DEVELOPING AN INFORMATION TECHNOLOGY-ORIENTED BASIC RESEARCH PROGRAM FOR SURFACE TRANSPORTATION SYSTEMS

Report to the
National Science Foundation
and
US Department of Transportation

Based on a Joint NSF/USDOT Workshop Held at the University of Illinois at Chicago
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0. Abstract

US Department of Transportation and the National Science Foundation (NSF) are developing a basic research agenda that will integrate new technology into the supply and demand for surface transportation systems by the year 2025. This agenda will provide a deeper and broader understanding of the likely impacts of innovations in technology and the social, economic, and environmental changes.

The purpose of this joint program is to establish a jointly funded, 10-year basic research program, and a 25-year vision. The proposed program is intended to:

- Incorporate all modes of surface transportation
- Consider technical and non-technical influences, including the environment
- Incorporate "supporting" disciplines, such as computer sciences, computer engineering, social sciences (social, behavioral, and economic factors), operations research, systems engineering, telecommunications, and others as they emerge.

There has been virtually no basic research program in transportation. NSF has a research network that can be tapped to provide a new perspective on transportation. Successful congressionally supported, NSF collaborations with HUD, EPA, and others provide good models to pursue. NSF is anxious to establish a significant partnership with USDOT. This will launch a process that will provide important new ideas for longer-term USDOT programs.

This report documents the discussion and outcomes from an October 2000 workshop in Chicago. The workshop brought together researchers from diverse disciplines to develop a basic research program for surface transportation. The proposed program should address technology-based issues, as well as with those non-technical issues that have an equal or often a predominant influence on surface transportation.

1. Executive Summary

1.1. Description and Purpose of This Initiative

US Department of Transportation (USDOT) and the National Science Foundation (NSF) are developing a basic research agenda that will integrate new technology into the supply and demand for surface transportation systems by the year 2025. This agenda will provide a deeper and broader understanding of the likely impacts of innovations in technology and social, economic, and environmental changes.

The purpose of this joint program is to establish a jointly funded, 10-year basic research program, and a 25-year vision. The program will move transportation research toward a more rigorous process that address local issues, and add some diversity to the current research that is largely applied research. The proposed program is intended to:

- Incorporate all modes of surface transportation
- Consider technical and non-technical influences, including the environment
- Incorporate "supporting" disciplines, such as computer sciences, computer engineering, social sciences (social, behavioral, and economic factors), operations research, systems engineering, telecommunications, and others as they emerge.

1.2. Motivation for This Initiative

Concerns related to transportation congestion, safety, and the use of energy and the degradation of the environment point to the need for a radically different approach to surface transportation and provide the motivation needed for a basic research program. At the same time, advances in technology, changes in the regulatory climate (including deregulation), a strong economy, and an increasing awareness of the role of social and cultural values in transportation decisions underscore the need for a multidisciplinary approach.

The US Department of Transportation (USDOT), through FHWA, FTA, and the ITS Joint Program Office (JPO) is currently sponsoring applied transportation research in a number of areas related to surface transportation systems. USDOT is also developing agendas for new short and medium research initiatives with the Transportation Research Board (TRB), the Institute of Transportation Engineers (ITE) and the ITS America (ITSA).

The National Science Foundation (NSF) is an important new player in these initiatives. Until about 1995, NSF assumed that USDOT, under its various programs, was supporting basic research in surface transportation. NSF Grants were awarded on components of the transportation system, like materials and structures. Recently, some unsolicited proposals in transportation have received NSF support, and a few CAREER awards have been made to eligible young investigators that have addressed transportation issues. A workshop was held in 1997 on logistics and transportation. The Operations Research and Production Systems program in the Design, Manufacturing and Industrial Innovation Division, also in the Engineering Directorate, sponsored it. However, the subsequent solicitation (managed by the CMS division) was broadened to "engineering the transport industries" where transportation was only one of a set of industries. Word-

of-mouth solicitation by CMS program officers has resulted in proposals in transportation, primarily from faculty in civil engineering.

Despite NSF's recent involvement in transportation research, it has not had either programs or specific solicitations dedicated to surface transportation. In addition, there still is not any unique program or solicitation for surface transportation under way or planned for the future. The purpose of the joint NSF/USDOT research program is to provide such a focus.

The objective of the joint USDOT/NSF program is to get the attention of researchers in the scientific and engineering disciplines, including new technologies and the social, behavioral, and economic sciences that are not traditionally involved in basic research in surface transportation systems. This will be a targeted program, a follow-up to the workshop held in Chicago October 15-17, 2000.

While this initiative will not solve the nation's surface transportation problems, it will raise interest and awareness in these issues. It will also serve as the first steps in developing a basic research program.

Summary

There is virtually no basic research program in transportation. NSF has a research network that can be tapped to provide a new perspective on transportation. Successful congressionally supported, NSF collaborations with HUD, EPA, and others provide good models to pursue. NSF is anxious to establish a significant partnership with USDOT. This will launch a process that will provide important new ideas for longer-term USDOT programs.

1.3. Expected Outcomes from This Initiative

The "vision," to help launch this program that emerged from the October 2000 workshop is summarized as follows.

> *We will have a customer responsive, managed, safe, efficient, and integrated transportation system for the movement of people, services, and goods. Advances in information technology will enable the system to be both flexible and optimal through productive operations and control. Communications technologies and advanced traveler information systems will provide optimal information and knowledge to the customer to support equity, mobility, and accessibility. This seamless transportation system will preserve privacy and individual rights, provide choices, and be environmentally sustainable.*

When we achieve that vision, our goal is to provide all customers with the following:

> *No matter who or where they are, all customers will have in their hand the knowledge and ability to choose, make, and pay for a safe, efficient, cost-effective trip or multiple trip segments for themselves, their families or their goods to any location in the world. This will be true whether the trip is to or from home or work, to or from any recreation or business location, or for any other purpose.*

1.4. Achieving This Goal through Basic Research

The October 2000 workshop in Chicago brought together researchers from diverse disciplines. The workshop provided the following conclusions on the research themes to be considered by this program. They deal with technology-based issues, as well as with those non-technical issues that have an equal or often a predominant influence on surface transportation. In summary, they include:

1. Technical Themes

These include technology that supports integrated systems operation, systems integration to build on ongoing research on the supply side and integrate the demand side to produce transportation services for both people and goods that are seamless to the customer, and data and analysis tools to develop the knowledge that allows us to achieve our vision.

2. Non-technical Themes

These include issues related to safety, energy and the environment to capitalize on past and ongoing research in vehicle technology to produce systems with zero fatalities and zero emissions by 2025; i.e., institutional issues, equity and cultural values, and impact assessment.

1.4.1. Technical Themes

1. Technology Supporting Integrated Systems Operations
   - New vehicle navigation system with a computer-human interface
   - Safe systems and vehicles to substantially reduce crashes
   - Development of virtual reality systems (e.g., for training, evaluation, analysis, and operation)
   - Impact of nano-technology
   - Wireless impact on short- and long-haul travel
   - Proliferation of GPS
   - New hardware and software inventions now unknown
   - Environmentally friendly systems
   - Automated vehicle carpool systems
   - Tunnel technology (tube transportation)
   - New fuels and power platforms

2. Systems integration
   - Ground control systems with open control structure
   - Travel management/optimization (software, hardware, modeling)
   - Unexpected event management; i.e., accidents or traveling roads when extreme events (for example, earthquakes) occur
   - Infrastructure management requiring integration with bridges and pavements
   - Fusion of mobile communication and road infrastructure
   - Transition to controlled systems
   - New technologies to move goods in congested areas

3. Data and Analysis Tools
   - Better measurement, use of metrics, standardization of measurements

- Fusion and management
- Need for better data presentation, distribution, analysis and processing
- Integrated sensing/information collection without control (integrated at the vehicle level and platoon level as applied to system design)
- Advanced modeling and simulation of unique systems

1.4.2. Non-Technical Themes

1. Institutional Issues
   - Information ownership
   - Standards/laws—market standard to universal standard set by governing body
   - Governance of technology infrastructure
   - Addressing transportation related privacy — computer science, social science (perceptions)
   - Develop and test theories for new institutions

2. Equity and Cultural Values
   - Assessment of transport technology on social equity
   - Relationship between cultural values and social equity
   - New ways to work; a highly educated IT-based workforce

3. Impact Assessment and Analysis
   - E-commerce implications
   - Pricing in demand and supply
   - Determination of the value of data to travelers, vehicles, and the system
   - International globalization and impact on supply and demand
   - Human capability to direct the use of technology
   - Re-invent surface transportation planning and analysis
   - Role of the private sector
   - De-regulation of transit and highway systems
   - Alternative environmental scenarios
   - Alternative economic scenarios

1.5. Essential Principles to Achieve These Goals

As research proposals are being developed and evaluated, it is essential that the following principles be maintained. Future transportation systems must:

- Be customer driven, for people, goods, and services, and consequently, be market driven and performance based
- Preserve individual rights, preserve privacy and maintain freedom of choice
- Maintain community rights and ensure that government and institutional constraints are minimized
- Provide mobility, accessibility, and equitable benefits among and between citizens of varying social, cultural, and economic strata
- Establish ground control operation and management capabilities
- Be technology friendly
- Give full consideration to social, environmental, and economic impacts

1.6. Research Options to Achieve the Vision

In order to develop this approach and achieve the vision, there are three options for research.

1. The easy evolutionary option is to fix, polish, and/or add on to the current way of doing business. It is more certain and less risky. This option advances the current research agenda of US DOT's Joint Program Offices and other transportation research related to telecommunications in transport, the Intelligent Vehicle Initiative (IVI), intelligent infrastructure research, and the use of existing JPO/ITS/DOT community building blocks--systems, supply side/infrastructure advances, vehicle advances, information technology, and social sciences and non-transport influences

2. The more difficult evolutionary option is to build dramatically upon disparate technologies and bring together new or emerging "things" and events. This is more risky. This approach would explore in more detail how other disciplines (technology and non-technology based) are conducting research that will affect transportation. It could also involve research to fill in missing gaps, such as customer orientation, market forces providing customer needs, regulation/deregulation as an alternative, topics from the workshop themes, likely, but possible unexpected events, and political, institutional, and technical obstacles.

3. The revolutionary approach, which is very risky, would explore how things might be, and tear-up what we have and redo everything. It would be analogous to DNA and genome research with possible dramatic breakthroughs. This involves unknown factors and the need to explore ill-defined problem areas. One approach is to put together the right people, events, and things that may already exist in a disorganized, disparate, or disaggregated way.

Our goal is a revolutionary approach with a touch of the "more difficult evolution." We are seeking dramatic breakthroughs and recognize the inherent risk with the opportunity for significant payback. Obviously, there are significant obstacles that must be overcome and constraints that must be recognized. Innovative changes to surface transportation systems must overcome three significant obstacles to change: (1) institutional complexity and political driving forces influence changes in the surface transportation system; (2) the absence in the transportation research community of a different "community" of researches from other supporting disciplines that have research relevant to transportation; and (3) recognition of income disparity and the technology/digital divide among customers which must be addressed.

1.7. Products Expected

In the short term, there are several other products. The proposal themselves will be a resource for setting future directions for research, the proposals and projects will identify new and different criteria for research that will provide DOT with an opportunity to explore new ways to evaluate the value of basic research, and, most important, the

proposals will bring together new people in teams that will propose innovative and high risk strategies.

The products of basic research are difficult to specify because the very nature of basic research defies such specificity. Basic research is high risk, high payoff. It involves discovery and innovation. Over the course of the 10-year program, many of the products will be other research programs that focus on product development, additional testing, market studies, and feasibility studies. Ultimately, these will lead to commercialization of products, but, more important, an improved transportation system.

At the end of Year One, we anticipate new ideas from other supporting disciplines from the many proposals expected, new researchers engaged in transport, new approaches to old problems, and a foundation for more detailed, in-depth research to support 25 year vision. At the end of Year Five, we anticipate the first glimpses of promising new solutions, heavy private sector involvement, and promising development ideas. At the end of Year Ten, we expect to see new solutions being tested, and more advanced research underway.

1.8. What Is Different about This USDOT/NSF Initiative?

Fundamentally, this initiative addresses basic research. In addition it has a 25-year vision with a focus on "other" nontraditional supporting disciplines. By its nature, such research is risky and results are not certain or predictable. Ultimately, customer demand will dictate results. The availability of real-time information on both supply and demand will create market demand and opportunities to respond to existing mismatches and then the private sector is expected to move rapidly to fill gaps.

1.9. The Process to Achieve Our Vision

The following significant milestones are critical to achieve our vision.

- Initial DOT/NSF discussion in February 2000
- Interagency agreement in May 2000
- Workshop on October 15-17, 2000, at UIC
- This report to NSF and DOT; January 15, 2001
- Solicitation for NSF under development by NSF; expected March 1, 2001
- Start first-year proposals Fall 2001
- Coordinating with ITSA, ITE, TRB research initiatives

The following resources commitments based on equal funding for US DOT and NSF are expected:

- Workshop: $100,000
- First year research: $1,000,000
- Anticipated: $2,000,000 per year for ten years

1.10. Summary and Conclusions

In summary, transportation and communications have always been linked. The past 25 years have seen remarkable, evolutionary change. For example, in 1975, the hand held computer to do simple calculation was available; in 1995, we had the Internet and widespread use of it; and in 2000, wireless communication was widely available. To

achieve our vision by 2025, we must explore new horizons. We are about to embark upon a new journey to the future of transportation. A sustained basic research program is critical to success.

2. Background

2.1. Objectives of a Basic Research Program for Surface Transportation Systems

The objective of the proposed program for surface transportation systems is to support basic research that provides the science and technology to ensure the following:

- The use of IT will make our surface transportation system safer, more reliable, and more productive.
- The impact on our human and natural systems of the use of IT to sustain and revitalize our transportation system must be understood well enough that we can capitalize upon the opportunities it presents to improve performance, as well as to identify and mitigate any unwanted consequences.
- Knowledge must be made available that will support managing both the complexity and the vulnerability of surface transportation systems.

The proposed 10-year basic research program will have a 25-year focus. It will incorporate the disciplines that are not traditionally included in transportation research, such as computer science, computer engineering, and social sciences, cognitive sciences, operations research, systems engineering, and telecommunications.

The research will provide a foundation for the future and set directions for future research programs. As the research is inherently multidisciplinary, team building is important and changes will be slow.

Three forces are likely to affect the surface transportation system in the early part of the 21st century. We will continue to extend the life, improve the performance, and expand the capabilities of our present transportation system by using IT. An example is the ITS program. We will create new information infrastructures, which, in turn, will put new demands on our existing surface transportation systems. An example is web shopping: the supporting logistics are putting new demands on our transportation systems. As a result of the use of IT, its coupling with existing transportation systems, and the new demands and expectations, our transportation systems will become both more complex and more vulnerable. An example is smart or platooned vehicles, a more complex system that may be more vulnerable to incidents.

2.2. Why Basic Research?

"Basic research really is applied research, with a long-term perspective."[1] Basic research, applied research, and development represent a continuum of activities with a common goal of producing new and useful products, processes and knowledge. The

[1] "Basic Research and Kindred Collaboration: A 21st Century Strategy," Alan Schriesheim, Ph.D., director and chief executive officer, Argonne National Laboratory, presentation at the Korea Institute of Science & Technology Symposium, Seoul, Korea, March 12, 1996.

American Institute of Aeronautics and Astronautics defined basic research in engineering as follows:

> Basic research in engineering is concerned with the study and discovery of fundamental phenomena in science and physics as they relate to engineering, and the development of new and improved applications of the basic sciences to engineering. Its fundamental aims are to improve understanding and develop new concepts and paradigms, to indicate the limits of current thinking and the direction of subsequent work. It also serves as the major training ground for participants in the R&D process. Applied research is the process by which engineering applications are examined and analyzed in terms of the underlying principles and to verify new concepts. So applied research also leads to new concepts and methods. Development is the process by which a new or improved engineering concept is incorporated in a device, which is scheduled for production. [2]

The nation's long-term commitment to basic research has forged our world leadership in the basic sciences. Long-term sustained funding of basic research has had a significant impact on the US economy (Wong, 1996). The importance of basic research to address areas of national importance such as surface transportation cannot be denied. The US Department of Transportation and the National Science Foundation (NSF) have agreed to jointly fund this effort in order to establish an innovative, forward-looking, and non-traditional program that will provide funding for a 10-year basic research program.

The existing multi-modal surface transportation system that provides access and mobility for people and commodities is well established and in place throughout the United States. However, congestion in many locations and its associated consequences for all modes has created the need to develop more innovative, technology-based tools for managing and operating transportation systems more efficiently and safely.

There is a practical limit to the ability of more efficient operation and management of those systems, without further expansion of the in-place infrastructure. That is the situation if the current physical, social, economic, environmental, and technology bases remain, as we know it today. The social, environmental, and technical changes occurring in the United States and in the world are likely to alter that basic framework in ways we do not realize or understand today.

2.3. The Need for a New Paradigm

A recent conference conducted by the General Accounting Office "Surface Transportation: Moving into the 21st Century," noted some common themes based on participants' comments at another conference on the topic (GAO, 1999):

1. Surface transportation faces significant challenges and demands.
2. In the future, passengers and businesses will demand cost-effective, efficient transportation services.

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[2] http://www.aiaa.org/policy/papers/basic-res.html

3. The automobile will remain the dominant mode of travel.
4. Automobiles will continue to be perceived as faster, cheaper, safer and more flexible than other modes.
5. The fast movement of freight through the transportation system is key to competitiveness.
6. Different types of travelers (e.g., the elderly and leisure travelers) will impose different demands on the systems, adding to the complexity of the systems.
7. Emphasis on the users of the system, rather than the system itself is needed.
8. There is a shift from constructing the system to operating the system.
9. More collaboration with the private sector is needed if the complex demands are to be met.
10. Transportation is vital to the nation's economic health.

These themes respond to the challenges and issues identified by the participants that included (GAO, 1999):

1. The existing network is aging.
2. Highway congestion continues to be an issue.
3. Social and environmental concerns are major constraints on system expansion.
4. The majority of mass transit users are concentrated in a few large urban areas.
5. Freight shippers are major transportation users and are critical to the economic health of the nation.
6. In general the public does not have access to information about transportation.

Explicitly included in examples of how to address these issues was the need for basic research:

> Federal policy makers need to renew their commitment to funding nationally important research. While TEA-21 substantially increased states' research funding, it considerably reduced funds for federal research, one participant stressed. While state research programs focus on short-term, practical problems, federal research must focus on long-term and high-risk research, intermodal problems, and transportation policies. (GAO, 1999, page 6).

These ideas are consistent with an earlier GAO study to prepare for ISTEA reauthorization (GAO, 1996). One of the principle findings of this report was that emerging areas, (specifically systems assessment, policy research, and intermodal research) and basic research are not adequately addressed.

The National Science and Technology Council (NSTC) through the subcommittee on Transportation R&D defines the direction for research in terms of economic growth, competitiveness, environmental issues, safety, congestion and mobility (Smallen, 2000). Enabling research on technological innovations is the third of a four-tiered research strategy that was identified as key to addressing long-term national needs.

The workshop provided an opportunity to address these issues and to obtain expert input on new and emerging technologies and the role they may play in shaping the surface transportation systems of the future. Although transportation professionals do not

necessarily agree on the solutions they do agree that radical change is needed if future transportation systems

2.4. Role of History - A Brief History of Information Technology

We can trace the computer component of the IT revolution from the beginnings of mechanical computations in the early 20th century; followed by electromechanical computers during WW II, to vacuum-tube computers following WW II in the early 1950s. However, we typically think of the transistor-based computers of the late 1950s to mid-1960s and the integrated circuit computers of the 70s to the present as having the most impact on our daily lives.

The same is true of communications; the invention of the telephone in 1876 made voice communications possible. But the 1958 successful test of passing data over phone circuits, electronic phone exchanges in 1965, cellular phone networks in Japan in 1979 and the US in 1983, and the 1980 installation of fiber optics in Atlanta heralded the widespread use of communications, as well as highlighted the need to integrate computing and communications into networks. The launching of Landsat I in 1972 introduced sensing and location technologies into the IT systems.

Today, we have an early version of cyberspace consisting of computer platforms and their associated equipment; hardware, software, and associated human-machine interface technology; and networking technology that enables computers to communicate with one another (Bell and Gray, 1997).

The process of integrating communications and computing started with time-sharing in 1960s, then came Arpanet and later the Internet, in 1970s and 80s. But it wasn't until 1993 that PCs running browser software led to the realization of the World Wide Web running on the Internet. Now we have various types of low cost web access devices, wired and wireless, mobile and stationary, personal and public. The growth of the Internet is dramatic, but what may be as important for the future is the growth of "intelligent" technologies like vehicles "that use a local area network to coordinate their components and the global network to report diagnostic information and get traffic updates" (Frankston, 1997).

The ongoing research in cognitive science and artificial intelligence will result in tools that will assist us and our "machines" to make effective use of advances in computing and communications. However, we should not expect to see any time soon a robotic taxi tooling around New York City, one that can understand and follow our instructions and do the sensing, processing, motor coordination and reasoning needed to get us to our destination safely (Franz, 1997).

2.5. Technology Change and the Future

In a critique of innovation processes related to transportation, Garrison (Garrison, 2000) suggests that technological changes are in some sense "technological fixes," innovation often occurs fortuitously rather than under a guided strategy, and radical changes are influences by a complex set of market forces and regulatory process.

Furthermore, forecasting technological changes is difficult. The following examples illustrate the lack of success of some well-known figures.

> Predicting changes in technology and their impact is challenging. Historically, many of our technological leaders have not had a clear vision of the future: In 1943, IBM's Thomas Watson suggested that there was a world market for maybe five computers. In 1949, “Popular Mechanics” suggested that, "Computers in the future may weigh no more than 1.5 tons." In 1977, Ken Olson, President of Digital Equipment Corporation, said, "There is no reason anyone would want a computer in their home." While Bill Gates clearly realized that his predecessors got it wrong, even he underestimated the power of this industry. In 1981, he said, "640K [of memory] ought to be enough for anybody." (Blair, 1997)

Of all the technological developments that are expected to occur by 2025, advances in information technology (IT), computing, and communications will make the greatest impact on our surface transportation system. IT has already made fundamental changes in many aspects of our lives, particularly in how we work and play. But our transportation systems really have not experienced the radical transformations that will be the consequence of new advances in IT.

Fiber optics and other optical technologies will enhance the performance while reducing the costs of communications. The vision of a tether-free world will become a reality, with wireless communications becoming the primary flow in and out of fiber networks. Low-cost communications will continue to change the way we work, as individuals, groups, and teams and as organizations and businesses. As computer capacity and speed continue to increase, we will have the ability to manage dispersed and distributed systems in real time.

However, the result will be systems that may become too complex for traditional forms of management control and decision-making. IT will enable us to simulate the consequences of decisions and analyze the results in time to make a difference. "Smart" technologies will become commonplace. Every tool will have its own sensors, microprocessors, and actuators and will be able to evaluate its performance, to assess the environment, and to initiate calls for action—repair, adjust process, help, etc. Smartness will be evident in other ways. Advances in the cognitive sciences will enable us to have electronic personal assistants that monitor our performance and suggest corrections or make them for us. Education and training will capitalize upon virtual reality and artificial intelligence systems.

At the same time, we need to understand the context and the importance of multidisciplinary research. At the ABET Annual Meeting, October 28, 1999, in a speech titled “Trends in Science, Engineering, and Technology Policy,” Joseph Bordogna, NSF Deputy director and chief operating officer, said: "The future is never easy to 'see.' But the chances of having good vision are much better if you understand the larger context in which you work... Learning to read the larger context gives you a path for imagining the

future."[3] In developing a basic research program for surface transportation, we seek to include this larger context.

Fundamental issues need to be better understood in order to develop future surface transportation systems. What changes are likely to occur, and how will those changes affect transportation? How do we deal with them and use them to our advantage? How will transportation supply and demand be affected by those changes?

The civil engineering and related transportation professions have historically provided the major source of transportation professionals and the technologies and services currently in place. However, over the past decade or so, other supporting disciplines and skills have become more prominent in just about every aspect of surface transportation affecting the movement of both people and commodities.

2.6. Related Research Efforts

Several related research efforts are currently under way. These programs focus on near-term results and will be complementary to the proposed program.

- Engineering the Transport Industries. This NSF sponsored effort (NSF 00-49) is intended to foster the development of a science base for the transport industries. (www.nsf.gov/home/programs/eng.htm)
- IVI. This DOT program is intended to accelerate the development and deployment of advanced safety and is applied to all types of motor vehicles. (www.its.dot.gov/ivi/ivi.htm)
- Research & Technology Partnership. This partnership--co sponsored by TRB, AASHTO, and FHWA--is developing a new framework for coordinating highway research and technology including broad-based stakeholder involvement and interaction, better awareness and appreciation of existing research programs, formation of productive partnerships, demonstrate needs and opportunities for research, and addressing operations and mobility. (www4.nationalacademies.org/trb/homepage.nsf/web/R&T_Forum)
- ITS Initiative. ITS America is about to launch a planning effort to develop a request to Congress for the 2003 budget for a research program for ITS-related research with a 3-5 year time frame. This effort is supported by AASHTO, APTA and TRB. (www.itsa.org)
- ITE. ITE is currently supporting an Electronic National Dialog on Transportation Operations to share ideas, thoughts, and/or comments on how we can manage and operate the existing transportation system so that its performance meets or exceeds customer expectations.
- FSHRP. A study for a future Strategic Highway Research Program as mandated by TEA-21 is being conducted by the Transportation Research Board. (www4.nas.edu/trb/newshrp.nsf)

[3] http://www.nsf.gov/od/lpa/news/media/qst_trends.htm

Table 1 summarizes the status of these programs and the areas being addressed. While each of these research efforts has a significant technology component, they focus on a shorter time frame than the proposed program and, more important, on the existing surface transportation system.

2.7. Where Are the Gaps?

While there are many ongoing and planned efforts, there are some significant gaps in terms of providing a comprehensive research program for surface transportation. These gaps may be characterized as follows:

- No existing or planned NSF-supported program or initiative is focused on surface transportation.
- No existing or planned program, DOT-related effort, or initiative addresses basic research.
- Planned programs focus on incremental change to the surface transportation systems, as we know them today.
- No existing or planned program is focused on innovation.
- No existing or planned program addresses both technology and the social sciences.
- No existing or planned program draws in researchers from disciplines not traditionally involved in transportation research.

Table 1. Summary of Related Research Programs and Studies

Program/ Study	Description	Agencies Involved	Status	Areas
ETI NSF 00-49	Aimed at developing a science base for the transport industries	NSF	First round proposals currently under review	Operations Logistics
IVI	Advanced motor vehicle safety	US DOT	First round of field operational tests is occurring.	Vehicle safety for light vehicles, heavy vehicles, transit, special vehicles
R&T Partnership	New framework for coordinating highway research and technology	TRB, AASHTO, FHWA	Initial phases	Infrastructure renewal Safety Planning & environment Operations & mobility Policy analysis & system monitoring
ITS Initiative	Development of research program	AASHTO, APTA, TRB	In planning stages	ITS technologies
ITE	An electronic dialog to develop a vision for transportation operations with links to the R&T partnership	FHWA, AASHTO, State DOTs	Ongoing	Operations
FSHRP	Study to set priorities and design a focused R&D effort	TRB, DOT	Preliminary stages	Accelerate the renewal of America's highways Make a quantum leap in highway safety Reduce the delay for highway users Meet highway demand to support economic and social goals

3. A Technology-Oriented Basic Research Program for Surface Transportation

3.1. US Department of Transportation Perspective

US DOT has an historical interest in transportation and technology. However, this interest is not purely academic but driven by the health, safety, and economic issues that drive our current surface transportation system.

Crashes are a public health problem. Each year, there are 41,000 deaths, 3 million injuries, and 10 million crashes on our roads. This represents an economic loss of $150 billion. At the same time, congestion is choking the system. Congestion has increased 400% in the last 20 years and will increase 50% in the next 10 years. Americans spend a week each year stuck in traffic.

The information revolution is shaping transportation. Intelligent Transportation Systems (ITS) is information and communication applied to transportation problems. It includes travel management, fleet management, government transactions, and intelligent vehicles.

The Federal ITS Program has as its vision a safer, more responsive, and more efficient national transportation system within 20 years through the application of ITS technology. Looking back through history, we see that DOT has emphasized particular aspects of surface transportation. In the 1960s the emphasis was on transportation for defense. In the 1980s, the emphasis was "Mobility 2000." In 1991, ISTEA and, later in 1997, TEA-21 placed emphasis on intermodal travel and equity. With reauthorizing looming in 2003, what will be the next area of emphasis? Ideally, we would like a seamless transportation network. The challenge is to develop a renewed vision for the program.

TEA 21 included a National ITS Program Plan. This plan was based on a 5-year planning horizon, state and local deployment strategy. We now need to look at an additional 10-year (2000-2015) horizon with a 25-year vision of technology and its impact on surface transportation. The current 10-year ITS program plan development that is occurring as the basic research plan is being formulated is looking toward reauthorization in 2003.

The NSF/DOT research program involves a commitment for 2001 of $1million. This funding provides an opportunity to lay the groundwork for a larger program in the next reauthorization.

3.2. National Science Foundation Perspective

3.2.1. Background

The National Science Foundation (NSF) is an independent agency of the US government, established by the National Science Foundation Act of 1950, as amended, and related legislation, 42 USC 1861 et seq., and was given additional authority by the

Science and Engineering Equal Opportunities Act (42 USC 1885), and Title I of the Education for Economic Security Act (20 USC 3911 to 3922). NSF's mission is to promote the progress of science; to advance the national health, prosperity, and welfare; and to secure the national defense. NSF supports a wide range of activities, including basic and applied research, education, scientific exchange, and international cooperation.

The president's budget request for NSF for 2001 is nearly $4.6 billion, 17% higher than the current year (2000) budget of about $4 billion. Nearly half of the increase is aimed at core research and education activities; the rest will go toward four focused areas (information technology research, biocomplexity in the environment, 21st century workforce, and nanoscale science and engineering). Internal operations--including staff salaries and expenses--account for only about 5% of NSF's overall budget.[4]

NSF is organized into directorates, with each directorate having divisions; and each division having program. For example, the Engineering Directorate has a Division of Civil and Mechanical Systems (CMS). Priscilla Nelson is the head; Infrastructure and Information Systems is a program within CMS, with Miriam Heller the program officer. Researchers, typically academics, submit unsolicited proposals to programs based upon the program descriptions and discussions with program officers. Proposals are reviewed either by mail or by panels of reviewers brought to Washington, DC. Twice each year, after October 1 and February 1, panels are convened, recommendations made, and awards given. These proposals are typically single investigators, with an average award of $67,000 per year for three-year awards. The acceptance rate varies but is generally 28% per panel.

NSF can decide (sometimes with the help of the president and Congress) that a research area is being overlooked because it either doesn't fall within any one program or is a very new topic. Then an initiative soliciting proposals for that area is announced. The initiative may come from NSF itself or one of its directorates or divisions, with either new monies or a combination of new monies and program funds. These initiatives may become institutionalized, like the Engineering Research Centers, or may last just for just one solicitation. They can range in funding and time periods. For example, multiple one-year awards of $100,000 were made for the Exploratory Research on Engineering the Transport Industries (ETI) solicitation, while one award of $1million a year for five years for the urban infrastructure solicitation was won by the center at NYU. However, the peer review process is the same; reviewers are sent the proposals and panels are convened. In the case of major awards, site visits may be made after the panel review.

3.2.2. Transportation Research at NSF

For many years, until about 1995, NSF assumed that USDOT under its various programs was supporting basic research in surface transportation. Grants were awarded on components of the transportation system, such as materials and structures. However, there were neither programs nor specific solicitations dedicated to surface transportation.

[4] http://www.nsf.gov/od/lpa/news/media/fsnsf.htm

And there still are no unique programs or solicitations. The purpose of the joint NSF/USDOT research program is to provide such a focus.

A few recent awards have been made in transportation, notably CAREER awards to young investigators, primarily due to the efforts of Priscilla Nelson. In the same time frame, Joseph Bordogna, then the director for engineering, provided funding for an initiative called Systemic Change in Urban Infrastructure. Six multidisciplinary projects were funded that included some transportation related research. In 1996, a workshop on civil infrastructure systems was held. This workshop led to a competition in 1997, which led to the establishment of the Institute for Civil Infrastructure Systems at New York University. In 1998, another effort, the Urban Research Initiative, was launched. That competition involved collaboration between the engineering directorate and the social, behavioral, and economic sciences directorate to support about $7 million in research.

A 1998 workshop was held on logistics and transportation and was sponsored by the Operations Research and Production Systems program in the Design, Manufacturing, and Industrial Innovation Division in the Engineering Directorate. However, the subsequent solicitation (managed by the CMS division) was broadened to engineering the transport industries where transportation was only one of a set of industries. Word-of-month solicitation by CMS program officers has resulted in proposals in transportation, primarily from faculty in civil engineering.

3.3. NSF Partnerships with Other Federal Agencies

NSF has a long history of partnerships with other federal agencies. These include:

1. Joint Program on Phytoremediation (EPA/ NSF/ ONR). This program is administered by EPA and solicits applications for research projects that address the fundamental mechanisms of interactions between microorganisms, plants, and contaminant chemicals in soils and sediments (which might include marine, estuarine, or freshwater systems) which result in the degradation, extraction, volatilization, or stabilization of the waste chemical.
2. Decision-Making and Valuation for Environmental Policy (EPA/NSF). The DMVEP competition encourages research that will contribute to the development of practical, credible approaches for estimating the benefits and costs of environmental programs and improving decision making about environmental issues.
3. Technology for a Sustainable Environment (EPA/ NSF). This competition is designed to address pollution avoidance and prevention processes, methodologies, and technology research.
4. Engineering Sciences for Modeling and Simulation-Based Life-Cycle Engineering (NSF and Sandia National Laboratories). These two organizations have entered into a collaborative program to fund research projects that are focused on advancing the fundamental knowledge base needed to support advanced computer simulations.
5. President's Partnership for Advancing Technology in Housing, or PATH (NSF/ HUD). The National Science Foundation will support fundamental research that can help to advance PATH's program goals to improve the quality, affordability, durability, environmental performance, and energy efficiency of today's new and

existing homes; to strengthen the technology infrastructure of the United States; and to help create the next generation of American housing.

3.4. The Joint USDOT/NSF Research Program: Schedule

The objective of the joint program is to get the attention of researchers in disciplines, including the social, behavioral, and economic sciences, not traditionally involved in basic research in surface transportation systems. In order to complete the 2001 solicitation and satisfy the interagency agreement, the following schedule of events is proposed. This schedule is set by the need to have awards by August 1, 2001, in order to complete granting requirements to affect start dates for the research before October 1, 2001.

January 15, 2001: the 2-3 pages of program description for the solicitation prepared and approved by representatives of the USDOT Joint Program Office and CMS division at NSF.

March 1, 2001: Solicitation released by NSF

June 1, 2001: Proposals due to NSF.
Reviewers selected including researchers from USDOT, and panels convened.
Recommendations from the panels reviewed by NSF staff and USDOT Joint Program Office, and funding decisions made.

August 1, 2001: Awards made.

It is expected that the proposals received from this first year solicitation of a five-year program will help shape the subsequent solicitations and result in research that can be reported on by 2003, in time to influence reauthorization of the research programs of USDOT.

4. Input from the Research Community

To gain input from the research community, the Chicago workshop discussed earlier included 31 participants from government, academe, and private industry. Participants are listed in Appendix A. Participants came from 10 different disciplines, including computer science, electrical engineering, mechanical engineering, civil engineering, urban planning, public policy, physics, industrial engineering, decision sciences, and information technology. The workshop agenda is Appendix B.

Participants were asked to submit answers to the following questions prior to the workshop:

1. From the perspective of your discipline and profession, what topics and areas in technology and its impact on society might influence surface transportation in the next 25 years?
2. What five to seven major trends do you see in technology and its impact on society?
3. What five to seven possible indicators of change, or major discontinuities might occur in technology and its impact on society?
4. How might these trends and indicators of change in technology and its impact on society influence surface transportation? Please identify three or four major implications in terms of each of the following:
    a. Supply
    b. Demand
    c. New ways of thinking about transportation

Responses are included in Appendix C.

The following sections summarize the results of the workshop. Where appropriate, additional details are included in appendices.

4.1. Principles or Assumptions

In guiding the discussion relating to directions for the research, several basic assumptions were discussed. While not everyone agreed on the principles or assumptions, they provided a foundation for the discussion. They can be grouped into three areas: external factors (policy, state of the economy etc), the state of technology, and expected outcomes.

4.1.1. External Factors/ Givens

These factors are considered to be beyond our control but must be recognized in guiding future directions. They include the absence of any broad policy level sets of priorities, the existence of good opportunities, basic research serving as an opportunity to answer questions that we are not able to formulate, and uncertainty of the future. A fifth factor is the need to understand the implications, both public and private, of many current technological advances.

4.1.2. Expected Outcomes

The expected outcomes from a basic research program are assumed to meet some specific criteria.

- Some outcomes are more incremental and some are more revolutionary.
- The fundamental issue is being able to extract value from data (real time or otherwise) for whatever reason we would like to use it.
- Outcomes must be robust to alternative scenarios
- Individual social engineering biases should not be part of the basic research agenda.

4.1.3. Status of Technology

There are some givens regarding the current and future states of technology:

- Universal monitoring, universal sensing, large scale monitoring, and control will be available within10 years.
- Look at what might happen if technology continues moving in the direction it is moving.
- What technologies have the potential to enable a revolution?
- Some constants, for example, personal distributed computing, must be kept.

4.2. Trends and Indicators of Change

Participants were asked to describe trends in technology and its impact on society. One participant summarized their views in terms of people, freight, and the transportation system as a whole as follows:

> *Person*
> Thanks to telecommunication and easier communication, the future will see a growing importance of alternative working time and working place arrangements that will have impacts on transport demand. There will also be a substitution of physical transport by telecommunication, E-mail, e-commerce, and e-marketing will have major impacts on all aspects of society (sometimes increasing transport, e.g., small package delivery, meeting people you have "met" on the Internet, and sometimes reducing transport, reducing face-to-face meetings.)
>
> New technologies can also facilitate "seamless multimodal mobility" between origins and destinations. Information systems can provide a timetable for any origin-destination trip before the person leaves, and can even print out all tickets needed. (Payment, of course, would be made electronically at the time the timetable was printed.) Off-line timetable data as well as on-line traffic management data can be used to give the most up-to-the-minute information on alternative modes, routes, departure, and arrival times to the individual traveller. On the infrastructure side, there are new possibilities for the design of multimodal networks that will incorporate the interconnection of modes and services.

Freight
Information and communications technology interacts with the organization and logistics of production and distribution. First, technological change will influence the demand for factors of production and thereby indirectly the demand for transport services. Second, new concepts of logistics (e.g., supply chain management) are facilitated by ICT developments. These will have a major effect on transport demand.

New technologies can facilitate intermodal freight transport. For example, information technologies can be used to reduce the waiting time at transfer stations (e.g., advanced information can be used to improve the scheduling of shipments).

New technologies can also provide possibilities for (automated) underground transport, e.g., to and from airports, for air freight, or as urban distribution systems to reduce truck congestion in urban areas.

Transport System
The intelligent transport system means different things to different people. But there is no doubt that technological changes are being rapidly integrated into the transport supply system. One of the most important areas of development is that of dynamic traffic management. This area involves traffic control measures that allocate temporal and spatial utilization of infrastructures and vehicle fleets by means of dynamic signals. These measures include electronic tolling (variable by time of day), traffic information systems, on- and off-ramp control systems, etc.

This response reflected the views of many participants that are summarized in Appendix C.

4.3. Influences

To better understand the role these trends play in surface transportation, the influences of current and future radical changes in technology were explored.

4.3.1. Influence of Current Technologies

Current technologies already significantly influence the surface transportation system including:

- Explosion of large scale distributed data and information
  - Car to car (position communication and other information)
  - Car to road
  - Road to car
  - Car to archive/black box
  - Roadside real-time traffic monitoring
- User Service
  - Effect of E-commerce as integrated system of goods movement
  - Seamless intermodal personal travel
  - Common payment system across different services provided

Restructuring taxes/user fees/tolls

- Equity, in terms of accessibility, is improved for disabled and older travelers. However, there are income questions.
- Data quantity/quality management issues, included how to deal with this at multiple levels to make effective decisions.
- Simulation capabilities to demonstrate potential realities are improving.
- Safety improvements, in-vehicle, roadside, are effective as people are willing to spend money for safety.
- Freight: supply chain management/ logistics, and LTL, package
- Telecommuting impacts on life style change and job market
- Globalization is well established.
- Telematics
- Massive amounts of data
- Increased availability of sensors
- Environmental impact
- Training testing in virtual environments

4.3.2. Influence of Radical Changes

Radical changes are also possible including the following areas:

- Safety (elimination of fatalities): collision avoiding cars, direct/peer-to-peer real-time safety information sharing, roadway friction
- Road infrastructure: sensor friendly road, sensors in the road
- Automated highways
- User services (personal and industry): location information, wireless technology and e-commerce integration, better operation of unscheduled paratransit type services, possibilities of passenger pooling as alternatives to fixed route, fixed schedule mass transit, potential for demand management. e.g., pricing
- Equity
- Smart growth
- Full cost of transportation (passenger, goods)
- Extreme events: reliability, robustness of system, security for non-natural hazards (computer viruses, etc.), natural hazards (storms, floods, etc.), major energy shock
- Environment, e.g., global warming, invasive species (caused by global trading)
- Privacy backlash
- Globalization backlash
- Full automation
- Telecommuting
- Energy/environmental crises
- Shared (“half”) vehicles
- Airborne personal rapid transit
- Dedicated and variable lanes for transit or trucking

4.3.3. Proposed Basic Research Program

Working backward from the research themes identified in breakout groups, participants grouped the themes together. They wanted to avoid the dichotomy of

disciplines and chose to include social, behavioral, and economic sciences in everything. Any research program/ project should have a social science aspect. Therefore, two dimensions were created--technology and social science--that should be addressed to some extent in all research.

Within each of these broad themes are more specific themes organized as follows:

1. Technology: data, systems integration, technology that supports vehicle operation
2. Social Sciences: impact assessment, equity, institutional issues

Specific examples of projects include:

Data

Better measurement/ metrics/ standardization
Fusion/ management
Need for better data presentation, distribution, analysis, and processing
Integrated sensing/information collection without control (integrated at the vehicle level and platoon level as applied to system design)

Systems integration

Implication of ground control system with open control structure.
Traffic management/optimization (software, hardware, modeling)
Unexpected event management: accidents, roads when extreme events hit
Infrastructure management integration with bridge and pavements

Technology that supports vehicle operation

New vehicle navigation system, computer-human interface
Safe systems
Development of virtual reality systems (e.g., for training, evaluation and operation)

Impact assessment

E-commerce
Pricing and demand
Determination of the value of date to travelers, vehicles and the system

Equity

Assessment of transport technology on equity
Relationship between cultural values and equity

Institutional issues

Information ownership
Standards/laws, market standard to universal standard set by governing body
Governance of technology infrastructure
Addressing privacy (transportation related), computer science, social science (perceptions)

These examples of research areas illustrate the breadth and depth of such a program.

4.3.4. Discussion of the Proposed Research Program

Characterization

The proposed areas build on the general agreement that the explosion and ubiquity of data will affect transportation. The question is how to do this. There are many

non-technical and technical issues raised including policy and social science. Integrating these is not an easy task because different subsystems are involved and proper function depends on real time control. This underscores the highly interdisciplinary nature of this effort and the limitations of the proposed resources.

Observations

The proposed topics and areas are relatively conservative. No breakaway R&D efforts are proposed. Many of the topics have been mentioned before. The challenge lies in taking them to implementation and doing it well, which can take 25 years. Perhaps conservative is a good way, as many research topics have been identified that have not been dealt with so far. Other observations include:

1. Crises figure prominently, and there is a large emphasis on congestion, not safety.
2. Role of the private sector is not explicit. We need to rethink transportation services and how to develop markets.
3. Getting some of the agencies and stakeholders involved in an NSF project, especially the non-technical issues, is difficult.
4. The domestic focus is limiting. There is a strong case for international developed markets.
5. It is difficult to focus and articulate research on institutional issues.

Gaps

Several gaps were also identified:

1. Full automation is ambitious but interesting.
2. Standardization, interoperability, and systems architecture were insufficiently discussed.
3. Not much emphasis was placed on user behavior and human factors dimension.
4. Ownership of data is important and requires further discussion.

4.4. Passionate Topics

Participants were also asked to identify topics they felt passionate about. Surprisingly, responses related to the motivation for basic research and modeling dominated the discussion. The topics included:

4.4.1. Models

1. Lack of fundamental basic models with any reliability: traffic flow, behavior, etc. We owe it to ourselves to go back and study these things
2. There have been no good ways until now to verify models, but now the data are available.
3. There is no good basic research on modeling and control at the network level.
4. Transportation industry makes decisions without models, yet the rest of the world makes models.
5. Europe is doing modeling; we can learn from them and they want to learn from us.
6. How should we compare benefits? How do we increase control of the vehicle from the driver?
7. Models for demand forecasting assume everyone has perfect information and is making rational decisions; we need case-based reasoning models.
8. We need driver behavior data on which to base models, but it is expensive to obtain.
9. How do we model and understand the benefits that could accrue?

4.4.2. Motivation

1. We must solve the problem before there is a crisis. For example, using an analogy to power systems, research should explore the dangers and causes of transportation failure rather than wait for a critical event, such as the loss of power in California.
2. Japan seems to be planning and executing things like 0 accidents, 0 congestion, 0 environmental impact.
3. We were very dependent on the interstate program for the past 50 years, yet we do not have a new framework. Currently, it is a command and control system. There is an urgent need to deregulate that system and let local areas experiment with ways to meet their needs. Deregulation is forcing radical change in railroads etc. How do we regulate transit, urban planning, and the environment and allow states, localities, and neighborhoods to implement variety and experimentation?
4. Making these changes requires changing the fundamental mood of Congress, which has happened in aviation.
5. How can new technology make public transportation more competitive? Some of these new technologies will not be possible under the current regulatory model.

4.5. Key Elements of a Research Program

In developing a program, we believe that by Year 3 of the 10-year program there must be adequate funding to support an array of large and small projects. The large projects will take advantage of the multi-year commitment for support to assemble an interdisciplinary and if appropriate multi-institutional team. The first year of the program is the most challenging. Assuming approximately $2million funding, there are three possible strategies:

Breadth--10 small one-year projects
Depth--3 medium-sized two-year projects
Hybrid--5 small, 1 medium-sized project

4.5.1. Approach/Principles

The proposed research program must build on two principles: bringing technology and social sciences together (also public/private/academic) and covering multiple areas.

4.5.2. Evaluation

<u>Strengths</u>

Such a program provides a structure that's broad and inclusive with an opportunity to add priorities to particular areas. Emphasis is on new capabilities.

<u>Concerns</u>

Some important issues may get lost. For example, human factors are not explicit. It is also important that impact assessment be done faster and cheaper as data is being processed faster. There is also some concern that the "new frontier" is lost.

4.6. What is the Opportunity Now? (Why Now?)

These concepts developed in the previous section are driven by current opportunities. These opportunities can be classified as technical, social science-related, or interdisciplinary as described in the following subsections.

4.6.1. Technology

- Automation and real time information
- Low cost computing integrated with the vehicle and the human operating the vehicle to provide new ways of sensing and controlling coupled to automatic transportation systems
- High performance computing, networking, and software development
- Pervasive sensing, which is available now if we want to, such as network sensors
- Ubiquitous computing
- Wireless communication and Internet technologies providing access to traffic and transportation data in a way and volume never before possible; real time transportation data information with mobility; availability of simultaneous mobile communication, real time data collection, and widespread distribution

4.6.2. Social Sciences

- Data help make choices before the driver gets into the vehicle.
- Faster, more efficient deployment must use the private sector.
- Market for new technology has to be from the bottom up to cut down on production costs.
- Because our institutions are incapable of keeping up with technology, we need new paradigms. We need to face the problems, understand them, come up with theories, and test them.
- Public must be made open and willing to make use of information and alter established patterns of transportation.
- To move beyond the interstate and urban transportation system, we must reinvent surface transportation planning, operation and management. We understand the efficiencies and opportunities of deregulation.
- There is a sense of frustration among users of the systems.

4.6.3. Multidisciplinary

- A lot of groundwork is in place through investments of last decade.
- There is an increased willingness to pay for safety and we have realized that we lack the right tools to anticipate consequences.
- The increased power of computation and wireless communication must be used to increase connectivity, comfort, and safety.
- We must model, understand and test the system under new scenarios to improve systems performance.
- Technologies will make competing modes more competitive.
- The information will provide a means of determining where people and vehicles are at all times. How will transportation address this?
- The path to full deployment of automation in a distributed system makes safety extremely important.
- Users should have access to all kinds of information in real time, including safety, environmental, and travel information.
- We are about to the limits of what human drivers can deal with without changing. Fundamentally, they must give up control or be able to take in more information.

4.7. Priorities for a 10-Year Basic Research Program

Participants were asked to identify priority areas in terms of "What is it most important to do?" Responses included:

4.7.1. Technology

- Co-design of sensors, vehicles and infrastructure (sensor friendly design)
- Collision avoidance (We already have the technology to prevent most collisions.)
- Connection between the vehicle and the roadway
- Construct databases and information architecture
- Developing a vision of information driven mobility; model, analyze, and test both coordinated and autonomous movement with real-time data distribution
- What does everything being interconnected through an IP address do to transportation, control, information, and sensing?
- Excellent and well-constructed databases obtained with privacy
- Experimental monitoring and verification of new technology
- Information delivery to traveler
- Integration of transportation and information networks
- Look at technologies like ground control and evaluate what they can offer
- Mining of new communication, sensing, and control technologies
- Moving goods by ground/air/pipeline (down or up) in a way that is more incremental
- Simulation and modeling techniques to evaluate safety impacts and implications
- Use the data that is out there to evaluate transportation systems and create user-friendly tools for modeling and evaluation

4.7.2. Social Sciences

- Addressing aging of the driving community
- Better life cycle perspective on environment and energy use in terms of vehicle and transport system
- Defining the role of the public and private sector
- Develop and test theories for new institutions
- Analyze and address injury severity and prevention of crashes holistically
- More impact assessment modeling including changes in behavior
- Trip suppression techniques recognizing cultural values of sectors of society
- Ways and procedures to take new forms, volumes, and rates of data to support effective decision making for planning and operations
- What thresholds on information can be processed in either system or individuals?

4.7.3. Multidisciplinary

- Incident-induced congestion is a high impact area for research and safety
- Marrying the individual and the vehicle using the technology available
- New methods for modeling and simulation of transport networks
- Simulation and modeling of the ubiquitous systems in transportation

- Top to bottom analysis, monitoring, control, etc., of transportation systems by transportation agencies; large-scale coordination, analysis and verification of centralized and decentralized feedback control systems for transportation
- Turning data into knowledge and information on which the user can make knowledgeable decisions
- Ways of perfecting the existing paradigm of transportation: how people move

4.8. Workshop Summary and Conclusions

The workshop brought together a diverse group of researchers from both technical areas and social sciences. While most of the concepts and ideas brought forward at the workshop are not new, they do require significant basic research to address the technical, and social issues that serve as barriers to the development of concepts and ultimately implementation. The concepts and ideas serve as a foundation for a research program that addresses issues of national important and will provide a structure and support mechanism for additional new and innovative areas of research.

Policy analysis, decision-making, and priority setting were considered important by both technologists and social scientists. For example, the Japanese goals of zero accidents, zero congestion, and zero environmental impact by 2020 (Hagino, 2000) were considered somewhat unrealistic, but important to define. Technologists and social scientists agreed that there is a need for innovative basic research for surface transportation.

5. Proposed 10-Year Program

An innovative basic research program needs an innovative non-technology companion program. Several non-technology issues that are formidable today and likely to be more daunting in the future will be serious obstacles to using new technologies.

State and local officials are approaching gridlock in making decisions about how to deal with passenger and freight needs. The proliferation of interstate, state, regional, county, and city government entities has contributed substantially to this problem. For example, nearly 100 separate jurisdictions have a role deciding how incidents on a major St. Louis expressway will be managed and whether and/or how IT will be used in incident management.

State and local transportation officials also are facing another type of decision gridlock - increasingly complex transportation problems - with little to guide them about the impacts of alternative technologies and other interventions.

Similarly, research about how passenger and freight users experience the transportation system's performance is very limited. Without better system-wide, cross-modal research that helps to explain traveler/vehicle/infrastructure/policy relationships, it is difficult for decision-makers to determine how innovative technologies are best used.

To address these issues, we believe that a clearly articulated vision of the surface transportation system of the future is required. This vision is described in the following sections.

5.1. The Vision

The "vision," to help launch this program that emerged from the October 2000 workshop is summarized as follows.

> We will have a customer responsive, managed, safe, efficient, and integrated transportation system for the movement of people, services, and goods. Advances in information technology will enable the system to be both flexible and optimal through productive operations and control. Communications technologies and advanced traveler information systems will provide optimal information and knowledge to the customer to support equity, mobility, and accessibility. This seamless transportation system will preserve privacy and individual rights, provide choices, and be environmentally sustainable.

When we achieve that vision, our goal is to provide all customers with the following:

> No matter who or where you are, you will have in your hand the knowledge and ability to choose, make, and pay for a safe, efficient, cost-effective trip or multiple trip segments for your, your family or your goods to any location in the world. This will be the case whether the trip is to or

from home or work; to or from any recreation or business location; or for any other purpose.

5.2. Areas

The areas of research follow the technical and non-technical themes identified at the workshop.

Technical themes are broadly defined as technology to support safer, more efficient and less damaging to the environment surface transportation. However the workshop did identify three important areas:

- Technology that supports integrated systems operation
- Systems integration, to build on ongoing research on the supply side and integrate the demand side to produce transportation services for both people and goods that are seamless to the customer
- Data and analysis tools, to develop the knowledge that allows us to achieve our vision

Non-technical themes include issues related to safety, energy, and the environment to capitalize on past and ongoing research in vehicle technology to produce systems with zero fatalities and zero emissions by 2025.

- Institutional issues
- Equity and cultural values
- Impact assessment

5.3. Essential Principles to Achieve Our Goals

As the research proposals are being developed and evaluated, it is essential that the following principles be maintained. Future transportation systems must:

1. Be customer driven, for people, goods, and services and, consequently, be market-driven and performance-based
2. Preserve individual rights, preserve privacy, and maintain freedom of choice
3. Maintain community rights and ensure that government/institutional constraints are minimized
4. Provide mobility and accessibility and provide equitable benefits among and between citizens of varying social, cultural, and economic strata
5. Establish ground control operation and management capabilities
6. Be technology friendly
7. Give full consideration of social, environmental, economic impacts

5.4. Research Options to Achieve the Vision

In order to achieve this approach, there are three options:

The easy evolutionary option assumes that the current surface transportation system remains in place. The outcomes are more certain and less risky as we seek to fix, polish, or add on to the current way of doing business.

The more difficult evolutionary option builds dramatically on disparate technologies, bringing together new or emerging “things” and events. The outcomes from

the research may not necessarily be anticipated. It is more risky, and the products are less well defined.

The revolutionary approach is very risky. It involves exploring how things might be, and it will ultimately involve tearing up what we have and redoing everything. In the past revolutionary change in transportation systems has been associated with major technological breakthroughs. Garrison (1999) describes the architects of such breakthroughs as "blind giants" having tremendous power but little knowledge of where they are headed. Other revolutionary research projects have focused on exploration of promising areas. For example, understanding DNA and human genome research are high-risk – high-payoff research areas in which it is clear that research is required for any possible dramatic breakthrough to occur.

Our goal for the 10-year basic research program for surface transportation is to develop a revolutionary approach with a little bit of "more difficult evolution."

5.5. How Will the Research Help Achieve the Vision?

5.5.1. Option One—Easy Evolution

This involves advancing JPO and current transportation research from other sources:

- Telecommunications in transport
- Intelligent vehicle initiative
- Intelligent infrastructure research
- Use existing JPO/ITS/DOT community building blocks: systems, supply side/infrastructure advances, vehicle advances, information technology, and social sciences and non-transport influences.

5.5.2. Option Two—More Difficult Evolution

This approach would explore in more detail how other disciplines (technology and non-technology based) are conducting research that will affect transportation. It could also involve research to fill in missing gaps, such as customer orientation, market forces providing customer needs, regulation/deregulation as an alternative, topics from the workshop themes, based upon likely, possible unexpected events, and overcome political, institutional, technical obstacles.

5.5.3. Option Three—Revolutionary

This involves unknown factors and the need to explore ill-defined problem areas. One approach is to put together the right people, events, and things that may already exist in a disorganized, disparate, or disaggregated way.

5.6. Obstacles/Constraints/Issues We Must Overcome

Innovative changes to the surface transportation must overcome three significant obstacles to change. First, institutional complexity, and political driving forces influence changes in the surface transportation system. Second, there is an absence in the transportation research community of a different "community" of researches from other supporting disciplines that have research relevant to transportation. Third, income disparity among customers and the technology/digital divide among customers must be

recognized and addressed. Other obstacles, constraints, and issues will be identified as the program is developed.

5.7. Risks

Risks in developing a 10-year research program relate to the program objectives, uncertainties that cannot be controlled and secondary benefits.

5.7.1. Risks Related to Program Objectives

Setting objectives related to safety and efficiency can be challenging. For example, the elimination of fatalities and injuries is probably not realistic, but saving time, lives, and monetary resources will increase the quality of life. An undesirable outcome would be to have accident rates increase and more people die. Similarly, innovations should avoid increased damage to environment and dependency on fossil fuels. Other objectives include implementation strategies that maximize the use of the existing infrastructure, making travel more predicable and reliable and developing transportation strategies that are robust and quickly adaptable.

5.7.2. Uncertainties

There are uncertainties in both the inputs to the research, such as new technology developed for other applications and the products. For example, information architectures, sensors and control systems could be configured in a way not favorable to mobility. Similarly, the outcomes of the research may have unanticipated consequences. For example, (1) the system could be extremely vulnerable to failures; (2) all big corporations want to be in the US; and (3) the US economy becomes less economically competitive.

5.7.3. Secondary Benefits of Such a Program

There are also some secondary benefits from the types of research products envisioned for this program.

In terms of personal travel:

- No one will ever be lost again
- We will be able to drive until the day we die.
- Travelers will have enriching, enjoyable, and productive experiences while in transit, with improved comfort and convenience.
- There will be better connectivity for pedestrian, bike, and scooter mode.

In terms of safety:

- Vehicles will know the state of the road and nearby objects.

In terms of system-wide impacts:

- Real data will be available for managing user expectations.
- There will be economic advantages from freight and personal transportation.
- Improved mobility and smart urban development will occur.
- The paradigm of travel will change.
- Competitive and sustainable growth are possible.
- Robustness and adaptability enable us to evaluate alternatives.
- There will be a reduction in housing prices.
- Better ideas of pricing and readiness for deregulation are possible.

- Transportation systems will respond to extreme events and minimize impacts.
- Cities will become more livable.
- The negative view of public transportation will be destigmatized.
- Well-educated transportation professional will be available.
- Better land use will occur.

6. Suggested First Year Research Initiative

Based on the discussion at the workshop, we present a suggested first year NSF research initiative. The proposed first year initiative for the research program will seek proposals for exploratory projects. These projects will build a foundation for future projects and research and may be referred to as foundational projects. Given the funding constraints, the expectation is to fund approximately ten small projects of one-year duration or a smaller number of projects with multiple investigators. Industry/ agency participation is encouraged.

6.1. Relating the First Year Projects to the Overall Program

These first-year projects could help set the stage for understanding the research agenda for the next 10 years. Focus should be on the merits of the individual projects rather than parameters that define the number of investigators, the budget (within reason), or the involvement of industries or agencies. Care must be exercised to ensure that projects are not fundable under existing grants for unsolicited single investigator projects.

6.2. Suggested Documentation to Support Initiative

The following material derived from the workshop provide an introduction and program description to support the research initiative. It is expected that the focus and wording will change as NSF and DOT define how they want to approach this program.

I. INTRODUCTION

Concerns related to transportation congestion, safety, and the use of energy and the degradation of the environment point to the need for a radically different approach to surface transportation and provide the motivation needed for a basic research program. At the same time, advances in information technology (IT), changes in the regulatory climate (including deregulation), a dynamic economy, and an increasing awareness of the role of social and cultural values on transportation decisions underscore the need for a multidisciplinary approach.

USDOT and NSF are committed to a basic research agenda that will integrate new technology into the supply and demand for surface transportation systems by the year 2025. This research agenda will ensure that:

- The use of IT to make our surface transportation system safer, more reliable, and more productive.
- The impact on our human and natural systems of the use of IT to sustain and revitalize our transportation system will be understood well enough so that we can capitalize upon the opportunities it presents to improve performance, as well as to identify and mitigate any unwanted consequences.
- Knowledge will be made available that will support "managing" both the complexity and the vulnerability of surface transportation systems.

The objective of this research initiative is to foster research on the technologies needed to ensure a customer focused, safe, productive surface transportation system and research on the non-technical issues that need to be addressed to ensure the development and implementation of these technologies. Proposals are solicited in such technical areas as:

- Technology that supports systems operations and permits both centralized and decentralized management and control.
- Systems integration to build on ongoing research on the supply side and integrate the demand side to produce transportation services for both people and goods that are responsive and seamless to the customer.
- Data and analysis tools and methods to develop the knowledge needed for customers and managers of surface transportation systems to achieve an optimal transportation system.

Proposals may also address and must recognize such non-technical issues related to safety, energy and the environment and the related areas as:

- Institutional issues, including market integration and deregulation
- Equity and cultural values
- Impact assessment

Examples of technical areas include:

1. Technology that supports integrated systems operation
   New vehicle navigation system and computer-human interfaces
   Safe systems and vehicles to substantially reduce crashes
   Development of virtual reality systems (e.g., for training, evaluation, analysis and operation)
   The impacts of wireless communications on short and long-haul travel
2. Systems integration
   Ground control systems with open control structure.
   Travel management/optimization (software, hardware, and modeling)
   Unexpected event management
   Fusion of mobile communication and road infrastructure
   Transition to controlled systems
   New technologies to move goods in congested areas
3. Data and analysis tools
   Better measurement/metrics/standardization
   Data fusion and management
   Need for better data presentation, distribution, analysis and processing
   Advanced modeling and simulation of unique systems

Examples of non-technical areas include:

1. Institutional issues

Information ownership
Governance of technology infrastructure
Addressing privacy (transportation related) computer science, social science (perceptions)

Develop and test theories for new institutions

2. Equity and cultural values

Assessment of impact of transport technology on social equity
Relationship between cultural values and social equity

3. Impact assessments and analysis

E-commerce implications
Private sector role
Deregulation of transit and highway systems
Alternative environmental scenarios
Alternative economic scenarios

Researchers are encouraged to visit the ENG web-site (www.eng.nsf.gov/programs/XXX) for information related to this initiative.

II. PROGRAM DESCRIPTION

BACKGROUND

While US DOT has invested heavily in applied research and has considerable success in improving safety, reducing congestion, and improving operations, it is widely believed that incremental improvements are not adequate to address the surface transportation needs of the future. NSF and US DOT supported a workshop to explore the research needs related to basic research, which was held at the University of Illinois at Chicago in October 2000. The report from the workshop may be found at XXXX.

The "vision," to help launch this program that emerged from the October 2000 workshop is summarized as follows.

> We will have a customer responsive, managed, safe, efficient, and integrated transportation system for the movement of people, services, and goods. Advances in information technology will enable the system to be both flexible and optimal through productive operations and control. Communications technologies and advanced traveler information systems will provide optimal information and knowledge to the customer to support equity, mobility, and accessibility. This seamless transportation system will preserve privacy and individual rights, provide choices, and be environmentally sustainable.

When we achieve that vision, our goal is to provide all customers with the following:

> No matter who or where they are, all customers will have in their hand the knowledge and ability to choose, make, and pay for a safe, efficient, cost-effective trip or multiple trip segments for

themselves, their families or their goods to any location in the world. This will be true whether the trip is to or from home or work, to or from any recreation or business location, or for any other purpose.

While these concepts are not new, they have not been articulated nor have research projects specifically addressed this vision. This research initiative seeks such proposals.

PROGRAM DESCRIPTION

One-year projects addressing the themes identified above in the context of this vision are invited. The projects may be single-investigator projects but must recognize the inherent multidisciplinary nature of the issues being addressed. The projects should also be foundational in nature in terms of providing a base for future applied research. While the one-year projects cannot expect to include industry and government participation, the future roles for partnerships should be addressed in the research. Approximately $1 million in funding is available. NSF / US DOT expect to make between five and ten awards. The number of awards will be subject to the availability of funds and the quality of the proposals. Awards are expected to be made in September 2001.

7. Recommendations

The payoff from a basic program in research will be robust and quickly adaptable transportation infrastructure that can react to changing situations including emergencies and changes in the market. It will be safer, more fuel efficient, less congested, and more efficient than today's surface transportation systems. Achieving these results depends on a sustained commitment to basic research that addresses both the technical and non-technical issues related to surface transportation.

To do this a basic research culture must be developed. This culture must include the continued involvement of disciplines not traditionally involved in transportation and continued dialog between NSF and DOT. While the Chicago workshop provides some initial ideas, the concept needs to be expanded. The ideas must be embraced by the state Department s of Transportation in principle. Partnerships among academia, government and industry must develop. Strategies to move ideas and concepts from basic research to workable solutions must be explored. The proposed initiative is a first step but is the beginning of new approach to transportation research.

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Appendix A. Workshop Participants

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Appendix B. Workshop Agenda

The purpose of this workshop is to develop a proposed basic research program for surface transportation systems that integrate advanced information and control technologies, not traditionally included in surface transportation research.

More specifically, the desired outcomes of the workshop are:

- A report documenting a proposed 10-year research program and the rationale behind it
- Elements of a draft research initiative for the first year of a basic research program in surface transportation sponsored by the National Science Foundation and the US Department of Transportation

Sunday, October 15

Time	Topic
5:00	Registration: Rathskellar, Basement, Student Residence and Common, University of Illinois at Chicago
6:30	Opening reception
7:00	Dinner
8:00	Dinner speaker: Marc Chason, Motorola, Inc.
9:00	Close for the evening – Transportation provided to hotel

Monday, October 16

Time	Topic
7:45	Hotel van available for transportation to UIC
8:00	Continental breakfast, Room 509/510, Chicago Circle Center, University of Illinois at Chicago
8:30	Opening session Welcome: Dr. Sue McNeil, director, Urban Transportation Center; Dr. David Perry, interim dean College of Urban Planning and Public Affairs; and Dr. Lawrence Kennedy, dean College of Engineering, University of Illinois at Chicago Introductions by participants Overview of the workshop objectives, agenda and operating principles
9:15	Discussion of National Science Foundation and US Department of Transportation perspectives on this project Remarks, Jeff Paniati, program manager, Intelligent Transportation Systems, US Department of Transportation, and Priscilla Nelson, director, Division of Civil and Mechanical Systems, National Science Foundation Discussion
9:45	Break

10:00 Trends and indicators of change in technology and its impact on society which might influence surface transportation in the next 25 years

1. Topics and areas in technology and its impact on society that will influence surface transportation in the next 25 years, trends, and indicators of change
    a. Review summary of input submitted in advance by participants
    b. Individually list other topics, trends, and indicators of change
        - Post all of them
        - Review, discuss, and group in categories the trends and indicators of change identified
2. The influence of these trends and indicators of change on surface transportation in terms of: (a) supply, (b) demand and (c) new ways of thinking about transportation
    a. Work in small groups by common perspective
    b. Review summary of input submitted in advance by participants
    c. Add other possible influences
    d. Identify the 2-4 most critical influences on each of supply, demand and new ways of thinking about transportation

12:30 Lunch on site

1:00 Key elements of a basic research program for surface transportation

1. Report out the small group work
2. Discussion based on this assessment of how technology might impact surface transportation in the next 25 years, what information and knowledge will need to be available in the next 10 years
3. In small, cross-disciplinary groups discuss:
    a. Which of this information and knowledge is likely to be available given existing basic research programs?
    b. Where do you see three to five major gaps in the information and knowledge that is likely to be available given existing basic research programs?
    c. What might be the key elements of the NSF/USDOT-sponsored basic research program?
4. Report out and discuss in the full group
5. End with check on degree of agreement on the key elements of a 10-year technology-oriented basic research program for surface transportation systems and the rationale for it

5:00 Close for the day, transportation provided to hotel

6:00 Optional dinner off site in Greektown, transportation provided to hotel

Evening Workshop organizers and facilitator prepare summary of day's conclusions for discussion next morning

Tuesday, October 17

Time	Topic
7:45	Hotel van available for transportation to UIC
8:00	Continental breakfast
8:30	Proposed research program and rationale Presentation by Sue McNeil, Al Wallace, and Tom Humphrey on the paper drafted the previous night Focus on several questions that need further input or feedback
9:30	Research directions and priorities to form the basis for a draft research initiative and report 1. Discussion on possible elements of a 10-year program of basic research for surface transportation systems to clarify where there is: a. Agreement among all participants b. Wide divergence in views among participants c. Lack of clarity about extent of agreement among participants that might require further exploration **2.** Assessment of the degree of risk involved in each possible element of the 10-year program of basic research for surface transportation systems
11:30	Closing session Remarks by Priscilla Nelson and Jeff Paniati Check with each participant Thanks from Sue McNeil
Noon	End of workshop (box lunches provided)

Appendix C. Workshop Participant Input

Participants were asked to answer several questions prior to the workshop. This appendix documents the responses. Additional responses from the workshop were also documented.

QUESTION 1.

From the perspective of your discipline and profession, what are the topics and areas in technology and its impact on society that might influence surface transportation in the next 25 years?

We have grouped the responses to the question into four areas: (1) market forces; (2) government, regulation, interventions, and policies; (3) technologies related to a specific car; and (4) technologies related to the system. We then grouped the market forces into external factors, trends, and changes in approaches.

Market Forces (People and Business)

External forces

1. Changes in business practices and work systems (how work is organized, e.g., global, 24-hour design teams and the enabling technology; how work is shared between suppliers and OEMs)
2. E-business integration of business-to-business and business-to-consumer
3. Environmental science and technology: biology, chemistry, ecosystems, global climate change, impacts of human activities on the environment
4. Freight-related issues: growing economy, increased trade with Latin America, e-commerce, just-in-time delivery
5. Synergies and interdependence of global operations
6. Change in housing demand-dense communities with Starbucks on every corner?
7. Technology is not destiny; society shapes and conditions adoption
8. Breakdown of command and control environmental regulation
9. Shifting locus of demand for transport; is infrastructure in the right place or is the location obsolescent?
10. E-commerce to reduce vehicle miles relative to economic activity
11. Ability to know real time where everyone is and what they are doing
12. Social issues: pricing of transportation via technology, haves vs. have nots, privacy
13. Sprawl? More? Land use?
14. People living where they want to
15. Computer simulation becoming more (controllable) accurate than reality; that is, reality will come to you, rather than you travel to get to it
16. Stability of constitutional organizations (states, counties, etc.), which are unlikely to change much
17. Air quality, land use constraints, fossil fuel depletion/economics may move us away from individual transport

Trends

1. Attitudes toward institutions, public and private, and expectations of how they should perform and what roles they should play
2. Attitude toward the environment (more concern, less concern?)
3. Attitudes toward work, leisure, and family (especially regarding time spent on each)
4. Cultural integration and expectations
5. Distance learning
6. Infotainment, customization, ease of use, e.g., digital telephone calls
7. Mature and emerging market dynamics
8. New customer expectations
9. Organizational and workforce evolution
10. Role of marketing and media in the formation of public opinion
11. Safety, security, and privacy
12. Shifts in demographics (older population, more immigrants, baby boomlet)
13. Demographic shifts (older, more immigrants, baby boomlet, the ratio of drivers to cars will be approximately one, women's labor force participation)
14. No need to drive; driving ranges in Nevada for fun!
15. Robotics: will robots enable tele-physical work as an analog to tele-information work, e.g., praxitele "station car"?
16. Increased dependence on software
17. Reliability and safety evaluation
18. Fault tolerant computing (especially for safety critical systems)
19. People travel for pleasure, not work as work will be done in the virtual work/office
20. Will robots enable tele-fun as an analog to tele-work
21. Infrastructure interdependencies, e.g., decoupling where one lives from where one works places stresses on other types of infrastructure such as water, waste water, and garbage collection
22. Trends such as dematerialization, and the rise of the service sector
23. Insufficient research funding for ITS and IT
24. State DOTs have difficulties with IT
25. Current ITS focus may do little to solve problems
26. Shift in where and how people work will increase goods movement demand on system
27. Trends: decentralization of decision-making/consumption
28. Energy use
29. Developing a research program that is not vision driven or goal driven
30. Ritcher people choose to travel more, not less, worldwide
31. Operation and maintenance does not receive as much attention as building new components

Changes in approaches

1. Interactive collaborative work and play environments.
2. Lean thinking, quality engineering, concurrent design, 6-sigma
3. Shared risk

4. Ultra-efficient bus/rail transportation coordinated with shared vehicles at origin/destination
5. Use of (real-time) information to reduce uncertainty will increase productivity, and reduce waste
6. Policies derived from analyses of constraints and existing infrastructure
7. "Sensor-friendly" infrastructure, co-design of environment and vehicle-based sensors
8. Benefit evaluation used to set funding priorities
9. Paying full costs of transportation
10. Demand analysis influencing market research
11. Converging infrastructure management model
12. How to model large-scale efforts of values, population trends, etc.
13. How we teach/understand ITS beyond technical details
14. Integration of information and combination of different streams of data
15. How soon? Virtual office in 2 years, 5 years, or 10 years. Robotic labor in 5 years, 10 years or 15 years. Automatic distribution (goods, groceries)
16. Facilitating societal choices between competing, incompatible objectives, e.g., no congestion vs. preserving open space, "we want it all"
17. Business plan to drive technology
18. Virtual integration versus vertical integration
19. Meter everything with pricing

Government, regulation, intervention or policy

1. Widespread use of automated toll collection, bus/train tickets, etc. (Short term)
2. Developing statewide networks that use a combination of private sector and public agency infrastructure
3. Changes in international trade policies and governmental regulations

Technologies related to a specific car

1. Advances in key technologies such as energy systems (alternative fuels, batteries, fuel cells), high tech and engineered materials, robotics, electronics, micro and nano technology, bio systems, coupled with improved human computer interfaces and a better understanding of the role of cognitive science/psychology of human behavior ("human factors")
2. Smart-sensor technology
3. Smart vehicle diagnostics
4. Sensor technology: geographical, weather, drivability
5. Safety-enhanced devices and control technology
6. Driver safety assistance and collision warning

Technologies related to the system.

1. Advances in systems engineering, simulation techniques, and information technology, including wireless communication and control, artificial intelligence and distributed database management enable system level enhancements.
2. Widespread end user access to real-time information regarding the state of the highway traffic, bus and train schedules, etc. thought the Internet (This trend has already started in California through PeMS.) (short term)
3. Widespread coordinated traffic control through ramp/metering, real-time driver trip assistance, and driving instructions (medium term)
4. Ultra-efficient bus/rail transportation (online user ticket reservation) coordinated with shared vehicles at origin/destination (medium term)
5. Smart roads
6. Real-time roadside vehicle traffic data collection and control: vehicle velocity, origin/destination, vehicle performance (e.g., braking/acceleration capability, etc.) (medium term)
7. Real-time roadside coordination of intelligent cruise control (medium term)
8. On-line highway lane reconfiguration (medium term)
9. On-line highway entrance reservation to avoid long entrance cues (medium term)
10. Interactive collaborative learning environments for engineering education
11. Intelligent carpooling trough the Internet and mobile telecommunication (short term)
12. Intelligent bus priority urban traffic control (medium term)
13. Integrated coordinated control of car/rail/bus traffic (medium term)
14. Automated vehicle control and automated highway systems will begin to be deployed in several urban sectors (long term)
15. Automated traffic lanes for trucks and buses (medium term)

QUESTION 2.

What are five to seven of the major trends you see in technology and its impact on society?

We have organized these responses in terms of their relationship to personal travel, vehicles, infrastructure, societal changes, and organizational or general technology.

Personal Travel

1. As this technology becomes ubiquitous, surface travel may become far less necessary because work, study, and entertainment will likely be more home and immediate community centered. People will travel for the pleasure of travel, not for work.
2. Every person will have an integrated personal communication device this will also serve as an electronic wallet.

Vehicles

1. Car user interfaces will not change much, but there will be significant computing/communication infrastructure put into cars.
2. Fuel cells – hybrid vehicles
3. Real time control systems
4. Vehicle operator performance analysis devices and evaluation
5. Energy efficient/ low pollution transportation systems and housing
6. The car is becoming a mobile platform for multimedia (AMI-C), wireless communications, and computing. Once the linkage between the vehicle and the roadside really takes place (e.g., DSRC), the driver will be more of a supervisor and less of an operator.

Infrastructure

1. Bridges/highways will be heavily instrumented

Societal

1. There will be a dire shortage of labor skilled in technology that will be willing to work in the mundane maintenance jobs of state agencies
2. E-commerce
3. Shift the work force from moving physical items to manipulating data
4. Need for bridging the digital divide
5. Universal design, including accommodation of individuals with disabilities
6. Promoting globalization via instant communication
7. Improvements in health-care by advances in biotechnology

Organizational

1. This will lead to an even more dramatic shift to outsourcing maintenance
2. National transportation system database
3. Large scale coordinated control of complex systems
4. The use of the vast resource of small airports will accelerate, and there will be less hub traffic and air traffic control disruption. The breakthroughs that will be required are significant cost reduction for small jet aircraft construction and operation and the development of a significantly more sophisticated air traffic control system that can handle far more complexity than the current ATC system can handle.

Technology

1. Computer networking
2. Wireless communication and networks

3. Video conferencing and streaming, workplace anywhere
4. Microelectronics technology, microelectromechanical systems, microprocessors
5. Modeling, simulation, and control; parallel computing, hierarchical and distributed control
6. Pervasiveness of information and communication technologies, notably the World Wide Web
7. Increases in computing power, information storage capacity, and networking
8. Universal Internet usage.
9. Universal mobile telecommunication.
10. Universal online health monitoring
11. Widespread use of automated/intelligent machines.
12. Real time traffic, construction, and weather data will be used to improve fleet management (taxis, trucks), allowing, for example, re-routing in-route for JIT pick up and delivery
13. Cell phones will be used as traffic probes
14. The enablers of the above are increased Internet and wireless communications bandwidth, concomitant software that will rely on more powerful computers than are now available, and systems interoperability brought on by common architectures and standards.

QUESTION 3.

What are five to seven possible indicators of change, or major discontinuities that might occur in technology and its impact on society?

We organized these as quantifiable, qualitative, or reflective an area of change.

Reflecting an area of change

1. Biology and IT joined to form biological computers (which I understand would increase speed significantly?)
2. Biology and fuel, where some work is already going on using biomass for fuel
3. Artificial intelligence and simulation, where some efforts have already gone on but significantly better simulation of some human activities (such as driving) could be achieved
4. Materials science, IT, and AI to produce “smart materials” that not only tell you when they should be maintained/repaired, but also contribute data to self-modifying performance models (for asset management)
5. IT and cognitive psychology to understand better what information human operators need and how they react to information and stimuli presented to them
6. Systems engineering and environmental sciences along with tradition facility planning, design, construction, maintenance, and operations, to develop a realistic, comprehensive systems model or paradigm of transportation that would revolutionize the way that transportation service is provided
7. When visualization approaches visual acuity (displays with 5000x5000 resolution, 6 bits of color, brightness of daylight), virtual reality will become more pleasing

than much of physical reality, so reality will come to you, rather than travel to get to it

8. When computer simulation becomes more accurate than reality, will reality also come to you, rather you than travel to get to it
9. Increasing amounts of our energy will go into authentication/archiving of information and protection from viruses, denial of service, etc.
10. Digital divide (educationally disadvantaged individuals falling farther behind with respect to information technologies)
11. New ways for production, marketing, and distribution of consumer goods

Quantifiable

1. Technology not only allows us to do more and do it faster; it virtually requires us to do so. As people learn the impact this is having on health and relationships, they may back off from the relentless trend toward more and faster.
2. If there is any significant environmental or fuel crisis, there may be a big change in behaviors related to vehicle size, fuel consumption, use of public transit, etc. On the other hand, if things continue as they have, there may arise a public demand for greater accountability from environmental concerns where they impede development. Or people may just continue to want everything.
3. Labor shortages at technician/laborer level
4. Government agencies will have to deal with difficult privacy/legal issues when people subpoena data for lawsuits
5. Additional taxes will have to be imposed to pay for improved technologies.
6. Reduction in accidents
7. Vehicle operator performance analysis; monitors for fatigue, DWI, DWIA, attentiveness
8. Increased scientific and technological literacy in the general population (hasn't happened yet)
9. Improved ability to communicate at long distances (reducing need for travel)
10. Increased inclusion of individuals with disabilities in the workplace and in society in general
11. Life extension from medical biotechnology (desirable for individuals, but constraint resources of society)

Qualitative

1. Technology may take too much control. People may demand some back. We may discover that one of the reasons people like to drive is precisely to feel “in control.” This would have implications for automated systems in vehicles.
2. User interfaces/human factors/ safety; driving becoming a multitasking job
3. People are going to feel like “big brother” is watching them.
4. Efficient transportation and flow control systems
5. Efficient distribution systems
6. Transport information system security
7. Real time traffic flow information systems on wireless networks

8. When networking becomes very cheap, the need to travel will diminish.
9. When networking becomes faster than computers' disk drives, computers will get smaller and ubiquitous.
10. Greatly improved tracking of vehicles will optimize existing road usage.

Question 4.

How might these trends and indicator of change in technology and its impact on society influence surface transportation? Please identify three or four major implications in terms of each of the following:

- *Supply*
- *Demand*
- *New ways of thinking about transportation*

Supply

1. The trend toward doing things faster puts tremendous pressure on public agencies which are generally not able to implement new technologies quickly and which must balance multiple objectives (including mobility, environmental regulations, politics, fiscal constraints, human resource constraints) in the face of increasing performance demands from the public and from elected and appointed officials.
2. "Wanting everything" makes simple, straightforward performance measures very difficult.
3. Demand for more data to run new technologies is a real barrier for many agencies; data collection and management (especially if the data must be periodically or continually updated) is very expensive and human resource intensive.
4. The official line seems to be that we are not going to "build our way out of congestion, we are going to manage what we have better." This policy is destined to fail and create a shortage of surface transportation in some areas.
5. Optimal supply infrastructure, distributed control systems, flow management systems, stochastic process modeling
6. Travel will be to provide physical services and for leisure.
7. A better educated population will be more able to provide the workforce to develop and advance transportation technologies.
8. Improved robotics and other automation technologies should improve production efficiency of vehicle manufacturing.
9. New transportation modalities should emerge, in view of new design and manufacturing capabilities.

Demand

1. Communications technologies (such as tele- and video-conferencing) are less substitutes for travel as they are ways of increasing human interaction. My experience is that these technologies allow people to be present at meetings they would otherwise have missed and allow additional meetings to take place that otherwise would not have occurred. People may become more discerning about

when face-to-face meeting is necessary and when it is not. This may even lead to a greater realization of the importance of face-to-face meetings in certain circumstances. Even telecommuting may only displace travel from work commute to other purposes to satisfy the need for interaction and even for movement. I think what this means for transportation is that we will no longer be able to rely on traditional demand trends (morning and evening rush, weekend beach and mountain traffic). Demand may even out naturally as people find the optimal routes and times (using other communication technologies) to fit their flexible schedules. But demand patterns may simply be more erratic. Or there will be such an increase across the board that congestion will be a 24-7 problem (as is nearly the case in some major metropolitan areas). Managing the operation of facilities with erratic or constantly near or over capacity flows will require much better knowledge of and control over the system. Information and communication technologies could help here, as could better simulation and prediction models—using artificial intelligence techniques such as self-modifying models that re-adjust themselves as real-time data is collected and analyzed.

2. The changing demographics (older drivers, more immigrants, and the baby boomlet reaching driving age) will have impacts on demand and on safety that will need to be addressed. These impacts may include slower reaction times for much older drivers, language issues and desire to quickly own a car for immigrants, and a learning curve for the new younger drivers.
3. A growing economy, including increasing trade with Latin America, together with trends to "just-in-time" delivery and the potential effects of e-commerce will required increased capacity to move freight in a very time-reliable manner.
4. I personally do not think telecommunication will reduce demand significantly.
5. Time critical delivery, price-sensitivity, service differentiation, customer diversity, demand modeling
6. Demand will be lessened unless new travel concepts are developed.
7. If we can bridge the digital divide, then families in rural and inner city areas will have greater need for personal transportation and delivery of goods.
8. Already we see trends for decentralization in delivery of goods to homes and businesses, instead of at wholesale and retail outlets.
9. If transportation costs - including vehicle purchase and maintenance, and fuel - can be made more economical, this will increase demand for transportation.

New ways of thinking about transportation

1. The surface transportation system needs to be thought of more as an ongoing process than as a collection of products. Information must be seen as a tool for operating the system, not just as static data for reporting on it. At the same time, the system has to be seen as including the people who use it, not just containing them. But the change of thinking is not relegated only to transportation professionals. At some level, the public and its leaders need to see transportation as something worth investing the resources it really takes to operate the system this way and to see themselves as part of the system, not just "users" of it with no thought of how they contribute to the situation they are in. As transportation

professionals, we may need to recognize that people do not travel only to get somewhere; travel is not merely a means to an end that can be achieved by other means (such as communication). This is often true. But people also travel as an end in itself; we like to move and to see new places. Where does this need fit into how we provide transportation services?

2. Perhaps telecommuting will be considered a transportation mode?
3. Competition for fiber optic routes along interstate routes will create incredible demands on some state DOTs.
4. Public bike paths will be under pressure to allow fiber optic lines in their right of way.
5. Some railroads will derive more revenue from fiber right-of-way leases than from hauling freight.
6. New concepts in control of transportation systems and networks; new concepts in distribution systems; new congestion management approaches
7. Virtual travel is the obvious concept.
8. We need new ways of moving people between home and workplace to avoid roadway congestion and other inefficiencies, telecommuting can provide a limited solution, but new forms of mass transit are needed.
9. With emerging smart vehicle technologies, commuters and commercial vehicle operators may be able to free themselves of continuous concentration on driving, thereby opening opportunities for learning, entertainment, communication, and productive work while on the road.
10. Air pollution is attributable in part to exhaust from motor vehicles; new technologies, such as hydrogen fuel cells, may help alleviate this problem.
11. We should increase availability of high-speed surface transportation so that individuals can spend their time more efficiently and desirably at home and work.
12. The current level of death and mayhem on our highways is intolerable; we need to develop smart vehicles, smart highways, and emergency response systems, so that people are not at substantial risk while taking advantage of transportation and the freedom and opportunity it provides.