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RESPONDING TO IVHS TRAINING NEEDS: A CURRICULUM FOR 21ST CENTURY PROFESSIONAL EDUCATION

Paul P. Jovanis
Associate Director, Institute of Transportation Studies
Professor, Civil & Environmental Engineering
University of California, Davis

ABSTRACT

There is little question that IVHS systems are presenting tremendous challenges to the transportation community in the areas of continuing education and training of new engineers. In response to these challenges, Caltrans has contracted with the Institute of Transportation Studies at U.C. Davis to develop a curriculum for advanced technology training for their employees. Among the issues of concern are the development of a set of core educational materials that could be used to introduce advanced technology concepts to current transportation professionals. The curriculum is developed from the perspective that all IVHS systems are developed from technology building blocks that include: communications; computers; software; sensors and detectors; and vehicle systems. The curriculum uses a discussion of these building blocks to discuss how they are used in the broad array of IVHS systems. In addition, there is a need to understand how these technologies and systems affect the roles of state transportation agencies in dealing with current and new user groups and the agency's own employees.

The research team addressed these needs by undertaking two sets of activities: a set of over 15 interviews with active IVHS researchers, principally within California; and, an extensive review of over 20 documents describing Caltrans' current mission and how they have evolved organizationally to respond to that mission.

Based on the interviews, the five technologies listed above are characterized in the curriculum in terms of their most important technical attributes and the management challenges they pose to engineers attempting to use the technology for the public good. A matrix structure is used to connect each technical and management issue for each technology to five functional areas of activity identified by the review of the transportation agency's mission documents (i.e. planning, design, construction, operations and maintenance). The matrix can thus be used to understand how advances in computer networking, for example, may differentially influence transportation planning functions compared to design or maintenance activities. In addition, important topics in human factors, user policy, and state agency policy (e.g. in dealing with their own employees) are directly connected to IVHS technologies and systems through the matrix structure.

The paper focuses on a description of the matrix structure that is the foundation of the study. In addition, the paper describes how the matrices were used to develop a 3-day course specifically targeted for mid level operations engineers. This abstract responds to the topic area of education and training in the Call for Papers.

INTRODUCTION

Background

In the coming decades, the deployment of Intelligent Vehicle-Highway Systems (IVHS) and other advanced technologies will substantially alter the ways in which transportation departments deliver services to their constituents. To ensure that a department continues to deliver quality transportation services, its employees need to be aware of the coming technological changes, their probable effects and how to take advantage of them.

In response to these concerns, Caltrans' Division of New Technology, Material and Research contracted with the Institute of Transportation Studies at U.C. Davis to develop a curriculum to discuss advanced technology opportunities and challenges and how Caltrans might respond to them. In concert with ITS Berkeley and ITS Extension, the project "Transportation Technology in the 21st Century" was undertaken in May 1991. This paper summarizes the findings of the project.

Curriculum Objectives

Advanced technologies in transportation are progressing rapidly beyond the stages of research, development, testing, and evaluation. These new technologies will impact all functions of the department and challenge paradigms of transportation in ways that may not currently be appreciated. Transportation advances in the past have made fundamental changes in approaches to traffic engineering. For example, early highways did not have exit or entrance ramps. Originally, traffic engineers balked at the idea that entering traffic should achieve the speed of the traffic flow before merging. As understanding of highway driver behavior increased, however, merge lanes were introduced and grew in length.

The understanding, cooperation, and contribution of transportation department employees is vital to the successful implementation of new technologies. Each department as an organization, must be prepared to address issues that arise as advanced technologies are introduced into highway (auto and bus), rail, and air transportation.

Six objectives have been developed for the curriculum:

1. Increase employees' understanding of the role of advanced technology in transportation departments and their future.

2. Familiarize employees with the capabilities and benefits of advanced transportation technologies.

3. Introduce employees to liabilities and risks associated with advanced transportation technologies, both for the department and for system users.

4. Provide employees with a basic framework which will allow them to understand the forces at work in the development of advanced transportation technologies in the economy as a whole.

5. Suggest new skills necessary to apply advanced transportation technologies to their jobs, which may require additional in-depth courses to accomplish.

6. Identify opportunities in managing technological changes and understanding how technology may change the form and function of the transportation department organization.

Curriculum Approach

Using Caltrans as a prototype transportation department, five major functional areas of responsibility (planning, design, construction, operations and maintenance) were determined from interviews with Caltrans employees and a review of Caltrans documents.[2-13] The primary tasks associated with each function spanned the Caltrans sphere of control including highway (auto and bus) and rail. A few of the primary tasks and activities within each function are mode-specific.

Figure 1 illustrates the Caltrans organizational structure as of early 1992, mapped against the 5 functional areas of responsibility: planning, design, construction, operations and maintenance. In Figure 1, a filled circle indicates that the organizational unit directly participates in the functional area of responsibility and is directly applicable (e.g. division of structures in planning, design, construction and maintenance of structures). A circled "x" indicates limited participation or partial applicability; a

	Caltrans Functional Area				
Caltrans Organizational Unit	Plan	Design	Construction	Operations	Maintenance
Division of Structures	●	●	●	⊗	●
Division of Rail	●	○	○	○	○
Division of Aeronautics	●	○	○	○	○
Division of Traffic Operations	⊗	⊗	○	●	○
Division of Highways	●	○	○	○	○
Division of Information Services	●	⊗	○	●	⊗
Division of Mass Transportation	●	○	○	○	○
Office of Asset Management	●	○	○	○	⊗
Office of Environmental Analysis	●	●	○	○	○
Office of Engineering Service	●	⊗	○	○	○
Division of Maintenance	⊗	○	○	○	●
Division of Construction	●	●	●	○	○
Office of Project Planning and Design	⊗	●	—	○	○
Office of Traffic Improvement	●	○	○	⊗	○
Division of New Technology, Material and Research	●	●	●	●	●
Western National R&D Center	●	●	⊗	○	⊗

Figure 1. Relationship of Caltrans Organization Structure to Caltrans Functional Areas

simple "o" implies virtually no participation or not applicable to Caltrans activities within a function.

Planning responsibilities are the most varied and wide-ranging of the five areas. Planning functions include responsibilities for project and program management, forecasting, long-term planning and short-term system management. At the project and program level, planning responsibilities include: recommending funding; administering funds; coordinating and managing projects and programs; evaluating and approving projects; and monitoring on-going projects for schedule adherence.

Forecasts are developed to predict the impact of forecasted trends on projects and programs. Long-term planning activities include problem identification and advice on policy direction. Short-term system management activities include development of procedures and standards, review of regulation influencing Caltrans, coordination with other agencies and institutions in responding to transportation demands, project and program marketing (where appropriate) and participation in environmental reviews.

The remaining four functional areas of responsibility each include developing cost estimates and unique tasks. Designers at Caltrans have responsibility for developing plans, specifications, and estimates. Additional unique responsibilities may involve acquiring right-of-way when required. Construction activities include undertaking or administering project construction and inspecting projects after construction. Operational responsibilities include project implementation and assistance to local agencies in their service provision. Caltrans operations are continuously monitored for adequacy and impact on traffic conditions. Lastly, maintenance activities include reviewing maintenance impacts, inspecting state-owned facilities, and recommending changes in maintenance or needs for new construction.

In describing advanced technologies, two categories are developed: a set of five technology building blocks consisting of Computer Systems, Communication Systems, Sensors and Detectors, Vehicles, and Human Factors; in addition, there is discussion of Policy Issues that arise concerning Users and Caltrans. Advancements in each of the five technology areas are extremely rapid. In addition, strong interrelationships exist between the technologies (e.g. vehicles make increasing use of on-board computers to assist in various functions). For these reasons, each technology building block is discussed in terms of the functions performed, technology issues and management issues. The discussions within the Policy Issues arise from a concern that Caltrans respond to the needs of transportation system users and the needs of its own employees regarding organizational management.

Figure 2 illustrates this overall structure with references to all subsequent figures. The seven building blocks are broken down into two lower levels in the figures that follow. The next level below that shown in Figure 2 defines a series of issues related to each building block. At the second level below that of Figure 2 the applicability to Caltrans major functions is indicated. The filled circles, crosses in the circle, and empty circles in the figures depict whether the item in the respective column is directly applicable, partially applicable, or not applicable to Caltrans' activities.

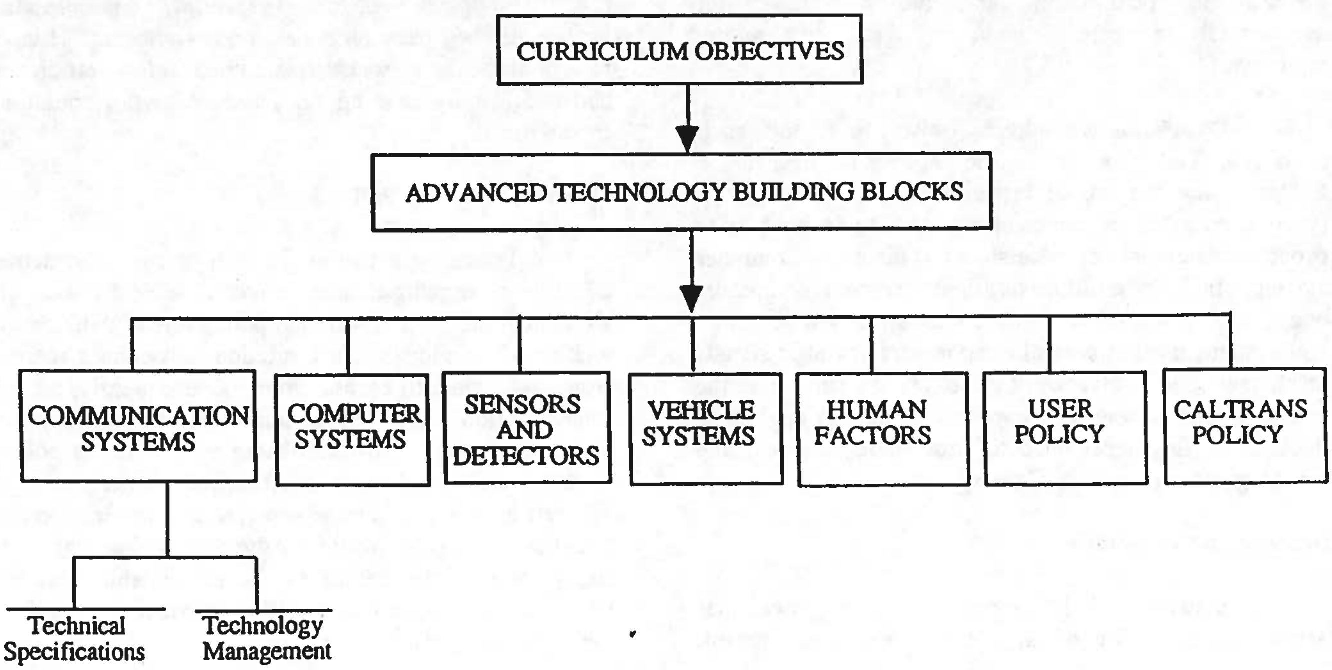

Figure 2. Technology Curriculum Overview

While it is recognized that there are substantial differences between state and local transportation departments, the curriculum structure is such that it should apply to a range of organizations. Indeed, the use of functional responsibilities is specifically intended to make the curriculum more generalizable.

OVERVIEW OF TECHNOLOGY BUILDING BLOCKS

Communications Systems

The purpose of a communications system is to transfer information from one physical location to another. Communications systems consist of a data transmitter and receiver and the network upon which the information travels. Examples of communication media include microwave, satellite, laser and electronic. A network is the path the information takes to arrive at its final destination; the path may be air, fiber optic cable, twisted wire pair or coaxial cable, for example. Communications systems are critical components in distributing information within advanced technology systems. Engineers need to understand the capabilities and implications of the system as they influence advanced technology system performance and as they influence the user community.

Computer Systems

Computer systems are composed of electronic components (circuitry), electro-mechanical components, data items, data files, and programs. Electrical components perform calculations, check logic, store data, and provide a path for data movement throughout the computer system. Electro-mechanical components are responsible for mechanical movement such as data input-output equipment.

Data items are individual elements of data, such as words. Data files are the storehouses for data items. Programs are the sets of instructions written by people (programmers) to tell the computer what to do and how to process (manipulate or calculate with) the data. Computer systems include multiple-terminal personal computers connected via a communications network to a mainframe, and systems used to control ramp meters or traffic signals at intersections. Advanced technology systems stress the computational power of computers to support engineers' decisions. Engineers need to understand technical and sociological implications of the system.

Sensors and Detectors

Sensors and detectors comprise a system that allows identification of an event or entity of interest. Examples of sensors and detectors include magnetic, radar, sonic, radio frequency, infrared beam, optical and microwave systems. Examples of entities monitored include the count, classification and direction of individual vehicles along a road segment or the acceleration of bridge segments during earthquake conditions.

Vehicle Technology

A vehicle is a device that gives an object or a person propelled mobility on a path over land or space. A vehicle also serves to protect its contents from damage. Cars, buses, trucks, airplanes and trains are broad vehicle types in common use on right-of-way. Vehicle technology is changing rapidly, with many implications for the interface with the roadway.

Human Factors

Human factors engineering is the applied science which aims to match the demands of products, equipment, jobs and places of work, with the characteristics of the people who use them. Human factors engineers take into account the person-machine interface by systematically looking at the capabilities and characteristics of the users, the machine, the interface and the environment. In the context of automotive information systems, human factors engineering seeks to present information that can be easily seen, heard, understood and effectively used in a range of conditions by a variety of people. Traffic engineers use human factors principles in studying the design and use of traffic control devices that need to be systematically understood by the public. Human factors are also important for vehicle operations such as snow plows and road maintenance vehicles. The variety of people may include drivers, passengers or service engineers. Human factors engineering seeks to maximize safety, efficiency and comfort by shaping the machine to the operator's capabilities.

Caltrans and User Policy Issues

Policies are a principal plan or course of action taken by an organization or individual to deal effectively with situations. Transportation policy directly affects the welfare of individuals and institutions throughout society, from consumers to corporations. Consequently, setting transportation policy should not be the responsibility of government alone. In formulating transportation policy, Caltrans will need to take into account the range of interests at stake, encourage wide public participation and negotiate with user groups. Advanced technologies are likely to alter the nature of the relationship between Caltrans, the transportation service provider, and each of the interested parties.

Caltrans needs to develop policies to promote productive use of advanced technologies in transportation. Caltrans will also need to develop policies to address issues which arise within the organizations such as manpower management and upgrading of job skills.

Because of paper length requirements, user policy and department policy issues are not discussed. Interested readers are referred to the project final report(1) for further details.

COMMUNICATION SYSTEMS

Definitions and Functions

Communication systems are one of the fundamental building blocks of any computer-based system. The communication system provides the capability to transmit information to additional system components which are in need of data, commands or both.

Components of a communication system are:

1. The Transmission Device: the unit that actually generates the signals upon which information is encoded.

2. Receiving Device: the recipient of the information. Frequently the same physical devices can transmit information while receiving additional information; these devices are called transceivers.

3. A Medium of Transmission: the physical body through which the communication takes place; examples include telephone wire (twisted pair), fiber optic cable, coaxial cable (e.g. cable T.V.) or the air itself (radio waves).

The primary use of communications systems is to transfer information from one location to another where it has a higher value (i.e., higher enough to justify the cost of moving it). As such, the demand for communication has very strong conceptual connections to the demand for travel.

Technical Specifications

Three important technical specifications of a communication system are its capacity or *bandwidth*, its transmission rate and its cost. The bandwidth of a communication system is the range, from maximum to minimum frequency, that it can handle. The maximum and minimum values themselves are important as the communication must be compatible with the maximum and minimum frequencies allowed by the transmission medium. Bandwidth may be best understood by analogy to the capacity of a road segment. An eight-lane freeway has much more capacity than a two-lane rural road; similarly a coaxial cable will have much greater bandwidth than a twisted pair of telephone wires.

Transmission rate has to do with the speed of transmission of information along a medium. This is particularly due to the technical characteristics of the device and partially due to the medium. An example may be illustrative. For many years, the expansion of video teleconferencing was constrained by the need for wider bandwidth and higher transmission rates than those available on twisted pair. With the advent of packet switching technology, software and hardware are used to send more densely encoded information along a twisted pair. While the result is not smooth motion, it is sufficient to allow "freeze frames" or snapshot identification of the other communicator. This is the first example of many of a characteristic that is attributable to one technology building block (i.e., communications) using computers (another building block) to expand capability. The transmission rate of a device can thus be thought of as similar to the speed of vehicles on a highway.

Cost is a critical component of any communication system. Capital costs are associated with the purchase of the hardware and the physical installation of the transmission medium (if necessary). Operating costs are those incurred in keeping a system running once it is constructed.

There are a great many possible combinations of cost/system attribute tradeoffs. One of the most important is the physical condition of existing communication media. Is coaxial fiber optic cable available? Is it in good condition? Does it have spare capacity? Communication errors in advanced technology systems could be much more severe than in regular voice communication, for example. If one or two words are lost or garbled, the speaker can simply repeat the statement; if a command to change signal timing at the intersection is garbled, an inefficient or unsafe condition may result.

Cost considerations are thus highly site specific in nature. One very difficult aspect is unforeseen changes. The UTCS traffic signal control project in Washington D.C. used nearly 100 twisted pair phone lines to communicate at a monthly cost of approximately $650 per month. After a "tariff" adjustment the rate went to $30,000 per month. This 3,000% increase could not be absorbed, so the system closed down. Presumably, the phone company is now more familiar with high quality data transmission requirements than in the 1970s. Rapid cost increases imposed by utilities have led some organizations to install their own communication systems. This is the most extreme example of the implications of a communication system for advanced technology systems.

Bandwidth and transmission rate are highly technical aspects of alternative communications devices. Operations functions will need primary knowledge in these areas; planning, design, construction and maintenance functions will need some technical expertise to develop and deploy the systems. Traffic control systems are expected to be very heavy users of communications systems, so they appear in Figure 3 as being most directly affected. The other four functions are shown as particularly unaffected; however, this could change depending on the deployment of new systems, particularly within the maintenance function (e.g. automatic pavement and bridge monitoring systems).

Caltrans Functions	Planning	Design	Construction	Operations	Maintenance
Communications System					
Technical Specifications					
Bandwidth	⊗	⊗	⊗	•	⊗
Transmission Rate	⊗	⊗	⊗	•	⊗
Cost	•	⊗	⊗	•	⊗
Technology Management					
Technical Training	•	•	•	•	•
Management Of Information	•	O	O	•	O
Backup System	⊗	⊗	O	•	O
Computer Systems					
Technology Specification					
Performance Requirements	•	⊗	⊗	•	⊗
Systems Architecture	•	⊗	⊗	•	⊗
Technology Management					
System Integration	•	•	⊗	•	O
Private Sector Partnership	•	•	•	•	O
Regulation	•	⊗	⊗	⊗	O
Sensors And Detectors					
Technical Specifications					
Sensitivity To Environmental Change	•	⊗	O	•	O
Reliability	⊗	⊗	⊗	•	•
Technology Management					
Compatibility	•	•	⊗	•	O
Financing	•	⊗	•	O	O
Liability	•	⊗	O	•	⊗
Vehicle Technology					
On Board Communications					
On-Board Devices	⊗	O	⊗	•	•
External Communications	⊗	⊗	O	•	⊗
Vehicle Safety	•	O	O	•	•
Emissions	•	O	•	•	⊗
Technology Management					
Reliability	⊗	•	⊗	•	⊗
Certification	•	O	O	•	•
Compatibility	•	⊗	O	•	⊗
Roadway Implications					
Redesign Roadways	•	•	⊗	⊗	•
Human Factors					
Perception of System Performance					
Safety	•	•	⊗	•	⊗
Reliability	•	⊗	⊗	•	⊗
Human Information Processing					
Human Information Processing	•	•	•	•	•
Behavioral Changes					
Operator Control	•	•	⊗	•	•
Higher-Level Cognitive Decisions	•	•	⊗	•	⊗

Figure 3. Summary of Training Needs

Technology Management

Technical training is required to enable individuals to plan, design, construct, operate and maintain communication systems. If the department is to perform any of these functions, technical staff possessing these skills will be needed. This may necessitate hiring electrical and communication system engineers (rather than civil engineers) and retraining existing staff. These communication system training needs are likely to map directly onto existing functional areas.

In addition to recruiting and supervising technical staff, the operator of the systems will have to deal with *management of information* generated. Employees will have to plan for accessing, managing and disseminating this additional information, while dealing with the potential liability resulting from handling the information. Planning and operations functions are most heavily affected by these needs.

Lastly, as part of any system, a *backup system* needs to be explicitly planned and designed. Operational functions need to be consulted during this effort as they are likely to be the most directly affected.

Curriculum Implications

All department engineers should have a basic understanding of communication system concepts and available technologies. Each course should thus begin with a discussion of definitions and a summary of available technologies and their application to the five functions. Selected technology example applications can then be covered in depth depending on the functional area and management level of the audience. For example, entry level or senior engineers could receive more quantitative training concerning conducting communications system tradeoff studies. Mid- to upper-level managers may cover this material in overview while spending more time on technology management.

COMPUTER SYSTEMS

Definition and Function

The very name "computer" suggests a machine for computing -- taking in information, performing calculations, presenting results. Computers accept, store, process and present information. Obviously, most information manipulation can be conducted more quickly by a computer than by a human.

A computer system can be either a single electronic device executing programs and communicating with the outside world or it can be a number of electrical devices that perform the above tasks, as well as communicate between devices. Examples of computer systems range from multiple-terminal personal computers, connected through a communications network, to a mainframe which is a single large computer that often supports numerous terminals. A computer system is composed of several components including a central processing unit, input/output interfaces, data items, and programs. The central processing unit is the heart of the computer system. The CPU executes programs which perform calculations, check logic, store data, and provide a path for data movement throughout the computer system. The CPU consists of:

a. main memory: stores data;

b. control sections: sequences the computer's activities, decodes program instructions, and directs data traffic within the CPU;

c. arithmetic logic unit (ALU): performs arithmetic calculations and logic comparisons according to instructions held in instruction registers.

The input/output interface permits information to be supplied and received both to and from the computer. This allows the operator to carry on a dialogue with the program.

Data items are individual elements of data, such as words. Programs are the sets of instructions written by people (programmers) to tell the computer what to do and how to process (manipulate or calculate with) the data.

The function of a computer system is to use programs to create or manipulate existing data from the information obtained from the input device, such as the keyboard, and transmit this to an output device, such as a printer or a graphics terminal.

Because the computer manipulates information and communication systems transmit information, there are very strong linkages emerging between the two. Image processing uses computers to interpret and enhance information obtained from some camera device. Applications include processing of video pictures to measure traffic delays or identify cracks in road pavement surfaces. Another application could be a "smart" camera at a high risk location that is activated to record only when a vehicle deviates from a nominal path. High speed image processing is thus one important contemporary function of computers.

Computers are also used for simple information storage and retrieval. An example is the input of police accident report data into a central computer file (called TASAS in California). This data is then available to researchers and others to study accident trends on state highways. Significant research is currently underway at the federal level to use advanced communication and computer systems to immediately store accident data in a computer at the accident scene. More accurate reliable information is expected; it can then be electronically downloaded to a mainframe, obviating the need for paper computations and collection.

Computer systems are also commonly used for transactional services. Bank ATM machines are a most recent innovation in this area. Similar concepts are leading to point of purchase use of bank cards and credit cards in which the customer directly transacts with the credit source. Interestingly, some hardware and software advances that enable the banking applications will allow virtually contemporaneous access to the safety data discussed in a prior paragraph.

As discussed earlier, computers traditionally excel at repetitive, algorithmic computations. Solving complex mathematical equations is an example of this application. A special type of arithmetic computation is control theory. These calculations determine optimal control policies (for chemical plants, nuclear plants, traffic signals, or ramp meters along freeway segments).

Substantial current interest in computer systems includes applications to decision support: that is, use the computer for repetitive arithmetic calculations and provide the user with alternative solutions. Freeway traffic management and bridge monitoring during earthquakes are examples of the use of computers for decision support.

Technical Specifications

Concerns for the *performance requirements* of computer systems evolve directly from their components. Main memory requirements are expressed as megabytes or gigabits of storage available in main memory, hard disk or floppy disk. Control section operation is described as the ability to multitask or use particular operating systems. Arithmetic operations and speed are described in millions of instructions per second (i.e., MIPS) or clock speed (e.g. 60 hertz). The technology is moving so quickly in this area that it is a virtual requirement that the department use either a hired consultant or their own highly trained engineers with computer system specialization.

Operations are likely to be the most directly affected by implementing actual systems. The planning function may need to expand to contain specialists who develop systems to meet long range needs. Design, construction and maintenance may be less affected.

Systems architecture is concerned with the distribution of computers with a given system. Should there be many small computers or one large one? There are strong interrelationships with communications systems alternatives because a distributed computer system requires a sophisticated communications system to support information transfer. Again, planning and operations functions are most directly affected.

Clearly the *cost* of a computer system is an important attribute. Costs of hardware have been plummeting at the same time that performance is improving. Engineers should be made generally aware of the way the computer price and performance curves are changing. They should also appreciate the differences in performance between different levels of systems. For example, the difference in cost and performance between Unix-based work stations and PC's. Yet another difference is between mini-computers and supercomputers.

Technology Management

The drive to maximize system efficiency by full *systems integration* creates a strong push for compatible hardware and software. Whether the hardware and software are produced by a transportation department or by an external agency, criteria must be developed to ensure compatibility across physical and legal boundaries and to allow for system expansion. System integration will likely involve a need to communicate information between machines.

There are thus important technical and managerial issues that need to be resolved concurrently and compatibly. For example, allowing for automated entry of safety data at the accident scene will reduce data collection time for the officers but necessitate the transmission of confidential accident victim data. There is a need for the computer and communication systems to act together to achieve system goals. Managing computer technologies will require that departments work in *private sector partnership* to coordinate development of systems. The partnership must include all phases of system development, including planning, design, construction and operation.

Departments will have to make choices about how to assume or assign the responsibility for *regulation*, particularly in software and hardware compatibility. Developing these regulations will shape not only the department's role in providing transportation, but the nature of transportation itself. The resulting regulations will affect all functions of planning, design, construction and operations.

Curriculum Implications

Engineers should be well-versed in the basic concepts and definitions of computing. As in communications, the entry level and senior engineers will require more technical training; managers more of an orientation toward system management. Examples can be drawn from functions that are most relevant for the course attendees. For example, operations engineers have numerous examples from traffic control and IVHS. Maintenance and construction engineers can use examples from the computers used to control the robots and apply sealer in automated highway maintenance and construction systems. The interrelationship of the microcomputers performing different functions is another way to illustrate system integration concepts.

SENSORS AND DETECTORS

Definition and Function

A sensor is a device used to identify the onset of an event of interest and to measure relevant attributes of the event. The event may be the passage of a vehicle over a road segment, for example. Operations interests may be concerned with the number of such counts (to estimate hourly volumes or AADT); trucking interests (such as those in CRESCENT or HELP) may want to know the weight, axle configuration, hazardous material status and other attributes of the truck or its driver. Maintenance engineers may be particularly interested in axle weights, so sensors used for this measurement may be located close to bridges.

Sensor and detector technologies are evolving rapidly, enabled by outright advances in microelectronics (lighter, smaller, more accurate devices) as well as computer technological advances. Possible applications span a range of needs from automatic sensing of bridge motion (for earthquake monitoring or pavement management) to a range of traffic sensors for IVHS systems.

Other examples of emerging sensor technologies and applications include:

1. Piezoelectric Cells - these electronic devices can be used for weighing trucks in motion or estimating forces acting on a body. The forces acting on the body are proportional to the electric voltage produced.

2. Radar - new lightweight radars can be mounted on bridges and overcrossings to measure traffic beneath. These may replace currently used inductive loops because of more reliable operation and easier, less obstructive maintenance. Radar may also be useful in car following for automatic vehicle control.

3. Inductive Loop - a wire imbedded in the road which sets up an electro-magnetic field when connected to detector electronics at the roadside. The field is disturbed by the passage of a metallic vehicle. This sensor is the backbone of current traffic surveillance systems. Caltrans is experimenting with transmitting limited information between roadside and car using advanced electronics (INRAD); this offers the promise of new uses for inductive loops.

4. Vehicles as Probes - there is great interest in obtaining traffic and incident data from vehicles directly through two-way communications.

5. Load Cells - can be used to measure forces on structures; particularly important for bridges.

6. Lasers - lasers can be used as part of a range finding system (measuring distance very precisely) to control robot arms and fill cracks in automated highway maintenance systems or as distance measurement devices for automatic vehicle control.

7. Accelerometers - these devices are used to measure accelerations and, by integrating over time, velocity. They can be used as part of navigation systems or automatic vehicle control. Advances in silicon chip technology promise the evolution of micro accelerometer costing ten dollars or less and of a size smaller than a fingernail.

8. Gyroscopes - these devices measure changes in directions. They are critical components of navigation systems. Advances in silicon chip technology imply that gyros the size and weight of a fingernail will soon follow.

9. Other Sensors - a variety of sensors have been used in prior traffic applications but are likely to see limited use in advanced technology. These include magnetometers, pneumatic tubes, pressure plates and photo-electric cells.

One of the more important technological trends is the linkage of the computer to the sensor through image processing. How can anyone forget the images from the Gulf War of smart bombs and the like produced by military image sensors. An example of this image processing capability applied to transportation is the use of cameras for traffic surveillance (so called Video Image Detection Systems, VIDS). The computer processes images from camera pixels and infers vehicle counts and movement. Most current systems convert these images to standard traffic stream measures (e.g. volume, speed, density, occupancy). The systems will ultimately directly measure queues and delays and perform area wide incident detection. Video techniques allow visual verification of events so they can be assessed for their importance. Continuous motion surveillance requires high communications bandwidth, with its resulting high cost.

The overwhelming applications of sensors will be in operations functions, although planning and design engineers may use data obtained from sensors. For example, design engineers may use vehicle detector counts from roadway sensors to estimate AADT to use in road design.

Technical Specifications

The reliability of the sensors and detectors and their sensitivity to environmental change will determine how accurately events may be monitored. Environmental *sensitivity* in this context is intended to include changes in sensor performance due to climatic changes (temperature, humidity), variations in entities of interest (e.g. counting or weighing trucks and autos) and changes in material characteristics over time. As sensors expand in application to more critical control tasks, stringent requirements will be needed regarding *reliability* (such as the mean time between failures). In some cases it may be advisable to initially construct automated and advanced technology systems using proven off-the-shelf technology. Such an approach was adopted in the initial development of the UTCS traffic signal control system because a primary concern was establishing the credibility of the concept.

Similar emphases are being placed on reliability in the early demonstration of automated highway maintenance technologies. Once concepts are proven, a continued evolution of new components can be added to enhance performance.

Planning and operations functions are most directly affected. Environmental sensitivity must be a primary consideration in selecting the types of sensors and detectors to be used.

Sensors and detectors must meet acceptable accuracy requirements for recording events of interest. The accuracy most directly affects operations and maintenance functions as they are likely to be the most frequent and critical users of sensor outputs. Planning and design inputs are less time critical and probably less severe in consequences resulting from minor information errors.

Technology Management

Realizing the potential of advanced transportation technologies requires system integration. The hardware of sensors and detectors must be compatible across technologies and geographic bounds. These *compatibility* issues will be most critical to the functions of planning, design and operations and, to a lesser extent, to the function of construction. Employees from all districts will have to work cooperatively to ensure compatibility and thus directly experience the influence of the need for total system integration upon their jobs.

Who will receive benefits and how much benefit they will receive, while unclear at this time, are important concepts underlying *financing* technologies. Identifying who should be responsible for funding particular components of the new systems is an issue that requires detailed analysis. For example, the cost of installing a station for new technologies such as AVI, HELP and WIM ranges from $10,000 to $20,000.

In determining how the planning, design and construction of the system will be funded, departments should initially identify the most important players in the technologies and consider the degree to which those players might be allowed to influence the development of the technologies in their own interest.

Concerns for sensor and detector sensitivity lead directly to a need to understand the potential *liability* associated with advanced transportation sensor and detector technologies. What are the liability consequences of a defective sensor that leads to an incident? In traffic operations, for example, failure to detect a vehicle in highly traffic responsive control may result in premature or erratic termination of the green. Methods need to be devised to limit the liability of individuals using the system and of the organizations that design, operate and maintain the system.

Curriculum Implications

Sensors offer an exceptionally broad range of application in support of different functions. Once again, basic definitions and functions should be stressed; example applications discussed. Cost and reliability are important attributes to stress as part of any examples. The text accompanying the curriculum and the examples would greatly benefit from review and input by engineers on the cutting edge of applications. While electrical and computer engineers will be heavily involved in the curriculum development for communications and computers, practicing civil engineers at the cutting edge of their field may be best able to convey the application of sensors to transportation functions.

VEHICLE TECHNOLOGY

On-Board Communications

Advanced transportation technologies will facilitate the communication of information both on-board the vehicle and externally. *On-board devices* include a variety of vehicle status displays to inform the driver of how well the vehicle is performing. On-board black boxes could provide better measurement of individual vehicle activity, such as vehicle speed distribution, number of trips, speed, stops, rpms, travel times and VMT. This information could be used to develop more accurate profiles of vehicle activity that are crucial to air quality planning models.

Advanced vehicle technology is also crucial to the communication of vehicle status information to an external control center. As discussed earlier, vehicles may be used as probes to monitor road traffic speeds and delays. The *external communications* require transmission hardware on the vehicle along with compatible receiving hardware at the roadside.

The introduction of robotics into maintenance functions will directly affect department employees. Improved worker safety will be an important benefit. Employees will be able to perform tasks such as litter removal and crack repair on the highway from inside their vehicles, instead of being physically exposed on the roadway. Nevertheless, *vehicle safety* will be an area of concern. Vehicles must be tested to ensure that the new technologies do not impair operators' ability to operate their vehicles safely by distracting them.

Operators of a dynamic system will have liabilities and risks associated with this function. A warning and backup system is imperative for technologies where a system failure could result in injury or death, especially where control is removed from individual drivers.

New technologies are likely to alter not only design but also roadway maintenance. An important benefit of the technology is its potential to reduce *emissions* as a result of smoother flow and operations. Smoother flow and faster travel time might induce demand, however, offsetting the benefits. The effects of advanced technology on emissions must be thoroughly analyzed. While electric vehicle generate no mobile emissions, the production of electricity increases stationary emissions. The introduction of new fuels is likely to change levels of emissions discharged by vehicles and fuel producers. Questions that need to be addressed include:

1) How will these emissions be regulated?

2) Will minimum performance standards be set?

3) If so, who will set minimum standards?

Technology Management

Levels of accuracy, maintenance and performance of vehicle technology and the frequency of adjustments will be important determinants of the use made of the system. Thus minimum standards of *reliability* must be established before the introduction of the new technology. If transportation departments were to take on the role of establishing design and operations standards, employees would need to acquire the skills needed to fulfill those responsibilities.

Since certain new technologies will have individually owned equipment or vehicles interacting with the system and with other privately owned vehicles, both equipment and vehicles have to be *certified*. Periodic checks and certification that equipment and vehicles are functioning properly will ensure the safety of system users. A department might take on this responsibility or it could be delegated to another agency with oversight. In either case, employees would have added responsibilities.

System integration of vehicle hardware and software requires *compatibility* across geographic and technological boundaries. Compatibility might ultimately be extended to a nationwide system and might require an agency having this responsibility. If a department were to assume responsibility for regulations and coordinating compatibility, employees would need to acquire new skills. If no one agency is responsible for ensuring compatibility, it is even more important that the department coordinate internally among its functions, as well as externally with other organizations. An examination of the difficulty in undertaking these activities is Caltrans' recent experience with an Automatic Vehicle Identification (AVI) specification.

Roadway Implications

New technologies such as the electric commuter vehicle might precipitate a need to *redesign roadways* and construction of a safer more efficiently operated highways. The redesign would be needed to provide a buffer between the smaller electric vehicles and the trucks and standard size vehicles of today. Accidents between the smaller commuter vehicles would be less damaging, but accidents between the smaller vehicles and larger ones could be serious. If market penetration of small commuter vehicles is sufficient to warrant it, safety concerns might lead to a grade separated roadway. Another redesign might be to modify passing lanes to compensate for alternative fuel vehicles which accelerate at slower rates than gasoline-powered vehicles. New technologies are likely to alter not only design but roadway maintenance.

HUMAN FACTORS

Perception of System Performance

The public's perception of the *safety* of the system will be a critical factor in its acceptance. For example, the public might be concerned about the flammability and explosive potential of vehicles fueled with compressed natural gas, even though experiences in New Zealand and Italy demonstrate that these fuels are very safe.

Similarly, the public's perception of *reliability* of the system will be another factor determining its use. No matter how objectively safe and reliable the advanced transportation system may be, it could fail simply because the public does not perceive it as so. Consequently, any advanced technology systems must perform to high levels of reliability, to convince the public of its safety and reliability. This will require departments to present information to the public to ensure a positive perception of the safety and reliability of the system. Operating problems with BART in the mid-1970's affected ridership and public support because the system could not, at that time, deliver reliable service.

Human Information Processing

The nature of *human information processing* needs to be understood to determine the content, format, and modality of information. Controls must also be placed in convenient locations. Providing advanced transportation technology users with information may increase the liability exposure of the operator of the system and the regulator of information. If a department is to assume either role, system operator or information regulator, it needs expertise in understanding how individuals cope with increased amounts of information while operating a vehicle or attending to a control system.

There are numerous application of human information processing needs to advanced transportation technology. For example, engineers need to understand how vehicle operations differ from traffic operations center (TOC) operators in their information processing requirements. Can different formats be used? What is the proper mix of voice and visual? What are the drivers' needs for full automation? Is the publics' need for information different from the operations of maintenance vehicles? How? These issues all involve human information processing.

Department safety engineers may have some knowledge of these issues due to their experience with traffic control device information processing. Their expertise needs to be broadened to include in-vehicle displays and TOC information.

Behavioral Changes

New technology can change individual behavior, possibly with negative effects. For example, how will a driver *operator* respond to giving up full or partial *control* of the vehicle? Are drivers in automated systems apt to be less alert and more erratic in their responses?

It is important to recognize that operators may re-allocate their attention when confronted with advanced technology. Drivers may be distracted from controlling their vehicle by an on-board message regarding congestion ahead. Fully or partially automated highways may allow the driver to monitor other surrounding traffic or the traffic may be completely ignored. These operator responses need to be understood. Behavioral changes also can occur in *higher level cognitive decisions.*

The potential for behavioral changes of users needs to be analyzed prior to implementation of the system and steps taken to minimize any negative impacts predicted by the analysis. Once the technology is implemented, further analysis will be required to determine the changes that actually occurred and what steps should be taken to minimize negative effects. Transportation departments do not currently perform this type of analysis. Employees will need to acquire new skills to execute this function.

Applications include driver response to in-vehicle route guidance; transit operator response to congestion information; traveler response to in-home or office pre-trip planning information; TOC operators response (in setting metering rates) to congestion in the network.

Baseline data describing driver behavior prior to implementation of advanced transportation technologies needs to be collected before proceeding to examine changes that may occur with implementation of new technologies. Transportation departments will need to develop measures of effectiveness of driver performance. Observed behavioral changes will influence the planning and operation of the system.

SUMMARY

It is clear that IVHS is having and will continue to have a substantial impact on the involved state and local governments. Rather than develop a curriculum around the concepts of the IVHS technologies (i.e., ATIS, ATMS, etc.), a building block approach is considered. This seeks to develop knowledge and skills in the fundamentals of advanced systems. Once these fundamentals are understood, their application to particular IVHS systems will be even more effective.

It is intended that this curriculum be used to guide the development of detailed readings in each of the six areas. It is important that the readings be applied to the five functional areas of transportation department responsibility. Sample curricula have been developed for operations and planning responsibilities. We are working with Caltrans to offer these and other courses developed around this core approach.

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