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EXECUTIVE SUMMARY

Intelligent Vehicle Highway Systems (IVHS) comprise a spectrum of technologies, with both short-term and long-term applications. Eventually, deployment of IVHS may lead to fully automated, hands-off and feet-off, driving. In the short-term, IVHS has included traffic control systems, in-vehicle information systems, and a range of new roadway sensors.

This paper develops a framework for planning the evolutionary deployment of IVHS technologies. It defines an evolutionary deployment sequence, identifies baseline assumptions, and presents strategies for achieving success. This paper also develops an evaluation framework, consisting of strategy development, strategy evaluation, technology and barrier identification and strategy refinement. Lastly, the paper presents examples of evolutionary deployment sequences, and discusses both the market and technological ramifications of these sequences.

1. INTRODUCTION

1.1 PURPOSE

This concept paper explores the development of an analytical approach for delineating and evaluating evolutionary deployment of Intelligent Vehicle Highway Systems (IVHS). Discussion of evolutionary deployment strategies must address technological, institutional, legislative, and public acceptance issues, including time-dependencies. As part of the development, criteria and approaches are needed to evaluate both qualitatively and quantitatively the advantages and disadvantages of alternative deployment strategies. This paper includes:

1. Definition of a deployment strategy, and what it encompasses;

2. Criteria and an evaluation framework for identifying, comparing, and selecting among alternate deployment options;

3. Identification of barriers, uncertainties, and contingency planning, wherever applicable.

The analysis presented here takes advantage of and builds upon the multitude of ongoing and completed studies regarding the various IVHS technologies, as well as those addressing societal and environmental impacts of IVHS and Automated Highway Systems (AHS).

1.2. ELEMENTS OF INTELLIGENT VEHICLE HIGHWAY SYSTEM TECHNOLOGY

Intelligent Vehicle Highway Systems (IVHS) refers to the application of advanced technology to improve the operations of transportation systems. A large number of technologies are being developed under IVHS research. These include sensors and communication technologies, information processing, and controls. **A** large number of publications are available covering various aspects of IVHS. The IVHS America Strategic Plan issued in May 1992 [1] provides a detailed discussion of IVHS components and presents a long-term strategic plan for the development of IVHS in the United States, focusing on the role IVHS can play in addressing current and future transportation problems. The document describes in detail five IVHS functional areas:

1. **Advanced Traffic Management Systems.** ATMS uses detection, communication, and control technologies to detect traffic conditions, and transmit the information to traffic management centers. The centers process the information and use the results to manage the traffic, advise motorists about traffic conditions and manage incidents.

2. **Advanced Traveler Information Systems.** ATIS provides information to travelers on traffic conditions, schedules, and routes from starting point to their destinations. The information can be communicated to the travelers using a variety of modes, including kiosks, at home computers, or portable equipment.

3. **Advanced Vehicle Control System.** AVCS uses in-vehicle control systems, sensors and communication technologies to enhance vehicle control, enhance the driver's awareness of road and vehicle conditions, and assist in driving tasks. These may include automated steering, braking and acceleration.

4. **Commercial Vehicle Operations.** CVO provides IVHS technologies to commercial vehicles: trucks, delivery vans, inter-city buses, end emergency vehicles. These technologies include: Automated Vehicle Identification (AVI); Automated Vehicle Classification (AVC); Automated Vehicle Location (AVL); and Weigh-In-Motion (WIM). These technologies could provide significant improvement in safety, productivity and cost reduction.

5. **Advanced Public Transportation Systems.** APTS applies advanced electronic technologies to high occupancy vehicles, including buses, rail

and para-transit vehicles. These technologies can assist in fee collection, ride-matching, providing more reliable and accurate schedule and route information and controlling route schedule and routes.

For each of these functional areas, the IVHS America Strategic Plan provides detailed discussion of the state-of-the-art, ongoing research as well as operational testing and future plans. The document also presents a vision of how research, development and implementation of IVHS capabilities should evolve over the next 20 years. While selected ATIS and ATMS functions are already in the testing and/or operational phases, many IVHS elements are still in research and development, and will possibly encounter extensive institutional and legal barriers. An extensive discussion of these issues as well as approaches to deal with the identified barriers are also presented in the Strategic Plan.

1.3 BACKGROUND AND REVIEW

The need for investigating alternate evolutionary deployment strategies has been recognized by many as an essential element of the development, introduction and eventual acceptance and/or rejection of the many IVHS technologies, possibly leading to automated highway implementation. Below is a brief discussion of selected papers or reports in the literature addressing deployment of IVHS. Though all of these reports acknowledged the evolutionary nature of the problem, none of them explicitly addressed the development of a framework for evaluation.

The May **1992** IVHS America Strategic Plan [1] provided a set of milestones for each of the five areas as shown in Table 1.1. Although the IVHS America list provides a possible progression, it does not present a strategy that deals with potential barriers to deployment. More importantly, it does not provide a framework for evaluating alternate strategies as to the many uncertainties surrounding the possible successes or failures in developing these technologies.

One should also note that according to the IVHS America Strategic Plan, developing and deploying IVHS technologies is a major undertaking. For instance, a span of almost 20 years is required for AHS deployment. The plan also discusses both the societal and legal concerns including product liability and other tort liability, antitrust, privacy, procurement, intellectual property and regulation, and provides a summary of ongoing studies to identify and address these concerns.

In his February **1993** paper, Varayia [2] states that there are five aspects of development of IVHS. These are: function, architecture, design, evolution and evaluation. Evolution is defined as the timing of system development and deployment, and the extent to which the architecture should accommodate new functions not included in earlier designs, while evaluation is defined as the effectiveness, costs and benefits of different IVHS proposals. Varayia's paper focuses on the first three aspects of design. The later two functions, evolution and evaluation, are the focus of this paper.

Though not addressed explicitly, many authors have discussed general premises regarding evolutionary development of IVHS. For example, auto manufacturers **[3, 4]** often focus on the extent to which individuals are likely to purchase automation equipment prior to the construction of the Automated Highway System (AHS) infrastructure (or at least prior to conversion of lanes from manual to automatic).

Heinrich [3] believes that "the ultimate success (of IVHS) will be highly dependent upon the acceptance and continued use of in-vehicle IVHS equipment by the vehicle driver." The author also draws a link between what he termed "smart vehicles" and "smart highways" and argues that smart highways have to exist before smart vehicles become a reality. He also asserts that car buyers are generally conservative on what they buy and are looking for practical solutions for their needs, and argues that "the capability of the IVHS infrastructure to provide timely and credible traffic advisories will play a key role in forming and more importantly maintaining the buyer's interest in IVHS."

In an earlier paper entitled "Automated Urban Freeways: Policy Research Agenda," Johnston et al [5] provided an initial attempt at the development of a staged deployment of automated freeways. The paper proposed five stages for implementation:

1. Voluntary on-board navigation and route-guidance devices;
2. On-board longitudinal control;
3. Lateral control and dedicated lanes;
4. Full automation of some lanes;
5. Full automation of all lanes.

Their paper, however, didn't specify how these stages are to be deployed nor did it address the stimulus by which the development would move from one stage to the next.

In a recent report entitled "**AHS** Deployment: **A** Preliminary Assessment of Uncertainties," [6] a discussion of factors that may influence the acceptability of automated highways is provided. These issues include: technological feasibility; opposition of special interest groups, and inability of auto makers to provide the needed automation. The study synthesizes the results of elicitation of expert opinions "to identify the critical issues, technical or not, that need to be resolved to ensure timely and efficient deployment of **AHS.**" The paper highlights many technical and institutional issues that need to be addressed, and emphasized the need for "a more integrated vision of AHS within which research issues can be coordinated."

1.4 PAPER OUTLINE

The remainder of this paper consists of five sections. Section 2 provides a summary listing of IVHS projects in the United States. Only operational tests and deployment activities are included. The reader is referred to the Federal Highway Administration report [8] for additional information. Section **3** provides a definition of evolutionary deployment strategies and introduces a set of ground rules for development of evolutionary deployment strategies.

Next, Section 4 presents a framework for developing and evaluating these strategies and includes a set of performance measures against which a deployment strategy can be evaluated. These performance measures can help examine the tradeoffs among proposed deployment scenarios. This is followed by an example "basic" deployment sequence, and a discussion of enabling technologies and possible barriers to adoption. These barriers or constraints include economic, environmental and societal factors. This basic sequence is used to demonstrate the use of this approach to evaluate the deployment sequence and to compare the impacts and benefits of alternate strategies. This section also presents an illustrative example of how the evaluation framework can be used. This report concludes with Section 5, where a discussion of future steps needed for using the framework is presented.

Table 1.1 A SELECTION OF POTENTIAL IVHS MILESTONES*

		1992 – 1996	1997 – 2001	2002 – 2011
ATMS Advanced Traffic Management Systems	Research and Development	■ Traffic monitoring hardware and software ■ Traffic control systems logic ■ Database specification ■ Traffic management center user interfaces	■ Multi-source traffic data fusion ■ Predictive traffic modeling ■ Dynamic optimal routing strategies ■ Adaptive traffic control	■ Site-specific refinement of applications and technologies
	Operational Tests	■ Traffic monitoring systems ■ Vehides as probes ■ Traffic control systems ■ Inadenl detection and management ■ Traffic modeling ■ Traffic management center operations	■ Network-wide traffic optimization ■ Area-wide traffic management	■ Multiple transportation mode information integration
ATIS Advanced Traveler Information Systems	Research and Development	■ Navigation software ■ Map and business/tourist services databases ■ Communication alternatives	■ Dynamic, optimal route guidance ■ Portable information systems ■ In-vehide signing	• Multi-modal trip planning
	Operational Tests	■ Navigation route planning and guidance ■ AVI and AVL in various applications ■ Alternative presentation and delivery modes	■ Dynamic route guidance ■ Emergency Mayday ■ Safety/warning systems	■ Demand-responsive system capabilities

* Source: Strategic Plan for IVHS [1]

Table 1.1 A SELECTION OF POTENTIAL IVHS MILESTONES* (CONT.)

		1992 – 1996	1997 – 2001	2002 – 2011
AVCS Advanced Vehicle **Control Systems**	Research and Development	■ Sensors ■ Collision warning ■ Driving simulators	■ Perceptual enhancement systems ■ Vehicle/driver monitoring systems	■ Collision avoidance systems ■ Obstacle avoidance systems ■ Automated network operations
	Operational **Tests**	■ Roadway/environment safely warning systems ■ Intelligent cruise control ■ Test facility devebpment	● Collision warning systems ■ Automated highway demonstration ■ Lane departure control a Intersection hazard warning	■ Automated freeway lane operation ■ Automated HOV
CVO Commercial Vehicle Operations	Research and Development	■ Weigh-in-Motion ■ Electronic toll collection ■ Driver warning systems ■ Eledronic record-keeping	8 HAZMAT cargo information systems ■ Automated vehide and driver safely inspections	
	Operational Tests	■ AVI/AVL in multiple applications ■ Electronic credential checking ■ Electronic permitting	■ Electronic record keeping	a Automated heavy vehide lane testing
APTS Advanced **Public** Transportation **Systems**	Research and Development	■ Customer interfaces ■ Customer service systems ■ HOV verification ■ Electronic fare collection	■ Interactive displays ■ HOV guide controls ■ smart cards	
	Operational Tests	■ Kiosks ■ Audio/video text ■ Portable traveler information ■ Fleet management systems # Maintenance tracking systems	■ Interadive customer service systems ■ Integration of customer and fleet management information	■ Automated transit vehide operation on specially equipped (HOV) lanes

* Source: Strategic Plan for IVHS [1]

2. INTELLIGENT VEHICLE-HIGHWAY SYSTEM PROJECTS IN THE UNITED STATES

As mentioned in Section 1, establishing a starting point and development cycle for alternate deployment strategies requires an understanding of the current status of the technology. This section summarizes current operational and deployment projects in the United States. A recent report prepared for the Transportation Research Board entitled "Freeway Operations Projects Summary," [7] which provides an up-to-date summary of freeway operations projects in the U.S. and Canada, highlights the role new technological advances have been playing in freeway operations. Examples include:

- Large scale integrated freeway management systems to enhance total system efficiency.

- Incident detection, verification and response. These include the use of electronic surveillance, cellular phone 911, and fleet dispatchers. Closed Circuit Television and CB radio monitoring for verifying incidents. Owned or franchised tow trucks are used to expedite response to incidents

- Ramp metering systems as part of the freeway traffic management systems.

- Highway Advisory radio and variable message, especially in construction zones, to provide up to the minute information to motorists.

In a January 1992 report, the Federal Highway Administration (FHWA) compiled a listing of various IVHS projects in the U.S. [8]. The report divided these projects into three areas: on-going FHWA research activities; IVHS operational tests; and IVHS deployment projects. Of importance here are the deployment and operational tests. The reader is referred to the report for additional information on the research activities.

2.1 IVHS OPERATIONAL TESTS

The report lists 16 operational tests divided into three categories: Advanced Traffic Management Systems, Advanced Traveler Information Systems, and Commercial Vehicle Operations. Eight of these operational tests are in the ATMS category. These are:

1. INFORM. The Information for Motorists project being deployed in Long Island, New York, integrates surveillance and control of three freeways with cross and selected parallel arterial streets, with a Traffic Information Center to facilitate corridor traffic flow.

2. TRANSCOM Congestion Management Program. This program, in Northern New Jersey and Metropolitan New York Area, uses commercial vehicles equipped with transponders and readers for automatic toll collection. Equipped vehicles are also used as traffic probes. Data collected will provide real-time traffic information for traffic monitoring and incident detection for improved incident response.

3. SMART Corridor. This is a demonstration program along a portion of the Santa Monica freeway corridor in Los Angeles, California. SMART uses advanced technologies including Changeable Message Signs (CMS) and Highway Advisory Radio (HAR) to advise travelers of current route conditions and alternate routes to provide improved traffic management and emergency response.

4. Guidestar. This project, in the Twin Cities metropolitan area in Minnesota, integrates a variety of ATMS/ATIS efforts to reduce congestion and to improve safety throughout the state. The effort includes the development of the Autoscope video imaging vehicle detection system

5. Satellite Communications Feasibility Study for the Pennsylvania Department of Transportation (PADOT). This is part of an area-wide traffic and incident management program and is designed to investigate the use of satellite as a communication medium in conjunction with freeway surveillance hardware.

6. Urban Congestion Alleviation Demonstration Project. This project is designed to test Video Imaging Detection System (VIDS) on the Woodrow Wilson Bridge, Virginia, to evaluate its ability to measure traffic flow and detect freeway incidents.

7. Live Aerial Video, Maryland. This project will test the feasibility of transmitting live video from aircraft to county and state traffic management centers.

8. Connecticut Freeway ATMS, in Hartford Connecticut, uses roadside mounted radar detectors in combination with Closed Circuit Television (CCTV) for incident detection and verification. It also includes an evaluation of compressed video transmitted over leased phone lines.

Table **2.1** provides a summary of these ATMS projects. Under ATIS, the report includes six activities:

1. Pathfinder. An in-vehicle navigation system project performed in conjunction with the SMART Corridor project to provide drivers of specially equipped vehicles with congestion information in the form of an electronic screen map or digital voice.

2. TravTek, Orlando. Similar to Pathfinder. In addition, drivers of equipped vehicles are provided with route guidance, tourists information and "yellow pages" information.

3. ADVANCE, Chicago. ADVANCE—Advanced Driver and Vehicle Advisory Navigation Concept—is the first large-scale dynamic route guidance system in the **U.S.** The project involves equipping up to 5000 private and commercial vehicles with in-vehicle navigation and route guidance systems. Vehicles will gather real-time traffic information. This information is transmitted to the equipped vehicles and used to develop preferred routes. The routing information is provided to the driver in the form of dynamic routing instructions.

4. DIRECT, Detroit. DIRECT—Driver Information Radio Experimenting with Communication Technology— is deploying and evaluating low cost methods for communicating advisory information to motorists along 21 miles of the 1-94 corridor in Detroit. These methods include: Radio Data Systems; Automatic Highway Advisory Radio, Highway Advisory Radio using AM and cellular phone.

5. FAST-TRAC, Michigan. FAST-TRAC— Forum for Advanced Safe Travel through Traffic Routing and Advanced Control— combines ATIS and ATMS techniques to improve mobility and road safety. Vehicles will be equipped with a route guidance and driver information systems.

6. Urban Congestion Alleviation Demonstration. This project is designed to evaluate the effectiveness of Variable Message signs and Traffic Advisory radio to provide motorists on 1-95 between Washington D.C. and Baltimore with accurate and timely traffic information. This project complements CHART (Chesapeake Highway Advisories Routing Traffic), Maryland's statewide program for providing traffic advisories.

For commercial vehicle operations, the report lists two activities:

1. HELP/Crescent. HELP—Heavy Vehicle Electronic License Plate Program) is a multi-state effort to test an integrated heavy vehicle monitoring system using Automated-Vehicle-Identification (AVI) and Weigh-in-Motion (WIM) technology. HELP/Crescent is the demonstration phase of HELP and will include approximately **40** equipped sites. A goal of this activities is to have a system in which a heavy vehicle entering the system in British Columbia, can drive through the entire network without having to stop at other weigh stations or ports-of-entry.

2. Advantage 1-75. This project is a public and private partnership along the 1-75 corridor from Florida to Michigan. This project will allow specially equipped trucks to travel any segment along the length of I-75 with minimal stopping at weigh/inspection stations.

2.2 IVHS DEPLOYMENT PROJECTS

Most of the deployment projects focus on providing traffic management with enhanced incident management response capabilities. According to the FHWA report these deployment activities have the following objectives:

"• Enable State and local governments to develop reasonable and realistic plans leading to deployment of ATMS and/or ATIS projects,
- Leverage existing plans and activities for accelerating deployment of IVHS technologies,
- Establish proper groundwork for deployment of future advanced IVHS technologies,
- Identify implementation schedules, including cost quantification for procurement, operations and maintenance."

Below is a listing of the six deployment projects:

1. Advanced Traffic Management Systems Model Study for the Portland metropolitan area, Oregon.

2. Advanced Traffic Management Systems Model Study for the Denver metropolitan area, Colorado

3. Incident Management, Seattle, Washington. A part of a broader project known as FAME—Freeway and Arterial Management Effort.

5. Integrated System Project, Anaheim, California

6. Incident Management, Minneapolis/St. Paul, Minnesota.

Information presented in this section establishes a starting point for evolutionary deployment strategies. Moreover, experience gained in these projects provides a basis for assessing the time required for research and development, operational testing and demonstration of various technologies.

An important observation is that much of the focus has been on providing better information for motorists and on improving detection, assessment and response to traffic incidents. These, to a large extent, provide immediate benefit by improving traffic conditions and relieving congestion caused by incidents. Moreover, many of these benefits can be achieved without the need for large infrastructure investments or for purchasing in-vehicle equipment.

Table 2.1 Summary of IVHS Advanced Traffic Management Systems Operational Tests

Project	Location	Summary Description
INFORM	Long Island, New York	Integrates Surveillance and Control of three freeways with cross and arterial streets
TRANSOM	Northern New Jersey Metropolitan New York Area	Uses transponders on commercial vehicles as traffic probes. Automatic toll collection
SMART Corridor	Santa Monica Freeway, Los Angeles	Traffic management using communication systems such as HAR, CMS, kiosks and teletext
Guidestar	Twin Cities Metropolitan Area, Minnesota	Gathers and distributes traffic information. Includes development of Autoscope Video imaging vehicle detection system
Satellite Communication Feasibility Study	Pennsylvania Department of Transportation	Part of an area-wide traffic and incident management. Use of Satellite as a communication medium
Urban Congestion alleviation Demonstration Project	Woodrow Wilson Bridge, Virginia	Video Imaging Detection System
Live Aerial Video	Montgomery County, Maryland Fairfax County, Virginia	Live video from aircraft to traffic management centers
Connecticut Freeway ATMS	Hartford, Connecticut	Use of roadside radar detection and CCTV for incident detection and verification

3. GROUNDRULES FOR DEVELOPING EVOLUTIONARY DEPLOYMENT STRATEGIES

This section presents an operating definition of what is meant by an evolutionary deployment strategy. Naturally, there will be many alternate approaches for deployment, each with its advantages, disadvantages and different chances of acceptance or rejection by users. To guide the selection among these alternatives, a set of constraints is chosen to help screen out those alternatives that will not be acceptable. These constraints have been constructed from a variety of sources including guidelines issued by FHWA.

3.1 CONSTRAINTS TO BE CONSIDERED WHILE DEVELOPING EVOLUTIONARY DEPLOYMENT STRATEGIES

The FHWA Precursor Systems Analysis of Automated Highway Systems (AHS) Broad Agency Announcement (BAA) defined a set of baseline assumptions for AHS development. A subset of those included in the FHWA list, together with others that we believe are necessary assumptions for developing evolutionary deployment strategies, form the basis of the set of assumptions selected and presented here. These assumptions represent a collection of constraints that must be met by an IVHS deployment strategy. Assumptions 1 through 4 are adapted from the FHWA list.

1. All vehicle types (automobiles, buses, trucks), although not necessarily intermixed, must be supported in the mature system. Initial deployment emphasis will be on automobiles and vehicles with similar dynamics and operating characteristics.

2. Not all vehicles nor roadways will be instrumented.

3. An AHS will perform better than today's roadways in all key areas including safety, throughput, user comfort and environmental impacts.

4. IVHS technologies will operate in a wide range of weather conditions typical of those experienced in the continental U.S. These include snow, low-visibility fog and heavy rain conditions.

5. Vehicle equipment provides substantial user benefits, even where AHS is not implemented. User benefits could include enhanced performance, or driver comfort. These benefits are needed to motivate drivers to acquire the equipment and to provide sufficient incentive for manufacturers to invest in tooling and infrastructure needed to produce the needed technologies.

6. Full vehicle automation requires minimal retrofit to autonomously equipped vehicles in order to operate within an AHS environment.

7. Automation does not require demolition or relocation of houses/businesses or result in negative impacts on neighborhoods surrounding a freeway.

In summary, automation should provide the capability to operate at much higher capacity, without increased delays, with much higher safety and energy savings, and with a decrease in pollution and possibly labor costs. Moreover, automation will be introduced in an equitable manner, and, ideally, does not cause any loss or penalties to any individual or groups.

With the guidelines and constraints described above, one can envision that initially vehicle automation will be in the form of autonomous vehicles (i.e., vehicles that do not demand active road-vehicle or vehicle-vehicle communication); lateral and longitudinal automation may be offered as manufacturer options, with longitudinal likely coming first. This is because lateral automation may demand installation of new infrastructure, such as magnetic lane markers. Based on prior experience in the automobile market, any new automation devices will likely be sold initially to the high-end of the car market on the basis of comfort and enjoyment of drivers and/or passengers, possibly for use on low traffic roads for reasons of safety. As the use of these equipment increases, the cost would be reduced making it possible to equip lower cost vehicles. In parallel to vehicle automation, ATMS deployment would continue. These could provide the communication and control infrastructure for eventual **AHS** deployment.

When the equipped vehicle population becomes sufficiently large, special use facilities might be constructed. These facilities would follow existing highway right-of-ways, or perhaps new right-of-ways. The existence of such facilities would motivate sales of vehicle equipment. However, if these facilities are only available in a few regions, the sales volume might not be sufficient to motivate manufacturer investment in the required infrastructure. Therefore, the broad market will still need to be stimulated by the comfort and enjoyment objectives, as above. Eventually, when the market penetration becomes large enough, manual lanes might be converted to automation, which may further stimulate market demand.

3.2 DEFINITION OF AN EVOLUTIONARY DEPLOYMENT STRATEGY

A deployment strategy specification should include: a starting point, combinations of supporting or enabling technologies, market penetration scenarios, possible barriers (if any), contingency planning, and any major uncertainties. In this paper, we define an evolutionary deployment strategy as consisting of deployment steps, each providing the user with increased functionality. In developing alternate strategies, we adopt these guidelines:

- Increasing functionality often requires increased infrastructure;
- Functionality provided at each step is useful by itself and does not require full development of subsequent steps;
- Each development step has a high likelihood of acceptance by the user;
- Success in each step increases the chance of public acceptance of the following development step;

- Development steps take into consideration the long lead-time requirements for research and development prior to deployment.

- Ideally, increasing functionality can be achieved without the need for discarding major portions of the system.

4. EVALUATION FRAMEWORK

This section presents a framework for developing, evaluating and comparing alternate strategies, and consists of four subsections describing the framework, and presents a sequence of technology introduction. The following two subsections discuss enabling technologies and possible barriers to implementation. Such a process can be used to refine the strategy and identify possible approaches and timelines for dealing with these barriers.

4.1 ELEMENTS OF THE EVALUATION FRAMEWORK

Figure 4.1 presents a framework for structuring the process of developing and evaluating alternate deployment strategies. The framework divides the process into four elements:

1. Strategy Development;
2. Strategy Evaluation;
3. Technology and Barrier Identification;
4. Strategy Refinement.

As shown in the figure, two models are needed: Benefit-Impact Model and the Concept-to Deployment Model. In the first, we select a set of measures that can be used to evaluate both the benefits and the impacts resulting from a given deployment strategy. Using these measures will allow for comparing alternative strategies and identifying possible areas for modifications. The second recognizes the fact that IVHS technologies are at different stages of development and often will require a long development cycle. In this model we identify the various steps in a development cycle. Using expert opinions one could identify the barriers for implementation and develop timelines for various activities for the strategy being evaluated.

Below, we provide a more detailed discussion of each element.

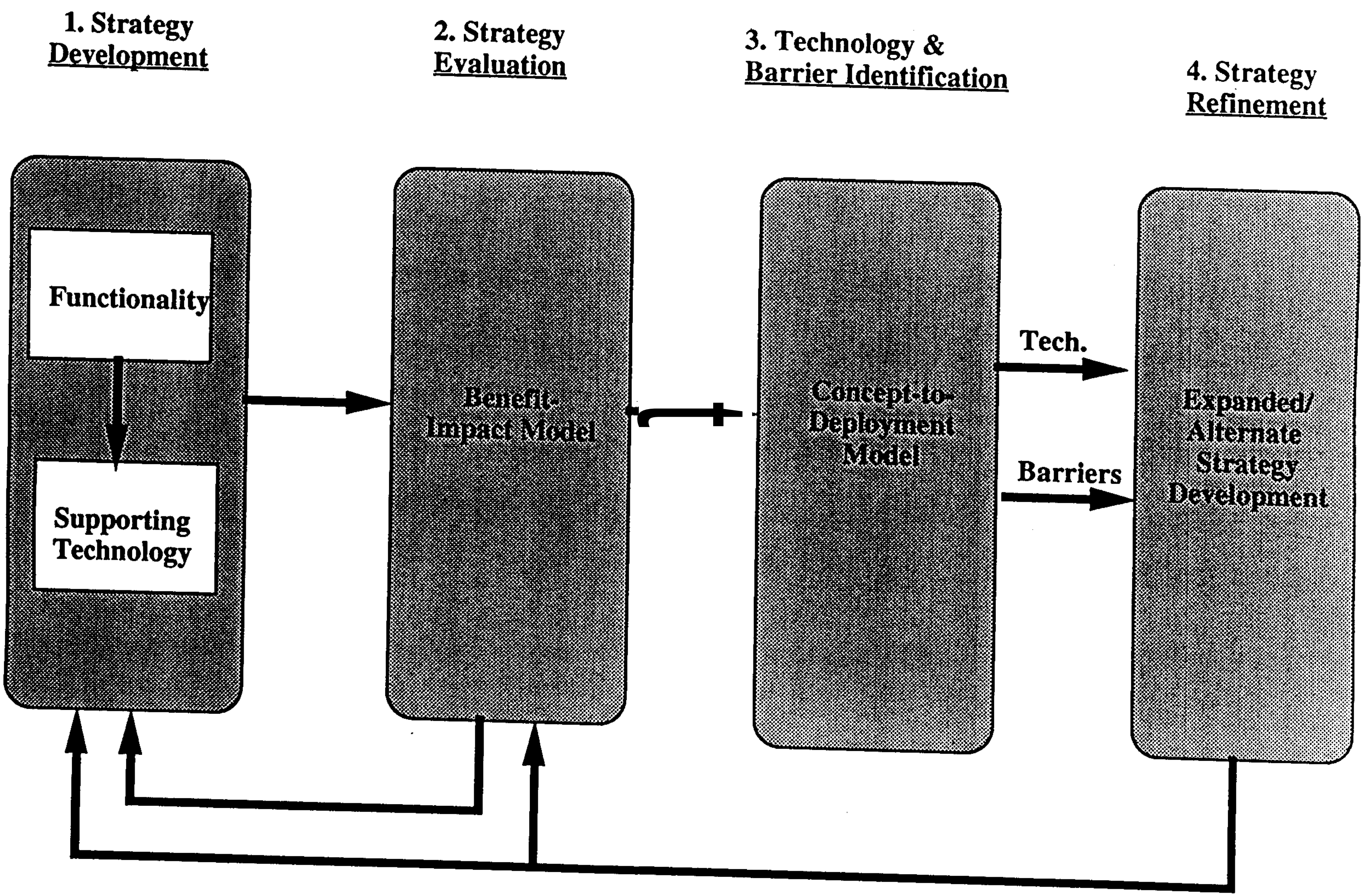

Figure 4.1. A Schematic of the Elements of the Evaluation Framework

4.1.1 Strategy Development. Developing alternate deployment strategies requires: (a) an understanding of the functionalities required to support an evolutionary IVHS deployment; (b) alternate technologies that are capable of providing these functions to the users, and (c) adherence to the guidelines specified in Sections **3.1** and **3.2.** The development begins with a baseline sequence of technology introductions. This sequence is then evaluated and refined in the subsequent steps. Refinements will be based on an assessment of the potential benefits, impacts, barriers, uncertainties and development cycles. Alternate deployment strategies will then be suggested to address each of these factors.

4.1.2 Strategy Evaluation. In this step, the technology sequences generated in the previous stage are evaluated. This evaluation uses what we termed the Benefit-Impact model. The model provides a set of benefit-impact attributes against which a proposed evolutionary deployment strategy will be evaluated. Initially, evaluation will be assessed qualitatively, (e.g., positive; negative; or no impact) and will be based on expert elicitation and literature reviews. **As** the development proceeds, a more structured analytical evaluation scheme and quantitative measures will be used for comparing the different strategies.

Benefit-impact attributes are defined as:

1. Congestion/Capacity. Ideally these technologies could help alleviate freeway congestion, and provide for capacity increase. Capacity could be expressed in number of vehicles per hour per lane, and congestion could be expressed in vehicle hours of delay.

2. Improved safety. Deployment strategies should provide significant reduction in collisions, minimize the severity of any collisions that do occur, and result in reduction of injuries and fatalities.

3. Energy use. To be useful, a deployment strategy should result in decreased use of energy resources by reducing fuel consumption. This

benefit could be, however, offset by the potential increased number of vehicles used.

4. Reduced noise and air pollution impacts. Again, this benefit might not be realized due to potential increased in traffic.

5. Improved performance in adverse weather conditions, including poor visibility, rain, fog or snow.

6. Increased passenger/driver comfort and enjoyment by providing a less stressful and smoother ride and reducing uncertainties in road conditions.

7. Reduced land requirements.

Based on the results of the benefit-impact assessments, the preliminary strategy can be refined as follows:

- Use the evaluation process to refine the basic deployment strategy.

- Expand the preliminary strategy to develop alternate implementation approaches.

- Reevaluate the attributes (if possible, quantitatively) and refine strategies.

- If quantitative assessment of attributes is feasible, develop or use existing software.

Various parameters can be used to develop alternate strategies, including:

- Vehicle type: private auto, corporate fleet, buses/trucks.

- Area for deployment: urban/existing right-of-way; urban/new, rural.

- Technology selection.

- Weather conditions.

4.1.3 Technology and Barrier Identification. The concept-to-deployment cycle will be used to develop timelines and to identify important activities. This will help identify possible barriers and issues to be resolved, and propose timelines for the various activities.

The concept-to-deployment cycle includes:

- Research;
- Development;
- Operational testing;
- Education;
- Technical Standards Development;
- Market Penetration; Public Acceptance;
- Legislation, Regulation and Rule-making; if needed,
- Deployment.

One should note that the length of the cycle can vary considerably among the technologies considered. Moreover, rule-making or technical standards development often have long time requirements to allow for public comments, legislative approval and, at times, litigation. Another important observation is that while some of the activities in the cycle are time-dependent, many can be accomplished in parallel. **As** such for each technology, a careful development of the cycle and a clear understanding of special dependencies and uncertainties must be carefully evaluated.

In this stage an assessment of the status of the technologies needed for each of the steps in the deployment strategy is needed. Such an assessment includes the development of estimates of the time and likelihood of success in each technology as well as the possible dependencies among the technologies. This will help identify the barrier and the cumulative influence of the success or failure of any one technology on the whole sequence.

4.1.4 Strategy Refinement. Based on the results of the concept-to-deployment cycle evaluation, a set of possible barriers for each deployment stage can be suggested and used to refine these strategies. These barriers can fall in any of these categories:

1. ***Cost and cost-effectiveness*** is an important factor in determining the extent that the technology will be used and attain a sufficiently high level of market penetration to achieve the desired result.

2. ***Product reliability*** in terms of the accuracy of information provided and high level of availability, is essential in a product that is expected to have a large number of users.

3. ***Liability*** will likely represent one of the major obstacles. This is primarily due to the fact that liability concerns require legislative actions with many interested parties involved. As such, addressing them will require a long lead-time, large cost and major efforts in education of the public, legislators and special interest groups.

4. ***Environmental concerns,*** including increased emissions resulting from increased traffic and land use. Though this barrier only appears with the last step in the event tree, some environmental impacts might be also present in earlier steps. Again, though much work has been done in this area, a definitive answer is not yet available.

Other factors include the need for standardization, accuracy and market penetration.

Later in the development, an influence diagram structure will be used to enable the development of a more refined timeline for refining the deployment strategy.

4.2 BASIC EVOLUTIONARY DEPLOYMENT SEQUENCE

Figure **4.2** provides a schematic of a basic evolutionary deployment sequence. Later in the paper we describe how to expand on this sequence to generate more detailed sequences. The figure, using the construct of an event tree, attempts to capture two factors. First, each step introduces a new set **of** functionalities that are time-sequenced to follow the previous step. The time-sequenced events have been selected to reflect currently available technologies and those in the R&D stage, likelihood of public acceptance and concerns of various special interest groups, as well as the need for large investment in infrastructure. Second, once a functionality has been introduced, it becomes part of the portfolio of available technologies. This is depicted on the figure by having each branch extend to the end of the time frame used.

This deployment strategy has the following features:

- Improved monitoring and surveillance which can provide immediate benefits to travelers by providing timely advice regarding road conditions ahead, and can improve emergency dispatching and response.

- In-vehicle capabilities are added in an incremental manner.

- A technological foundation to facilitate eventual AHS introduction. This includes capabilities to enable vehicle inspection and control in an automated highway setting.

  E.g., - Automated vehicle inspection
  - Longitudinal control
  - Automated lane keeping

- Once these enabling technologies are introduced and proved feasible and acceptable to users, AHS can then be deployed.

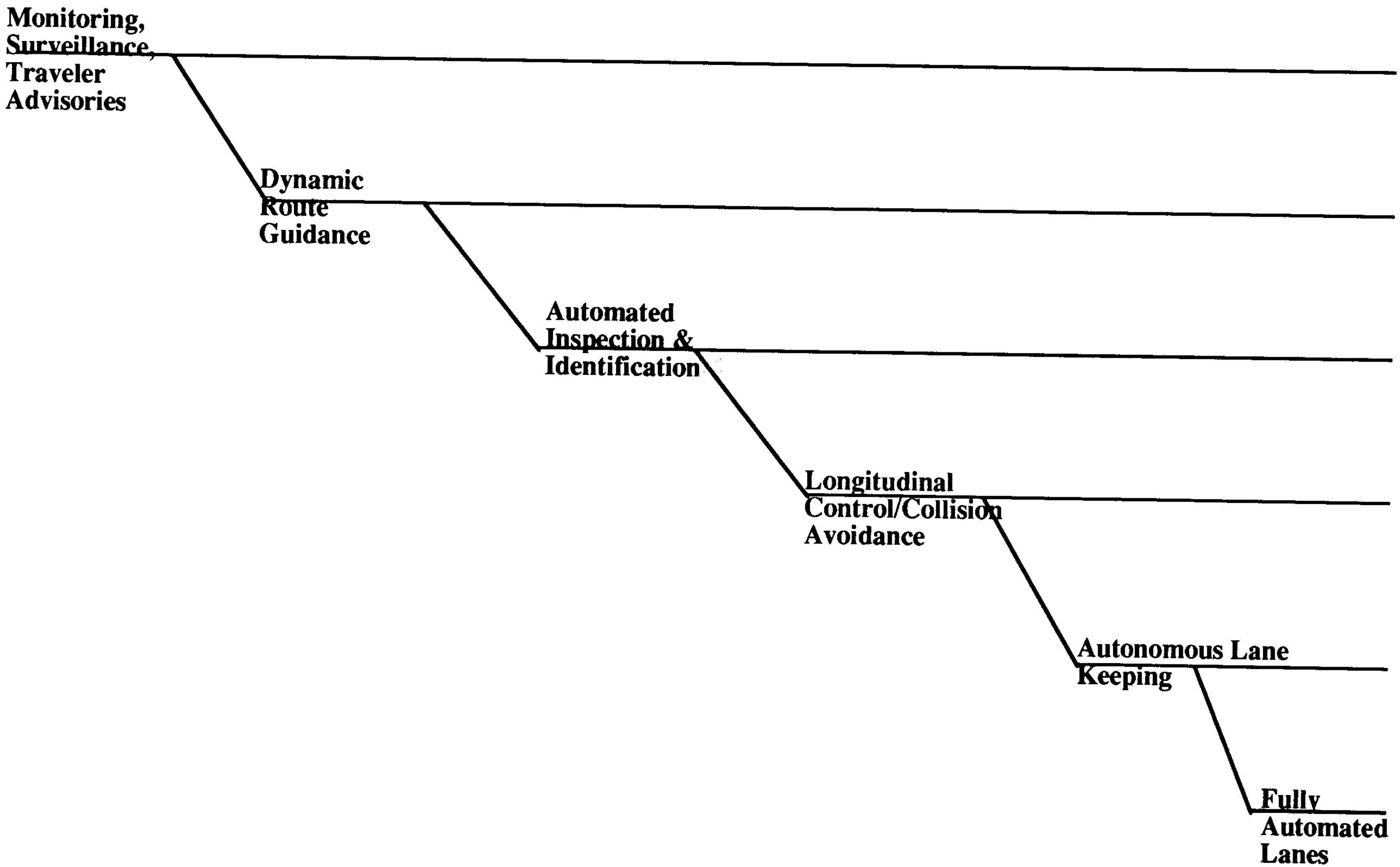

Figure 4.2. A Basic Evolutionary Deployment Sequence

The figure shows a six step sequence:

1. **Monitoring, Surveillance, and Traveler Advisories.** This functionality is focused on monitoring and surveillance of the traffic conditions to provide driver advisories regarding accidents, congestion and route conditions. These can be provided via Changeable Message Signs (CMS) on the road or through Highway Advisory Radio (HAR). A traveler may also call ahead requesting specific information. No specialized on-board equipment or communication is required.

2. **Dynamic Route Guidance.** Providing route guidance on board a vehicle requires the ability to monitor traffic, identify optimal routes and communicate the information to the users. Though much progress in development has been made, full implementation will be costly.

3. **Automated Vehicle Inspection and Identification.** In an AHS, one may need to inspect the vehicle prior to joining an automated lane. This includes real-time monitoring of status of brakes, tires and other vital mechanical systems and ability to communicate the information to both the driver and the infrastructure. Such a capability, however, can be very useful unto itself. Inspection can minimize the chance of delays and or accidents caused by disabled vehicles in current highway environments. In particular, this could be useful on rural freeways where services are not easily available. **As** the development moves to automated lanes, inspection facilities capable of communicating the status of the vehicle to a wayside computer and accepting or rejecting the vehicle will be needed. In addition, these facilities must provide the means for the rejected vehicle to exit the facility.

4. **Longitudinal Control/Collision Avoidance.** In this step, the capability for sensing vehicles ahead, and either providing warning to the driver or automatically maintaining a safe distance, will be introduced. Again, this functionality can be achieved without the need for major investments in infrastructure. There may, however, be some concern regarding product liability if such a system failed to perform its stated function.

5. **Lane Keeping.** This includes the ability to track the lane, and adjacent obstacles, to help vehicles travel safely in their lanes and, when needed, ensure safe transition to an adjacent lanes. Unlike the collision avoidance system described in 4, lane keeping may require major expenditures in roadside sensors and communications systems. Moreover, the choice of a system that is robust enough to function in various road and environmental conditions could be a significant challenge.

6. **Fully Automated Lanes.** With all of the above functionality in place, addition of automated lanes can become feasible. Decisions of how and where these automated lane can be implemented would involve consideration of many alternate implementation scenarios for AHS, each with a different set of technical requirements and potential barriers for deployment. A discussion of possible scenarios was presented in a report by Jacob Tsao et al. [10] The report discussed six possible scenarios:

   - Segregated Highway (no mixing with manual traffic) with Platooning.
   - Segregated Highway with Free-Agent Vehicle Following
   - Shared Highway (dedicated automated lanes; no manual traffic on these lanes) with Barriers and Platooning.
   - Shared Highway with Barriers and Free-Agent Vehicle Following
   - Shared Highway without Barriers under Platooning.
   - Shared Highway without Barriers under Free-Agent Vehicle Following.

   These scenarios may be sequenced, so that manual lanes are not converted to automation until there is sufficiently large market penetration.

Each technology will also progress through stages of market penetration: introduction, growth and maturity. At any point in time, one technology may be at the introduction phase (perhaps autonomous lane keeping), another at the growth phase (perhaps automated inspection) and other at the maturity phase (perhaps dynamic route guidance). Hence, the technology deployment is not just concerned with the initial introduction of the technology, but also with how the technology spreads across classes of users and across regions.

Put another way, the ultimate success of AHS, or any intermediate technology, hinges on introducing technologies into the right markets so that future growth can be sustained. This in turn depends on achieving sufficiently large up-front benefits to justify initial prices. For example, autonomous lane keeping might first be implemented on highly traveled intercity freeways, frequented by business travelers. Comfort would then be a major benefit, which may induce motorists to invest in necessary in-vehicle technologies. Once market penetration becomes sufficient, the technology may then spread to lower traffic roads, lower-end users and, once safety is proved, intracity freeways. Most importantly, a critical mass of users is likely needed before, first, special facilities are constructed and, second, existing roadways are converted to automation (Table 4.1).

4.3 ENABLING TECHNOLOGIES FOR THE BASIC EVOLUTIONARY DEPLOYMENT SEQUENCE

To implement the basic sequence, infrastructure and several technologies are needed. While a few are already deployed, many of these technologies are in the R&D stages. Table 4.2 lists some of the technologies for each of the steps in the basic deployment strategy.

Technologies identified can then be evaluated using the Benefit-Impact model shown in the second box of the evaluation framework (Figure 4.1). Table 4.3 shows example supporting technologies against the performance measures suggested above. These measures can be refined based on the results of the expert elicitation process. The assessment provides the basis for generating the possible barriers for implementation discussed below.

Table 4.1 Market Penetration

	Introduction	**Growth**	**Maturity**
Incentives for User to Purchase	Comfort Convenience Energy Savings Enjoyment Performance Safety (subsidy?)	Travel Time Savings Others (subsidy?)	Travel Time Savings Others (subsidy?)
Infrastructure	Minimal (Autonomous Vehicles:	Limited Special Facilities	Roadway Conversion & Special Facilities
Local Market Penetration	Very Small (<5% of vehicles on the road)	Small *(5-20%)*	Moderate to High (20%+)

Table 4.2 Example Supporting Technologies

Function	Example Supporting Technology
1. Monitoring, Surveillance, and Traveler Advisories	CMS, HAR, Traffic Operations Centers, Traffic Sensors Incident response
2. Dynamic Route Guidance	Traffic management algorithms, On-vehicles computers, Wireless communication
3. Automated Vehicle Inspection, Identification and Toll Collection	AVI, Automated toll collection, On-vehicle monitoring, Inspection facilities
4. Longitudinal Control/ Collision Avoidance	Longitudinal control, Distance sensors
5. Autonomous Lane Keeping	Lateral control, Lane markers, Communication
6. Fully Automated Lanes	Lane barriers, Entry/Exit facilities, Roadside inspection facilities

Table 4.3 Benefit-Impact Matrix for Example Supporting Technologies

Technologies	Congestion Capacity	Safety	Energy Use	Pollution	Perform in Adverse Conditions	Comfort/ enjoyment	Land Consumption
CMS							
HAR							
TOC							
Traffic Sensors							
Incident Response							
Traffic Management Tools							
on-board Computers							
Communication							
AVI							
On-vehicle Monitors							
Inspection Facilities							
Longitudinal Control							
Distance Sensors							
Lateral Control							
Lane Markers							
Roadside Comm							
Lane Barriers							
Entry/Exit Facilities							
Roadside Inspection Facilities							

Needless to say, the technologies presented above are at different stages of development. While some are already operational, many are still in the R&D stages and some have large uncertainties about when will they become available for testing and evaluation. Understanding the time dimension and the possible dependencies can benefit from exploring qualitatively as well as quantitatively the product cycle for each of the technologies.

Table **4.4** displays a list of the technologies together with the steps in the product cycle described in **4.1.3** above. Section 2 of this report provides basic information regarding operational and deployment tests in the U.S. Additional information regarding those in the research stages needs to be elicited from the various experts involved. Using this information, we can develop an understanding of possible dependencies between the technologies and the time and funding requirement for achieving full deployment.

4.4 BARRIERS TO IMPLEMENTATION OF THE BASIC EVOLUTIONARY DEPLOYMENT SEQUENCE

Figure **4.3** depicts a preliminary assessment of the types of barriers that are likely to inhibit advancement to subsequent steps. The heavy vertical line at the beginning of each set indicates a barrier for successful introduction of the functionality that follows. Understanding of these barriers and the likelihood of overcoming them is essential to planning for successful implementation. Though the barriers differ slightly among the steps, four factors dominate the process:

1. Cost and cost-effectiveness is an important factor, especially where the cost must be borne by motorists. **As** shown in the figure, cost appears as a potential barrier for almost all of the steps.

2. Product reliability in terms of the accuracy of information provided and high level of availability are essential in products that are expected to have a large number of users and involve the safety of the traveling public.

Table 4.4. Concept-to-Deployment Matrix for Example Supporting Technologies

Technologies	R&D	Operational Testing	Education	Standards	Market Penetration	Legislation/ Regulation	Deploy-ment
CMS							
HAR							
TOC							
Traffic Sensors							
Traffic Management Tools							
On-board Computers							
Communication							
AVI							
On-vehicle Monitors							
Inspection Facilities							
Longitudinal Control							
Distance Sensors							
Lateral Control							
Lane Markers							
Roadside Comm							
Lane Barriers							
Entry/Exit Facilities							
Roadside Inspection Facilities							

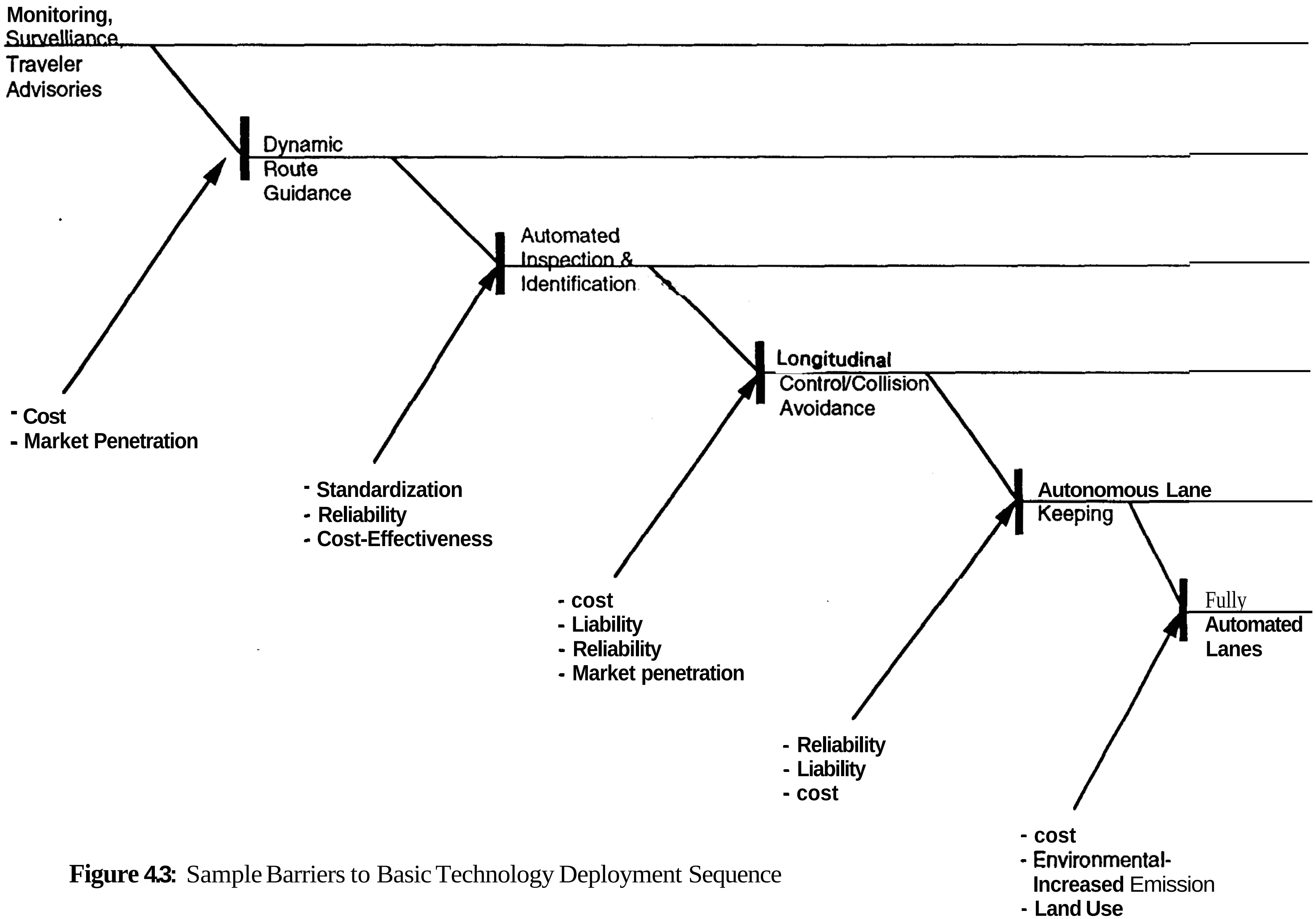

Figure 4.3: Sample Barriers to Basic Technology Deployment Sequence

3. Liability will likely be one of the major obstacles for both longitudinal control and autonomous lane keeping . Although not shown, automated inspection may also raise liability concerns, such as when a vehicle that was inspected and allowed to proceed fails and is involved in an accident.

4. Environmental concerns, including increased emissions resulting from increased traffic and land use. Though this barrier only appears with the last step in the event tree, some environmental impacts might be also present in earlier steps. Again, though much work has been done in analyzing the impact of IVHS and AHS on the environment, a definitive answer is not yet available.

Other factors included are: need for standardization, accuracy and market penetration.

Information gathered in the above steps can be used to develop an influence diagram. Analyzing the influence diagram can help identify the critical sequence for development. An example influence diagram is shown in Figure 4.4.

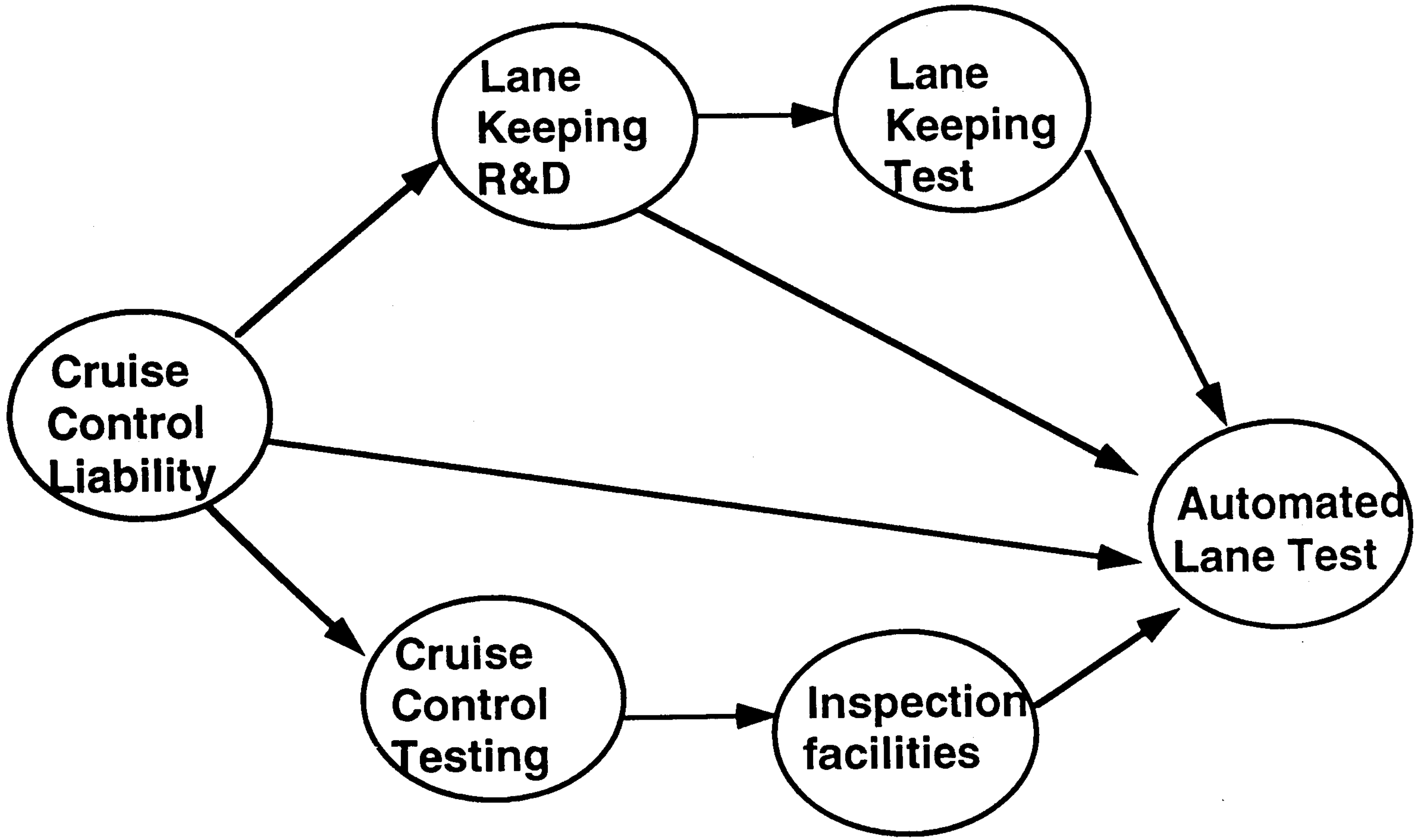

Figure 4.4: Example Influence Diagram

5. FUTURE DIRECTIONS AND CONCLUSIONS

This paper focuses on development of a conceptual framework for delineating and evaluating evolutionary deployment of Intelligent Vehicle/Highway Systems. Evolutionary deployment strategies require clear understanding and explicit consideration of the many complex technological, institutional, legislative, and public acceptance issues involved.

The conceptual framework proposed consists of several elements addressing strategy development, benefit-impact assessment, consideration of product cycle to capture time-dependency issues, as well as an identification of possible barriers for deployment. As part of the development, criteria were introduced to help evaluate both qualitatively and quantitatively the advantages and disadvantages of alternative deployment strategies.

This conceptual framework, when fully developed, has the potential for integrating the many ongoing R&D, operational tests and implementation projects within the IVHS community. Such an integration could identify areas requiring early attention. Although some technical issues may emerge as possible barriers, such as developing and adopting technical standards or technology for emission reductions, many of the insights will likely relate to legislative, educational and rule-making concerns.

To make this conceptual framework operational, several efforts are needed for data gathering, model development and analysis. Below are a few of the actions needed:

- Inventory the status of the various IVHS efforts in detail, including an assessment of time commitment, likelihood of success and dependencies among the various efforts. Such data are needed for understanding the development cycle.

- Establish a clear goal for deployment, to enable an evaluation of costs, benefits and impacts of implementation.

- Develop questionnaires and initiate expert elicitation processes to provide better understanding of the barriers and times for initiating various actions, especially for dealing with societal, environmental and legislative concerns.

- Develop the analytical machinery for evaluating and analyzing the benefits and impacts of alternate evolutionary deployment strategies.

Another important aspect is the development **of** detailed cost models that address cost of research and development efforts, costs **for** developing the required infrastructure as well as the cost to the users.

Finally, any meaningful analysis must consider the wide spectrum of organizations that are involved in and interested in the implementation of IVHS. These include but are not limited to: American Association of Retired Persons; American Automobile Association, the National Safety Council; the Highway Users Federation, and the American Association of State Highway and Transportation Officials. Each has a different set of concerns that, if not properly addressed, may become a barrier to implementation.

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