Title

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Publication Date
2013-03-01

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2013 Transportation Research Record

March 15, 2013

EXPLORING THE FUTURE OF INTEGRATED TRANSPORTATION SYSTEMS IN THE UNITED STATES FROM 2030 TO 2050: APPLICATION OF A SCENARIO PLANNING TOOL

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ABSTRACT

Intelligent transportation systems (ITS) have primarily focused on systems management. To further improve connectivity and safety in the future, ITS might embrace a more holistic planning approach. While the future of ITS remains an open question, its evolution is closely linked to how the world evolves on many dimensions—social, political, economic, legal, and environmental. In this paper, the authors present results from four expert workshops. These consisted of an initial steering committee workshop (February 2011), two expert scenario-planning workshops (June 2011), and a final steering committee workshop (July 2011). The scenario planning workshops explored the implications of alternative futures on ITS and incorporated a broad interdisciplinary approach in developing a long-term transportation vision (2030 to 2050 time horizon) for the United States.

Twenty-four experts, representing diverse disciplines, participated in a series of workshops to envision plausible futures and to assess their effects on the transportation system. By exploring different futures, experts identified opportunities and barriers for implementing advanced seamless transportation systems. Opportunities included the deployment of adaptable, integrated technology and transportation infrastructure to address natural disasters and climate change. The most significant barriers were funding and politics. The experts suggested that financial barriers be overcome through innovative funding techniques and improved public outreach. Building upon the experts' recommendations, several visions for an integrated ITS approach, which addresses social and environmental challenges in the future, were created. These included private-public partnerships; distributed implementation models (e.g., localized); and the development of seamless transportation systems to reduce energy consumption, emissions, and road congestion.

KEY WORDS: Intelligent transportation systems, ITS, expert scenario planning, workshops, future

WORD COUNT: 7,500 words, including 2 tables and 1 figure

INTRODUCTION

Over the past 20 years, the Federal Highway Administration (FHWA) has conducted research to improve the safety and mobility of the road network through the use of intelligent transportation systems (ITS) technologies. The Federal Transit Administration (FTA) and the Research and Innovation Technology Administration (RITA) have conducted additional research through Advanced Public Transportation Systems (APTS) state-of-the-art reports and triennial surveys of transportation agencies' ITS deployment (*1*,*2*). The scope of ITS, as it is currently deployed, is primarily defined by the passive provision of information, which serves to inform decisions made by travelers, as well as infrastructure operators. Furthermore, the current scope of ITS is most often focused on single transportation modes. This approach has resulted in improvements in system monitoring and control. However, there is greater potential for ITS to optimize transportation efficiency and safety through the integration of all transportation modes. This intermodal system calls for a more active ITS role, employing modern communication and sensor technologies to merge all aspects of the transportation network including: vehicles, road topology, traffic controllers, and sensors. For the purpose of this study, the concept of a fully integrated and advanced transportation system, with the goal of optimizing safety and mobility, was defined as an "Integrated Active Transportation System" (or IATS).

This paper explores the future of integrated transportation systems in the United States (U.S.)—particularly how ITS and other technologies could evolve to meet major societal and environmental challenges. The project is motivated by a need to advance understanding on what types of strategies and transportation investments—with an ITS emphasis—are most practical under a range of plausible future scenarios. Between February and July 2011, researchers implemented four workshops with 24 experts from a variety of fields to examine the effects and connections among public perception, consumer acceptance, political jurisdiction, economic feasibility, legal implications, and environmental constraints on the future of transportation (2030 to 2050) in the U.S. The first workshop (February 2011) convened a steering committee of seven experts that laid the groundwork for the two expert scenario planning workshops that took place in June 2011, with a total of 16 experts. The steering committee was reconvened to evaluate the outcomes of the scenario planning workshops and to provide recommendations on next steps. The study's intent was to provide a collection of strategic actions for stakeholders to consider in developing an active, safe, and integrated transportation system in the future.

This paper has three main sections. First, the authors provide background on previous ITS research and societal/demographic trends that contribute to the future scenarios. Next, the paper describes the scenario planning methodology employed. Third, the authors present key results from the workshops and discuss their implications on planning and preparing for the evolution of ITS.

BACKGROUND

During the past two decades, several governmental research programs have collaborated with private industry to integrate advanced technologies into transportation infrastructure and vehicles (*3*). One of the more prominent efforts was the research and development of technologies for automated highway systems (AHS). While research addressing some of the complex technical challenges of car following was successful, the effort to advance and disseminate the technology beyond research and development largely failed because it did "not pay attention to the full range of issues […] focused on developing the technologies and disregarded or downplayed issues that would later become the stumbling blocks for the whole program" (*4*). Difficulties in implementing these systems were often blamed on economic and systems integration concerns (e.g., implementation costs and hesitation to install and invest in technology without a guarantee of compatible infrastructure investment by other stakeholders) (*5*). The lack of network-wide integration, despite advancements in transportation technology during the past decades, suggests broader efforts to develop ITS require the understanding of economic and human forces affecting the future of transportation and its infrastructure including: economics, funding, population, housing, driving trends, and privacy concerns. These high-level trends are described in the following subsections.

Economics and Funding

Funding represents a significant obstacle to developing advanced ITS due to its capital-intensive infrastructure requirements. The federal, state, and local governments are the primary source of investment for transportation projects (*6*). Thus, the U.S. economy and federal budget have a notable impact on ITS deployment. Public perception plays a crucial role in determining governmental priorities. Attempts at traveler information systems revealed consumers required significant improvements to their traveling experience to justify their use of new transportation technology (*7*). Thus, near-term return on investment in ITS is critical.

The public's ability to pay for ITS will likely influence its development. Peoples' income levels are known to affect technology purchases, transportation access, mode choice, and amount of travel (*7, 8, 9*). Socioeconomic fluctuations may also affect the development of ITS, but there is limited research on this topic.

Population and Housing Growth

The U.S. Census Bureau forecasts the 2050 U.S. population at over 400 million people (*10*). In 2010, 13% of the American population was foreign born. Pew Research predicts immigrants will comprise 19% of the U.S. population by 2050 (*11*). This share of immigrants exceeds its previous record of 15% from 1890 through 1910 (*11*). Growing immigrant populations will likely impact housing choice and locations. According to a Joint Center for Housing Studies of Harvard University study, 96% of foreign-born, first-time homebuyers in the U.S. purchased homes in metropolitan areas since 1997, 62% of which were in the suburbs (*12*). Comparatively, only 78% of native, first-time homebuyers purchased homes in metropolitan areas (*12*). These data suggest increasing immigrant populations could lead to housing growth concentrated in urban environments.

During the last decade, a trend has emerged toward housing in cities, away from the suburbs. Although it is not clear if this trend will continue, densification of cities could support planning concepts such as new urbanism, which promotes walkability, connectivity, and sustainability through the construction of dense, mixed-use developments and alternative transportation (*13, 14*). Demand for this type of development is growing. In 2011, 56% of respondents to a National Association of Realtors survey preferred mixed-use neighborhoods featuring attractions within walking distance to suburban neighborhoods that rely on private-vehicle use (*15*). Given this focus on reduced auto dependency, furthering mixed-use communities could lead to changes in how information technology enables transportation services.

Between 1983 and 2008, the percentage of people with a driver's license declined for all age groups under 45 (*16*). A study by Zipcar found that Millennials (i.e., 18-34 year olds)—more than any other age group—use the Internet to communicate with friends rather than driving to see them and would prefer to lose access to a personal car over a phone or computer (*17*). While the U.S. population has increased since 2006, the number of vehicles on U.S. roads has leveled off after years of steady increase (*18*). These trends suggest a movement away from the personal automobile as the primary means of transportation for populations that traditionally demanded the greatest mobility.

In contrast, older adults have increased the length of time they retain their driver's licenses. In 1983, 55% of people over 70 maintained a driver's license (*16*). By 2008, that percentage increased to 78% (*16*). This increase in older drivers introduces a safety issue, as people over 75 have the highest collision fatality rate of 11.5 deaths per 100 million miles (*16*). Fewer than 10% of seniors walk, bike, or use public transit as their primary transportation mode. Thus, the aging of Baby Boomers (i.e., those born from 1946 to 1964) will likely have an important influence on transportation demands and safety (*16*). Increases in the population of older drivers may influence the role ITS plays in improving safety, while generational differences may affect how much and what type of information ITS collects and the amount of control that users are willing to entrust to vehicles and infrastructure.

Emerging Technology: Privacy Concerns

Concerns around privacy and ITS have already resulted in 12 states outlawing automated speed cameras and 9 banning red light enforcement cameras (*19*). As new technologies have the potential to track users to provide more informed and tailored transportation information, privacy concerns may influence social and behavioral roles in the development of ITS in the future. For example, a study on mobile phone tracking determined that consumers opposed sensor tracking, if they did not perceive the benefits as compelling enough to overcome privacy invasion (*20*). The study found that 42% of the participants were concerned about global positioning systems (GPS) recording their position all day, and half of the participants disapproved of the use of permanently-stored GPS data; however, 96% did not object to the use of GPS information deleted immediately after its use (*20*). Another study found people preferred position-awareness systems (i.e., where a device determines its own location) to location-tracking systems (*21)*. According to a survey performed by Informatica, younger people are more willing to share their personal information than older adults (*22*). As socio-behavioral changes continue to influence transportation, and as the future evolves to include higher levels of human machine interface, it is important to consider the impact of such changes on ITS planning and deployment in the future.

Emerging Technology: Uptake and Obsolescence

Technological barriers contribute to a "disconnect" between technical possibility and system realization. Slow vehicle turnover exacerbates this barrier. A 2010 report from the Environmental Protection Agency indicated that it takes 15 to 20 years for vehicle technology to reach maximum market penetration (*23*). Technological advancement outpaces the procurement cycle and inhibits decision-making and product adoption, for example, an in-vehicle ITS was rendered inoperable when mobile providers discontinued analog service (*2*).

METHODOLOGY

In this study, researchers employed a three-stage scenario planning process. This consisted of four workshops: an initial steering committee meeting (February 2011), two expert scenario planning workshops (June 2011), and a final steering committee session (July 2011).

Scenario planning can serve as an enhancement to the traditional planning process and can aid decision makers in organizing their strategic thinking. It envisions plausible and provocative descriptions of how exogenous forces may interact and unfold to influence society. Organizations use scenario planning to prepare, plan, and develop robust alternatives to manage risk (*24*). While scenario planning can minimize future surprises, it is time consuming, imprecise, and qualitative in nature.

It can be used to examine social and economic variables that may affect transportation systems. Transportation stakeholders can then monitor key indicators, or "signposts," enabling them to recognize shifts leading to the unfolding of one future over another. Thus, scenario planning allows for adaptive decision-making or strategic planning that can optimize outcomes.

Peter Schwartz of the Global Business Network (GBN) has developed a scenario planning methodology in which scenarios are developed by exploring "driving forces," which are plausible and uncertain bi-axial trajectories of change that could have a significant impact on the future. These driving forces "shape…future dynamics in predictable and unpredictable ways" (*25*). Critical uncertainties are unpredictable driving forces that have the most impact on the contextual environment (*25*). Within a scenario, two critical and impactful uncertainties are chosen, and their four most extreme outcomes are mapped on two-dimensional axes. This creates a set of four divergent scenario quadrants.

Delphi Approach

The Delphi approach is a structured survey method based on the assumption that collective judgments are more reliable than individual ones (*26*). The application of this approach requires the consultation of experts in two or more phases. Results from a previous stage are provided to the next round's experts, who can alter or maintain the previous experts' assessment.

For this study, the Delphi approach was applied to the formation of a focal question and scenario quadrants through four workshops: an initial steering committee gathering of seven members; two expert scenario planning sessions with six and ten members, respectively; and a final steering committee meeting. Individuals, representing a wide range of disciplines, were selected to encompass social, political, legal, economic, environmental, energy, and technological expertise.

Scenario Planning Workshop Administration

Initial Steering Committee Session

The steering committee, comprised of seven diverse experts, first met in February 2011. They represented the following disciplines: transportation, technology, sociology, economics, energy, policy, planning, freight transport, and futuristics. The committee laid the groundwork for the scenario planning workshops by identifying a range of driving forces, which would ultimately create scenario worlds for the years 2030 and 2050. Key driving forces included societal changes rooted in: demographic and behavioral trends; politics and the economy informed by financial resources and investment trends; energy informed by innovation, efficiency and dependency; environmental changes; and legal processes and their relationship with societal norms. The initial committee also developed a focal question to be addressed in each scenario world: *What is the* *most effective strategy for realizing IATS given the gap between what is possible and what is realizable?* Table 1 lists the scenario worlds.

TABLE 1 Scenario World Descriptions: 2030 and 2050

Year	World	Description
2030	Natural Disaster World	A major natural disaster takes place in a large urban setting; this can be any type of disaster (e.g., tsunami, earthquake, hurricane, tornado, etc.).
	Changing Economies World	The U.S. has outsourced the vast majority of its goods and services, so much so that 98% of products are, in some part, manufactured abroad.
	Cyber-Terrorism World*	A major cyber-terrorist attack has occurred on some part of the transportation system temporarily disabling it and severely shaking the public's trust in automated transportation systems (e.g., automated personal vehicles).
2050	Climate Catastrophe World	Extreme weather events are occurring. However, unlike the *Natural Disaster World*, these events are happening with alarming frequency and are highly unprecedented in location and magnitude.
	Changing Production World	The U.S. reaches energy independence, meaning that it does not rely on other countries for any form of primary energy.
	Resource Constrained World	Global food demand has doubled. Non-renewable resources, such as fossil fuels and minerals, are dwindling. Additionally, the world's fresh water supply is running dry.

*Note: This world initially had a timeframe of 2030, but it was later changed to an evolving one leading to 2050, as the transportation system is unlikely to be completely automated in 2030.

First Scenario Planning Workshop

A second group of six experts formed the first, two-day scenario planning workshop in early-June 2011. The experts represented the following disciplines: transportation, technology, sociology, economics, policy, freight transport, and futuristics. Experts during this workshop substituted the term "IATS" with "seamlessly interconnected transportation systems" in the focal question. They later altered the focal question to: *What is the most effective strategy for evolving a convenient, safe (i.e., system security and human safety), robust (i.e., survivable, adaptable, and resilient), and efficient transportation system in 2030 and 2050?* This change narrowed the focal question to the creation of priorities for the transportation system in both timeframes. The group discussed what is predicted to change in 2030 and 2050, such as demographics. Building upon these assumptions, experts developed the future scenarios described in Table 1. Driving forces were examined for each world to ensure that they were appropriate given each scenario. Experts selected the five most uncertain and impactful driving forces for each scenario world, as well as five critical uncertainties: 1) localized vs. meshed communications, 2) proactive vs. reactive government response, 3) low vs. high emissions, 4) independent vs. interdependent technological systems, and 5) weak vs. strong economy. These uncertainties and the focal question were presented to the next round of experts in the second scenario workshop.

Second Scenario Planning Workshop

A different group of ten experts comprised the second, two-day scenario workshop in mid-June 2011. The second workshop experts voted on two crucial uncertainties from the five critical uncertainties identified earlier. By treating the two crucial uncertainties as axes of a graph, the experts formed four scenario quadrants for each scenario world.

Within each quadrant, the experts analyzed the role of transportation, identified the societal and environmental challenges and opportunities for transportation, and devised the best potential strategic responses for the conditions present in each quadrant. This input was used to write narratives about each scenario quadrant. Figure 1 displays the axis and quadrant names for the scenarios from 2030 and 2050. A set of recommendations for how stakeholders could optimize transportation and a collection of signposts indicating the unfolding of a particular future were also developed for each quadrant.

Final Steering Committee

The steering committee, comprised of three members from the initial group plus one other, was presented with the results of the first and second scenario workshops. They commented on the scenarios presented and provided feedback on the methodology. Their feedback included a recommendation to conduct a national survey of transportation stakeholders on their current ITS deployment strategy and response to IATS. Further, additional interviews with energy experts were recommended, as this area was not as strongly represented in the workshops. Both actions were undertaken in the final project year.

RESULTS

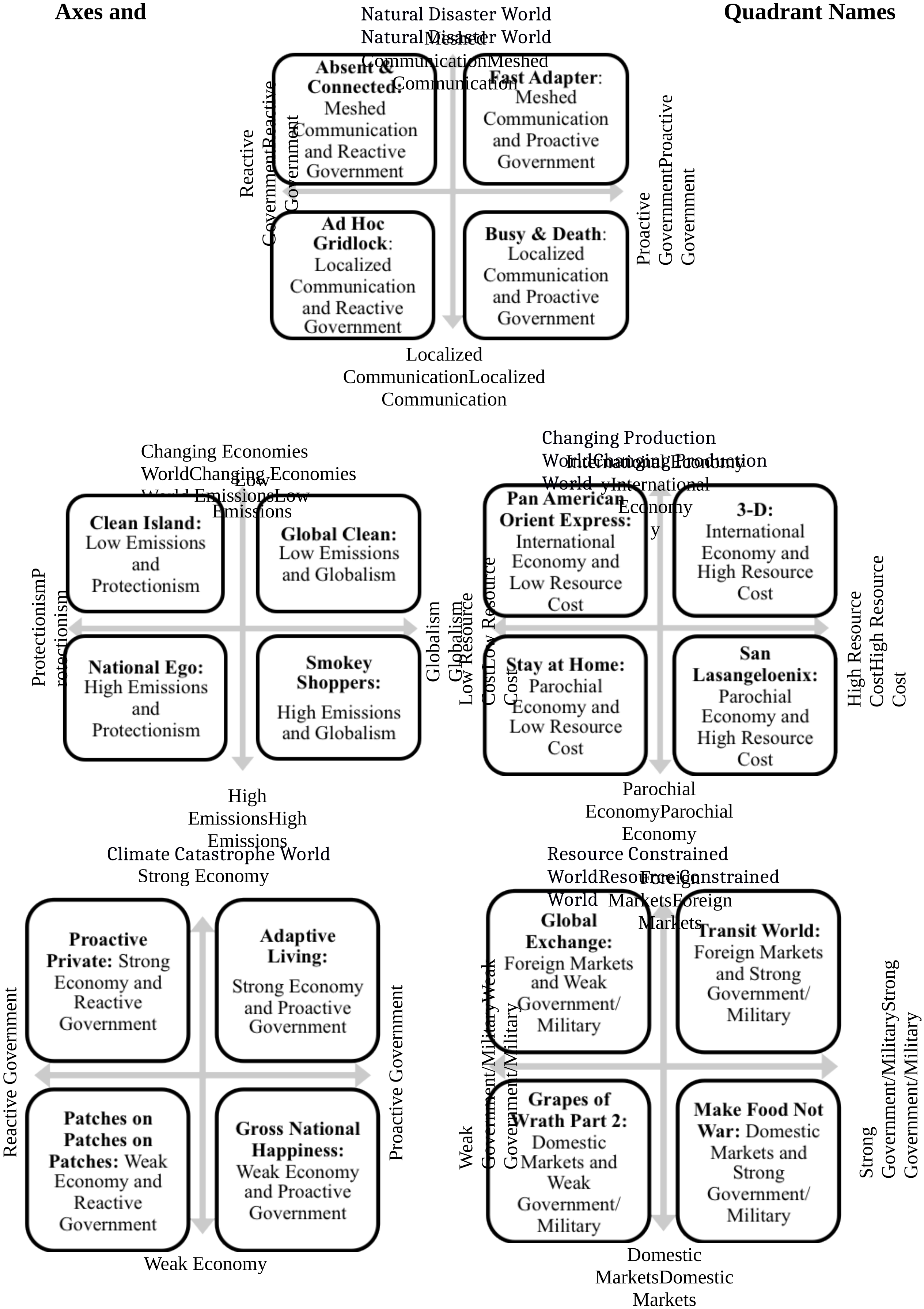
In the following sections, the authors discuss the scenario quadrants, signposts for each world, and common themes from the scenario quadrants.

Scenario Quadrants

The experts developed 20 scenario quadrants, four for each world, except the *Cyber-Terrorism World*, which was explored differently. The discussion of *Cyber-Terrorism World* was a small source of dispute prompting further questions about the implications of the scenario. In the first workshop, some of the experts opined that a cyber-terror attack could not be carried out on the transportation system in the year 2030 because the transportation system is unlikely to be completely automated. Upon bringing these concerns to the experts in the second workshop, they agreed that the transportation system would not be completely automated in 2030. Thus, this scenario was analyzed with an eye toward an evolving timeframe leading to 2050. As such, the discussion of *Cyber-Terrorism World* did not follow the standard format of exploring the driving forces and creating scenario quadrants from these forces. Instead, experts had a detailed discussion about which types of transportation technology would be available leading up to 2050 and how this technology might be vulnerable to a cyber-terror attack. The fully developed quadrants are outlined in Figure 1, below.

After establishing all the driving forces for the other worlds, the most impactful and uncertain forces (critical uncertainties) were chosen and placed along an axis, highlighting the two most extreme directions in which these forces may manifest. Using the example of the economy, the range of the axis could be a weak economy at one extreme and a strong economy at the other. The two most significant critical uncertainties were chosen and structured to create a frame of four possible scenario quadrants within each scenario world. Each quadrant is defined by a combination of the possible extremes of each driving force. Considering the chosen critical uncertainties in each scenario quadrant, the final steps of the scenario planning process involve evaluation of the driving forces within each quadrant.

FIGURE 1 Axes and Scenario Worlds: Quadrant Names



Signposts for Each World

The experts identified a series of "signposts, " which helped to form the basis of each scenario world; they are presented in Table 2. These signposts resulted from the critical uncertainties identified in the first workshop. They act as tools to help transportation stakeholders determine which future(s) might be emerging. Some of the signposts indicate the development of a world, whereas others show the evolution of a specific quadrant(s). For example, the signpost of increased regularity of severe weather events suggests the formation of *Climate Catastrophe World*. If extreme weather events occurred more frequently and governments were not actively planning for these events, transportation stakeholders might anticipate that a quadrant with a reactive government in *Climate Catastrophe World* was developing. They could then apply the experts' recommendations from the appropriate quadrant(s).

Signposts for *Natural Disaster World* include more frequent extreme weather events and technology-based prediction systems. While more frequent extreme weather events result in the formation of *Natural Disaster World*, an increase in technology-based prediction systems indicates meshed versus localized communications. The signpost of outsourced manufacturing signifies the creation of *Changing Economies World*, whereas increased greenhouse gases (GHGs) indicate the formation of high-emissions quadrants instead of the low-emissions quadrants. In the *Changing Production World*, the energy investment signpost indicates the formation of this world, while the decline of imports hints at insular versus international economies. The signpost of increasing product prices due to rising input costs denotes the *Resource Constrained World*, and the signpost of political gridlock results in weak government quadrants in contrast to stronger ones.

TABLE 2 Signposts for Each World

Natural Disaster World (2030) Signposts	Changing Economies World (2030) Signposts	Climate Catastrophe World (2050) Signposts	Changing Production World (2050) Signposts	Resource Constrained World (2050) Signposts	Cyber-Terrorism World* (2030 - 2050)
Meteorological conditions that result in many unpredictable	Increased outsourcing of manufacturing to foreign	Degradation of environment as a result of	Breakthroughs and investments in alternative	Product prices increasing due to rising	Fully autonomous technologies realized

disasters	countries	carbon dioxide and other GHG emissions	energy sources	input costs	
Technology-based prediction systems	Increased unemployment (lack of jobs and skilled labor force)	Increased regularity of severe weather events	Use of clean energy	International food shortages	Multiple failback systems in effect
No additional signpost	Increasing import/export ratio	Changes in animal migration patterns and extinction of certain species	Creation of more efficient energy products	Increase in international competition for resources	No additional signposts
No additional signpost	Economic slowdown	Adoption of green lifestyle choices	Reduced dependency on petroleum	Collapse of resource-poor nations	No additional signposts
No additional signpost	No additional signpost	Increase in the number of green businesses	Decline in imports	More cold wars	No additional signposts

*Note: This world initially had a timeframe of 2030, but it was later changed to an evolving one leading to 2050, as the transportation system is unlikely to be completely automated in 2030.

Common Themes Within Scenario Quadrants and ITS Technology and Policy Response

Not surprisingly, there were no common themes or recommendations present throughout all 20 quadrants due to the polar nature of the quadrants. However, five themes appeared in more than one quadrant: 1) severe weather, 2) a decrease in personal vehicle use, 3) constrained resources, 4) abundant energy resources, and 5) a fiscally challenged government. Each of these themes was associated with a series of recommendations. This section discusses the role of these themes in future ITS strategic deployment.

Severe Weather

Although the name *Climate Catastrophe World* conjures images of the world's end, it should be noted that this scenario focuses on how ITS could be used to adapt the existing transportation system to respond to more frequent extreme weather events (e.g., increased flooding, ice storms, etc.). The experts tended to treat natural disasters in the *Natural Disaster World* as being weather related. This action resulted in the two worlds sharing similar signposts and recommendations. The experts believed that in a future of increased storm severity and frequency, the transportation system should focus on saving lives; ITS could be used as part of a larger adaptive strategy to combat climate change.

ITS Role in Evacuation In order to preserve lives, ITS could be adapted to efficiently and effectively evacuate people. This new role for ITS could mitigate the effects caused by disproportionate vehicle access, which adds to the casualties and suffering caused by natural disasters, such as Hurricanes Katrina and Sandy (*27*). Apps could be developed to assist in evacuation in lieu of individual auto access. In-vehicle and handheld device apps could help organize ridesharing and inform evacuees about available modes near their location. Incentives could be tied to these apps to encourage people with extra space in their vehicles to offer rides to other evacuees. In addition, if apps included location awareness technologies, governments would have information on the location and number of people requiring evacuation and could use it to more effectively dispatch evacuation shuttles. It is essential that the public be aware of these technologies prior to a disaster to ensure that they are used properly. The government or other organizations could inform people about the apps and encourage their use as part of warnings prior to storms.

ITS Role in Rescue Operations As with evacuations, apps could be used to assist rescue operations. Such an app would act like an emergency flare, broadcasting a distress signal, location, and user injuries. It is important that all rescue apps report to one authority: emergency services. Thus, some regulation and standardization of the apps would be needed to ensure people are not transmitting a distress signal to nowhere. ITS could also adapt to improve the distribution of road status information to emergency vehicles/responders, facilitating their routing around destroyed infrastructure. Routing systems could also be programmed to perform triage, based on the injuries and situation reported from the rescue app users.

As cell towers may be damaged or destroyed in the event of a severe storm, the road network could act as a redundant communication network. Provided that the roadway sensors were advanced enough to transmit data through fiber, dedicated short range communications, or Bluetooth®, the emergency app signals could align with transmissions made by road sensors to ensure connectivity in a disaster. This auxiliary network would need to be designed and built to survive severe storms and flooding. As with the evacuation app, it is important that the public be educated that such a network exists, so they know how to locate a road that is equipped with sensors to ensure that their distress signal reaches emergency responders.

Using ITS As an Adaptive Strategy in Transportation The workshop experts believed that increased implementation of ITS sensors, along with the development of stronger infrastructure, could be implemented as part of an adaptive strategy to combat the effects of climate change and severe weather.

Adaptive strategies are already being explored around the world to counter the effects of climate change. The United Kingdom (UK) formed the Adapting Climate Change Program to determine strategies to "improve the long-term resilience of new and existing infrastructure in energy, transportation, and water sectors due to future climate change impacts" (*28*). Another policy in the UK, the Adaptation Reporting Power Regulation, required climate change impact assessment of essential services and infrastructure and action taken to minimize these impacts (*28*). Technology can be used to assist in the assessment of infrastructure, as well as system monitoring. In the U.S., the Transportation Research Board's Special Report (SR) 299 recommended that infrastructure be increasingly monitored to detect how climate change adds stress on infrastructure (*29*).

Workshop experts noted that the increased implementation of sensors to monitor physical conditions and infrastructure status (e.g., road-weather information systems) would be important in these worlds to accelerate the process of alerting users of road closures and dangers, as well as informing state departments of transportation of the need to repair or replace infrastructure.

The expense of replacing existing infrastructure poses a barrier to ITS approaches that require dedicated infrastructure, such as vehicle-to-infrastructure (V2I) communications. V2I is the exchange of data between vehicles and the roadway infrastructure to improve safety and operations. While this economic barrier hinders ITS deployment, the continual damage or destruction of infrastructure by severe weather led the workshop experts to suggest that technology requiring dedicated infrastructure could be constructed following disasters as a means to overcome the cost barrier.

Decrease in Personal Vehicle Use

A common theme in many of the scenario world quadrants was a decrease in personal vehicle use. Experts typically associated this decrease with a lack of energy resources, increased population density, and heightened environmental awareness. The groups concluded that greater public transit use would replace personal vehicle travel; thus, transit-based ITS would play a greater role in these worlds, as well as alternatives such as carsharing (i.e., short-term vehicle use). Experts noted that a decrease in vehicle ownership poses a barrier to the implementation of vehicle-based ITS, such as vehicle-to-vehicle (V2V) technology, as fewer personal vehicles on the road would decrease the benefits of vehicle-based ITS and result in higher vehicle production costs due to reduced economies of scale. V2V involves the dynamic data exchange via wireless communication between vehicles, which offers safety and system management benefits.

Under these conditions, ITS does not require a new role but rather an expanded one in providing safe and efficient public transit services. Transit signal priority and bus rapid transit systems could be augmented to improve mobility. Greater communication and cooperation between public transit agencies could ensure seamlessness among regions. In addition, technology standardization that enables seamless electronic fee collection across public transit agencies could increase the efficiency of public transportation by decreasing boarding times and increasing user convenience.

Constrained Resources

Experts concluded that future scenarios involving constrained resources would shift the focus of ITS toward the streamlining of the nation’s freight system, allowing it to transport goods without severely impacting dwindling resources. In the context of diminishing resources, the experts supported the increased use of electrically powered rail, such as maglev, for freight and public transit.

Abundant Energy Resources

Due to low resource costs or an assumed advance in energy production, several scenario quadrants developed futures where energy resources were abundant. In these quadrants, experts suggested an introduction of truck-only lanes to expedite freight movement and an electricity metering system to collect taxes on electric vehicles to pay for transportation infrastructure maintenance and improvements.

Role of ITS in Future Goods Movement In the scenario worlds that emphasized a reliance on foreign goods, the experts suggested that ITS be used to streamline and optimize freight, ensuring an uninterrupted flow of goods into and across the nation. In these scenarios, ITS could expand into the realm of detection and tracking. The increase in imported goods necessitates an improvement in goods scanning and tracking to increase freight system security. Such technologies would need to rapidly and efficiently scan for radiological, biological, and chemical threats intentional or otherwise.

To improve the efficiency of these “sniffer” technologies, these devices could be applied while the freight is in transit. When a threat is detected, it could be reported to security personnel at the port along with information on the cargo vessel’s location, its expected arrival time, and vessel schematics, which identify where the threat is located. Such technologies also could prepare emergency responders, ensuring the safety and efficiency of the freight system.

Fiscally Challenged Government

Scenarios involving a weak government or economy typically resulted in a fiscally challenged government. When governments are fiscally constrained, the high capital costs associated with infrastructure sensorization, as well as the need for long-term maintenance and operations funding, pose additional economic obstacles, especially as technology funding may be perceived as regressive taxes on lower-income brackets. Since ITS project investments, such as roadway sensor installments, are primarily supplied by public entities, the deployment of infrastructure improvements is impacted by the state of the economy. Because the experts viewed increased ITS and infrastructure development and implementation as less likely under poor economic conditions, they suggested changing ITS funding schemes as well as a private buyout of sections of the transportation infrastructure.

New ITS Funding Mechanisms In a fiscally challenged environment, experts identified alternative funding mechanisms to support the development of transportation infrastructure and technology including: public-private partnerships, international collaboration, incremental implementation, and tax policy changes.

New funding schemes could facilitate the introduction of innovative ITS approaches, such as V2V and V2I, as well as the increased deployment of ITS sensors needed to bolster the resolution of network information. The increase in transportation data resolution through higher levels of sensorization and communication could allow for the entrance of third parties to develop better dynamic routing and mode-choice tools in the future. In light of this, public support for ITS expansion is crucial. The scenario workshop experts agreed that ITS concepts and benefits should be marketed to the public who may not be aware of the many challenges facing the transportation system. Awareness could result in increased support for technologies that improve safety, efficiency, and connectivity among transportation modes.

Furthermore, making ITS data more readily available to third parties could create new businesses that design tools to inform system users of alternative routes or modes. These businesses could help to stimulate job creation, while their tools promote strategies to reduce congestion and emissions and foster innovative modes, such as ridesharing, carsharing, and public bikesharing (*30, 31*, *32*). A great deal of research has been conducted on these technologies, illustrating the potential for new business models and opportunities for implementation within the ITS framework. Such technologies include after-market navigation devices and smart phone applications (or apps) that employ real-time sensor data on road network status to inform users about faster routes or the availability of shared-use vehicles.

Gamification or incentives could also be applied to these technologies to promote the use of alternative modes. Cooperation among and within government and non-government transportation entities is critical to promoting streamlined information sharing. Apprehension of the private and public sector in sharing data hinders such cooperation (*33*). In the past, the failure of entities to cooperate or communicate effectively has created barriers to transportation projects (*34*).

Private Buyouts of Public Infrastructure The experts believed that industries benefiting from a functional transportation system, such as the freight industry, could buyout sections of the transportation system. The privatization of U.S. roadways could prove favorable for ITS, as government fiscal barriers could be circumvented, hastening implementation. However, privatization would necessitate that ITS devices and vehicles be compatible to ensure a seamless U.S. transportation infrastructure across operators. Compatibility issues would require a policy to establish industry standards, which could pose a legal barrier due to intellectual property rights.

CONCLUSION

As part of this study, the scenario planning workshops identified societal and environmental forces affecting the future of transportation technology. By providing recommendations and signposts, the results provide planners with tools and recommendations on how to address uncertain and impactful events. Signposts enable stakeholders to foresee the unfolding of a particular future. Guidance on how to respond to such futures can enable better risk management.

ITS will likely need to adapt in different ways to tackle future problems. If the U.S. imports the majority of its goods, ITS may need to play a more active role in hazards detection to enhance freight security. Under resource constraints, public transit may be more heavily used, thereby increasing the need for public transit-based ITS solutions. If climate change results in increased storm frequency and severity, ITS may need to adapt to provide more efficient evacuation and rescue operations.

Innovative funding mechanisms may be needed to increase sensorization and improve transportation data resolution in light of funding constraints. Such mechanisms include public-private partnerships and road privatization. Readily supplying road sensor data to the public and third parties could create new industries focused on optimized routing and mode choice information. This could help to promote the use of alternative transportation modes, including public transit and shared-use vehicle services, which could alleviate congestion and reduce emissions.

The purpose of this study was to assess risk and to plan for possible futures in which ITS technologies could be employed to create a more integrated, advanced, and adaptive transportation system. As part of this research, an interdisciplinary panel of experts analyzed the impacts of a range of societal and environmental forces that might impact ITS deployment in the 2030 and 2050 timeframes. Workshop outcomes included signposts to gauge whether or not a scenario was unfolding and recommendations for preparing and responding to each. Building upon this understanding, stakeholders could develop an adaptive and long-term research and policy roadmap to guide transportation-related decision making in the future.

ACKNOWLEDGMENTS

The Federal Highway Administration generously funded this research. The authors would like to thank the many experts that participated in this study. Thanks go to Scott Andrews, Susan Takami, and Dan Lyke of Cogenia Partners, who participated this study. The authors also acknowledge the input of Transportation Sustainability Research Center researchers at the University of California, Berkeley including: Rachel Abdul-Azim, Lauren Cano, Marissa Goodman, Dr. Elliot Martin, William Ullom, Rachel Whyte, and Kate Yu. The contents of this paper reflect the views of the authors and do not necessarily indicate acceptance by the sponsors.

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