - Labor, parts, contracted services, etc.

TYPICAL BENEFITS TO BE CONSIDERED

i.e., performance measures as valued by:

1. MOTORISTS, AHS & NON-AHS USERS
Trip reliability and convenience: value of reduced travel times
Comfort and stress relief: value of reduced travel times
Safety awareness: value of societal costs of accidents and property damage averted from introducing AHS

2. SOCIETAL:
Savings in lost labor time and property damage due to incidents
Savings in lost labor time due to congestion
Multiplier (secondary) benefits from constructing AHS roadways
Multiplier (secondary) benefits from operating and maintaining AHS roadways

While there are a whole host of benefit measures to be considered in a typical cost-benefit analysis, we judged the following categories to be the most important, since they are most readily quantifiable and have been documented elsewhere:

a. Value of travel time savings;
b. Value of incidents and accidents averted;
c. Multiplier (secondary) benefits of both construction of a system as well as ongoing operations and maintenance.

### 3.1.2 List of Typical Cost Categories

Costs to be included in an effective project evaluation or appraisal of projected costs and benefits include the following major categories (again, the list is not meant to be exhaustive):

TYPES OF COSTS

1. CAPITAL IMPROVEMENTS
   A. Highways:
      Roadway — earthwork, pavement, drainage, landscaping, etc.
      Structures — new/widen, bridges, viaducts, walls, etc.
   B. Systems:
      Equipment — servo, sensors, self-diagnostics, etc.

Hardware — barriers, signs, striping, tracking/flow monitoring devices, etc.
Maintenance of Traffic — during construction/maintenance
Instrumentation — computer, navigation, communication, etc.

C. Facilities
Buildings — administration, control, maintenance, garages, koisks, etc.
Vehicles — patrol, response, maintenance, etc.
Equipment — building services, control room, maintenance service, traffic, etc.

2. ONGOING (ANNUAL) EXPENSES

A. Operations
Labor — administration, control, enforcement, response, etc.
Expenses — consumables, etc.

B. Vehicular
Servicing — inspection, repairs, etc.
Fees — licenses, etc.

C. Maintenance
Labor — skilled, helpers, etc.
Expenses — parts, consumables, etc.
Contracted — special services, etc.

We have ranked the most important categories of cost that are readily quantifiable as follows:

a. Construction costs of the roadway infrastructure
b. System infrastructure costs
c. Operations and maintenance costs attributable to the AHS roadway
d. On-board vehicle electronics costs.

### 3.1.3 AHS System Evolutionary Costs and Benefits

In this section, we will outline the evolutionary steps of the typical costs and benefits of deploying an AHS program.

#### 3.1.3.1 AHS Evolutionary Process - Base Costs and Benefits

OPERATIONAL FEATURES

The first step in one evolutionary process begins with existing cruise control (electronic activation of the throttle) combined with gap sensors and auto braking to form the first intelligent cruise control ( gap control ). The entire control package is resident in the user's vehicle with self-diagnostics and fail safe disable/shut down. This package is designed for driver convenience and can be abused requiring the following use restrictions, enforcement and management control:

Use Restrictions — Freeway through lanes only ( no right lane use )
Maintain safe gap to allow weaving
No platooning
Gap control disabled during any maneuvering

Enforcement — Increase patrols
Ticketing using video/electronic surveillance
Management — Monitor traffic flow
Broadcast motorist information

## CAPITAL COST ITEMS

Highways — Installation of regulatory signing and CCTV

Vehicular — Installation of : auto braking servos, forward range sensors, throttle actuation, computer/electronic control, self-diagnostics/fail safe and radio receiver override.

Facilities — Mini control center within State Police (and other) facilities
Additional patrol cars
Control center equipment

## ANNUAL EXPENSES

Operations: Labor costs with markup for benefits, overhead and admin.
Consumable costs for building, vehicles and appurtenances

Vehicular: Servicing costs estimated at 10% of capital costs

Maintenance: Servicing costs estimated at 5% of capital costs.

## BASE PERFORMANCE MEASURES

The national freeways typically operate at a low level of efficiency in terms of available capacity. Drivers may believe that they operate at close headways (of one second), but real world impedances such as throttle responses, weaving and inertia render true average headways to closer to between 2 and 2.5 seconds. To estimate how effective gap control may be in improving vehicular headways or average vehicle flow, we can draw on commuter behavior. Motorists on their way to work may maintain uniform flow/vehicle gap with little lane changing except for entry and exit. Vehicular flows with 1.6 second headways is common but is not a stable situation, subject to interruption at any time. It is envisioned that the provision of gap control will promote increased driver discipline with flows at 2 second headways and a reduction in rear-end incidents. Such a level of performance gains will also result in qualitative benefit gains.

In the next stage of the AHS system, there are a whole new host of benefit and cost items typically encountered, and they are outlined below.

### 3.1.3.2 AHS Evolutionary Process - More Advanced "AHS I"

#### OPERATIONAL FEATURES

This next step involves adding automatic lane holding to the vehicle intelligence to provide automatic cruise control - hands-off cruising. Vehicles equipped with this package will continue to use the mixed vehicle freeway through-lanes with further restrictions. As the market (number of equipped vehicles) increases, high use segments of freeways will designate existing lanes and/or construct exclusive lanes for automatic cruise control. The only additions to mixed-use freeway lanes is restrictive signing and installation of center-line tracking devices (i.e. magnetic nails) in the inside/left lanes. The freeway through-lanes will continue to be available for gap control but only the inside/left lane will allow automatic lane holding.

The AHS designation of an existing freeway lane should require no additional construction work. Where a freeway requires widening to provide a designated lane, with or without exclusive entry/exit provisions, or a new AHS roadway is constructed, a major investment in construction, implementation time and maintenance of traffic is required.

The introduction of lane holding adds to use restrictions, enforcement and management control as follows:

Use Restrictions — Freeway inside/left lane only
Maintain safe gap to allow entry
Operate under Management speed control

Enforcement — Further increase patrols particularly on separated lanes

Management — Full time monitoring traffic flow
Develop speed control on a real time base
Expand incident management
Transmit voice/data information to motorists

#### CAPITAL COST ITEMS

Highway, Existing: Installation of tracking nails, signs & radar monitor

Widening: Excavation, construction, maintenance of traffic and installation of vehicle tracking/traffic control devices.

New: Property acquisition, excavation, construction, maintenance of traffic and installation AHS devices.

Vehicular: Sensors, steering servos, computer/diagnostics enhancement, data receiver.

Facilities: Increase in number and size of control centers

ANNUAL EXPENSES

No different from the Base AHS expenses.

PERFORMANCE GAINS

Flow in a preferential lane with gap control and lane holding, in addition to managing speed control, should allow for a 1.2 second headway with higher average travel speeds. The freeway will be safer but at the lower end of the potential gains from safety improvements, because of the mix of non-AHS and partially-equipped AHS vehicles in the adjacent lanes.

Further along in the evolution of an AHS system:

3.1.3.3 AHS Evolutionary Process - "AHS II"

OPERATIONAL FEATURES

The introduction of automatic lane changing and the management of freeway trips and vehicle spacing, both separate improvements, represents a quantum leap in vehicle intelligence and management control of individual vehicles plus a quantum increase in costs. The envisioned social benefit of these improvements is increased capacity, less roads to build, greater safety and less travel time. It is doubtful both improvements will be introduced simultaneously nor readily accepted by motorists. Initial introduction of automatic lane changing must be viewed as an aid to manual lane changing until proven in use. Likewise, management control initially must rely on a mix of "AHS I" & "AHS II" equipped vehicles. It should also be noted that an increase in market penetration will bring about the change of freeway lanes to AHS lane thus reducing the need for roadway construction.

This package re-defines the rules-of-the-road in terms of individual driver behavior within manual or automatic vehicle control and management's role for greater overall and individual control

Use Restrictions — Freeway separated lanes only
Safe gap maintained to allow manual/automatic maneuver
Platooning only under management control
AHS I & II operate under management speed/spacing control

Enforcement: — Increase patrols, video/electronic surveillance

Management: — Phase-in individual (request from AHS II vehicles) trip control while expanding area gap control to individual vehicle

CAPITAL COST ITEMS

Highway: Re-arrangement of signing, stripping , barriers, etc. to convert mixed use lanes to AHS lanes.

Vehicular: Installation of peripheral sensors, vehicle to vehicle communicators, computer/diagnostics enhancement

Facilities: Phase-in control centers similar to air traffic control.

ANNUAL EXPENSES

No change from before.

OPERATIONAL IMPROVEMENTS

The primary performance gain of this evolutionary step is a less than 1 second headway differential and preferential lane separation.

The final step in the evolutionary process is the transition to the most advance stage of AHS, known here as "AHS III:

3.1.3.4 AHS Evolutionary Process - AHS III

OPERATIONAL FEATURES

The deployment of this step - full management control - will be driven by the high cost to user's vehicle for full AHS II, particularly the peripheral sensing and data processing needed to maneuver in traffic. To operate under management control vehicles need only to be equipped for a low level of AHS II. A second driving force for management control will be the prioritizing of the entrance and exiting to local streets. A total conversion to full management control in terms of freeway mileage and timing appears difficult to attain or is unnecessary. Segments of freeways and/or designated lanes may remain under driver control with management supervision.

Considering the level of communication and readability required to attain full management control, it is envisioned that a high degree of down-line intelligence (within the vehicle) is needed to lock into an electronic highway generated by management. This will share the decision load - driver operated while queuing to enter, management's controls on the electronic highway.

There is no clear departure from prior steps, therefore the use restrictions, enforcement and management continue with the following additions:

Use Restrictions — Driver decision to enter management control
Dedicated entrance/travel/exit lane(s) for management control

Enforcement — Monitoring and ticking shift to video/electronic surveillance

Management — Trip and gap control on dedicated lane(s)

## CAPITAL COST ITEMS

Highway — Increase in quality/maintenance of travel lanes

User's Vehicle — Performance/quality upgrade of vehicle/intelligence to match operational requirements of management control

Facilities — Data processing and communication for management control

## ANNUAL EXPENSES

Same as before.

## OPERATIONAL IMPROVEMENTS

It is envisaged that trip management (platooning) will begin by designating a special priority lane for full management control. This will allow a subsystem to operate within the AHS system. There will be benefits associated with these improvements.

### 3.1.4 Summary of AHS Evolution

To summarize the discussion on the evolution of an AHS system, table 2-1 illustrates the major transition points. Each transition point will incur a milestone of costs to be incurred, very often major costs, as well as benefit realized. To better understand the ranges of such benefits and costs, we considered setting up AHS configurations within several real world scenarios, and these are discussed below.

## 3.2 Summary of Important Cost-Benefit Factors

In table 2-2, we summarized some of our findings on the quantitative measures of performance expected from the successful deployment and operation of an AHS system, as well as on the relative importance of some of the more readily recognized benefit measures. AHS will undoubtedly be compared to other modes of transportation when attempting to achieve certain highway performance measures such as greater vehicular throughput, or even less noise pollution. Other modes were ranked qualitatively here for comparison purposes. AHS will have to show that it has potential gains in many of such areas for it to be acceptable as public policy. The column on the extreme right hand side is very much a "wish list" for AHS. It remains up to subsequent research on the performance gains of AHS to see whether these goals can be realized.

The table also distinguishes between general societal benefits as a whole, and benefits that are important to both roadway operators (often mentioned as the key "stakeholders") and roadway users alike. Clearly, some of these goals are mutually contradictory. As an illustration, a perceived benefit goal to individual roadway users is increasingly better comfort and convenience in highway travel. This can be achieved, on the whole, usually at an ever increasing cost of operation, which goes against the goal of reducing roadway operational costs from the point of view of roadway operators. An AHS demonstration along a given corridor that achieves as many of these often contradictory goals is then most beneficial and will be most easily accepted from a political viewpoint.

Table 2-1. AHS Evolutionary Process — Limited Access Highways (Freeways) — Auto Equivalent Only Equipped to Perform Operations, Self Diagnostics and Fail Safe

Table 2-2. Public Interest Evaluation of AHS Roadways

PUBLIC INTEREST
EVALUATION OF AHS ROADWAYS

Qualitative Benefit Factors as Measured by Performance Criteria

| A. Performance Measures / Benefits Important to Society as a Whole | Mode: Walking | Transit | Non-AHS Vehicle Use | AHS Vehicles |
|---|---|---|---|---|
| • Greater Capacity | S | S | P | S |
| • Greater Energy Efficiency | S | S | P | I |
| • Less Air Pollution | S | S - I | P | P |
| • Less Noise Pollution | S | I - P | P | P |
| • Better Aesthetics | S | I - P | I - P | P |
| • Lower System Vulnerability | S | P | P | S |
| • Higher System Sustainability | S | I | P | S |
| • Less Public Expense | S | P | I - P | P |
| • More Healthful | S | I - P | P | P |
| • Fewer Accidents, Injuries, Property Damage, etc. | S - I | S - I | P | S |

| B. Measures Important to Roadway Operators | Mode: Walking | Transit | Non-AHS Vehicle Use | AHS Vehicles |
|---|---|---|---|---|
| • Increased Vehicular Freight Throughput | S | S | P | S |
| • Increased People Throughput | S | S | P | S |
| • Increased Customer / Patron Satisfaction | S | I | P | S |
| • Lower System Vulnerability | S | P | P | S |
| • Higher Ease of Operation | S | I - P | P | S |
| • Lower Costs of Operation | S | P | P | P |
| • Higher Profit in Operating | S | P | I - P | S - I |
| • Increased Roadway Revenues | P | I - P | S - I | S |

Table 2-2. Public Interest Evaluation of AHS Roadways (continued)

| C. Measures Important Primarily to Individuals | Mode: Walking | Transit | Non-AHS Vehicle Use | AHS Vehicles |
|---|---|---|---|---|
| • Lower Costs to Uses | S | S - I | I - P | P |
| • Better Personal Microenvironment | S | S - P | S | S |
| • Greater Flexibility | S | P | S | S |
| • Higher Frequency of Service | S | I | S | S |
| • Greater System Reliability | S | P | P | S |
| • Greater Comfort / Convenience | I | I | S | S |
| • Better Orientation to Destinations | S | S | S - I | S |
| • Greater Ease of Use | S - I | S - I | S - I | S |
| • Greater Ease of Transporting Things | P | I - P | S - I | S |
| • Less Total Travel Time (Approx. Ranges) | | | | |
| Short Distances | S - I | I - P | I - P | I - P |
| Long Distances | P | S - I | S - I | S |

### 3.3 Results of Evaluation of Costs and Benefits for Four Scenarios: LIE, I-93, Thruway, I-495.

#### 3.3.1. Guiding Assumptions

No analysis of costs and benefits can be complete without some numerical examples using real world roadways. While the results often can be somewhat misleading, since they depend crucially on the assumptions used, they can be indicative of the sorts of relationships that can be expected when more compete information is known. Our assumptions included several areas of uncertainty. We are not sure as to what the AHS system will necessary look like, so we had to incorporate estimates on roadway infrastructure costs, roadway electronics (system) costs, in-vehicle electronics, and so on. Any component of any one of these and other cost items can and will change depending on the final configuration of the AHS system. The point of this section of our costs and benefits report was to determine some estimated relationships of costs and benefits factors to develop useful insights for further research.

We had to decide on the perspective for these relationships early on. That is, from whose point of view should the cost-benefit factors be developed? A useful starting point was to consider societal benefits. The guiding assumption here is that a national AHS system program will incur substantial public monetary resources. To justify the expenditure and commitment of such resources, sponsoring agencies must outline all of the possible benefits of AHS, while at the same time accounting for the incremental costs to deploy it. Therefore, on the positive side of the societal cost-benefit ledger, we included travel time savings accrued by roadway users themselves, the value of avoided roadway accidents accruing from the safety features of AHS, as well as the "secondary" or multiplier benefits of operating and maintaining the system (economic effects on regional, statewide or local output from expenditures on roadway repair and maintenance activities). On the cost side, we included the capital costs of construction, operating and maintenance costs over and above existing costs, system infrastructure costs, and on-board vehicle electronics costs.

One obvious question arises: if the typical AHS roadway will also feature tolls to finance the system, why are not toll revenues included in such a societal cost-benefit factor analysis? Toll revenues will accrue to roadway operators and are an undoubtable benefit. But from society's standpoint, toll revenues are a redistribution of resources from one section of society to another. And since we are charged with analyzing net incremental costs and benefits, it may be misleading to include toll revenues as a net addition to society's worth. On the other hand, travel time savings do accrue to roadway users. Or, alternatively, genuine societal resources will have to be expended on system construction or ongoing maintenance and repair costs. And thus these categories we felt were appropriate for inclusion.

Our starting point was a determination of our overall benefits analysis. As we outlined earlier, our most important benefits category was assumed to be travel time benefits. AHS roadways would save travel time, time which is valued by roadway users at rates corresponding to rates of take-home pay. To calculate travel time benefits, we first analyzed some performance measures such as average speed improvements and vehicle hours of travel (VHT).

### 3.3.2. Operational Results for Four Representative Roadways

#### 3.3.2.1 Calculating Travel Time Savings

If an AHS roadway would result in an improvement in average speeds or a reduction in VHT, travel time savings would be realized. In table 2-3 (outlining a benefits "template" for future analysis), we provide estimates of performance measures for Boston's I-93 roadway, assuming an AHS system would be deployed. As the table shows, for the hours of travel closest to the peak hours of travel, average speeds increase following the deployment of AHS.

Vehicle miles of travel also increase, since more roadway capacity is achieved by squeezing more vehicles through at the hours surrounding the peak hour of travel. We used the traffic estimates as outlined in the Section on roadway capacity. The primary benefit of the AHS roadway can be seen in the savings in travel times, expressed as a reduction in VHT. The table shows that over 418 vehicle hours of travel were saved under AHS during the peak hour itself, which lasts for one hour during each day in one direction. If average vehicle occupancy is estimated at 1.2 persons per vehicle, and the average per-person value of in-vehicle travel time is equivalent to the 1994 value of the weighted average of hourly wages in the Boston metropolitan area, then the total value of travel time saved for that peak hour is given by the product of:

{Travel time savings per Hour} x {Number of Hours During Which Travel Time is Reduced} x {Average Vehicle Occupancy} x {Value of In-Vehicle Travel Time}, or $8,914.

To estimate the daily value of such savings, we added up all of the derived hourly values to get a daily total. Daily total travel time savings for this roadway were given by close to $50,000. In both directions, we multiplied this total by two (although traffic patterns and the peak period pattern are not symmetric depending on direction of travel) to get a bi-directional daily total travel time savings of close to $100,000. Multiplying this estimate by the number of days in the year yielded an annual total value of travel time savings of over $25.5 million. This is our first annual benefit estimate.

All of our estimates of hourly values of time were derived table 2-4, showing hourly adjusted income levels for major metropolitan areas throughout the United States.

The economic literature is full of references to value of time studies. And there is certainly no unique value of time. Value of time varies by individual, by mood, by time of day, by trip purpose, by urgency of trip, by type of trip, and so on. There are even variations in individual values by season. It is beyond the scope of this study to suggest even an acceptable range of values to be used. For simplicity of exposition,

**Table 2-3. Boston I-93: Northbound — Performance Results**

## PERFORMANCE RESULTS: A.M. PEAK PERIOD and HOURS CLOSEST TO PEAKS
## EVALUATION OF TRAVEL TIME SAVINGS

| M.O.E. | | 79% | 83% | 92% | 96% | 100% |
|---|---|---|---|---|---|---|
| | | **PERCENTAGE OF EXISTING PEAK VOLUMES** | | | | |
| SPEED (m.p.h.): | Existing Roadway | 53 | 45 | 36 | 34 | 33.5 |
| | AHS Roadway | 59 | 59 | 58 | 58 | 58 |
| | Speed Increase: | 6 | 14 | 22 | 24 | 24.5 |
| Vehicle Miles of Travel (VMT): | Existing Roadway | 51,623 | 52,126 | 52,011 | 51,770 | 51,642 |
| | AHS Roadway | 53,199 | 55,988 | 61,780 | 64,445 | 67,343 |
| | Change in VMT: | 1,576 | 3,862 | 9,769 | 12,675 | 15,701 |
| Vehicle Hours of Travel (VHT): | Existing Roadway | 957.4 | 1,143.4 | 1,426.3 | 1,511.0 | 1,542.0 |
| | AHS Roadway | 874.0 | 921.2 | 1,022.0 | 1,068.4 | 1,123.5 |
| | Total Travel Time Savings from AHS (VHT): | 83.4 | 222.2 | 404.3 | 442.6 | 418.5 |
| | Duration of Traffic Volume in Daily Traffic Totals (hrs): | 1 | 2.5 | 2 | 1 | 1 |
| | Average Vehicle Occupancy: | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| | Avg. Per-Person Value of In-vehicle Travel Time: | $17.75 | $17.75 | $17.75 | $17.75 | $17.75 |
| | Value of Travel Time Saved: | $1,776 | $11,832 | $17,223 | $9,427 | $8,914 |

| | |
|---|---|
| Total Value of Travel Time Saved per Day, SOUTHBOUND ONLY: | $49,173 |
| Daily Total Value of Travel Time, Both Directions: | $98,346 |
| **Total Annual Value of Travel Time Saved:** | **$25,570,054** |

| | Value of Total Annual Travel Time Benefits |
|---|---|
| **Sensitivity Analysis 1: Variation in the values of time** | |
| Average per-person values of in-vehicle travel time factors: | |
| at 67% of hourly wage rate: | $17,131,936 |
| at 200% of hourly wage rate: | $51,140,107 |
| at 300% of hourly wage rate: | $76,710,161 |
| **Sensitivity Analysis 2: Variation on Vehicle Occupancy** | |
| Using the Boston Metro Area's Average Vehicle Occupancy of: 1.07 | $22,799,964 |

**Sources:** All Speed, VMT & VHT figures are from Dunn Associates.
The Average Vehicle Occupancy figure for the Boston Metropolitan Area is from FHWA's *Journey-To-Work Trends in the United States and its Major Metropolitan Areas 1960-1990*
Hourly wage figures are estimated using data from the same FHWA publication.

## Table 2-4. Estimates of Hourly In-Vehicle Travel Time Values

| METROPOLITAN AREA | WORKERS PER HOUSEHOLD | MEDIAN HOUSEHOLD ANNUAL INCOME (1990 $'s) | MEDIAN PERSONAL ANNUAL INCOME (1990 $'s) | MEDIAN HOURLY INCOME (1990 $'s) | MEDIAN HOURLY INCOME (1994 $'s) | PERCENTAGE OF ALL HOUSEHOLDS EARNING ... $0-$14,999 (1990 $'s) | $15-29,999 (1990 $'s) | $30-49,999 (1990 $'s) | $50-$74,999 (1990 $'s) | $75,000 + (1990 $'s) | ADJUSTED MEAN HOURLY INCOME PER WORKER (=est. hourly Value of Time) (1990 $'s) | (1994 $'s) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| New York City | 1.29 | $37,869 | $29,356 | $14.11 | $16.51 | 20.3% | 19.4% | 23.4% | 18.8% | 18.1% | $15.80 | $18.48 |
| Los Angeles | 1.39 | 36,711 | 26,411 | 12.70 | 14.85 | 18.5% | 21.7% | 25.2% | 18.7% | 15.9% | $14.37 | $16.81 |
| Chicago | 1.32 | 35,916 | 27,209 | 13.08 | 15.30 | 19.1% | 21.9% | 27.1% | 18.9% | 13.1% | $14.62 | $17.11 |
| San Francisco | 1.37 | 41,459 | 30,262 | 14.55 | 17.02 | 15.1% | 19.3% | 25.5% | 21.2% | 18.9% | $15.79 | $18.47 |
| Philadelphia | 1.30 | 35,735 | 27,488 | 13.22 | 15.46 | 19.5% | 21.9% | 26.8% | 18.8% | 13.0% | $14.76 | $17.27 |
| Detroit | 1.21 | 34,729 | 28,702 | 13.80 | 16.14 | 22.0% | 21.2% | 25.8% | 18.7% | 12.3% | $15.45 | $18.07 |
| Boston | 1.39 | 40,647 | 29,242 | 14.06 | 16.45 | 17.5% | 18.4% | 24.9% | 21.3% | 17.8% | $15.17 | $17.74 |
| Washington, DC | 1.52 | 46,856 | 30,826 | 14.82 | 17.34 | 10.4% | 17.2% | 25.9% | 23.7% | 22.7% | $15.54 | $18.17 |
| Dallas | 1.36 | 32,825 | 24,136 | 11.60 | 13.57 | 19.3% | 25.6% | 26.8% | 16.9% | 11.3% | $13.47 | $15.75 |
| Houston | 1.32 | 31,488 | 23,855 | 11.47 | 13.42 | 22.3% | 25.0% | 25.2% | 16.3% | 11.2% | $13.51 | $15.80 |
| Miami | 1.21 | 28,503 | 23,556 | 11.33 | 13.25 | 26.0% | 26.1% | 24.0% | 14.1% | 9.8% | $13.73 | $16.07 |
| Atlanta | 1.40 | 36,051 | 25,751 | 12.38 | 14.48 | 17.2% | 23.1% | 27.8% | 19.0% | 12.9% | $13.89 | $16.25 |
| Cleveland | 1.17 | 30,332 | 25,925 | 12.46 | 14.58 | 24.0% | 25.4% | 26.8% | 15.3% | 8.5% | $14.39 | $16.84 |
| Seattle | 1.30 | 35,047 | 26,959 | 12.96 | 15.16 | 17.4% | 24.2% | 29.1% | 18.4% | 10.9% | $14.48 | $16.94 |
| San Diego | 1.39 | 35,022 | 25,196 | 12.11 | 14.17 | 17.9% | 24.3% | 26.7% | 18.2% | 12.9% | $13.78 | $16.12 |
| Minneapolis | 1.40 | 36,564 | 26,117 | 12.56 | 14.69 | 16.6% | 22.8% | 29.5% | 19.7% | 11.4% | $13.80 | $16.14 |
| St. Louis | 1.24 | 31,706 | 25,569 | 12.29 | 14.38 | 21.9% | 24.7% | 27.7% | 16.7% | 9.0% | $14.10 | $16.50 |
| Baltimore | 1.35 | 36,550 | 27,074 | 13.02 | 15.23 | 18.2% | 21.8% | 27.3% | 19.5% | 13.1% | $14.43 | $16.88 |
| Pittsburgh | 1.07 | 26,501 | 24,767 | 11.91 | 13.93 | 28.2% | 27.4% | 24.7% | 12.6% | 7.0% | $14.37 | $16.81 |
| Phoenix | 1.23 | 30,797 | 25,038 | 12.04 | 14.08 | 21.1% | 27.3% | 27.0% | 15.3% | 9.2% | $14.04 | $16.42 |
| Tampa | 1.05 | 26,036 | 24,796 | 11.92 | 13.95 | 26.3% | 30.8% | 24.9% | 11.5% | 6.5% | $14.46 | $16.91 |
| Denver | 1.31 | 33,126 | 25,287 | 12.16 | 14.22 | 19.5% | 25.0% | 27.4% | 17.4% | 10.7% | $13.95 | $16.32 |
| Cincinnati | 1.25 | 30,979 | 24,783 | 11.92 | 13.94 | 23.1% | 25.2% | 27.0% | 15.9% | 8.8% | $13.70 | $16.03 |
| Milwaukee | 1.28 | 32,359 | 25,280 | 12.15 | 14.22 | 21.3% | 24.5% | 28.7% | 17.1% | 8.4% | $13.68 | $16.00 |
| Kansas City | 1.28 | 31,948 | 24,959 | 12.00 | 14.04 | 20.9% | 25.9% | 28.0% | 16.4% | 8.7% | $13.61 | $15.92 |
| Sacramento | 1.23 | 32,734 | 26,613 | 12.79 | 14.97 | 20.2% | 24.9% | 27.0% | 17.7% | 10.2% | $14.72 | $17.22 |
| Portland | 1.26 | 31,070 | 24,659 | 11.86 | 13.87 | 20.8% | 27.1% | 28.5% | 15.4% | 8.2% | $13.60 | $15.91 |
| Norfolk | 1.41 | 30,841 | 21,873 | 10.52 | 12.30 | 20.1% | 28.2% | 28.8% | 15.7% | 7.2% | $12.04 | $14.08 |
| Columbus | 1.29 | 30,668 | 23,774 | 11.43 | 13.37 | 22.0% | 26.7% | 27.9% | 15.3% | 8.1% | $13.14 | $15.38 |
| San Antonio | 1.26 | 26,092 | 20,708 | 9.96 | 11.65 | 27.8% | 28.8% | 24.5% | 12.3% | 6.6% | $12.08 | $14.13 |
| Indianapolis | 1.30 | 31,655 | 24,350 | 11.71 | 13.70 | 20.4% | 26.5% | 27.9% | 16.5% | 8.7% | $13.45 | $15.73 |
| New Orleans | 1.13 | 24,442 | 21,630 | 10.40 | 12.17 | 32.7% | 26.1% | 22.7% | 11.8% | 6.7% | $12.97 | $15.17 |
| Buffalo | 1.15 | 28,084 | 24,421 | 11.74 | 13.74 | 26.8% | 26.1% | 26.4% | 14.0% | 6.7% | $13.75 | $16.08 |
| Charlotte | 1.37 | 31,126 | 22,720 | 10.92 | 12.78 | 21.2% | 26.6% | 27.9% | 15.9% | 8.4% | $12.57 | $14.70 |
| Providence | 1.27 | 31,857 | 25,084 | 12.06 | 14.11 | 23.5% | 23.3% | 27.4% | 16.7% | 9.2% | $13.71 | $16.04 |
| Hartford | 1.37 | 41,440 | 30,248 | 14.54 | 17.01 | 15.0% | 19.1% | 26.7% | 22.8% | 16.3% | $15.51 | $18.15 |
| Orlando | 1.38 | 31,230 | 22,630 | 10.88 | 12.73 | 19.2% | 28.3% | 28.4% | 15.6% | 8.5% | $12.59 | $14.73 |
| Salt Lake City | 1.38 | 30,882 | 22,378 | 10.76 | 12.59 | 19.7% | 28.4% | 29.8% | 15.1% | 6.9% | $12.22 | $14.30 |
| Rochester | 1.28 | 34,234 | 26,745 | 12.86 | 15.04 | 19.8% | 23.4% | 27.9% | 18.5% | 10.4% | $14.39 | $16.83 |
| UNWEIGHTED AVERAGES (not based on population) | 1.29 | $33,131 | $25,548 | $12.28 | $14.37 | | | | | | $13.99 | $16.37 |

Source: Journey-To-Work Trends in the United States and its Major Metropolitan Areas 1960-1990, FHWA, November 1993. Publication #FHWA-PL-94-012 HPM-40/12-93 (500)P. Pages 3-15 & 3-16.

we have assumed that individuals value their time in-vehicle at rates corresponding to the weighted average rates of take-home pay.

To show the sensitivity of our travel time calculations to variations in individual travel time values, we included such variations as "Sensitivity Analysis 1" in our table. Some research (for example, for more recreational-type trips or less urgent, non-commuting type trips) has suggested that travel time values are somewhere on the order of two-thirds of the individual's hourly wage rate. Other research has pointed out that commuting trips involve effective travel time values on the order of twice or even three times the individual's hourly wage rate. The reader will notice that our annual travel time savings estimates will vary correspondingly.

In the other sensitivity analysis, we varied our estimates of average vehicle occupancy rates. Using, in this example, the Boston metropolitan area's average vehicle occupancy rate of 1.07 for its urban expressways, we see that the annual travel time savings estimates drops to just under $22.8 million. In any case, the range of travel time savings estimates is carried over to our overall benefit/cost summary table 2-5.

The second major category of benefits are roadway accidents avoided as a direct result of some of the safety features of an AHS system (outlined in an earlier task on safety in this report). To estimate such savings, we first calculated the vehicle miles of travel on this portion of roadway (see table). Using the average societal costs of accidents on urban interstates developed by the National Highway Traffic and Safety Administration, we then estimated the cost of accidents on this portion of Boston's I-93 without the introduction of AHS. To calculate accident savings, we then used an upper and lower range to develop a mean value of reduction in this cost. Although an imprecise method for valuing accident savings, we believed that this method allows for useful insight to be developed on the order of magnitude of such savings. Clearly, valuing accident benefits from AHS will be a fruitful area for further research. A more detailed discussion on our accident benefits valuation now follows:

### 3.3.2.2 Calculating Accident Costs and Savings

To calculate the value of the savings to society of accidents avoided through the use of AHS, it was decided to use the widely-accepted figures produced by the National Highway Traffic Safety Administration (NHTSA). In its publication The Economic Cost of Motor Vehicle Crashes, 1990, NHTSA places a value on the total costs of all three types of accidents: fatal (those resulting one or more deaths), injury-causing (those producing at least one injury), and property-damage-only. The cost to society, as determined by NHTSA, includes only measurable items, such as medical costs, workplace productivity losses, household productivity losses, car repair/replacement costs, legal expenses, traffic delays experienced by other motorists, etc.. The figures do not include valuations of unmeasurable cost items such as emotional harm, negative impacts to family structure, etc.. Because of this, the cost estimates of automobile accidents, and thus also of savings from accidents avoided, can be considered conservative.

**Table 2-5. Boston I-93: Northbound — Costs/Benefits**

**OTHER BENEFITS**

**TOTAL VALUE OF ACCIDENTS AVOIDED AS A RESULT OF IMPLEMENTING AHS**

| | |
|---|---|
| Total cost of all types of accidents per million VMT on urban interstates: | $18,182 * |
| Estimated Annual VMT on Selected Portion of I-93 (millions) | 482.4 |
| Estimated cost of collisions on I-93 without AHS | $8,770,236 |
| Estimated Benefits (Savings) from Safety Improvements: | |
| Upper Range (85% reduction) | $7,454,701 |
| Lower Range (30% reduction) | $2,631,071 |

**Mean value of savings resulting from accidents avoided: $5,042,886**

**TOTAL MULTIPLIER BENEFITS OF CONSTRUCTING, OPERATING & MAINTAINING SYSTEM**
(the multiplier below reflects the difference between the effect of dollars spent on AHS minus the effect of the same amount spent by households)

| Total change in output: | | Multiplier Used | Additional Annual Output |
|---|---|---|---|
| Annual Operations & Maintenance Cost: | $4,070,000 | 1.0170 | $4,139,190 |

**COSTS**

| | Estimated Costs |
|---|---|
| **TOTAL CONSTRUCTION COSTS, ROADWAY PORTION:** | $454,415,500 |
| **ANNUAL O&M COSTS (above existing O&M expenses)**<br>$500,000 per mile for: 8.14 miles of roadway | $4,070,000 |
| **TOTAL INFRASTRUCTURE ELECTRONICS COSTS (10-year life cycle):** | $19,300,000 |
| **TOTAL ON-BOARD VEHICLE INSTRUMENTATION COSTS (8-year lifespan):**<br>Cost per car: $1,800 Est. number of cars regularly using AHS lanes: 98,200 | $176,760,000 |

* Source: Calspan safety analysis/NHTSA

The valuation figures provided in the NHTSA publication above are broken down only by type of accident (as opposed to cost per-injury, per-vehicle involved, or per Vehicle Miles Traveled). The total cost of each accident-type includes all types of damage suffered. For example, the figure for "fatal crashes" includes (in addition to the cost of all driving-related deaths) the cost of all injuries sustained by surviving vehicle occupants or involved pedestrians, and all property damage suffered by all vehicles involved in all crashes which resulted in at least one death, as well as the traffic delay, productivity losses, and other costs mentioned above.

The figures arrived at by NHTSA are as follows for 1990. Inflated figures shown in the 1994 column are updated based on changes in the national CPI.

| Figures are in millions of dollars: | 1990 $ | 1994 $ |
|---|---|---|
| Total cost of all fatal crashes: | $ 31,273 | $ 35,221 |
| Total cost of all injury-causing crashes | $ 70,614 | $ 79,529 |
| Total cost of all property-damage-only (PDO) crashes | $ 35,597 | $ 40,091 |

To make these value figures useful to our analysis, it was necessary to convert them into a cost per vehicle mile traveled (VMT) figure. The data also had to be adapted to interstates (the most likely candidates for automation) because these highways are much safer than the other road types which are included in NHTSA's all-roads value figures. These modifications were achieved, following the methodology outlined below, using information from other NHTSA sources, most from a 1993-4 publication: Traffic Safety Facts 1992 (Revised). All figures from NHTSA include estimates of unreported incidents.

To adapt the numbers for use on interstates, the following data was obtained on the total # of vehicle-collisions (the number of vehicles involved in crashes) and the total vehicle miles traveled on all Interstates in 1992.

| | Urban | Suburban | Rural |
|---|---|---|---|
| Vehicle-Collisions | 252,362 | 182,028 | 67,733 |
| VMT (millions) | 190,217 | 95,108 | 205,011 |

The number of vehicle collisions on the Interstates was broken down into severity types using the 1992 distribution for all roads in the United States:

| | Total for All Roads | | Vehicle Collisions on All Interstates | | |
|---|---|---|---|---|---|
| | Total Vehicle Collisions | Percent Distribution | Urban | Suburban | Rural |
| TOTAL | 10,447,878 | 100.0% | 252,362 | 182,028 | 67,733 |
| Fatal | 50,878 | 0.5% | 1,229 | 886 | 330 |
| Injury-causing | 3,554,000 | 34.0% | 85,845 | 61,920 | 23,040 |
| PDO | 6,843,000 | 65.5% | 165,288 | 119,222 | 44,363 |

Numbers in **bold** are from NHTSA, all others are calculated.

Using the above estimates of total vehicle collisions by type, simple multiplication by the cost per vehicle-collision values yields a total cost figure for the Interstates:

| | Total Estimated Vehicle-Collisions on Interstates | | | Cost per Veh-coll | Total Estimated Cost of all Interstate Veh-Collisions (thousands of 1994 $) | | |
|---|---|---|---|---|---|---|---|
| | Urban | Suburban | Rural | 1994 $ | Urban | Suburban | Rural |
| Fatalities | 1,229 | 886 | 330 | $609,814 | $749,416 | $540,552 | $201,140 |
| Injuries | 85,845 | 61,920 | 23,040 | $21,174 | $1,817,652 | $1,311,067 | $487,851 |
| PDO | 165,288 | 119,222 | 44,363 | $5,394 | + $891,505 | + $643,040 | +$239,277 |
| Total | | | | | $3,458,573 | $2,494,659 | $928,268 |

Dividing the total cost figure by the total number of vehicle miles traveled (VMT) on all Interstates yields a reasonable estimate of the total cost to society of all types of vehicle collisions on Interstates in 1992 (the most recent year for which data is available):

FOR ALL INTERSTATES

| | Total Cost of All Collisions (thous of 1994 $) | | Total Vehicle Miles Traveled (VMT) (millions) | | Cost per Million VMT (1994 $) |
|---|---|---|---|---|---|
| Urban | $3,458,573 | X | 190,217 | = | $18,182 |
| Suburban | $2,494,659 | X | 95,108 | = | $26,230 |
| Rural | $928,268 | X | 205,011 | = | $4,528 |

Numbers in bold are from NHTSA, all others are calculated.

These cost-per-VMT figures can then be easily applied to the annual VMT figures for the study's four sample AHS roadways to estimate the current and future cost of vehicular accidents.

#### 3.3.2.2.1 Accident Data Quality

One potential problem with the above estimates is that they may be too high for use in calculating accident costs in the next century. Looking at trends over the 1975-1992 period for which records have been kept, the number of vehicle collisions per VMT has decreased steadily every year. Additionally, the rate of (expensive) fatal collisions per VMT has dropped even faster than the injury and PDO collision rate. Thus by the time AHS is fully implemented, the cost of accidents per VMT could be far less than it was in 1992 (a year before the widespread use of airbags, anti-lock brakes, and any number of other upcoming improvements in safety standards). Or, it might similarly be envisioned that the accident rate may simply level off, as many of the basic safety improvements to cars, roadways, and human behavior have already been made (use of safety belts, reduced speed limits, decreasing incidences of DWI). Because of the lack of sufficient data to project future accident rates, particularly on Interstates, the estimates of future accident cost savings in this report will be based on 1990 costs and 1992 accident rates.

Other potential problems relate to the vehicle mix of traffic on AHS roadways. As the vehicle mix allowed onto the AHS lanes varies, so will the number and severity of accidents. Compared to passenger vehicles, large trucks, for example, have a much higher rate of fatal accidents, but a much lower rate of non-fatal accidents per vehicle miles traveled. Motorcycles, in particular, have a much higher rate of collisions per VMT than other vehicle types. Depending on how AHS is implemented, the collision rate could drop dramatically as human error and weather conditions are eliminated as factors, or, under some scenarios, with all the large trucks, motorcycles, and older, non-AHS-equipped vehicles confined to a single non-AHS lane or shunted onto non-interstates with lower safety standards, the overall collision rate can be imagined to increase. Considering the level of development of the full range of RSCs (with their various vehicle mixes), it would be impossible to estimate the overall effect of AHS on traffic safety. Additionally, at this stage, it would be unfair to use the most pessimistic assumptions in analyzing the full economic impact of AHS. For this reason, we have decided to apply CALSPAN's accident reduction range to all traffic in the four sample roadway segments.

#### 3.3.2.2.2 Accident Reduction: Summary

It was estimated by CALSPAN that there would be a 30% to 85% reduction in the total number of accidents. This figure was based on data on the reported causes of interstate accidents. Under AHS, not only would the number of accidents caused by human error decrease, but also the number of accidents due to equipment failure, as vehicles would have to meet higher inspection standards under most of the AHS scenarios.

#### 3.3.2.3 Multiplier Benefits

The third major category of benefits are the so-called "secondary" or multiplier benefits of operating and maintaining the AHS system. These effects arise out of the job creation and output-generating potential of AHS, and such benefits will be used to justify the use of public resources and other assistance to operate such systems nationwide. To estimate such effects, we had to determine the dollar value of all direct expenditures to be made on operating and maintaining the system. Typically, in secondary economic studies, one-time capital costs of construction are also used to generate construction multipliers. Construction benefits were specifically excluded from this analysis for a simple reason. Constructing the system involves essentially a transfer of resources from one type of highway construction to another, with the result that little net addition to societal output can be expected. Of course, there will be specific components of roadway construction (such as the embedded roadway) that will involve specialized labor resources put into a use not seen before the advent of AHS. And therefore, adding construction multipliers to estimate the secondary effects on temporary jobs and output could be appropriate. But we felt that the analysis should err on the conservative side here. Future cost-benefit analyses may appropriately include such effects on the benefits side.

Using our estimate of dollars to be used on ongoing operations and maintenance of the roadways, we then used a set of economic multipliers supplied by an input-output process known as RIMS II to determine the secondary or indirect economic effects of the direct expenditures. Such secondary effects include the economic influences on all businesses related to the direct operation and maintenance of the system, ranging from direct suppliers of goods and services (concrete manufacturers, asphalt producers, etc.) to the suppliers of manpower employed by this work. The U.S. Department of Commerce, Bureau of Economic Analysis, develops RIMS II multipliers for regions all over the country and for specific industrial and commercial classifications.

RIMS II is based upon an analytical framework called an input-output (I-O) table. An I-O table shows, for each industry classification, the distribution of inputs used in the process and the outputs sold. This framework is then used to quantify, for each dollar spent on that industry, the increase in total regional output (gross receipts or sales) over all industries or sectors generated as a result of activity in that industry. We used RIMS II multipliers adjusted for the region in which our representative roadway was located. For Boston's I-93, we used multipliers adjusted for 1994 conditions in Massachusetts. While the RIMS II process may be imprecise, it is widely used, it is easy to use, and for a minor investment, it is inexpensive to use. Empirical studies have shown that RIMS II multipliers generate results that are not substantially different in magnitude from those generated by more precise regional I-O models based on costly survey data. There are more complicated models to use in this type of analysis (such as the Wharton Econometric Forecasting Model), but there are universally more costly to procure and run, and may yield similar magnitude results anyway.

This concluded our benefits evaluation, and the estimates are shown in our final summary benefit-cost evaluation matrix which will follow below. On the cost side, we estimated first the one-time construction costs of our roadways; the annual operating and maintenance costs over and above existing roadway costs; total infrastructure electronics costs (roadway electronics, which we estimated carried a 10-year lifespan, with major replacement occurring once in a decade); and, finally, on-board vehicle electronics costs (which we estimated parametrically at $1,800 per vehicle). Our work on construction costs is now explained in greater detail.

#### 3.3.2.4 Construction Cost Estimates

The construction costs per mile for our four roadway deployment scenarios (Long Island Expressway (LIE), NYS Thruway, I-93 Boston and 405 Beltway Washington) were based upon factored cost estimates developed for New York's LIE. The I2 and I3 system configurations are presented in tables 2-6a through 2-6c.

The unit costs per mile estimated for the LIE project are based on the direct quantities taken from the conceptual horizontal alignment layouts and typical cross sections developed at this stage of the project. The LIE project extends for 17.6 miles from Exit 30 (Cross Island Parkway) in eastern Queens County to Exit 49 located near the Nassau County/Suffolk County line.

Based on the conceptual layouts developed for this stage of the project it appears that no significant R.O.W. acquisitions would be required to accommodate the proposed AHS scenarios. Cost estimates for the HOV alternative prepared for the LIE Capacity Improvement Project have been used as a basis for estimating AHS LIE project costs for the I2 and I3 concepts. These cost estimates are summarized in

Table 2-6a. AHS Construction Cost per Mile for all Roadway Deployment Scenarios with I2 and I3 Concept (in millions of 1994 dollars)

| ROADWAY | Length of Segment (miles) | I-2 | | I-3 | | HOV | |
|---|---|---|---|---|---|---|---|
| | | Per-Mile Cost | Total Cost | Per-Mile Cost | Total Cost | Per-Mile Cost | Total Cost |
| LONG ISLAND EXPRESSWAY | 14.8 | $31.6 | $468 | $36.1 | $16,883 | $16.2 | $239.8 |
| NYS THRUWAY | 31 | $22.8 | $707 | $24.2 | $17,105 | N/A | N/A |
| I-93 BOSTON | 8.14 | $55.8 | $454 | $64.0 | $29,080 | N/A | N/A |
| 495 BELTWAY WASHINGTON | 9.3 | $47.5 | $441 | $54.4 | $24,006 | N/A | N/A |

Table 2-6b. Construction Cost Estimates (continued)

ALTERNATIVE I2

| | AREA 1A ( 0.8 MI) | | | AREA 1B (1.1 MI) | | | AREA 1C (9.6 MI) | | | AREA 2 (6.1 MI) | | | TOTAL (17.6 MI) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HOV | d | AHS | HOV | d | AHS | HOV | d | AHS | HOV | d | AHS | HOV | d | AHS |
| PAVEMENT | 2.9 | 1.9 | 4.9 | 3.6 | 2.8 | 6.4 | 23.8 | 3.0 | 26.8 | 9.0 | 8.4 | 17.4 | 39.3 | 16.1 | 55.[illegible] |
| BRIDGES | 12.1 | 2.5 | 14.6 | 9.5 | 1.0 | 10.5 | 44.1 | 8.0 | 52.1 | 7.3 | 15.0 | 22.3 | 72.9 | 26.5 | 99.[illegible] |
| RETAINING WALLS | 2.3 | 2.9 | 5.2 | 8.7 | 2.6 | 11.3 | 12.0 | 38.2 | 50.2 | 0.7 | 13.0 | 13.7 | 23.7 | 56.7 | 80.[illegible] |
| MISC. ITEMS | 5.2 | 1.9 | 7.1 | 7.1 | 3.0 | 10.1 | 31.8 | 10.3 | 42.1 | 21.6 | 10.9 | 32.5 | 65.8 | 26.1 | 91.[illegible] |
| AHS LANES | | 3.8 | 3.8 | 0.0 | 5.3 | 5.3 | 0.0 | 45.8 | 45.8 | 0.0 | 12.8 | 12.8 | 0.0 | 67.7 | 67.[illegible] |
| TCO | 22.5 | 13.1 | 35.6 | 28.9 | 14.7 | 43.6 | 111.6 | 105.3 | 217.0 | 38.6 | 60.1 | 98.7 | 201.7 | 193.1 | 394.[illegible] |
| SURVEY (3%) | 0.7 | 0.4 | 1.1 | 0.9 | 0.4 | 1.3 | 3.3 | 3.2 | 6.5 | 1.2 | 1.8 | 3.0 | 6.1 | 5.8 | 11.[illegible] |
| MOT (10%) | 2.3 | 1.3 | 3.6 | 2.9 | 1.5 | 4.4 | 11.2 | 10.5 | 21.7 | 3.9 | 6.0 | 9.9 | 20.2 | 19.3 | 39.[illegible] |
| SUBTOTAL | 25.4 | 14.8 | 40.2 | 32.7 | 16.6 | 49.3 | 126.2 | 119.0 | 245.2 | 43.7 | 67.9 | 111.6 | 227.9 | 218.3 | 446.[illegible] |
| MOBILIZATION (4%) | 1.0 | 0.6 | 1.6 | 1.3 | 0.7 | 2.0 | 5.0 | 4.8 | 9.8 | 1.7 | 2.7 | 4.5 | 9.1 | 8.7 | 17.[illegible] |
| SUBTOTAL | 26.4 | 15.4 | 41.8 | 34.0 | 17.2 | 51.2 | 131.2 | 123.8 | 255.0 | 45.4 | 70.6 | 116.0 | 237.1 | 227.0 | 464.[illegible] |
| CONTINGENCIES (20%) | 5.3 | 3.1 | 8.4 | 6.8 | 3.4 | 10.2 | 26.2 | 24.8 | 51.0 | 9.1 | 14.1 | 23.2 | 47.4 | 45.4 | 92.[illegible] |
| TOTAL COST | 31.7 | 18.4 | 50.2 | 40.8 | 20.7 | 61.5 | 157.4 | 148.5 | 306.0 | 54.5 | 84.8 | 139.3 | 284.5 | 272.4 | 556.[illegible] |
| COST PER MILE | 39.7 | 23.0 | 62.7 | 37.1 | 18.8 | 55.9 | 16.4 | 15.5 | 31.9 | 8.9 | 13.9 | 22.8 | 16.2 | 15.5 | 31.[illegible] |

Table 2-6b. Construction Cost Estimates (continued)

ALTERNATIVE I3

| | AREA 1A ( 0.8 MI) | | | AREA 1B (1.1 MI) | | | AREA 1C (9.6 MI) | | | AREA 2 (6.1 MI) | | | TOTAL (17.6 MI) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HOV | d | AHS | HOV | d | AHS | HOV | d | AHS | HOV | d | AHS | HOV | d | AHS |
| PAVEMENT | 2.9 | 3.6 | 6.5 | 3.6 | 0.7 | 4.3 | 23.8 | 10.9 | 34.7 | 9.0 | 12.8 | 21.8 | 39.3 | 28.0 | 67. |
| BRIDGES | 12.1 | 15.1 | 27.2 | 9.5 | 0.3 | 9.8 | 44.1 | 36.2 | 80.3 | 7.3 | 13.8 | 21.1 | 72.9 | 65.4 | 138. |
| RETAINING WALLS | 2.3 | 2.9 | 5.2 | 8.7 | 1.9 | 10.6 | 12.0 | 38.2 | 50.2 | 0.7 | 10.0 | 10.7 | 23.7 | 53.0 | 76. |
| MISC. ITEMS | 5.2 | 4.4 | 9.6 | 7.1 | 1.3 | 8.4 | 31.8 | 13.0 | 44.8 | 21.6 | 16.6 | 38.2 | 65.8 | 35.3 | 101. |
| AHS LANES | | 3.8 | 3.8 | 0.0 | 5.3 | 5.3 | 0.0 | 45.8 | 45.8 | 0.0 | 12.8 | 12.8 | 0.0 | 67.7 | 67. |
| TCO | 22.5 | 29.8 | 52.3 | 28.9 | 9.5 | 38.4 | 111.6 | 144.1 | 255.8 | 38.6 | 66.0 | 104.6 | 201.7 | 249.4 | 451. |
| SURVEY (3%) | 0.7 | 0.9 | 1.6 | 0.9 | 0.3 | 1.2 | 3.3 | 4.3 | 7.7 | 1.2 | 2.0 | 3.1 | 6.1 | 7.5 | 13. |
| MOT (10%) | 2.3 | 3.0 | 5.2 | 2.9 | 1.0 | 3.8 | 11.2 | 14.4 | 25.6 | 3.9 | 6.6 | 10.5 | 20.2 | 24.9 | 45. |
| SUBTOTAL | 25.4 | 33.7 | 59.1 | 32.7 | 10.7 | 43.4 | 126.2 | 162.8 | 289.0 | 43.7 | 74.6 | 118.2 | 227.9 | 281.8 | 509. |
| MOBILIZATION (4%) | 1.0 | 1.3 | 2.4 | 1.3 | 0.4 | 1.7 | 5.0 | 6.5 | 11.6 | 1.7 | 3.0 | 4.7 | 9.1 | 11.3 | 20. |
| SUBTOTAL | 26.4 | 35.0 | 61.5 | 34.0 | 11.2 | 45.2 | 131.2 | 169.4 | 300.6 | 45.4 | 77.6 | 123.0 | 237.1 | 293.1 | 530. |
| CONTINGENCIES (20%) | 5.3 | 7.0 | 12.3 | 6.8 | 2.2 | 9.0 | 26.2 | 33.9 | 60.1 | 9.1 | 15.5 | 24.6 | 47.4 | 58.6 | 106. |
| TOTAL COST | 31.7 | 42.0 | 73.8 | 40.8 | 13.4 | 54.2 | 157.4 | 203.2 | 360.7 | 54.5 | 93.1 | 147.6 | 284.5 | 351.7 | 636. |
| COST PER MILE | 39.7 | 52.5 | 92.2 | 37.1 | 12.2 | 49.3 | 16.4 | 21.2 | 37.6 | 8.9 | 15.3 | 24.2 | 16.2 | 20.0 | 36. |

tables 2-6b and 2-6c. The project costs are estimated for the following "big ticket" items:

pavement
bridges
retaining walls
AHS lanes
other miscellaneous items (earthwork, drainage, conc. barriers, etc.)
survey (3% of total cost of operations - TCO)
maintenance and protection of traffic (10% of TCO)
mobilization (4% of TCO)
contingencies (20% of TCO)

The project cost estimates are prepared separately for four distinct LIE segments:

Area 1A covering Cross Island Parkway Interchange (0.8 miles),

Area 1B located between Douglaston Parkway and Marathon Parkway, (1.1 miles),

Area 1C which extends from Marathon Parkway to Exit 40, Jericho Turnpike (9.6 miles),

Area 2 which extends from Exit 40 to Exit 49 at the Nassau County/Suffolk County line (6.1 miles)

Proposed work in area 1A includes Cross Island Parkway Interchange redesign. Therefore, area 1A would have the highest unit costs per mile of highway. Proposed work in area 1B would involve outside widening with relatively high retaining walls because of the constrained R.O.W. conditions.

The physical features and R.O.W. constraints of the I-93 Boston Project and 495 Beltway Washington Project are similar to the ones of areas 1A and 1B of the LIE Project.

Therefore, unit costs per mile for areas 1A and 1B were averaged and then factored to derive to the unit costs for these projects.

The unit costs for area 2 are relatively low. This area contains a 38-foot-wide grassed center median which allows to avoid extensive use of retaining walls. It would also minimize required bridge reconstruction.

The physical features of the NYS Thruway Project are similar to the ones of area 2 of the LIE Project. Therefore, for the purpose of this cost estimate, the unit costs per mile for the NYS Thruway are assumed to be equal to the estimated unit costs for area 2.

### 3.3.2.5 Summary of Benefit-Cost Analysis: Net Present Value and IRR

To summarize our findings, we developed a cost-benefit template that we hope will be used for future economic and financial analyses of such systems. The template is given in table 2-7, in this case for Boston's I-93 corridor.

The table shows the benefit categories on the left hand side. Each annual estimate is inflated by a factor (3 percent) to reflect the growth of traffic or population. Although a classic analysis could be carried ad infinitum, we analyzed projected costs and benefits over a 50-year lifetime to capture any major upgrades or betterments that may be needed over typical systems.

Roadway construction costs as well as system infrastructure costs are incurred prior to the capture of system benefits. Since these dollars are the most "valuable" expenditures of society's resources, they are discounted by a present value factor of "one". All other costs are discounted to present value by an assumed social rate of discount of 7 (seven) percent. Costs are similarly inflated by an annual factor of 3 (three) percent.

The table is important. Total annual costs are subtracted from total annual benefits to yield a column headed "Annual Net Benefits". The net present value of these net benefits, at an assumed rate of discount of 7 (seven) percent, is given at the bottom of the column. If this NPV is positive, then the project should be undertaken. If the NPV is zero or negative, then the project should not be undertaken. Another way of evaluating the project is through the internal rate of return (IRR) calculation. The IRR is the interest rate that equalizes the stream of future discounted costs and benefits. That is, it is a derived rate that enables the sum of the "Discounted Net Benefits" column to be zero. This rate is calculated based upon the benefit and costs stream and is then shown at the top of the column titled "Discount factor at ___ %". Clearly, a negative IRR indicates that projected discounted project benefits are not sufficient to outweigh projected project discounted costs, and that the projects should similarly not be undertaken.

The entire cost-benefit summary analysis is then contained within a set of three analytical tables for each roadway examined. Three tables each (tables 2-8a through table 2-10c), ending with the final summary evaluation, for the I-495 Beltway in Maryland, the New York State Thruway 100 km/hour option, as well as the Thruway 129 km/hour option.

An analysis of the Long Island Expressway now follows. It is slightly different from the above estimates in that commercial and transit vehicles are specifically included as separate components of traffic flow. Doing this will yield some useful insight on commercial and transit costs and benefits.

### 3.3.3 Benefits and Costs of Commercial and Transit Vehicle Use of AHS:

The cost-benefit template for this roadway differs from the analysis presented above. Instead of concentrating on the hour surrounding the peak hour of traffic flow, the Long Island Expressway (LIE) scenario given in tables 2-11a through 2-11c focus on the morning peak period. For more specific descriptions of the roadway traffic profile, and a discussion of the many assumptions used, see this report's section on the Commercial and Transit applications of AHS, particularly the subsection on the LIE.

## Table 2-7. Boston I-93: Northbound

SCENARIO 12

| Year | Annual Travel Time Benefits | Annual Accident Benefits | Annual Multiplier Benefits from System O&M | TOTAL ANNUAL BENEFITS | CONSTRUCTION COSTS | O&M COSTS ABOVE EXISTING O&M | SYSTEM INFRASTRUCTUR COSTS | VEHICLE ELECTRONICS COSTS | TOTAL ANNUAL COSTS | NET BENEFITS | Discount Factor @: 1.2421% | DISCOUNTED NET BENEFITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | $0 | $454,415,500 | | $19,300,000 | $22,095,000 | $495,810,500 | ($495,810,500) | 1.000000 | ($495,810,500) |
| 1 | $25,570,054 | $5,042,886 | $4,139,190 | $34,752,129 | | $4,070,000 | | $22,757,850 | $26,827,850 | $7,924,279 | 0.987732 | $7,827,063 |
| 2 | 26,337,155 | 5,194,172 | 4,263,366 | 35,794,693 | | 4,192,100 | | 23,440,586 | 27,632,686 | 8,162,008 | 0.975614 | 7,962,970 |
| 3 | 27,127,270 | 5,349,997 | 4,391,267 | 36,868,534 | | 4,317,863 | | 24,143,803 | 28,461,666 | 8,406,868 | 0.963645 | 8,101,237 |
| 4 | 27,941,088 | 5,510,497 | 4,523,005 | 37,974,590 | | 4,447,399 | | 24,868,117 | 29,315,516 | 8,659,074 | 0.951823 | 8,241,905 |
| 5 | 28,779,321 | 5,675,812 | 4,658,695 | 39,113,828 | | 4,580,821 | | 25,614,161 | 30,194,982 | 8,918,846 | 0.940146 | 8,385,015 |
| 6 | 29,642,700 | 5,846,087 | 4,798,456 | 40,287,242 | | 4,718,245 | | 26,382,585 | 31,100,831 | 9,186,412 | 0.928612 | 8,530,611 |
| 7 | 30,531,981 | 6,021,469 | 4,942,409 | 41,495,860 | | 4,859,793 | | 27,174,063 | 32,033,856 | 9,462,004 | 0.917219 | 8,678,734 |
| 8 | 31,447,941 | 6,202,113 | 5,090,682 | 42,740,736 | | 5,005,587 | | 27,989,285 | 32,994,872 | 9,745,864 | 0.905967 | 8,829,430 |
| 9 | 32,391,379 | 6,388,177 | 5,243,402 | 44,022,958 | | 5,155,754 | | 28,828,963 | 33,984,718 | 10,038,240 | 0.894852 | 8,982,742 |
| 10 | 33,363,120 | 6,579,822 | 5,400,704 | 45,343,646 | | 5,310,427 | | 29,693,832 | 35,004,259 | 10,339,387 | 0.883874 | 9,138,716 |
| 11 | 34,364,014 | 6,777,217 | 5,562,725 | 46,703,956 | | 5,469,740 | 25,937,586 | 30,584,647 | 61,991,973 | (15,288,017) | 0.873031 | (13,346,906) |
| 12 | 35,394,934 | 6,980,533 | 5,729,607 | 48,105,074 | | 5,633,832 | | 31,502,187 | 37,136,019 | 10,969,056 | 0.862320 | 9,458,836 |
| 13 | 36,456,782 | 7,189,949 | 5,901,495 | 49,548,227 | | 5,802,847 | | 32,447,252 | 38,250,099 | 11,298,127 | 0.851741 | 9,623,077 |
| 14 | 37,550,486 | 7,405,648 | 6,078,540 | 51,034,673 | | 5,976,932 | | 33,420,670 | 39,397,602 | 11,637,071 | 0.841292 | 9,790,170 |
| 15 | 38,677,000 | 7,627,817 | 6,260,896 | 52,565,714 | | 6,156,240 | | 34,423,290 | 40,579,530 | 11,986,183 | 0.830970 | 9,960,164 |
| 16 | 39,837,310 | 7,856,652 | 6,448,723 | 54,142,685 | | 6,340,927 | | 35,455,989 | 41,796,916 | 12,345,769 | 0.820776 | 10,133,110 |
| 17 | 41,032,430 | 8,092,351 | 6,642,185 | 55,766,966 | | 6,531,155 | | 36,519,668 | 43,050,824 | 12,716,142 | 0.810706 | 10,309,059 |
| 18 | 42,263,403 | 8,335,122 | 6,841,450 | 57,439,975 | | 6,727,090 | | 37,615,258 | 44,342,348 | 13,097,626 | 0.800761 | 10,488,063 |
| 19 | 43,531,305 | 8,585,175 | 7,046,694 | 59,163,174 | | 6,928,903 | | 38,743,716 | 45,672,619 | 13,490,555 | 0.790937 | 10,670,175 |
| 20 | 44,837,244 | 8,842,731 | 7,258,095 | 60,938,069 | | 7,136,770 | | 39,906,028 | 47,042,797 | 13,895,272 | 0.781233 | 10,855,449 |
| 21 | 46,182,361 | 9,108,012 | 7,475,838 | 62,766,211 | | 7,350,873 | 34,857,947 | 41,103,209 | 83,312,028 | (20,545,817) | 0.771649 | (15,854,159) |
| 22 | 47,567,832 | 9,381,253 | 7,700,113 | 64,649,197 | | 7,571,399 | | 42,336,305 | 49,907,704 | 14,741,494 | 0.762182 | 11,235,705 |
| 23 | 48,994,867 | 9,662,690 | 7,931,116 | 66,588,673 | | 7,798,541 | | 43,606,394 | 51,404,935 | 15,183,739 | 0.752832 | 11,430,799 |
| 24 | 50,464,713 | 9,952,571 | 8,169,050 | 68,586,334 | | 8,032,497 | | 44,914,586 | 52,947,083 | 15,639,251 | 0.743596 | 11,629,281 |
| 25 | 51,978,654 | 10,251,148 | 8,414,121 | 70,643,924 | | 8,273,472 | | 46,262,023 | 54,535,495 | 16,108,428 | 0.734473 | 11,831,209 |
| 26 | 53,538,014 | 10,558,683 | 8,666,545 | 72,763,241 | | 8,521,676 | | 47,649,884 | 56,171,560 | 16,591,681 | 0.725463 | 12,036,643 |
| 27 | 55,144,154 | 10,875,443 | 8,926,541 | 74,946,139 | | 8,777,326 | | 49,079,381 | 57,856,707 | 17,089,431 | 0.716562 | 12,245,645 |
| 28 | 56,798,479 | 11,201,707 | 9,194,337 | 77,194,523 | | 9,040,646 | | 50,551,762 | 59,592,408 | 17,602,114 | 0.707772 | 12,458,275 |
| 29 | 58,502,433 | 11,537,758 | 9,470,167 | 79,510,358 | | 9,311,866 | | 52,068,315 | 61,380,180 | 18,130,178 | 0.699088 | 12,674,597 |
| 30 | 60,257,506 | 11,883,890 | 9,754,272 | 81,895,669 | | 9,591,222 | | 53,630,364 | 63,221,586 | 18,674,083 | 0.690512 | 12,894,676 |
| 31 | 62,065,231 | 12,240,407 | 10,046,901 | 84,352,539 | | 9,878,958 | 46,846,166 | 55,239,275 | 111,964,399 | (27,611,860) | 0.682041 | (18,832,408) |
| 32 | 63,927,188 | 12,607,619 | 10,348,308 | 86,883,115 | | 10,175,327 | | 56,896,453 | 67,071,780 | 19,811,335 | 0.673673 | 13,346,364 |
| 33 | 65,845,004 | 12,985,848 | 10,658,757 | 89,489,609 | | 10,480,587 | | 58,603,347 | 69,083,934 | 20,405,675 | 0.665408 | 13,578,107 |
| 34 | 67,820,354 | 13,375,423 | 10,978,519 | 92,174,297 | | 10,795,004 | | 60,361,448 | 71,156,452 | 21,017,845 | 0.657245 | 13,813,874 |
| 35 | 69,854,965 | 13,776,686 | 11,307,875 | 94,939,526 | | 11,118,855 | | 62,172,291 | 73,291,145 | 21,648,381 | 0.649182 | 14,053,735 |
| 36 | 71,950,614 | 14,189,987 | 11,647,111 | 97,787,712 | | 11,452,420 | | 64,037,460 | 75,489,880 | 22,297,832 | 0.641218 | 14,297,760 |
| 37 | 74,109,132 | 14,615,686 | 11,996,525 | 100,721,343 | | 11,795,993 | | 65,958,583 | 77,754,576 | 22,966,767 | 0.633351 | 14,546,023 |
| 38 | 76,332,406 | 15,054,157 | 12,356,420 | 103,742,983 | | 12,149,873 | | 67,937,341 | 80,087,214 | 23,655,770 | 6.3E-01 | 14,798,597 |
| 39 | 78,622,378 | 15,505,782 | 12,727,113 | 106,855,273 | | 12,514,369 | | 69,975,461 | 82,489,830 | 24,365,443 | 6.2E-01 | 15,055,556 |
| 40 | 80,981,050 | 15,970,955 | 13,108,926 | 110,060,931 | | 12,889,800 | | 72,074,725 | 84,964,525 | 25,096,406 | 6.1E-01 | 15,316,977 |
| 41 | 83,410,481 | 16,450,084 | 13,502,194 | 113,362,759 | | 13,276,494 | 62,957,329 | 74,236,967 | 150,470,790 | (37,108,031) | 6.0E-01 | (22,370,129) |
| 42 | 85,912,796 | 16,943,586 | 13,907,260 | 116,763,642 | | 13,674,789 | | 76,464,076 | 90,138,864 | 26,624,777 | 6.0E-01 | 15,853,516 |
| 43 | 88,490,179 | 17,451,894 | 14,324,478 | 120,266,551 | | 14,085,032 | | 78,757,998 | 92,843,030 | 27,423,521 | 5.9E-01 | 16,128,793 |
| 44 | 91,144,885 | 17,975,451 | 14,754,212 | 123,874,548 | | 14,507,583 | | 81,120,738 | 95,628,321 | 28,246,226 | 5.8E-01 | 16,408,849 |
| 45 | 93,879,231 | 18,514,714 | 15,196,839 | 127,590,784 | | 14,942,811 | | 83,554,360 | 98,497,171 | 29,093,613 | 5.7E-01 | 16,693,768 |
| 46 | 96,695,608 | 19,070,155 | 15,652,744 | 131,418,508 | | 15,391,095 | | 86,060,991 | 101,452,086 | 29,966,422 | 5.7E-01 | 16,983,635 |
| 47 | 99,596,477 | 19,642,260 | 16,122,326 | 135,361,063 | | 15,852,828 | | 88,642,821 | 104,495,649 | 30,865,414 | 5.6E-01 | 17,278,535 |
| 48 | 102,584,371 | 20,231,528 | 16,605,996 | 139,421,895 | | 16,328,413 | | 91,302,105 | 107,630,518 | 31,791,377 | 5.5E-01 | 17,578,555 |
| 49 | 105,661,902 | 20,838,474 | 17,104,176 | 143,604,551 | | 16,818,265 | | 94,041,168 | 110,859,434 | 32,745,118 | 5.5E-01 | 17,883,785 |
| 50 | 108,831,759 | 21,463,628 | 17,617,301 | 147,912,688 | | 17,322,813 | | 96,862,403 | 114,185,217 | 33,727,471 | 5.4E-01 | 18,194,315 |
| | $2,884,221,943 | $568,821,706 | $466,887,665 | $3,919,931,314 | $454,415,500 | $459,083,250 | $189,899,028 | $2,589,109,186 | $3,692,506,964 | $227,424,350 | | $0 |

NET PRESENT VALUE OF ANNUAL BENEFITS USING A DISCOUNT RATE OF 7% : ($334,213,711)

## Table 2-8a. Maryland I-495 (Beltway)

### PERFORMANCE RESULTS: A.M. PEAK PERIOD and HOURS CLOSEST TO PEAKS
### EVALUATION OF TRAVEL TIME SAVINGS

| M.O.E. | | PERCENTAGE OF EXISTING PEAK VOLUMES 79% | 83% | 92% | 96% | 100% |
|---|---|---|---|---|---|---|
| SPEED (m.p.h): | Existing Roadway | 59.5 | 56.6 | 48.8 | 41.4 | 35.5 |
| | AHS Roadway* | 61.0 | 60.6 | 60.1 | 59.5 | 56.5 |
| | Speed Increase: | 1.5 | 4.0 | 11.3 | 18.1 | 21.0 |
| Vehicle Miles of Travel (VMT) | Existing Roadway | 56,054 | 68,782 | 74,329 | 75,976 | 76,357 |
| | AHS Roadway | 54,264 | 66,075 | 74,350 | 81,667 | 88,425 |
| | Change in VMT: | (1,790) | (2,707) | 21 | 5,691 | 12,068 |
| Vehicle Hours of Travel (VHT) | Existing Roadway | 944.7 | 1,235.6 | 1,717.0 | 2,217.2 | 2,701.1 |
| | AHS Roadway | 894.8 | 1,099.6 | 1,250.6 | 1,395.0 | 1,715.2 |
| | Total Travel Time Savings from AHS (VHT): | 49.9 | 136.0 | 466.4 | 822.2 | 985.9 |
| | Duration of Traffic Volume In Daily Traffic Totals (hrs): | 1 | 2.5 | 2 | 1 | 1 |
| | Average Vehicle Occupancy: | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| | Avg. Per-Person Value of In-vehicle Travel Time: | $18.15 | $18.15 | $18.15 | $18.15 | $18.15 |
| | Value of Travel Time Saved: | $1,087 | $7,405 | $20,316 | $17,908 | $21,473 |

| | |
|---|---|
| Total Value of Travel Time Saved per Day, PEAK DIRECTION ONL | $68,189 |
| Daily Total Value of Travel Time, Both Directions: | $136,378 |
| **Total Annual Value of Travel Time Saved:** | **$35,458,188** |

| | Value of Total Annual Travel Time Benefits |
|---|---|
| **Sensitivity Analysis 1: Variation in the values of time** | |
| Average per-person values of in-vehicle travel time factors: | |
| at 67% of hourly wage rate: | $23,756,986 |
| at 200% of hourly wage rate: | $70,916,377 |
| at 300% of hourly wage rate: | $106,374,565 |
| **Sensitivity Analysis 2: Variation on Vehicle Occupancy** | |
| Using the D.C. Metro Area's Average Vehicle Occupancy of 1.13 | $33,389,794 |

* Assumes 50% of vehicles entering the corridor are AHS-equipped. (AHS & non-AHS-equipped vehicles both benefit, but at different rates.)

**Sources:** All Speed, VMT & VHT figures are from Dunn Associates.
The Average Vehicle Occupancy figure for the Washington, D.C. Metro Area is from FHWA's *Journey-To-Work Trends in the United States and its Major Metropolitan Areas 1960-1990*
Hourly wage figures are estimated using data from the same FHWA publication.

## Table 2-8c. Maryland I-495 (Beltway) (continued)

**SCENARIO I 2**

| Year | Annual Travel Time Benefits | Annual Accident Benefits | Annual Multiplier Benefits from System O&M | TOTAL ANNUAL BENEFITS | CONSTRUCTION COSTS | O&M COSTS ABOVE EXISTING O&M | SYSTEM INFRASTRUCTURE COSTS | VEHICLE ELECTRONICS COSTS | TOTAL ANNUAL COSTS | NET BENEFITS | Discount Factor @: -0.8749% | DISCOUNTED NET BENEFITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | $0 | $441,285,000 | | $19,300,000 | $30,397,050 | $490,982,050 | ($490,982,050) | 1.000000 | ($490,982,050) |
| 1 | $35,458,188 | $1,141,045 | $4,122,690 | $40,721,924 | | $4,650,000 | | $31,308,962 | $35,958,962 | $4,762,962 | 1.008826 | $4,805,001 |
| 2 | 36,521,934 | 1,175,277 | 4,246,371 | 41,943,581 | | 4,789,500 | | 32,248,230 | 37,037,730 | 4,905,851 | 1.017730 | 4,992,833 |
| 3 | 37,617,592 | 1,210,535 | 4,373,762 | 43,201,889 | | 4,933,185 | | 33,215,677 | 38,148,862 | 5,053,027 | 1.026713 | 5,188,008 |
| 4 | 38,746,120 | 1,246,851 | 4,504,975 | 44,497,946 | | 5,081,181 | | 34,212,148 | 39,293,328 | 5,204,617 | 1.035775 | 5,390,812 |
| 5 | 39,908,504 | 1,284,256 | 4,640,124 | 45,832,884 | | 5,233,616 | | 35,238,512 | 40,472,128 | 5,360,756 | 1.044917 | 5,601,544 |
| 6 | 41,105,759 | 1,322,784 | 4,779,328 | 47,207,870 | | 5,390,624 | | 36,295,667 | 41,686,292 | 5,521,579 | 1.054140 | 5,820,514 |
| 7 | 42,338,931 | 1,362,468 | 4,922,707 | 48,624,107 | | 5,552,343 | | 37,384,537 | 42,936,881 | 5,687,226 | 1.063444 | 6,048,044 |
| 8 | 43,609,099 | 1,403,342 | 5,070,389 | 50,082,830 | | 5,718,913 | | 38,506,074 | 44,224,987 | 5,857,843 | 1.072830 | 6,284,468 |
| 9 | 44,917,372 | 1,445,442 | 5,222,500 | 51,585,315 | | 5,890,481 | | 39,661,256 | 45,551,737 | 6,033,578 | 1.082299 | 6,530,134 |
| 10 | 46,264,893 | 1,488,805 | 5,379,175 | 53,132,874 | | 6,067,195 | | 40,851,093 | 46,918,289 | 6,214,585 | 1.091851 | 6,785,403 |
| 11 | 47,652,840 | 1,533,469 | 5,540,551 | 54,726,860 | | 6,249,211 | 25,937,586 | 42,076,626 | 74,263,423 | (19,536,563) | 1.101488 | (21,519,294) |
| 12 | 49,082,425 | 1,579,473 | 5,706,767 | 56,368,666 | | 6,436,687 | | 43,338,925 | 49,775,612 | 6,593,054 | 1.111210 | 7,326,268 |
| 13 | 50,554,898 | 1,626,858 | 5,877,970 | 58,059,726 | | 6,629,788 | | 44,639,093 | 51,268,881 | 6,790,845 | 1.121018 | 7,612,659 |
| 14 | 52,071,545 | 1,675,663 | 6,054,309 | 59,801,518 | | 6,828,682 | | 45,978,265 | 52,806,947 | 6,994,571 | 1.130912 | 7,910,246 |
| 15 | 53,633,692 | 1,725,933 | 6,235,939 | 61,595,563 | | 7,033,542 | | 47,357,613 | 54,391,156 | 7,204,408 | 1.140894 | 8,219,465 |
| 16 | 55,242,702 | 1,777,711 | 6,423,017 | 63,443,430 | | 7,244,548 | | 48,778,342 | 56,022,890 | 7,420,540 | 1.150964 | 8,540,772 |
| 17 | 56,899,983 | 1,831,043 | 6,615,707 | 65,346,733 | | 7,461,885 | | 50,241,692 | 57,703,577 | 7,643,156 | 1.161122 | 8,874,639 |
| 18 | 58,606,983 | 1,885,974 | 6,814,178 | 67,307,135 | | 7,685,741 | | 51,748,943 | 59,434,684 | 7,872,451 | 1.171371 | 9,221,557 |
| 19 | 60,365,192 | 1,942,553 | 7,018,604 | 69,326,349 | | 7,916,314 | | 53,301,411 | 61,217,725 | 8,108,624 | 1.181709 | 9,582,037 |
| 20 | 62,176,148 | 2,000,830 | 7,229,162 | 71,406,140 | | 8,153,803 | | 54,900,454 | 63,054,257 | 8,351,883 | 1.192139 | 9,956,608 |
| 21 | 64,041,433 | 2,060,855 | 7,446,037 | 73,548,324 | | 8,398,417 | 34,857,947 | 56,547,467 | 99,803,831 | (26,255,507) | 1.202661 | (31,576,485) |
| 22 | 65,962,676 | 2,122,680 | 7,669,418 | 75,754,774 | | 8,650,370 | | 58,243,891 | 66,894,261 | 8,860,513 | 1.213276 | 10,750,250 |
| 23 | 67,941,556 | 2,186,361 | 7,899,500 | 78,027,417 | | 8,909,881 | | 59,991,208 | 68,901,089 | 9,126,328 | 1.223985 | 11,170,488 |
| 24 | 69,979,802 | 2,251,951 | 8,136,485 | 80,368,239 | | 9,177,177 | | 61,790,944 | 70,968,121 | 9,400,118 | 1.234788 | 11,607,153 |
| 25 | 72,079,197 | 2,319,510 | 8,380,580 | 82,779,287 | | 9,452,493 | | 63,644,672 | 73,097,165 | 9,682,122 | 1.245687 | 12,060,888 |
| 26 | 74,241,572 | 2,389,095 | 8,631,997 | 85,262,665 | | 9,736,067 | | 65,554,013 | 75,290,080 | 9,972,585 | 1.256681 | 12,532,360 |
| 27 | 76,468,820 | 2,460,768 | 8,890,957 | 87,820,545 | | 10,028,149 | | 67,520,633 | 77,548,782 | 10,271,763 | 1.267773 | 13,022,263 |
| 28 | 78,762,884 | 2,534,591 | 9,157,686 | 90,455,161 | | 10,328,994 | | 69,546,252 | 79,875,246 | 10,579,916 | 1.278963 | 13,531,316 |
| 29 | 81,125,771 | 2,610,629 | 9,432,417 | 93,168,816 | | 10,638,864 | | 71,632,640 | 82,271,503 | 10,897,313 | 1.290251 | 14,060,268 |
| 30 | 83,559,544 | 2,688,948 | 9,715,389 | 95,963,881 | | 10,958,030 | | 73,781,619 | 84,739,648 | 11,224,232 | 1.301639 | 14,609,898 |
| 31 | 86,066,330 | 2,769,616 | 10,006,851 | 98,842,797 | | 11,286,770 | 46,846,166 | 75,995,067 | 134,128,003 | (35,285,206) | 1.313127 | (46,333,972) |
| 32 | 88,648,320 | 2,852,705 | 10,307,056 | 101,808,081 | | 11,625,374 | | 78,274,919 | 89,900,293 | 11,907,788 | 1.324717 | 15,774,454 |
| 33 | 91,307,770 | 2,938,286 | 10,616,268 | 104,862,324 | | 11,974,135 | | 80,623,167 | 92,597,302 | 12,265,022 | 1.336410 | 16,391,093 |
| 34 | 94,047,003 | 3,026,435 | 10,934,756 | 108,008,193 | | 12,333,359 | | 83,041,862 | 95,375,221 | 12,632,973 | 1.348205 | 17,031,836 |
| 35 | 96,868,413 | 3,117,228 | 11,262,799 | 111,248,439 | | 12,703,360 | | 85,533,118 | 98,236,477 | 13,011,962 | 1.360105 | 17,697,628 |
| 36 | 99,774,465 | 3,210,744 | 11,600,683 | 114,585,892 | | 13,084,460 | | 88,099,111 | 101,183,572 | 13,402,321 | 1.372109 | 18,389,445 |
| 37 | 102,767,699 | 3,307,067 | 11,948,703 | 118,023,469 | | 13,476,994 | | 90,742,085 | 104,219,079 | 13,804,390 | 1.384220 | 19,108,307 |
| 38 | 105,850,730 | 3,406,279 | 12,307,164 | 121,564,173 | | 13,881,304 | | 93,464,347 | 107,345,651 | 14,218,522 | 1.396437 | 19,855,269 |
| 39 | 109,026,252 | 3,508,467 | 12,676,379 | 125,211,098 | | 14,297,743 | | 96,268,278 | 110,566,021 | 14,645,078 | 1.408762 | 20,631,431 |
| 40 | 112,297,040 | 3,613,721 | 13,056,670 | 128,967,431 | | 14,726,675 | | 99,156,326 | 113,883,001 | 15,084,430 | 1.421196 | 21,437,934 |
| 41 | 115,665,951 | 3,722,133 | 13,448,371 | 132,836,454 | | 15,168,476 | 62,957,329 | 102,131,016 | 180,256,821 | (47,420,367) | 1.433740 | (67,988,473) |
| 42 | 119,135,929 | 3,833,797 | 13,851,822 | 136,821,548 | | 15,623,530 | | 105,194,946 | 120,818,476 | 16,003,072 | 1.446394 | 23,146,753 |
| 43 | 122,710,007 | 3,948,811 | 14,267,376 | 140,926,194 | | 16,092,236 | | 108,350,794 | 124,443,030 | 16,483,164 | 1.459161 | 24,051,583 |
| 44 | 126,391,307 | 4,067,275 | 14,695,398 | 145,153,980 | | 16,575,003 | | 111,601,318 | 128,176,321 | 16,977,659 | 1.472039 | 24,991,783 |
| 45 | 130,183,047 | 4,189,293 | 15,136,260 | 149,508,599 | | 17,072,253 | | 114,949,358 | 132,021,611 | 17,486,988 | 1.485032 | 25,968,736 |
| 46 | 134,088,538 | 4,314,972 | 15,590,347 | 153,993,857 | | 17,584,421 | | 118,397,839 | 135,982,259 | 18,011,598 | 1.498139 | 26,983,879 |
| 47 | 138,111,194 | 4,444,421 | 16,058,058 | 158,613,673 | | 18,111,953 | | 121,949,774 | 140,061,727 | 18,551,946 | 1.511362 | 28,038,706 |
| 48 | 142,254,530 | 4,577,754 | 16,539,800 | 163,372,083 | | 18,655,312 | | 125,608,267 | 144,263,579 | 19,108,504 | 1.524702 | 29,134,766 |
| 49 | 146,522,166 | 4,715,086 | 17,035,994 | 168,273,246 | | 19,214,971 | | 129,376,515 | 148,591,486 | 19,681,760 | 1.538159 | 30,273,673 |
| 50 | 150,917,831 | 4,856,539 | 17,547,073 | 173,321,443 | | 19,791,420 | | 133,257,810 | 153,049,231 | 20,272,212 | 1.551735 | 31,457,100 |
| | $3,999,572,580 | $128,706,329 | $465,026,517 | $4,593,305,426 | $441,285,000 | $524,505,433 | $189,899,028 | $3,561,949,825 | $4,717,639,286 | ($124,333,860) | | $0 |

NET PRESENT VALUE OF ANNUAL BENEFITS USING A DISCOUNT RATE OF 7% : ($392,571,184)

**Table 2-8b. Maryland I-495 (Beltway) (continued)**

## OTHER BENEFITS

**TOTAL VALUE OF ACCIDENTS AVOIDED AS A RESULT OF IMPLEMENTING AHS**

| | |
|---|---|
| Total cost of all types of accidents per one million VMT on suburban interstates: | $26,230 * |
| Estimated Annual VMT on Seclected Portion of I-495 (millions): | 75.7 |
| Estimated cost of collisions on I-495 without AHS: | $1,984,427 |

Estimated Savings from Safety Improvements:

| | |
|---|---|
| Upper Range (85% reduction) | $1,686,763 |
| Lower Range (30% reduction) | $595,328 |

**Mean value of savings resulting from accidents avoided: $1,141,045**

**TOTAL MULTIPLIER BENEFITS OF CONSTRUCTING, OPERATING & MAINTAINING SYSTEM**
(the multiplier below reflects the difference between the effect of dollars spent on AHS minus the effect of the same amount spent by households)

| Total change in output: | | Multiplier Used | Additional Annual Output |
|---|---|---|---|
| Annual Operations & Maintenance Cost: | $4,650,000 | 0.8866 | $4,122,690 |

## COSTS

| | Estimated Costs |
|---|---|
| **TOTAL CONSTRUCTION COSTS, ROADWAY PORTION:** | $441,285,000 |
| **ANNUAL O&M COSTS (above existing O&M expenses)** $500,000 per mile for: 9.3 miles of roadway | $4,650,000 |
| **TOTAL INFRASTRUCTURE ELECTRONICS COSTS (10-year life cycle):** | $19,300,000 |
| **TOTAL ON-BOARD VEHICLE INSTRUMENTATION COSTS (8-year lifespan):** Cost per car: $1,800 Est. number of cars regularly using AHS lanes: 135,098 | $243,176,400 |

* Source: Calspan safety analysis/NHTSA

Table 2-9a. New York State Thruway Assuming Speeds of 100 km/hour

PERFORMANCE RESULTS: A.M. PEAK PERIOD and HOURS CLOSEST TO PEAKS
EVALUATION OF TRAVEL TIME SAVINGS

| M.O.E. | | PERCENTAGE OF EXISTING PEAK VOLUMES 79% | 83% | 92% | 96% | 100% |
|---|---|---|---|---|---|---|
| SPEED (m.p.h.): | Existing Roadway | 51 | 51 | 50.3 | 50.3 | 49.7 |
| | AHS Roadway | 60.2 | 60.2 | 60.2 | 60.2 | 59.6 |
| | Speed Increase: | 9.2 | 9.2 | 9.9 | 9.9 | 9.9 |
| Vehicle Miles of Travel (VMT): | Existing Roadway | 42,619 | 45,854 | 47,478 | 49,480 | 50,835 |
| | AHS Roadway | 46,599 | 49,112 | 50,060 | 52,127 | 54,765 |
| | Change in VMT: | 3,980 | 3,258 | 2,582 | 2,647 | 3,930 |
| Vehicle Hours of Travel (VHT): | Existing Roadway | 821 | 889 | 928 | 975 | 1,008 |
| | AHS Roadway | 754 | 795 | 815 | 844 | 903 |
| | Total Travel Time Savings from AHS (VHT): | 67 | 94 | 113 | 131 | 105 |
| | Duration of Traffic Volume in Daily Traffic Totals (hrs): | 1 | 2.5 | 2 | 1 | 1 |
| | Average Vehicle Occupancy: | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| | Avg. Per-Person Value of In-vehicle Travel Time: | $18.50 | $18.50 | $18.50 | $18.50 | $18.50 |
| | Value of Travel Time Saved: | $1,487 | $5,217 | $5,017 | $2,908 | $2,331 |

| | |
|---|---|
| Total Value of Travel Time Saved per Day, SOUTHBOUND ONLY: | $16,961 |
| Daily Total Value of Travel Time, Both Directions: | $33,922 |
| **Total Annual Value of Travel Time Saved:** | **$8,819,616** |

| | Value of Total Annual Travel Time Benefits |
|---|---|
| **Sensitivity Analysis 1: Variation in the values of time** | |
| Average per-person values of in-vehicle travel time factors: | |
| at 67% of hourly wage rate: | $5,909,143 |
| at 200% of hourly wage rate: | $17,639,232 |
| at 300% of hourly wage rate: | $26,458,848 |
| **Sensitivity Analysis 2: Variation on Vehicle Occupancy** | |
| Using the New York Metro Area's Average Vehicle Occupancy of 1.1: | $8,084,648 |

**Sources:** All Speed, VMT & VHT figures are from Dunn Associates.
The Average Vehicle Occupancy figure for the New York Metropolitan Area is from FHWA's *Journey-To-Work Trends in the United States and its Major Metropolitan Areas 1960-1990*
Hourly wage figures are estimated using data from the same FHWA publication.

## Table 2-9c. New York State Thruway Assuming Speeds of 100 km/hour (continued)

SCENARIO 12

| Year | Annual Travel Time Benefits | Annual Accident Benefits | Annual Multiplier Benefits from System O&M | TOTAL ANNUAL BENEFITS | CONSTRUCTION COSTS | O&M COSTS ABOVE EXISTING O&M | SYSTEM INFRASTRUCTURE COSTS | VEHICLE ELECTRONICS COSTS | TOTAL ANNUAL COSTS | ANNUAL NET BENEFITS | Discount Factor @: -7.2444% | DISCOUNTED NET BENEFITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | $0 | $706,800,000 | | $19,300,000 | $4,696,875 | $730,796,875 | ($730,796,875) | 1.000000 | ($730,796,875) |
| 1 | $8,819,616 | $30,437 | $13,027,750 | $21,877,803 | | $15,500,000 | | $4,837,781 | $20,337,781 | $1,540,021 | 1.078102 | $1,660,300 |
| 2 | 9,084,204 | 31,350 | 13,418,583 | 22,534,137 | | 15,965,000 | | 4,982,915 | 20,947,915 | 1,586,222 | 1.162304 | 1,843,672 |
| 3 | 9,356,731 | 32,290 | 13,821,140 | 23,210,161 | | 16,443,950 | | 5,132,402 | 21,576,352 | 1,633,809 | 1.253082 | 2,047,297 |
| 4 | 9,637,433 | 33,259 | 14,235,774 | 23,906,466 | | 16,937,269 | | 5,286,374 | 22,223,643 | 1,682,823 | 1.350951 | 2,273,411 |
| 5 | 9,926,556 | 34,257 | 14,662,847 | 24,623,660 | | 17,445,387 | | 5,444,965 | 22,890,352 | 1,733,308 | 1.456463 | 2,524,498 |
| 6 | 10,224,352 | 35,284 | 15,102,733 | 25,362,369 | | 17,968,748 | | 5,608,314 | 23,577,063 | 1,785,307 | 1.570215 | 2,803,317 |
| 7 | 10,531,083 | 36,343 | 15,555,815 | 26,123,241 | | 18,507,811 | | 5,776,564 | 24,284,374 | 1,838,866 | 1.692853 | 3,112,929 |
| 8 | 10,847,015 | 37,433 | 16,022,489 | 26,906,938 | | 19,063,045 | | 5,949,861 | 25,012,906 | 1,894,032 | 1.825068 | 3,456,737 |
| 9 | 11,172,426 | 38,556 | 16,503,164 | 27,714,146 | | 19,634,936 | | 6,128,357 | 25,763,293 | 1,950,853 | 1.967609 | 3,838,517 |
| 10 | 11,507,598 | 39,713 | 16,998,259 | 28,545,570 | | 20,223,984 | | 6,312,207 | 26,536,192 | 2,009,379 | 2.121284 | 4,262,462 |
| 11 | 11,852,826 | 40,904 | 17,508,207 | 29,401,937 | | 20,830,704 | 25,937,586 | 6,501,573 | 53,269,863 | -23,867,926 | 2.286960 | -54,585,001 |
| 12 | 12,208,411 | 42,132 | 18,033,453 | 30,283,996 | | 21,455,625 | | 6,696,621 | 28,152,246 | 2,131,750 | 2.465577 | 5,255,993 |
| 13 | 12,574,664 | 43,395 | 18,574,456 | 31,192,516 | | 22,099,294 | | 6,897,519 | 28,996,813 | 2,195,702 | 2.658143 | 5,836,492 |
| 14 | 12,951,903 | 44,697 | 19,131,690 | 32,128,291 | | 22,762,273 | | 7,104,445 | 29,866,717 | 2,261,573 | 2.865750 | 6,481,104 |
| 15 | 13,340,461 | 46,038 | 19,705,641 | 33,092,140 | | 23,445,141 | | 7,317,578 | 30,762,719 | 2,329,421 | 3.089571 | 7,196,910 |
| 16 | 13,740,674 | 47,419 | 20,296,810 | 34,084,904 | | 24,148,495 | | 7,537,106 | 31,685,601 | 2,399,303 | 3.330873 | 7,991,774 |
| 17 | 14,152,895 | 48,842 | 20,905,714 | 35,107,451 | | 24,872,950 | | 7,763,219 | 32,636,169 | 2,471,282 | 3.591021 | 8,874,426 |
| 18 | 14,577,481 | 50,307 | 21,532,886 | 36,160,674 | | 25,619,138 | | 7,996,115 | 33,615,254 | 2,545,421 | 3.871487 | 9,854,563 |
| 19 | 15,014,806 | 51,816 | 22,178,872 | 37,245,495 | | 26,387,712 | | 8,235,999 | 34,623,711 | 2,621,783 | 4.173858 | 10,942,951 |
| 20 | 15,465,250 | 53,371 | 22,844,238 | 38,362,859 | | 27,179,344 | | 8,483,079 | 35,662,423 | 2,700,437 | 4.499845 | 12,151,547 |
| 21 | 15,929,208 | 54,972 | 23,529,566 | 39,513,745 | | 27,994,724 | 34,857,947 | 8,737,571 | 71,590,242 | -32,076,497 | 4.851292 | -155,612,449 |
| 22 | 16,407,084 | 56,621 | 24,235,453 | 40,699,158 | | 28,834,566 | | 8,999,698 | 37,834,264 | 2,864,894 | 5.230188 | 14,983,931 |
| 23 | 16,899,296 | 58,320 | 24,962,516 | 41,920,132 | | 29,699,603 | | 9,269,689 | 38,969,292 | 2,950,840 | 5.638676 | 16,638,834 |
| 24 | 17,406,275 | 60,069 | 25,711,392 | 43,177,736 | | 30,590,591 | | 9,547,780 | 40,138,371 | 3,039,366 | 6.079068 | 18,476,512 |
| 25 | 17,928,463 | 61,872 | 26,482,733 | 44,473,068 | | 31,508,309 | | 9,834,213 | 41,342,522 | 3,130,547 | 6.553856 | 20,517,152 |
| 26 | 18,466,317 | 63,728 | 27,277,215 | 45,807,260 | | 32,453,558 | | 10,129,240 | 42,582,798 | 3,224,463 | 7.065726 | 22,783,172 |
| 27 | 19,020,307 | 65,640 | 28,095,532 | 47,181,478 | | 33,427,165 | | 10,433,117 | 43,860,281 | 3,321,197 | 7.617574 | 25,299,462 |
| 28 | 19,590,916 | 67,609 | 28,938,398 | 48,596,923 | | 34,429,980 | | 10,746,110 | 45,176,090 | 3,420,833 | 8.212522 | 28,093,664 |
| 29 | 20,178,644 | 69,637 | 29,806,550 | 50,054,830 | | 35,462,879 | | 11,068,494 | 46,531,373 | 3,523,458 | 8.853937 | 31,196,472 |
| 30 | 20,784,003 | 71,726 | 30,700,746 | 51,556,475 | | 36,526,765 | | 11,400,548 | 47,927,314 | 3,629,161 | 9.545448 | 34,641,970 |
| 31 | 21,407,523 | 73,878 | 31,621,769 | 53,103,169 | | 37,622,568 | 46,846,166 | 11,742,565 | 96,211,299 | -43,108,129 | 10.290967 | -443,624,324 |
| 32 | 22,049,749 | 76,094 | 32,570,422 | 54,696,265 | | 38,751,245 | | 12,094,842 | 50,846,087 | 3,850,177 | 11.094712 | 42,716,611 |
| 33 | 22,711,241 | 78,377 | 33,547,534 | 56,337,153 | | 39,913,783 | | 12,457,687 | 52,371,470 | 3,965,683 | 11.961232 | 47,434,452 |
| 34 | 23,392,578 | 80,728 | 34,553,960 | 58,027,267 | | 41,111,196 | | 12,831,418 | 53,942,614 | 4,084,653 | 12.895429 | 52,673,356 |
| 35 | 24,094,356 | 83,150 | 35,590,579 | 59,768,085 | | 42,344,532 | | 13,216,360 | 55,560,892 | 4,207,193 | 13.902589 | 58,490,872 |
| 36 | 24,817,186 | 85,645 | 36,658,297 | 61,561,128 | | 43,614,868 | | 13,612,851 | 57,227,719 | 4,333,409 | 14.988410 | 64,950,903 |
| 37 | 25,561,702 | 88,214 | 37,758,045 | 63,407,961 | | 44,923,314 | | 14,021,237 | 58,944,551 | 4,463,411 | 16.159035 | 72,124,414 |
| 38 | 26,328,553 | 90,860 | 38,890,787 | 65,310,200 | | 46,271,014 | | 14,441,874 | 60,712,887 | 4,597,313 | 17.421089 | 80,090,204 |
| 39 | 27,118,410 | 93,586 | 40,057,510 | 67,269,506 | | 47,659,144 | | 14,875,130 | 62,534,274 | 4,735,233 | 18.781712 | 88,935,776 |
| 40 | 27,931,962 | 96,394 | 41,259,236 | 69,287,592 | | 49,088,918 | | 15,321,384 | 64,410,302 | 4,877,290 | 20.248603 | 98,758,299 |
| 41 | 28,769,921 | 99,286 | 42,497,013 | 71,366,219 | | 50,561,586 | 62,957,329 | 15,781,025 | 129,299,940 | -57,933,721 | 21.830060 | -1,264,696,635 |
| 42 | 29,633,018 | 102,264 | 43,771,923 | 73,507,206 | | 52,078,433 | | 16,254,456 | 68,332,889 | 5,174,316 | 23.535033 | 121,777,710 |
| 43 | 30,522,009 | 105,332 | 45,085,081 | 75,712,422 | | 53,640,786 | | 16,742,090 | 70,382,876 | 5,329,546 | 25.373168 | 135,227,464 |
| 44 | 31,437,669 | 108,492 | 46,437,633 | 77,983,795 | | 55,250,010 | | 17,244,352 | 72,494,362 | 5,489,432 | 27.354864 | 150,162,678 |
| 45 | 32,380,799 | 111,747 | 47,830,762 | 80,323,309 | | 56,907,510 | | 17,761,683 | 74,669,193 | 5,654,115 | 29.491336 | 166,747,414 |
| 46 | 33,352,223 | 115,099 | 49,265,685 | 82,733,008 | | 58,614,736 | | 18,294,533 | 76,909,269 | 5,823,739 | 31.794670 | 185,163,852 |
| 47 | 34,352,790 | 118,552 | 50,743,656 | 85,214,998 | | 60,373,178 | | 18,843,369 | 79,216,547 | 5,998,451 | 34.277899 | 205,614,297 |
| 48 | 35,383,374 | 122,109 | 52,265,965 | 87,771,448 | | 62,184,373 | | 19,408,671 | 81,593,043 | 6,178,404 | 36.955074 | 228,323,393 |
| 49 | 36,444,875 | 125,772 | 53,833,944 | 90,404,591 | | 64,049,904 | | 19,990,931 | 84,040,835 | 6,363,757 | 39.841341 | 253,540,598 |
| 50 | 37,538,221 | 129,545 | 55,448,963 | 93,116,729 | | 65,971,401 | | 20,590,659 | 86,562,060 | 6,554,669 | 42.953032 | 281,542,921 |
| TOTAL: | $994,825,056 | $3,433,166 | $1,469,489,388 | $2,467,747,610 | $706,800,000 | $1,748,351,443 | $189,899,028 | $550,383,445 | $3,195,433,916 | ($727,686,306) | | $0 |

NET PRESENT VALUE OF ANNUAL BENEFITS USING A DISCOUNT RATE OF 7% : ($680,792,762)

Table 2-10a. New York State Thruway Assuming Speeds of 129 km/hour

PERFORMANCE RESULTS: A.M. PEAK PERIOD and HOURS CLOSEST TO PEAKS
EVALUATION OF TRAVEL TIME SAVINGS

| M.O.E. | | PERCENTAGE OF EXISTING PEAK VOLUMES 79% | 83% | 92% | 96% | 100% |
|---|---|---|---|---|---|---|
| SPEED (m.p.h.): | Existing Roadway | 51 | 51 | 50.3 | 50.3 | 49.7 |
| | AHS Roadway | 71.4 | 70.8 | 70.8 | 70.2 | 69.6 |
| | Speed Increase: | 20.4 | 19.8 | 20.5 | 19.9 | 19.9 |
| Vehicle Miles of Travel (VMT): | Existing Roadway | 42,619 | 45,854 | 47,478 | 49,480 | 50,835 |
| | AHS Roadway | 49,279 | 51,648 | 52,917 | 54,901 | 57,713 |
| | Change in VMT: | 6,660 | 5,794 | 5,439 | 5,421 | 6,878 |
| Vehicle Hours of Travel (VHT): | Existing Roadway | 821 | 889 | 928 | 975 | 1,008 |
| | AHS Roadway | 670 | 703 | 721 | 747 | 788 |
| | Total Travel Time Savings from AHS (VHT): | 151 | 186 | 207 | 228 | 220 |
| | Duration of Traffic Volume in Daily Traffic Totals (hrs): | 1 | 2.5 | 2 | 1 | 1 |
| | Average Vehicle Occupancy: | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| | Avg. Per-Person Value of In-vehicle Travel Time: | $18.50 | $18.50 | $18.50 | $18.50 | $18.50 |
| | Value of Travel Time Saved: | $3,352 | $10,323 | $9,191 | $5,062 | $4,884 |

| | |
|---|---|
| Total Value of Travel Time Saved per Day, SOUTHBOUND ONLY: | $32,812 |
| Daily Total Value of Travel Time, Both Directions: | $65,623 |
| **Total Annual Value of Travel Time Saved:** | **$17,062,032** |

| | | | Value of Total Annual Travel Time Benefits |
|---|---|---|---|
| **Sensitivity Analysis 1: Variation in the values of time** | | | |
| Average per-person values of in-vehicle travel time factors: | | | |
| at | 67% | of hourly wage rate: | $11,431,561 |
| at | 200% | of hourly wage rate: | $34,124,064 |
| at | 300% | of hourly wage rate: | $51,186,096 |
| **Sensitivity Analysis 2: Variation on Vehicle Occupancy** | | | |
| Using the New York Metro Area's Average Vehicle Occupancy of | 1.1: | | $15,640,196 |

**Sources:** All Speed, VMT & VHT figures are from Dunn Associates.
The Average Vehicle Occupancy figure for the New York Metropolitan Area is from FHWA's *Journey-To-Work Trends in the United States and its Major Metropolitan Areas 1960-1990*
Hourly wage figures are estimated using data from the same FHWA publication.

Table 2-10b. New York State Thruway Assuming Speeds of 129 km/hour (continued)

## BENEFITS

TOTAL VALUE OF ACCIDENTS AVOIDED AS A RESULT OF IMPLEMENTING AHS:

| | |
|---|---|
| Total cost of all types of accidents per one million VMT on rural interstates: | $4,528 * |
| Estimated Annual VMT on Selected Portion of Thruway (millions) | 12.3 |
| Estimated cost of collisions on Thruway without AHS | $55,686 |

Estimated Savings from Safety Improvements:

| | |
|---|---|
| Upper Range (85% reduction) | $47,333 |
| Lower Range (30% reduction) | $16,706 |

**Mean value of savings resulting from accidents avoided: $32,019**

TOTAL MULTIPLIER BENEFITS OF CONSTRUCTING, OPERATING & MAINTAINING SYSTEM
(the multiplier below reflects the difference between the effect of dollars spent on AHS minus the effect of the same amount spent by households)

| Total change in output: | | Multiplier Used | Additional Annual Output |
|---|---|---|---|
| Annual Operations & Maintenance Cost: | $15,500,000 | 0.8405 | $13,027,750 |

## COSTS

| | Estimated Costs |
|---|---|
| TOTAL CONSTRUCTION COSTS, ROADWAY PORTION: | $750,200,000 |
| ANNUAL O&M COSTS (above existing O&M expenses)<br>$500,000 per mile for: 31 miles of roadway | $15,500,000 |
| TOTAL INFRASTRUCTURE ELECTRONICS COSTS (10-year life cycle): | $19,300,000 |
| TOTAL ON-BOARD VEHICLE INSTRUMENTATION COSTS (8-year lifespan):<br>Cost per car: $1,800 Est. number of cars regularly using AHS lanes: 21,961 | $39,529,800 |

* Source: Calspan safety analysis/NHTSA

## Table 2-10c. New York State Thruway Assuming Speeds of 129 km/hour (continued)

**SCENARIO 13**

| Year | Annual Travel Time Benefits | Annual Accident Benefits | Annual Multiplier Benefits from System O&M | TOTAL ANNUAL BENEFITS | CONSTRUCTION COSTS | O&M COSTS ABOVE EXISTING O&M | SYSTEM INFRASTRUCTURE COSTS | VEHICLE ELECTRONICS COSTS | TOTAL ANNUAL COSTS | ANNUAL NET BENEFITS | Discount Factor @: *0.4979%* | DISCOUNTED NET BENEFITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | $0 | $750,200,000 | | $19,300,000 | $4,941,225 | $774,441,225 | ($774,441,225) | 1.000000 | ($774,441,225) |
| 1 | $17,062,032 | $32,019 | $13,027,750 | $30,121,801 | | $15,500,000 | | $5,089,462 | $20,589,462 | $9,532,339 | 0.995046 | $9,485,118 |
| 2 | 17,573,893 | 32,980 | 13,418,583 | $31,025,455 | | 15,965,000 | | 5,242,146 | 21,207,146 | 9,818,310 | 0.990117 | 9,721,274 |
| 3 | 18,101,110 | 33,969 | 13,821,140 | $31,956,219 | | 16,443,950 | | 5,399,410 | 21,843,360 | 10,112,859 | 0.985212 | 9,963,309 |
| 4 | 18,644,143 | 34,988 | 14,235,774 | $32,914,905 | | 16,937,269 | | 5,561,392 | 22,498,661 | 10,416,245 | 0.980331 | 10,211,371 |
| 5 | 19,203,467 | 36,038 | 14,662,847 | $33,902,353 | | 17,445,387 | | 5,728,234 | 23,173,621 | 10,728,732 | 0.975475 | 10,465,609 |
| 6 | 19,779,571 | 37,119 | 15,102,733 | $34,919,423 | | 17,968,748 | | 5,900,081 | 23,868,829 | 11,050,594 | 0.970643 | 10,726,177 |
| 7 | 20,372,958 | 38,233 | 15,555,815 | $35,967,006 | | 18,507,811 | | 6,077,083 | 24,584,894 | 11,382,112 | 0.965834 | 10,993,232 |
| 8 | 20,984,147 | 39,380 | 16,022,489 | $37,046,016 | | 19,063,045 | | 6,259,396 | 25,322,441 | 11,723,575 | 0.961049 | 11,266,936 |
| 9 | 21,613,672 | 40,561 | 16,503,164 | $38,157,397 | | 19,634,936 | | 6,447,178 | 26,082,114 | 12,075,282 | 0.956289 | 11,547,455 |
| 10 | 22,262,082 | 41,778 | 16,998,259 | $39,302,118 | | 20,223,984 | | 6,640,593 | 26,864,578 | 12,437,541 | 0.951551 | 11,834,958 |
| 11 | 22,929,944 | 43,031 | 17,508,207 | $40,481,182 | | 20,830,704 | 25,937,586 | 6,839,811 | 53,608,101 | (13,126,919) | 0.946837 | (12,429,058) |
| 12 | 23,617,843 | 44,322 | 18,033,453 | $41,695,617 | | 21,455,625 | | 7,045,005 | 28,500,630 | 13,194,987 | 0.942147 | 12,431,617 |
| 13 | 24,326,378 | 45,652 | 18,574,456 | $42,946,486 | | 22,099,294 | | 7,256,355 | 29,355,649 | 13,590,837 | 0.937480 | 12,741,133 |
| 14 | 25,056,169 | 47,021 | 19,131,690 | $44,234,881 | | 22,762,273 | | 7,474,046 | 30,236,319 | 13,998,562 | 0.932836 | 13,058,356 |
| 15 | 25,807,854 | 48,432 | 19,705,641 | $45,561,927 | | 23,445,141 | | 7,698,268 | 31,143,408 | 14,418,519 | 0.928214 | 13,383,476 |
| 16 | 26,582,090 | 49,885 | 20,296,810 | $46,928,785 | | 24,148,495 | | 7,929,216 | 32,077,711 | 14,851,074 | 0.923616 | 13,716,692 |
| 17 | 27,379,553 | 51,381 | 20,905,714 | $48,336,648 | | 24,872,950 | | 8,167,092 | 33,040,042 | 15,296,606 | 0.919041 | 14,058,204 |
| 18 | 28,200,939 | 52,923 | 21,532,886 | $49,786,748 | | 25,619,138 | | 8,412,105 | 34,031,243 | 15,755,505 | 0.914488 | 14,408,218 |
| 19 | 29,046,967 | 54,511 | 22,178,872 | $51,280,350 | | 26,387,712 | | 8,664,468 | 35,052,180 | 16,228,170 | 0.909958 | 14,766,947 |
| 20 | 29,918,376 | 56,146 | 22,844,238 | $52,818,761 | | 27,179,344 | | 8,924,402 | 36,103,746 | 16,715,015 | 0.905450 | 15,134,607 |
| 21 | 30,815,928 | 57,830 | 23,529,566 | $54,403,324 | | 27,994,724 | 34,857,947 | 9,192,134 | 72,044,805 | (17,641,481) | 0.900964 | (15,894,346) |
| 22 | 31,740,406 | 59,565 | 24,235,453 | $56,035,423 | | 28,834,566 | | 9,467,898 | 38,302,464 | 17,732,959 | 0.896501 | 15,897,618 |
| 23 | 32,692,618 | 61,352 | 24,962,516 | $57,716,486 | | 29,699,603 | | 9,751,935 | 39,451,538 | 18,264,948 | 0.892060 | 16,293,429 |
| 24 | 33,673,396 | 63,193 | 25,711,392 | $59,447,981 | | 30,590,591 | | 10,044,493 | 40,635,084 | 18,812,897 | 0.887641 | 16,699,095 |
| 25 | 34,683,598 | 65,088 | 26,482,733 | $61,231,420 | | 31,508,309 | | 10,345,828 | 41,854,137 | 19,377,283 | 0.883244 | 17,114,861 |
| 26 | 35,724,106 | 67,041 | 27,277,215 | $63,068,363 | | 32,453,558 | | 10,656,203 | 43,109,761 | 19,958,602 | 0.878868 | 17,540,979 |
| 27 | 36,795,829 | 69,052 | 28,095,532 | $64,960,413 | | 33,427,165 | | 10,975,889 | 44,403,053 | 20,557,360 | 0.874514 | 17,977,706 |
| 28 | 37,899,704 | 71,124 | 28,938,398 | $66,909,226 | | 34,429,980 | | 11,305,165 | 45,735,145 | 21,174,081 | 0.870182 | 18,425,306 |
| 29 | 39,036,695 | 73,258 | 29,806,550 | $68,916,503 | | 35,462,879 | | 11,644,320 | 47,107,199 | 21,809,303 | 0.865871 | 18,884,051 |
| 30 | 40,207,796 | 75,455 | 30,700,746 | $70,983,998 | | 36,526,765 | | 11,993,650 | 48,520,415 | 22,463,582 | 0.861582 | 19,354,217 |
| 31 | 41,414,030 | 77,719 | 31,621,769 | $73,113,518 | | 37,622,568 | 46,846,166 | 12,353,460 | 96,822,194 | (23,708,676) | 0.857314 | (20,325,775) |
| 32 | 42,656,451 | 80,051 | 32,570,422 | $75,306,923 | | 38,751,245 | | 12,724,063 | 51,475,309 | 23,831,614 | 0.853067 | 20,329,958 |
| 33 | 43,936,144 | 82,452 | 33,547,534 | $77,566,131 | | 39,913,783 | | 13,105,785 | 53,019,568 | 24,546,563 | 0.848841 | 20,836,124 |
| 34 | 45,254,229 | 84,926 | 34,553,960 | $79,893,115 | | 41,111,196 | | 13,498,959 | 54,610,155 | 25,282,960 | 0.844636 | 21,354,892 |
| 35 | 46,611,856 | 87,473 | 35,590,579 | $82,289,908 | | 42,344,532 | | 13,903,928 | 56,248,460 | 26,041,449 | 0.840452 | 21,886,576 |
| 36 | 48,010,211 | 90,098 | 36,658,297 | $84,758,605 | | 43,614,868 | | 14,321,045 | 57,935,913 | 26,822,692 | 0.836288 | 22,431,498 |
| 37 | 49,450,518 | 92,801 | 37,758,045 | $87,301,364 | | 44,923,314 | | 14,750,677 | 59,673,991 | 27,627,373 | 0.832145 | 22,989,986 |
| 38 | 50,934,033 | 95,585 | 38,890,787 | $89,920,404 | | 46,271,014 | | 15,193,197 | 61,464,210 | 28,456,194 | 0.828023 | 23,562,380 |
| 39 | 52,462,054 | 98,452 | 40,057,510 | $92,618,017 | | 47,659,144 | | 15,648,993 | 63,308,137 | 29,309,880 | 0.823921 | 24,149,025 |
| 40 | 54,035,916 | 101,406 | 41,259,236 | $95,396,557 | | 49,088,918 | | 16,118,463 | 65,207,381 | 30,189,176 | 0.819839 | 24,750,276 |
| 41 | 55,656,993 | 104,448 | 42,497,013 | $98,258,454 | | 50,561,586 | 62,957,329 | 16,602,017 | 130,120,932 | (31,862,478) | 0.815778 | (25,992,709) |
| 42 | 57,326,703 | 107,581 | 43,771,923 | $101,206,207 | | 52,078,433 | | 17,100,077 | 69,178,510 | 32,027,697 | 0.811737 | 25,998,060 |
| 43 | 59,046,504 | 110,809 | 45,085,081 | $104,242,394 | | 53,640,786 | | 17,613,079 | 71,253,866 | 32,988,528 | 0.807716 | 26,645,347 |
| 44 | 60,817,899 | 114,133 | 46,437,633 | $107,369,665 | | 55,250,010 | | 18,141,472 | 73,391,482 | 33,978,184 | 0.803714 | 27,308,750 |
| 45 | 62,642,436 | 117,557 | 47,830,762 | $110,590,755 | | 56,907,510 | | 18,685,716 | 75,593,226 | 34,997,529 | 0.799733 | 27,988,670 |
| 46 | 64,521,709 | 121,084 | 49,265,685 | $113,908,478 | | 58,614,736 | | 19,246,287 | 77,861,023 | 36,047,455 | 0.795771 | 28,685,519 |
| 47 | 66,457,361 | 124,716 | 50,743,656 | $117,325,732 | | 60,373,178 | | 19,823,676 | 80,196,854 | 37,128,879 | 0.791829 | 29,399,717 |
| 48 | 68,451,081 | 128,458 | 52,265,965 | $120,845,504 | | 62,184,373 | | 20,418,386 | 82,602,759 | 38,242,745 | 0.787906 | 30,131,698 |
| 49 | 70,504,614 | 132,311 | 53,833,944 | $124,470,870 | | 64,049,904 | | 21,030,938 | 85,080,842 | 39,390,028 | 0.784003 | 30,881,902 |
| 50 | 72,619,752 | 136,281 | 55,448,963 | $128,204,996 | | 65,971,401 | | 21,661,866 | 87,633,267 | 40,571,728 | 0.780119 | 31,650,785 |
| | $1,924,543,750 | $3,811,064 | $1,400,400,300 | $3,307,644,811 | $750,200,000 | $1,748,351,443 | $189,899,028 | $579,016,567 | $3,267,467,038 | $130,177,774 | | $0 |

NET PRESENT VALUE OF ANNUAL BENEFITS USING A DISCOUNT RATE OF 7% : ($562,636,291)

Table 2-11a. Long Island Expressway Scenario #1, Option B

## PERFORMANCE RESULTS: A.M. PEAK HOUR
## EVALUATION OF TRAVEL TIME SAVINGS

| M.O.E. | Passenger Vehicles | Single-Unit Trucks | Tractor-Trailers | Buses |
|---|---|---|---|---|
| **Vehicle Miles of Travel (VMT):** | | | | |
| No-Build Roadway | 82,560 | 45,135 | 720 | 3,585 |
| AHS Roadway | 100,500 | 45,120 | 720 | 3,570 |
| Total Change in VMT: | 17,940 | -15 | 0 | -15 |
| **Person Hours of Travel (PHT):** | | | | |
| No-Build Roadway | 6,668 | 377 | 6 | 896 |
| AHS Roadway | 6,668 | 245 | 4 | 584 |
| Total Travel Time Savings due to AHS (PHT): | 0 | 132 | 2 | 312 |
| Value of Time per Person: | $18.50 | $60.00 | $60.00 | $18.50 |
| Value of Travel Time Saved in the peak hour: | $0 | $7,920 | $120 | $5,772 |

| | |
|---|---|
| Total Value of Travel Time Saved per Day, WESTBOUND ONLY: | $184,390 |
| Daily Total Value of Travel Time, Both Directions: | $368,780 |
| **Total Annual Value of Travel Time Saved:** | **$95,882,904** |

**Sensitivity Analysis: Variation in the values of time:**
Average per-person values of passenger vehicle occupants' and bus passengers' in-vehicle travel time factors:

| | | | Value of Total Annual Travel Time Benefits |
|---|---|---|---|
| at | 67% | of hourly wage rate: | $82,660,060 |
| at | 200% | of hourly wage rate: | $135,952,128 |
| at | 300% | of hourly wage rate: | $176,021,352 |

**Sources:** VMT & VHT figures are from Parsons Brinckerhoff
Hourly wage figures are estimated using data from the FHWA's
*Journey-To-Work Trends in the United States and its Major Metropolitan Areas 1960-1990*

**Table 2-11b. Long Island Expressway Scenario #1, Option B (continued)**

## OTHER BENEFITS

**TOTAL VALUE OF ACCIDENTS AVOIDED AS A RESULT OF IMPLEMENTING AHS**

| | |
|---|---|
| Total cost of all types of accidents per one million VMT on suburban interstates: | $26,230 * |
| Estimated Annual VMT on Selected Portion of LIE (millions) | 75.6 |
| Estimated cost of collisions on LIE without AHS | $1,983,782 |

Estimated Savings from Safety Improvements:

| | |
|---|---|
| Upper Range (85% reduction) | $1,686,215 |
| Lower Range (30% reduction) | $595,135 |

**Mean value of savings resulting from accidents avoided: $1,140,675**

**TOTAL MULTIPLIER BENEFITS OF CONSTRUCTING, OPERATING & MAINTAINING SYSTEM**
(the multiplier below reflects the difference between the effect of dollars spent on AHS minus the effect of the same amount spent by households)

Total change in output:

| | | Multiplier Used | Additional Annual Output |
|---|---|---|---|
| Annual Operations & Maintenance Cost: | $7,400,000 | 0.8405 | $6,219,700 |

## COSTS

| | | Estimated Costs |
|---|---|---|
| **TOTAL CONSTRUCTION COSTS, ROADWAY PORTION:** | | $467,680,000 |
| **ANNUAL O&M COSTS (above existing O&M expenses)** $500,000 per mile for: | 14.8 miles of roadway | $7,400,000 |
| **TOTAL INFRASTRUCTURE ELECTRONICS COSTS (10-year life cycle):** | | $19,300,000 |
| **TOTAL ON-BOARD VEHICLE INSTRUMENTATION COSTS (8-year lifespan):** Cost per car: $1,800 Est. number of cars regularly using AHS lanes: | 135,054 | $243,097,200 |

* Source: Calspan safety analysis/NHTSA

## Table 2-11c. Long Island Expressway Scenario #1, Option B (continued)

| Year | Annual Travel Time Benefits | Annual Accident Benefits | Annual Multiplier Benefits from System O&M | TOTAL ANNUAL BENEFITS | CONSTRUCTION COSTS | O&M COSTS ABOVE EXISTING O&M | SYSTEM INFRASTRUCTURE COSTS | VEHICLE ELECTRONICS COSTS | TOTAL ANNUAL COSTS | ANNUAL NET BENEFITS | Discount Factor @: *15.2412%* | DISCOUNTED NET BENEFITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | $0 | $467,680,000 | | $19,300,000 | $30,387,150 | $517,367,150 | ($517,367,150) | 1.000000 | ($517,367,150) |
| 1 | $95,882,904 | $1,140,675 | $6,219,700 | $103,243,279 | | $7,400,000 | | $31,298,765 | $38,698,765 | $64,544,514 | 0.867745 | $56,008,191 |
| 2 | 98,759,391 | 1,174,895 | 6,406,291 | 106,340,577 | | 7,622,000 | | 32,237,727 | 39,859,727 | 66,480,850 | 0.752982 | 50,058,863 |
| 3 | 101,722,173 | 1,210,142 | 6,598,480 | 109,530,794 | | 7,850,660 | | 33,204,859 | 41,055,519 | 68,475,275 | 0.653396 | 44,741,487 |
| 4 | 104,773,838 | 1,246,446 | 6,796,434 | 112,816,718 | | 8,086,180 | | 34,201,005 | 42,287,185 | 70,529,533 | 0.566981 | 39,988,936 |
| 5 | 107,917,053 | 1,283,839 | 7,000,327 | 116,201,220 | | 8,328,765 | | 35,227,035 | 43,555,800 | 72,645,419 | 0.491995 | 35,741,212 |
| 6 | 111,154,565 | 1,322,355 | 7,210,337 | 119,687,256 | | 8,578,628 | | 36,283,846 | 44,862,474 | 74,824,782 | 0.426927 | 31,944,692 |
| 7 | 114,489,202 | 1,362,025 | 7,426,647 | 123,277,874 | | 8,835,987 | | 37,372,362 | 46,208,349 | 77,069,525 | 0.370464 | 28,551,448 |
| 8 | 117,923,878 | 1,402,886 | 7,649,446 | 126,976,210 | | 9,101,067 | | 38,493,532 | 47,594,599 | 79,381,611 | 0.321468 | 25,518,643 |
| 9 | 121,461,594 | 1,444,973 | 7,878,930 | 130,785,496 | | 9,374,099 | | 39,648,338 | 49,022,437 | 81,763,059 | 0.278952 | 22,807,990 |
| 10 | 125,105,442 | 1,488,322 | 8,115,298 | 134,709,061 | | 9,655,322 | | 40,837,789 | 50,493,110 | 84,215,951 | 0.242059 | 20,385,269 |
| 11 | 128,858,605 | 1,532,971 | 8,358,757 | 138,750,333 | | 9,944,981 | 25,937,586 | 42,062,922 | 77,945,490 | 60,804,844 | 0.210046 | 12,771,811 |
| 12 | 132,724,363 | 1,578,960 | 8,609,519 | 142,912,843 | | 10,243,331 | | 43,324,810 | 53,568,141 | 89,344,703 | 0.182266 | 16,284,533 |
| 13 | 136,706,094 | 1,626,329 | 8,867,805 | 147,200,229 | | 10,550,631 | | 44,624,554 | 55,175,185 | 92,025,044 | 0.158161 | 14,554,750 |
| 14 | 140,807,277 | 1,675,119 | 9,133,839 | 151,616,235 | | 10,867,149 | | 45,963,291 | 56,830,440 | 94,785,795 | 0.137243 | 13,008,708 |
| 15 | 145,031,495 | 1,725,373 | 9,407,854 | 156,164,722 | | 11,193,164 | | 47,342,190 | 58,535,354 | 97,629,369 | 0.119092 | 11,626,891 |
| 16 | 149,382,440 | 1,777,134 | 9,690,090 | 160,849,664 | | 11,528,959 | | 48,762,455 | 60,291,414 | 100,558,250 | 0.103342 | 10,391,854 |
| 17 | 153,863,913 | 1,830,448 | 9,980,793 | 165,675,154 | | 11,874,828 | | 50,225,329 | 62,100,157 | 103,574,997 | 0.089674 | 9,288,006 |
| 18 | 158,479,831 | 1,885,361 | 10,280,216 | 170,645,409 | | 12,231,072 | | 51,732,089 | 63,963,161 | 106,682,247 | 0.077814 | 8,301,411 |
| 19 | 163,234,226 | 1,941,922 | 10,588,623 | 175,764,771 | | 12,598,005 | | 53,284,051 | 65,882,056 | 109,882,715 | 0.067523 | 7,419,615 |
| 20 | 168,131,253 | 2,000,180 | 10,906,282 | 181,037,714 | | 12,975,945 | | 54,882,573 | 67,858,518 | 113,179,196 | 0.058593 | 6,631,485 |
| 21 | 173,175,190 | 2,060,185 | 11,233,470 | 186,468,845 | | 13,365,223 | 34,857,947 | 56,529,050 | 104,752,220 | 81,716,625 | 0.050844 | 4,154,768 |
| 22 | 178,370,446 | 2,121,991 | 11,570,474 | 192,062,911 | | 13,766,180 | | 58,224,922 | 71,991,102 | 120,071,809 | 0.044119 | 5,297,484 |
| 23 | 183,721,559 | 2,185,651 | 11,917,588 | 197,824,798 | | 14,179,165 | | 59,971,669 | 74,150,835 | 123,673,964 | 0.038284 | 4,734,772 |
| 24 | 189,233,206 | 2,251,220 | 12,275,116 | 203,759,542 | | 14,604,540 | | 61,770,819 | 76,375,360 | 127,384,182 | 0.033221 | 4,231,833 |
| 25 | 194,910,202 | 2,318,757 | 12,643,370 | 209,872,328 | | 15,042,676 | | 63,623,944 | 78,666,620 | 131,205,708 | 0.028827 | 3,782,317 |
| 26 | 200,757,508 | 2,388,319 | 13,022,671 | 216,168,498 | | 15,493,957 | | 65,532,662 | 81,026,619 | 135,141,879 | 0.025015 | 3,380,550 |
| 27 | 206,780,233 | 2,459,969 | 13,413,351 | 222,653,553 | | 15,958,775 | | 67,498,642 | 83,457,418 | 139,196,136 | 0.021706 | 3,021,460 |
| 28 | 212,983,640 | 2,533,768 | 13,815,751 | 229,333,160 | | 16,437,539 | | 69,523,601 | 85,961,140 | 143,372,020 | 0.018836 | 2,700,513 |
| 29 | 219,373,150 | 2,609,781 | 14,230,224 | 236,213,155 | | 16,930,665 | | 71,609,310 | 88,539,974 | 147,673,180 | 0.016345 | 2,413,658 |
| 30 | 225,954,344 | 2,688,075 | 14,657,130 | 243,299,549 | | 17,438,585 | | 73,757,589 | 91,196,174 | 152,103,376 | 0.014183 | 2,157,273 |
| 31 | 232,732,975 | 2,768,717 | 15,096,844 | 250,598,536 | | 17,961,742 | 46,846,166 | 75,970,316 | 140,778,224 | 109,820,311 | 0.012307 | 1,351,578 |
| 32 | 239,714,964 | 2,851,778 | 15,549,750 | 258,116,492 | | 18,500,595 | | 78,249,426 | 96,750,021 | 161,366,471 | 0.010679 | 1,723,312 |
| 33 | 246,906,413 | 2,937,332 | 16,016,242 | 265,859,986 | | 19,055,612 | | 80,596,909 | 99,652,521 | 166,207,465 | 0.009267 | 1,540,258 |
| 34 | 254,313,605 | 3,025,452 | 16,496,729 | 273,835,786 | | 19,627,281 | | 83,014,816 | 102,642,097 | 171,193,689 | 0.008041 | 1,376,648 |
| 35 | 261,943,013 | 3,116,215 | 16,991,631 | 282,050,860 | | 20,216,099 | | 85,505,260 | 105,721,360 | 176,329,500 | 0.006978 | 1,230,417 |
| 36 | 269,801,304 | 3,209,702 | 17,501,380 | 290,512,385 | | 20,822,582 | | 88,070,418 | 108,893,000 | 181,619,385 | 0.006055 | 1,099,719 |
| 37 | 277,895,343 | 3,305,993 | 18,026,422 | 299,227,757 | | 21,447,260 | | 90,712,531 | 112,159,790 | 187,067,967 | 0.005254 | 982,904 |
| 38 | 286,232,203 | 3,405,172 | 18,567,214 | 308,204,590 | | 22,090,677 | | 93,433,907 | 115,524,584 | 192,680,006 | 0.004559 | 878,498 |
| 39 | 294,819,169 | 3,507,328 | 19,124,231 | 317,450,727 | | 22,753,398 | | 96,236,924 | 118,990,322 | 198,460,406 | 0.003956 | 785,181 |
| 40 | 303,663,744 | 3,612,547 | 19,697,958 | 326,974,249 | | 23,436,000 | | 99,124,032 | 122,560,031 | 204,414,218 | 0.003433 | 701,778 |
| 41 | 312,773,656 | 3,720,924 | 20,288,896 | 336,783,477 | | 24,139,080 | 62,957,329 | 102,097,753 | 189,194,162 | 147,589,315 | 0.002979 | 439,679 |
| 42 | 322,156,866 | 3,832,552 | 20,897,563 | 346,886,981 | | 24,863,252 | | 105,160,685 | 130,023,937 | 216,863,044 | 0.002585 | 560,607 |
| 43 | 331,821,572 | 3,947,528 | 21,524,490 | 357,293,590 | | 25,609,150 | | 108,315,506 | 133,924,655 | 223,368,935 | 0.002243 | 501,058 |
| 44 | 341,776,219 | 4,065,954 | 22,170,225 | 368,012,398 | | 26,377,424 | | 111,564,971 | 137,942,395 | 230,070,003 | 0.001947 | 447,834 |
| 45 | 352,029,506 | 4,187,933 | 22,835,332 | 379,052,770 | | 27,168,747 | | 114,911,920 | 142,080,667 | 236,972,103 | 0.001689 | 400,264 |
| 46 | 362,590,391 | 4,313,570 | 23,520,392 | 390,424,353 | | 27,983,809 | | 118,359,278 | 146,343,087 | 244,081,266 | 0.001466 | 357,747 |
| 47 | 373,468,103 | 4,442,978 | 24,226,003 | 402,137,084 | | 28,823,324 | | 121,910,056 | 150,733,380 | 251,403,704 | 0.001272 | 319,746 |
| 48 | 384,672,146 | 4,576,267 | 24,952,784 | 414,201,196 | | 29,688,023 | | 125,567,358 | 155,255,381 | 258,945,815 | 0.001104 | 285,782 |
| 49 | 396,212,310 | 4,713,555 | 25,701,367 | 426,627,232 | | 30,578,664 | | 129,334,378 | 159,913,042 | 266,714,190 | 0.000958 | 255,426 |
| 50 | 408,098,680 | 4,854,962 | 26,472,408 | 439,426,049 | | 31,496,024 | | 133,214,410 | 164,710,434 | 274,715,616 | 0.000831 | 228,294 |
| | $10,816,291,198 | $128,664,526 | $701,562,676 | $11,645,518,400 | $467,680,000 | $834,696,818 | $189,899,028 | $3,560,789,736 | $5,053,065,582 | $6,592,452,818 | | $0 |

NET PRESENT VALUE OF ANNUAL BENEFITS USING A DISCOUNT RATE OF 7% : $771,663,184

Vehicle miles of travel (VMT) as well as person hours of travel estimates were derived for passenger vehicles, single-unit trucks, tractor-trailers as well as buses. The results from deploying AHS are shown in table 2-11a.

Travel time savings accrue primarily to bus riders and single-unit truck riders. Since these savings are expressed as person-hours, they can be multiplied by our assumed values of time per-person to yield estimates of the total value of travel time saved in the peak hour of travel. Multiplying by a peak hour to daily factor yields the daily travel time savings, which are then converted into annual savings in both directions of travel of just under $100 million during the peak hour alone. Sensitivities for variations in the value of time are also shown for comparison purposes.

We assumed that commercial vehicle passengers, whether they are drivers or not, value their time at around three times the average values for passenger vehicle occupants. Bus occupants were assumed to value their time at the same rate as passenger vehicle occupants, although in reality estimates of transit rider value of time could be significantly lower.

The cost-benefit template then continues as it did before in the following pages. The results are shown in the financial summary table. The LIE project distinguishes itself in that it seems an ideal candidate for implementing AHS. Corridor volumes are high, and the opportunity is there for generating additional capacity while reducing travel times through AHS. The net present value of the project, given our assumptions and conditions, is large and positive; its internal rate of return over 15 percent, a healthy return sufficiently attractive to even private sector roadway operators who may be convinced to contribute equity in exchange for a portion of this return.

### 3.3.4 Summary of Real World Examples of Cost-Benefit Analysis

To summarize our scenarios on AHS benefits and costs, table 2-12 shows that the best overall results were achieved with the Long Island Expressway configuration. All of the other project scenarios achieved marginal returns at best, or as currently configured, probably should not be undertaken.

## 4.0 CONCLUSIONS

### 4.1 Summary

Much analysis needs to be done in the proper evaluation of potential AHS corridors. The tools currently available with conventional cost-benefit analysis may be sufficient to do so, but considerable uncertainty lies with projected operational savings, cost magnitudes, scope, on-board electronics components costs and the potential for passing through costs to users, as well as the overall market penetration of such systems. A socially useful cost-benefit analysis is only as good as the underlying analysis that will come up with values for such parameters. In the experimental stage that AHS seems to be in at the moment, there is sufficient uncertainty with regard to such parameters that a good judgment on the adequacy of the cost-benefit analytical framework needs to be deferred until a later date.

## Table 2-12. Cost-Benefit Analysis Results

| SCENARIO | Sum of Present Value of Total Annual Benefits (over 50 years) | Sum of Present Value of Total Annual Costs (over 50 years) | Net Present Value (over 50 years) | Internal Rate of Return (IRR) |
|---|---|---|---|---|
| LONG ISLAND EXPRESSWAY* | $2,053,229,508 | $1,281,566,324 | $771,663,184 | 15.2% |
| NYS THRUWAY (100 kph) | $435,090,310 | $1,115,883,072 | ($680,792,762) | -7.2% |
| NYS THRUWAY (129 kph) | $599,041,137 | $1,161,677,428 | ($562,636,291) | 0.5% |
| I-93 BOSTON | $691,125,836 | $1,025,339,547 | ($334,213,711) | 1.2% |
| 495 BELTWAY WASHINGTON | $809,848,898 | $1,202,420,082 | ($392,571,184) | -0.9% |

**Note:**

Net Present Value is calculated using the Federal Office of Management & Budget's discount rate of 7.0%.

* The Value of Time Saved for the LIE includes a $60/hour valuation of commercial vehicle travel time. Commercial vehicles are not included in the figures for the other roadways.

Additionally, annual Time Savings calculations for the LIE segment are extrapolated from figures for the peak AM hour. Annual Time Savings figures for all other roadway segments are based on traffic model results for a seven-and-a-half hour AM peak period.

In the interim, our research suggests that AHS corridors can be sufficiently evaluated on the basis of their potential to generate the following principal components of benefits: travel time savings, roadway safety improvements, and secondary or multiplier effects of ongoing system operational and maintenance activities.  Considerable research should be focused on the safety improvements component.

On the cost side, our research suggests that roadway and system infrastructure costs seem to be more readily accessible and easy to quantify than the other cost components.  More uncertainty exists with regards to ongoing operating and maintenance costs, over and above costs incurred on current roadways.  The greatest uncertainty exists with respect to on-board vehicle electronics costs.  The more advanced we are in the AHS planning process, the closer we will be towards reducing these uncertainties.

### 4.2 Issues/Risks

See Issues table 2-13.

2-13. Cost-Benefit Analysis Issues (continued)

| Issue No. | Issue/Risk Descriptive Title | Description/ Recommendation | RSC Impact | PSA Task Impact |
|---|---|---|---|---|
| **COST-BENEFIT ISSUES** | | | | |
| CB-1 | Traffic engineering and modeling state-of-the-art needs to advance to more accurately assess costs and benefits of AHS | Improved traffic engineering and modeling would allowcost benefit analysis to more accurately portray the performance, functional objectives and potential value of AHS. | All RSCs | All Tasks |
| CB-2 | Cost of equipping cars for AHS should be kept as low as possible, at least initially, to encourage wider use of AHS | Although costs of AHS equipment for vehicles will drop as demand grows, the lower the up-front cost of retro-fitting an old car or buying a new one, the faster the use of AHS will catch on. | All RSCs | L |
| CB-3 | Reliability of entity in charge of operating and maintaining the AHS system | Because AHS must provide a net benefit in order to attract users and make it worth investing in, it is vital that the agency or other body in charge of O&M be willing and able (i.e., have the incentive and the funding) to provide consistent, reliable and consumer-oriented service. | All RSCs | O |
| CB-4 | Costs of new rights-of-way, and even expansion of existing rights-of-way, could be costly enough to prohibit development of AHS | AHS plans should be designed to avoid the need for new or widened right-of-way acquisition, particularly in dense urban and suburban areas. The cost of obtaining such land, both in terms of money and in political capital, as well as the costly construction delays that can result from local opposition, can discourage private as well as public sector financing. | All RSCs | A, B,C,D,H,O |

## 2-13. Cost-Benefit Analysis Issues (continued)

| Issue No. | Issue/Risk Descriptive Title | Description/ Recommendation | RSC Impact | PSA Task Impact |
|---|---|---|---|---|
| CB-5 | Importance of Travel Time Savings | Although the safety benefits of AHS are important, the dollar value of driver and passenger travel time savings was found to be much larger in preliminary cost/benefit studies.<br>Because of this, AHS will be more likely to be of value to very congested corridors, where traffic is slowed below the speed limit. For this reason, AHS will be more likely to be implemented in congested urban corridors. | All RSCs | A,G,J,K,N |
| CB-6 | Importance of being able to acheive meausrable performance gains such as increased throughput, speed, etc. on AHS roadways | Another factor in increasing the time savings of AHS users is the speed attainable by the system. If maximum AHS speeds are close to today's non-AHS speed limits, time savings will only be realized by peak period users in congested corridors. However, if speeds can be safely increased above 100 kph/60mph, then time savings benefits can be experienced by a much larger pool of users. | All RSCs | A,D,G,J,K, L,M,N |
| CB-7 | Importance of ensuring that commercial vehicles receive benefits from AHS | Because commercial vehicles have a higher value of time savings than passenger vehicles, it is vital to the success of AHS that they do not suffer increased travel times, (as they might if car-only AHS systems squeezed all freight vehicles into a single, crowded non-AHS lane).<br>Conversely, if commercial vehicles are found to benefit from AHS implementation, the value of the time savings benefits could be the determining economic factor, as well as the source of critical political support for AHS. | All RSCs | A,D,G,H,I,J, K,L,M,N,O |

2-13. Cost-Benefit Analysis Issues (continued)

| Issue No. | Issue/Risk Descriptive Title | Description/ Recommendation | RSC Impact | PSA Task Impact |
|---|---|---|---|---|
| **FINANCE ISSUES** | | | | |
| CB-8 | Potential need for legislation to clarify fed/state/local gov't /private sector role, and/or to allow flexibility | Because the enabling legislation for AHS implementation would be different in each state, and, additionally, because of political and institutional barriers that may arise in many states and localities, it may be desirable to enact federal enabling legislation to facilitate nation-wide implementation. This may be particularly important if private involvement is sought, as some states' legal environment makes privatization of highway facilities very difficult<br><br>Allowance for flexibility in forming public/private partnerships may be a key to attracting and retaining private investment | All RSCs | O |
| CB-9 | Funding Source Issues: Reliability & Equity | Reliability: The funding source(s) must be reliable enough to allow for adequate and timely O&M, as well as the payment of any debt service that may be required.<br><br>Equity/Fairness: Alternative source must be evaluated for fairness. Should users be the sole source, or should non-users be assessed in some form for the benefits received? Should revenues from increased assessments on real estate which has had its value enhanced by AHS be dedicated to AHS? Should revenues come from more equitable sources such as personal | All RSCs | O |

2-13. Cost-Benefit Analysis Issues (continued)

| Issue No. | Issue/Risk Descriptive Title | Description/ Recommendation | RSC Impact | PSA Task Impact |
|---|---|---|---|---|
| | | income tax or even tolls, or from more politically "popular" taxes, such as sin, fuel, and auto taxes?<br><br>Possible sources: State gas or sales taxes, federal gas or sales taxes, general revenues, tolls, concession revenues | | |
| CB-10 | Liability issues may discourage private sector involvement | Fear of liability for accidents on AHS may scare away private investors and contractors. | All RSCs | O |
| CB-11 | Good long-term planning favors the careful selection of capital cost funding sources | One benefit of full federal (or other single-source) funding is that the implementation of AHS can be controlled and planned so that all systems will be compatible, that building standards can be easily enforced, and that linkages can be made to create a new travel market and new economic opportunities (instead of only serving existing markets which could guarantee the tolls to attract private investment, or provide the political benefits to attract local government support). | All RSCs | O |
| CB-12 | Heavy reliance on private sector capital provision would bring about changes in the implementation of AHS (both good and bad changes) | As local public and private sector entities become involved in funding, standards and configurations (RSCs) will increasingly be selected to serve local needs. This would give rise to a fragmented system of a few AHS roadways, which would make later conversion to a linked national network difficult and expensive, particularly if the RSC technologies used are very different.<br>Related issue.<br>If different RSCs are chosen for each city, the cost of AHS technology would be higher than | All RSCs | A,F,I,O |

2-13. Cost-Benefit Analysis Issues (continued)

| Issue No. | Issue/Risk Descriptive Title | Description/ Recommendation | RSC Impact | PSA Task Impact |
|---|---|---|---|---|
| | | if a single system were used nationally, creating a huge mass market for that technology.<br><br>Additionally, if private funding is relied upon for implementation, it is unlikely that low density markets will be served, as investment money will tend to seek out those links which can bring high and reliable toll revenues.<br><u>Related issues:</u><br>In one way, this is a benefit, as only those roadways for which user benefits outweigh costs (i.e., tolls) would be converted to AHS. Public sector money would not be wasted on routes where benefits would be low.<br><br>However, exclusive roadways, where drivers have no low-cost parallel options, would be taken over first, decreasing choices for consumers (drivers), and creating inefficiencies in the road network. And, perhaps, interfering with citizen's legal rights to publicly-paid-for infrastructure.<br><br>AHS might be limited to congested commuter corridors, ignoring the long-term benefits which could be achieved by automating less-well-used intercity links.<br><br>Private desire for increased revenues would put pressure on AHS R&D to allow for movement of transit and freight vehicles, preferably all on the | | |

## 2-13. Cost-Benefit Analysis Issues (continued)

| Issue No. | Issue/Risk Descriptive Title | Description/ Recommendation | RSC Impact | PSA Task Impact |
|---|---|---|---|---|
| | | same roadway. This could be a benefit, as it should increase economic productivity, but it would lower the maximum possible speed and safety benefits which could be reached by an automobile-only type of AHS.<br><br>Social and environmental benefits would not necessarily be valued by private AHS builders/ marketers. This might put pressure on AHS to be implemented in an unsustainable manner (encouraging increased SOV use, spread-out land use, and long-term growth of auto dependency and traffic congestion). | | |

## APPENDIX A: ENVIRONMENTAL ISSUES

The following tables are included as a brief evaluation of some of the environmental issues that AHS roadways will have to contend with in the current policy structure. As a capital change in the current roadway system, AHS will be evaluated partially on the basis of its effects on the environment. The principal environmental costs will include its effects on air resources (will AHS be able to reduce pollutants emitted by equipped vehicles by achieving more efficient travel patterns?), water resources, and so on (see table 2-A1).

Environmental impacts are further explored in table 2-A2.

On a comparison basis, AHS will be evaluated against other roadway demand and supply-side measures to deal with certain operational improvements or benefits. Table 2-A3 is considered useful for summarizing the effectiveness of other measures.

Table 2-A1. The Principal Environmental Costs of Transportation

**Main Impacts**

| Mode | Air Resources | Water Resources | Land Resources | Solid, Waste | Noise | Accident Risk | Other Impact |
|---|---|---|---|---|---|---|---|
| Rail | Depends on nature of propulsion - air pollution | Surface and ground water contamination potential | Land Taken for Rights-of-way & terminals; dereliction of obsolete facilities | Abandoned lines, equipment & rolling stock | Noise & vibration along lines & around terminals | Derailment or collision of freight-carrying hazardous substances | Partitions or destruction of neighborhoods farmland & wildlife habitats |
| Air | Air pollution | Modification of water tables, river courses & field drainage to support air fields | Land taken for facilities infrastructure; dereliction of obsolete sites | Scrapped aircraft | Noise envelopes around airports | Aircraft collisions, takeoff, & landing accidents | Congestion - air traffic or on access routes to/from airports |
| AHS Roadways | Local (CO, HC, $NO_x$, fuel additives such as lead & particulates) + Global ($CO_2$, CFC's) | Pollution of surface water & ground water by surface run-off; modification of water systems by road building | Land taken for infrastructure; extraction of road building materials | Abandoned rubble from road works; waste oil | Noise and vibration from cars & trucks | Deaths injuries property damage from accidents; risk of transport of hazardous substances; risk of structural failure in older or more worn road facilities | Congestion. Partition or destruction of neighborhoods farmlands & wildlife habitat |

**Table 2-A2. Principal Environmental Impacts Associated with Roadway Use that AHS will have to Contend With or Mitigate**

| Pollutant | Source | Effects on People | Effects on Vegetation | Effects on Climate | Effects on Materials, Buildings |
|---|---|---|---|---|---|
| **Hydrocarbons** | Incomplete vehicular combustion, carburetion | Direct, carcinogenic effects of individual components | Through build-up in soil, feed & food crops | Greenhouse potential (methane) ozone formation | |
| **Nitrogen Oxide** | Oxidation of $N_2$ and N-Compounds in Fuel additives | Effects on respiratory system | Acidification of soil, water, risk of leaf & root damage | Greenhouse potential ($NO_2$) + ozone | weathering erosion |
| **Carbon Monoxide** | Incomplete combustion | Inadequate oxygen supply - respiratory + circulatory systems | | Ozone formulation | |
| **Ozone** | Photo-chemical oxidization with $NO_X$ and HC | Respiratory system | Leaf and root damage | High greenhouse potential | Decomposition of polymers |
| **Noise** | Engine, drive and rolling noise | Nuisance | | | Reduced value |
| **Soot** | Incomplete combustion + source specific emissions throwing up dust | Respiratory system damage; toxicity effects | reduced assimilation | | Dirty Buildings |
| **Particulates** | Local (CO, HC, $NO_X$, fuel additives such as lead & particulates) + Global ($CO_2$, CFC's) | Pollution of surface water & ground water by surface run-off; modification of water systems by road building | Land taken for infrastructure; extraction of road building materials | Abandoned rubble from road works; waste oil | Congestion. Partition or destruction of neighborhoods farmlands & wildlife habitat |

Table 2-A3. Ratings of Selected Measures to Reduce Vehicular Congestion

| | *Supply-Side Measures* | | | | | *Demand-Side Measures* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Rapidly Removing Accidents | Improving Highway Maintenance | New HOV Lanes | New Roads Without HOV Lanes | Signals, TV Monitoring, Ramp Signals, VMS | Peak-Hour Tolls On Main Roads | Parking Tax on Peak-Hour Arrivals | Eliminate Tax Deduct'n On Free Employee Parking | Make Commute Allowance Tax-Deductable | Increase Gasoline Taxes |
| **EFFECTIVENESS** | | | | | | | | | | |
| Extent | Variable | Broad | Variable | Variable | Broad | Broad | Broad | Broad | Variable | Broad |
| Impact | High | Moderate | Moderate | Mod/Low | Moderate | Great | Great | Great | Great | Moderate |
| **COSTS OF IMPLEMENTATION** | | | | | | | | | | |
| Direct User Costs | None | None | None | None | None | Great | Great | Great | None | Great |
| Societal Costs | Minor | Moderate | Significant | Significant | Minor | None | None | None | Minor | Moderate |
| **EASE OF IMPLEMENTATION** | | | | | | | | | | |
| Institutional Changes | None | None | Cooperative | Cooperative | None | Regional | Regional | Cooperative | None | None |
| Ease of Admininstration | Easy | Moderate | Difficult | Moderate | Moderate | Moderate | Hard | Moderate* | Easy | Easy |
| Easy to Understand | Easy | Easy | Easy | Easy | Moderate | Moderate | Moderate | Moderate | Easy | Easy |
| Easy to Carry Out | Easy | Moderate | Difficult | Easy | Moderate | Moderate | Moderate | Easy | Easy | Easy |
| **POLITICAL ACCEPTABILITY** | Excellent | Moderate | Moderate | Poor | Good | Poor | Poor | Poor | Poor | Poor |
| **USER ACCEPTABILITY** | Excellent | Moderate | Moderate | Poor | Good | Poor | Moderate | Moderate | Good | Moderate |

## Table 2-A3. Ratings of Selected Measures to Reduce Vehicular Congestion (continued)

| | ***Demand-Side Measures (continued)*** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Promote High-Density Development in Growth Corridors** | **Encourage TMA's, Promote Ridesharing** | **Encourage People to Work at Home** | **Change Laws Discouraging Working at Home** | **Stagger Work Hours** | **Cluster High-Density Housing Near Transit** | **Concentrate Employment in New Growth Areas** | **Increase Automobile License Fees** | **Improve Jobs-to-Housing Balance** | **Adopt Local Growth Limits** |
| **EFFECTIVENESS** | | | | | | | | | | |
| **Extent** | Broad | Narrow | Broad | Broad | Variable | Narrow | Narrow | Broad | Broad | Narrow |
| **Impact** | Moderate | Moderate | Minor | Minor | Minor | Minor | Minor | Minor | Minor | Minor |
| **COSTS OF IMPLEMENTATION** | | | | | | | | | | |
| **Direct User Costs** | None | None | None | None | None | None | None | Moderate | None | None |
| **Societal Costs** | Minor | Minor | None | Minor | None | Minor | Great | Minor | Moderate | Minor |
| **EASE OF IMPLEMENTATION** | | | | | | | | | | |
| **Institutional Changes** | Regional | Cooperative | None | None | Cooperative | Cooperative | Regional | None | Regional | None |
| **Ease of Administration** | Hard | Hard | Moderate | Moderate | Moderate | Hard | Hard | Easy | Hard | Easy |
| **Easy to Understand** | Variable | Easy | Easy | Easy | Easy | Easy | Easy | Easy | Easy | Easy |
| **Easy to Carry Out** | Hard | Moderate | Moderate | Easy | Moderate | Hard | Hard | Easy | Hard | Moderate |
| **POLITICAL ACCEPTABILITY** | Poor | Moderate | Good | Moderate | Moderate | Moderate | Poor | Poor | Poor | Good |
| **USER ACCEPTABILITY** | Poor | Moderate | Good | Good | Good | Moderate | Poor | Poor | Poor | Good |

**Source:**

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